Calibration Standards: NIST to Secondary Laboratories

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Standards

- **Why do we need standards?**
- **For uniformity – illustrate by the quantity length**
- **In the ancient world the cubit was used.**
- **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**.

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.”
- 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.”

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.”**

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**

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 to the user.
- I will limit my talk to the US for the interest of completeness and time.

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

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 % ≤ D ≤ +10 % so that this balance between healthy tissue and cancerous tissue is not compromised**

Importance of Standards

- **These 10% criteria translate into necessity for standards and calibration requirements**
- **AAPM in conjunction with NIST set up secondary laboratories for medical ionizing radiation calibrations – (more later).**

Uncertainties (these are rough numbers)

- NIST claims 0.5% depending on the standard
- ADCLs add 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 %.

Standards

- These quantities are very important, especially for medical
- There are Standards for a number of quantities such as Absorbed dose to water. These are done with precision and uniformly.
- Calibration of Ionization chambers and sources essential for radiation therapy or Brachytherapy.
- Standards start with the primary laboratories, namely NIST or NRC-Canada, etc.

Absorbed Dose Standards

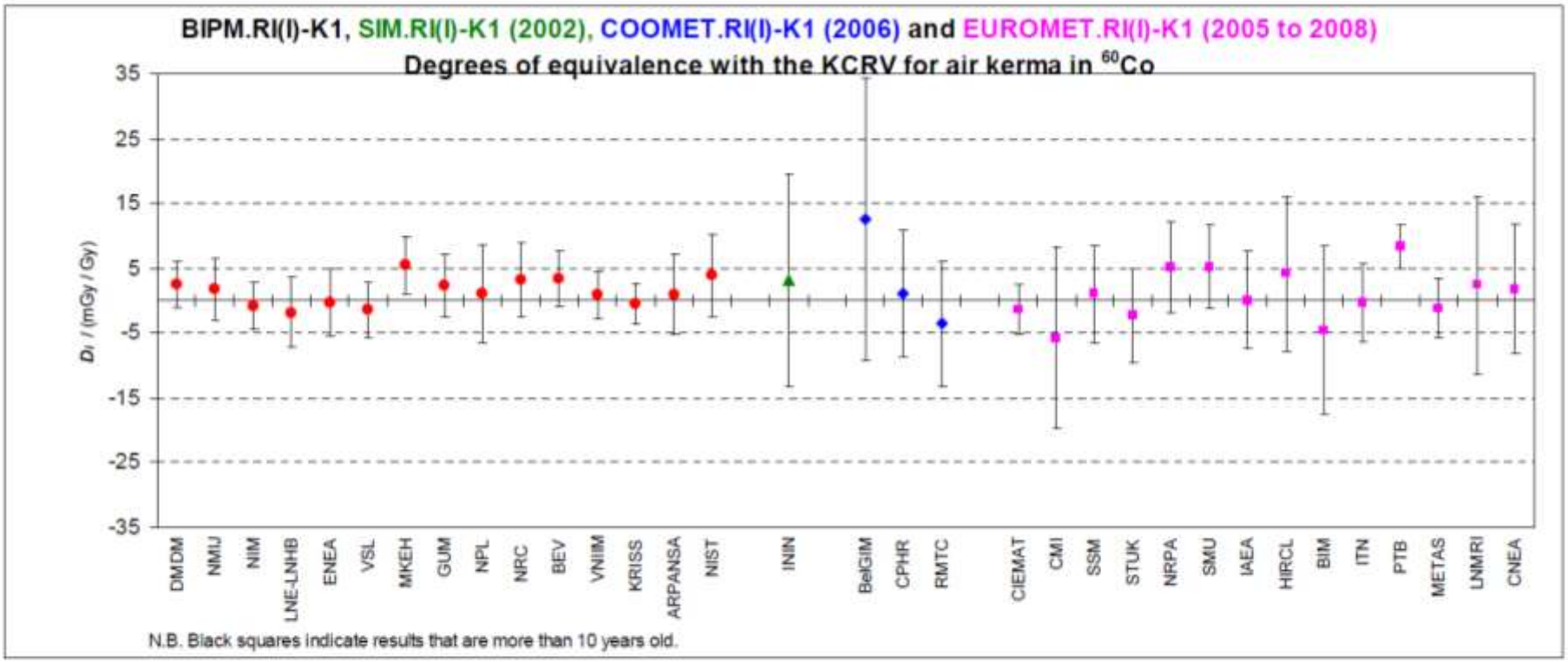
Different approaches with different uncertainties

