The History of Calibration Laboratories: The Transfer from Primary Standards to the Clinic

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Disclosure

- Larry DeWerd has a partial interest in Standard Imaging

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Outline

- What is a standard and why do we need standards
- What traceability to NIST means for the clinic
- NIST to the ADCLs
- TG 51 addendum

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Calibration for Protocols

- As given in the prior lecture, the protocol in use allows the determination of the dose to the patient
- TG 51 is the protocol of the day
- Each protocol requires a calibration of the ionization chamber to a standard

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Definitions

- A Standard refers to a quantity, like dose
- A physical standard is the apparatus that measures a fundamental quantity.
- The primary standard always resides at the primary laboratory (NIST).

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Standards

- There can be secondary standards at other laboratories that may be the same as the primary standard but it is not a primary standard.

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Physical Standards

- A physical standard is linked to and measures fundamental quantities.
- Some fundamental quantities are energy, mass, length, time

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Radiation Standards

- In radiation, a combination is considered a quantity: absorbed dose: energy per mass.
- Another standard would be the Air kerma: Charge per mass

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Standards

- Why do we need standards?
- One reason is For uniformity – this can be illustrated by the quantity length

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Length Standards

- In the ancient world the cubit was used. Cubits were used for the pyramids
- The basis of length needed some kind of standard. The start was Measurements of length based upon human body. The first standard used was the King but when a new king came in the standard of length changed.

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Length standards

- Countries having different kings would have different standards.
- Some cities would post their standards on the community center church or wall.
- All doing business had to use that standard in that city.
- Finally the meter was developed and kept at BIPM in Paris

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History of Radiation Quantities

- In 1899 Ernest Rutherford stated, "Radiation may be investigated by two methods, one depending upon the action of the photographic plate and the other on the discharge of electrification…much more rapid than the photographic method and admits of fairly accurate quantitative determination."

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More History

- Also in 1899 Marie Curie, "The electric method is based upon the measurement of the conductivity acquired by air… This method is fast and provides quantitative results that may be compared with one another."

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Measuring Dose

- Initially skin erythemia (skin redding) was used by physicians as a measure of dose.
- Dr. E. Williams, MD (~1899) stated for his dosimetry: "My rule is not to expose in ten days more than the number of minutes required to produce a dermatitis."

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Radiation Quantities

- Settled on ionization density in air caused by radiation which can be converted to absorbed dose or the energy deposited in tissue. Villard and many others.
- Absorbed Dose is the energy deposited in a mass of material with units of J/kg=1 Gy

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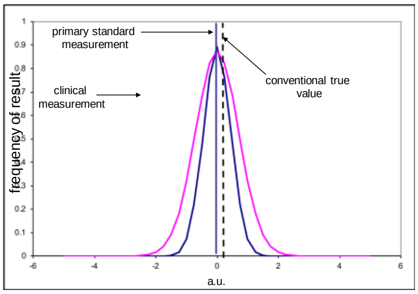

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Use of standards

- When ionizing radiation was first measured, the chamber was assumed to measure the quantity
- Since that point chambers have been found to need calibration to conform to the conventional true value (determined at NIST)
- Also manufacturer tolerances cause a variation in volume

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Examples for Standard use

- For example a 0.6cc farmer has variations of ± 3% because of tolerances in volume
- Calibration ranges at one standard deviation found from ADCL calibrations are about ± 1.5%
- Once calibrated the chambers remain within ± 0.2%

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Other chamber volumes

- For microchambers the manufacturer tolerances are larger up to $\pm$ 15%
- Calibration ranges at one standard deviation found from ADCL calibrations are about $\pm$ 7%

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Medical Application of Standards

- There are Standards necessary for
  - Radiation therapy, external beam or brachytherapy.
  - Diagnostic x-rays, e.g. Mammography and CT
- Standards start at primary labs through secondary labs (ADCL) to the user.

