Calibration Standards: History of NIST to ADCLs

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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
- Research in MRRC to produce secondary standards that are not available but clinically needed.
A Standard refers to a quantity
A physical standard is the apparatus that measures a fundamental quantity.
The primary standard always resides at the primary laboratory (NIST).
There can be secondary standards at other laboratories that may be the same as the primary standard but it is not a primary standard.
A physical standard is linked to and measures fundamental quantities.

Some fundamental quantities are energy, mass, length, time.

In radiation, a combination is considered a quantity: absorbed dose: energy per mass.

Another standard would be the Air kerma: Charge per mass.
Why do we need standards?
- For uniformity – illustrate by the quantity length
- 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.
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.”

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.”
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.”
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
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.
For example a 0.6cc farmer has variations of + 3%

Calibration ranges at one standard deviation found from ADCL calibrations are about + 1.5%

For microchambers the manufacturer tolerances are larger up to + 15%

Calibration ranges at one standard deviation found from ADCL calibrations are about + 7%
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).
NBS (Bob Loevinger) petitioned AAPM to create “Regional Calibration Laboratories” in 1975. In 1983 name change - called ADCLs.

- Started with 5 RCLs
- Now 3 ADCLs: UW, M.D. Anderson and K&S
- UWADCL founded 1981 by LAD
- The ADCL program is 43 years old
Transfer of standards to ADCL

- NBS/NIST acknowledges ADCL traceability to primary standards (using Proficiency tests)
- Agreement for Proficiency tests for ADCLs $\leq 0.5\%$
- The ADCLs have proven track records of providing precise calibrations of equipment
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
Consistency of ADCLs
- Maintenance of accuracy and precision
- Knowledge of characteristics of chambers
- ADCLs willing to discuss measurements and methodology
- ADCL discuss the operation of instrumentation.
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.
Hierarchy of Standards

- International & National Standards
  - Secondary Standards
    - ADCL
      - Hospital or Clinical Standards
        - Operational Standards
  - Primary Calibration
  - Secondary Calibration
  - Tertiary Calibration
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 $\pm 0.5\%$
NIST holds the primary standard for a calibrated Cobalt beam with Water Calorimeter for Absorbed Dose to Water

NIST has done Intercomparisons with National Primary Laboratories

NIST calibrated ADCL chambers for Absorbed Dose to Water
Comparison of Primary Labs Air Kerma for Cobalt


Degrees of equivalence with the KCRV for air kerma in $^{60}\text{Co}$

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

N.B. Black squares indicate results that are more than 10 years old.

Courtesy Michael Mitch, PhD, NIST
Comparison of Primary Labs Absorbed Dose to Water for Cobalt
Therapy involves treatment of diseased tissue, but involves healthy tissues also.

Brachytherapy is treatment interstitially or in body cavities.

Diagnostic involves getting the best image - measure exposure for image and safety considerations.

Will use External Beam Therapy to demonstrate need of standards.

Why are precise standards and calibrations necessary?
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
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 %.
There are formalized methods to obtain Dose from the ionization chamber measurements.

- AAPM ($C_{\lambda}$) TG- 21 or TG-51,
- IAEA (TRS 277 or TRS398)
- Measurements made in a water phantom (or other material) and converted to dose in water.
Protocols set by AAPM (other societies)

First one was $C_\lambda$. $C_\lambda$ was a constant to convert Exposure to dose.

Second was TG 21 to take into account different parameters of chambers and linacs to convert air kerma to dose.

Finally TG 51 which uses a $k_Q$ to convert absorbed dose to water to dose.
Calibration of ionization chamber in a cobalt beam - $N_x$ or $N_k$ for air kerma.

Convert to $N_{gas}$ the absorption in the gas (air) without chamber walls.

The measurement needs to have corrections applied, $P_{atm}$, $N_{gas}$, and electrometer correction factor, $P_{elect}$.

Apply other correction factors, ratios of absorption and stopping powers to convert to dose in water.
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.
Formalism Dose to Water

- \( D_w^Q = N_{D,w}^Q k_Q M_Q \)
- For small fields another \( k \) added in an attempt to correct for measurements done under non-standard conditions.
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
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 $k_Q$
For chambers listed in both the addendum and the original TG-51 protocol, the $k_Q$ factors listed in the addendum should be used.

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.
3 sub-types (NOTE: WGTG51 definitions) –

i. 0.6 cm³ reference chambers (e.g., NE2571, PR-06C)

ii. 0.125 cm³ scanning chambers (e.g., PTW31010, IBA CC13)

iii. 0.02 cm³ micro chambers (e.g., Exradin A16, Pinpoint™)
Majority are 0.6 cm³ ‘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
TG 51 modification for ion chambers. This is still an area of discussion.

- \( k \) is modification caused by phantom scatter conditions being different
- \( k \) is generally \(<0.5\%\)
The other modification that is especially appropriate for very small fields is the flatness of the field.

The chamber must be small enough to fit within the field.
Chambers in small fields

- Moving to smaller fields – IMRT, tomotherapy, cyberknife, gammaknife
- Remember conditions of TG51 calibration: 30 cm x 30 cm x 30 cm phantom with the correct scatter conditions.
- Small fields violate these scatter conditions – a modification needs to be made.
Just doing a measurement and applying ADCL calibration does not mean that it is right. You need to understand the equipment and see through the measurement. Numbers no matter how precise cannot by themselves imply anything.

Precision and accuracy of dose measurements and reporting of the measurement details should be sufficient to allow the work to be interpreted and repeated. The details should allow valid comparisons to be made, both in the same laboratory and by other laboratories.
MRRC produce secondary standards where needed
Mammography beams with a FAC
HDR Ir-192 Use NIST calibrated chambers and 7 distance
Eye plaques Ru-106 developed an extrapolation chamber.
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
All of my graduate students
All of the staff of the Radiation Calibration Laboratory
All of the UW MRRC customers whose calibrations support Metrology research