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Hierarchy of Standards

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

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Absorbed Dose Standards

Different approaches with different uncertainties at Primary Labs

A calorimeter measures energy

- Graphite calorimeter (NPL, BIPM, NIST, NRCC)
- Water calorimeter (NIST, NRCC, PTB)
- All agree to within ± 0.5%

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NIST Calibration Procedures

- NIST holds the primary standard for a calibrated Cobalt beam with a Water Calorimeter for Absorbed Dose to Water
- NIST has done Intercomparisons with National Primary Laboratories
- NIST calibrated ADCL chambers for Absorbed Dose to Water

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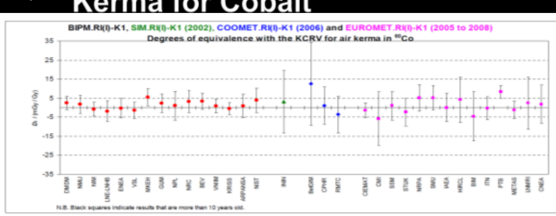
Comparison of Primary Labs Air Kerma for Cobalt



BIPM.RI(I)-K1 – red circles
SIM.RI(I)-K1– green triangle
COOMET.RI(I)-K1 – blue diamonds
EUROMET.RI(I)-K1 – pink squares

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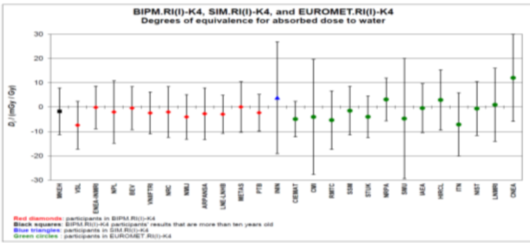
Comparison of Primary Labs Absorbed Dose to Water for Cobalt



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Why are precise standards and calibrations necessary?

- **Therapy involves treatment of diseased tissue, but involves healthy tissues also**
- **Brachytherapy is treatment interstitially or in body cavities**

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Dianostic x-rays

- **Diagnostic involves getting the best image - measure exposure for image and safety considerations.**
- **Will use External Beam Therapy to demonstrate need of standards**

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NIST transfer to Secondary Labs

- Before 1975, NIST used to calibrate all medical ionization chambers.
- This became a problem because of quantity of chambers to be calibrated
- NIST (NBS) was behind for a significant time period (up to a year)

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Start of ADCLs

- NBS (Bob Loevinger) petitioned AAPM to create "Regional Calibration Laboratories" in 1975 since NIST (then NBS) could not keep up
- In 1983 name change - called ADCLs.
- Started with 5 RCLs

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Accredited Dosimetry Calibration Laboratories

- Now 3 ADCLs: UW, M.D. Anderson and K&S
- UWADCL founded 1981 by LAD, now Wes Culberson
- M.D. Anderson: Bob Shalek, Will Hanson, Geoff Ibbott
- K&S: Tom Slowey, Kim Working
- The ADCL program is 43 years old

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Transfer of standards to ADCL

- NBS/NIST acknowledges ADCL traceability to primary standards (using Proficiency tests)
- Agreement for Proficiency tests for ADCLs ≤ 0.5%
- The ADCLs have proven track records of providing precise calibrations of equipment

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Intercomparisons with NIST

- Proficiency tests with NIST have been in place over 40 years
- NIST and ADCLs agree within 0.5% for Cobalt-60 beams
- NIST and ADCLs agree within 2.0 % for x-ray beams between 20 kVp and 250 kVp

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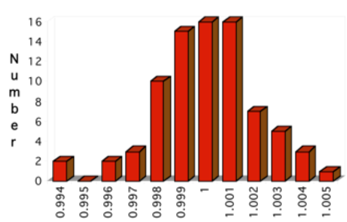
Consistency of ADCLs



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Calibration Laboratories Provide

- Maintenance of accuracy and precision
- Knowledge of characteristics of chambers
- ADCLs willing to discuss measurements and methodology
- ADCL discuss the operation of instrumentation.

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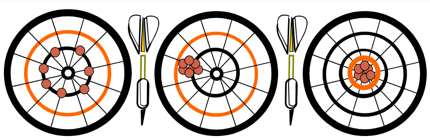
Accuracy and Precision



Accuracy for Radiation Therapy

- Balance between cure of cancerous tissue and complications with healthy tissue for cancer treatment
- Accuracy of dose delivered should fall within range of $-10\ \% \leq D \leq +10\ \%$ so that this balance between healthy tissue and cancerous tissue is not compromised

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Uncertainties (these are rough numbers)

- NIST claims 0.7% (k=1) depending on the standard
- ADCLs add uncertainty to be at 1.0%
- Hospital dosimetry measurements for the accelerator are at 2.0%
- Other dosimetric parameters can increase uncertainties to 3-4%
- Physician and clinical treatment can result in 6 - 8 %.

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Procedures to obtain Dose to Water or Dose to Tissue

- There are formalized methods to obtain Dose from the ionization chamber measurements based on TG-51
- Measurements made in a water phantom and converted to dose in water.

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AAPM TG 51 Protocol

- Protocol based on absorbed dose to water calibration in Cobalt 60.
- Simple to use. Corrections are "built in" the calibration factor and k_Q, an energy factor. Only a water phantom of minimum 30 cm x 30 cm x 30 cm
- Measured for a 10 x 10 cm^2 field at 10 cm deep as calibration point.

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Formalism for Dose to Water

- Calibration factors are determined depending on the energy, Q, represented by k_Q and the cobalt calibration.
- Small fields include another k to correct for fields less than 10 cm x 10 cm

$$D_W = MN_{DW}^{60Co} k_Q k$$

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Background of TG 51

- Reference dosimetry for linac beams based on a ^{60}Co calibration.
- k_Q is the factor that converts from the calibration beam (^{60}Co) to the user linac beam, defined by beam quality Q
- ADCLs provide the cobalt calibration
- Be careful with small fields.

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Corrections to reading

$$M_{corr,w} = M_{raw} P_{TP} P_{ion} P_{pol} P_{elec}$$

- Recombination correction directly affects measurement of absorbed dose
- Recombination correction well established but not always straightforward
- 2-voltage technique as set out in TG-51 applicable only to chambers exhibiting ideal behavior
- Many examples in literature of anomalous behavior

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TG 51 Addendum items

- Medical Physics 41:041501-1 through 20 (2014)
- Reference class ionization chambers
- k_Q factors for new chambers
- %dd(10) is used for k_Q

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Chambers and k_Q

- For chambers listed in both the addendum and the original TG-51 protocol, the k_Q factors listed in the addendum should be used.

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Chambers and k_Q

- For chambers that are not listed in either the original TG-51 protocol or in the addendum, the recommendations of Section XI of TG-51 should be followed.

XI. USING OTHER ION CHAMBERS

This protocol provides k_Q data for the vast majority of chambers used in clinical reference dosimetry in North America as evidenced by the data on ADCL calibrations. However, other cylindrical chambers can be used by finding the closest matching chamber for which data are given. The critical features are, in order, the wall material, the radius of the air cavity, the presence of an aluminum electrode, and the wall thickness. As long as the wall material is matched and the chamber is ''normal,'' these matching data should be accurate to within 0.5%. It is the responsibility of the user to confirm this by comparing the results to those of a calibrated cylindrical chamber for which data are given in the protocol.

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Ionization chambers

- The ionization chamber is the basic instrumentation for Therapy Medical Physicists. (e.g. TG 51)
- A reference class chamber must be used. (Definition as given in TG 51 addendum)
- There are precautions with small fields no matter what instrument is used.

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Ionization Dosimeters

- Chambers are high precision but need calibration.
- Reference class chamber meets the following conditions
  - Long term stability change $\leq$0.5% in 1 hour and leakage <0.5%.
  - Polarity between .997 and 1.003
  - Recombination <0.5%

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Specification for (cylindrical) chamber type

- 3 sub-types (NOTE: WGTG51 definitions)
  - i. 0.6 cm^3 reference chambers (e.g., NE2571, PR-06C)
  - ii. 0.125 cm^3 scanning chambers (e.g., PTW31010, IBA CC13)
  - iii. 0.02 cm^3 micro chambers (e.g., Exradin A16, Pinpoint^{TM})

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Chambers meeting reference class

- Majority are 0.6 cm^3 'Farmer-type' chambers
- A-150 chambers explicitly excluded
- 5 scanning chambers, NO microchambers
- (Possible Exception A26 from some preliminary measurements. Long term to come)
- No parallel plate chambers are included

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Small field Modification

- This is still an area of discussion.

$$D_W = MN_{DW}^{60Co} k_Q k$$

- k is modification caused by phantom scatter conditions being different
- k is generally <0.5% but can be more. See papers on k_{clin}

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Conclusions

- The AAPM should insist that new devices should have a standard
- NIST needs more support
- ADCLs can play a vital role in resolving calibration problems

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