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

NIST Calibration Procedures

- **NIST 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**

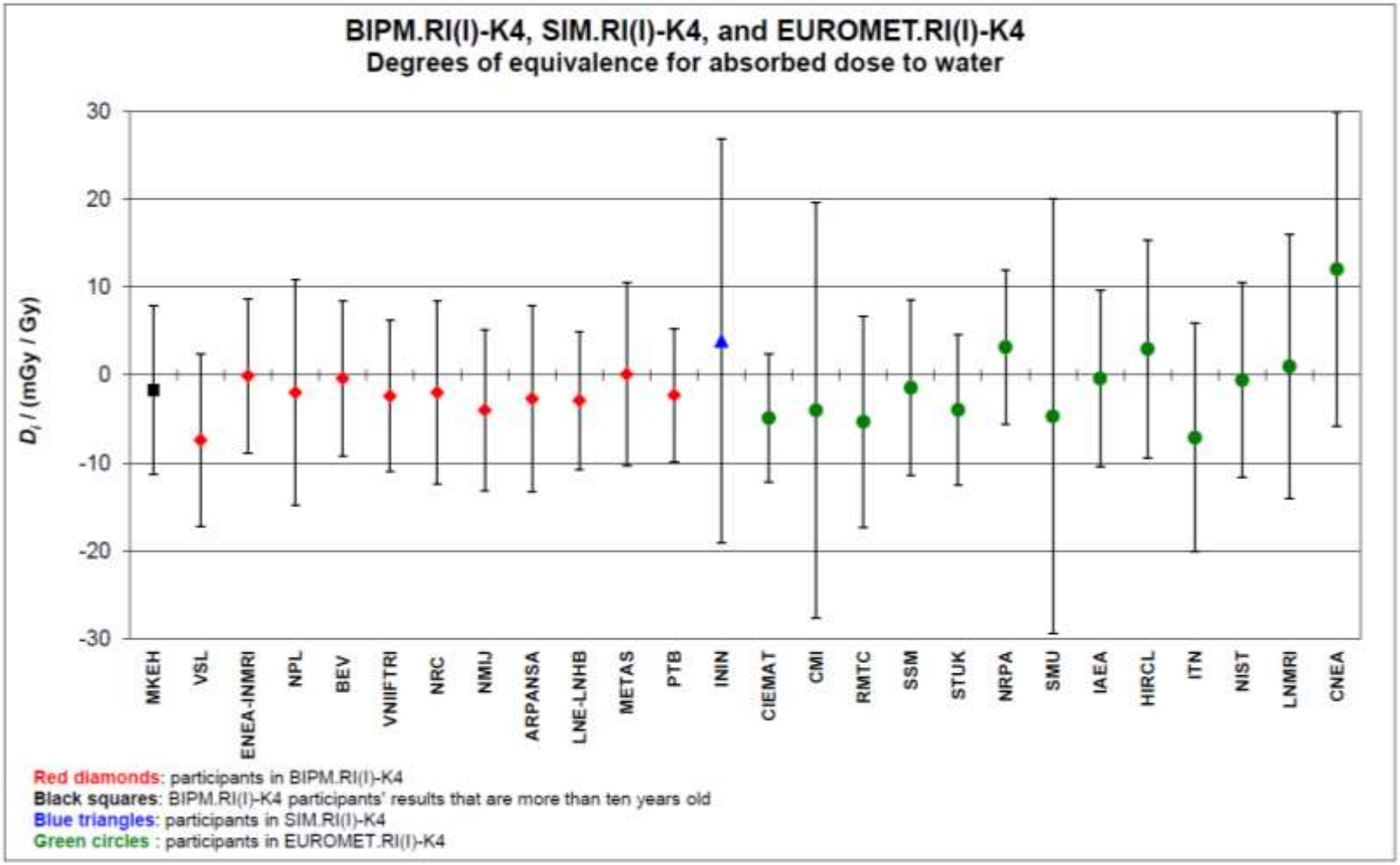
Comparison of Primary Labs Air Kerma for Cobalt



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

Courtesy Michael Mitch, PhD, NIST

Comparison of Primary Labs Absorbed Dose to Water for Cobalt



Courtesy Michael Mitch, PhD, NIST

NIST transfer to Secondary Labs

- **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**

Accredited Dosimetry Calibration Laboratories

- 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
- 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

ADCL Calibrations Provided

- **Therapy applications - ADCL**
  - **External beam: Cobalt and X-ray**
  - **Brachytherapy sources and chambers**
- **Diagnostic applications – chambers – generally through an M series x-ray standard**

ADCL activities

- There is a need to have traceability delivered by the Accredited Dosimetry Calibration Laboratories
- Hospital Physicists generally have requests and ask questions about the traceability or “how to measure”
- Users must insist on traceable standards from NIST through the ADCLs

AAPM: NIST and ADCL

- **AAPM has established protocols to determine dose to the patient.**
- **Task Groups formed to provide method of calculation.**
- **For example: Absorbed Dose to Water results in a calibration coefficient, $N_{D_W}^{^{60}Co}$ for the ionization chamber transferred to the user.**

Intercomparisons with NIST or Measurement Quality Assurance

- **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**

Calibration Laboratories Provide

- **Maintenance of accuracy and precision is very important for Medical Applications**
- **Knowledge of characteristics of chambers is very important**
- **Medical Applications rely heavily upon precise traceable calibrations.**

Brachytherapy

- **Generally NIST calibrates sources, which are then transferred to the ADCL**
- **The secondary transfer standard at the ADCL is a well ionization chamber**
- **Well ionization chambers are calibrated for the Medical Physics users.**

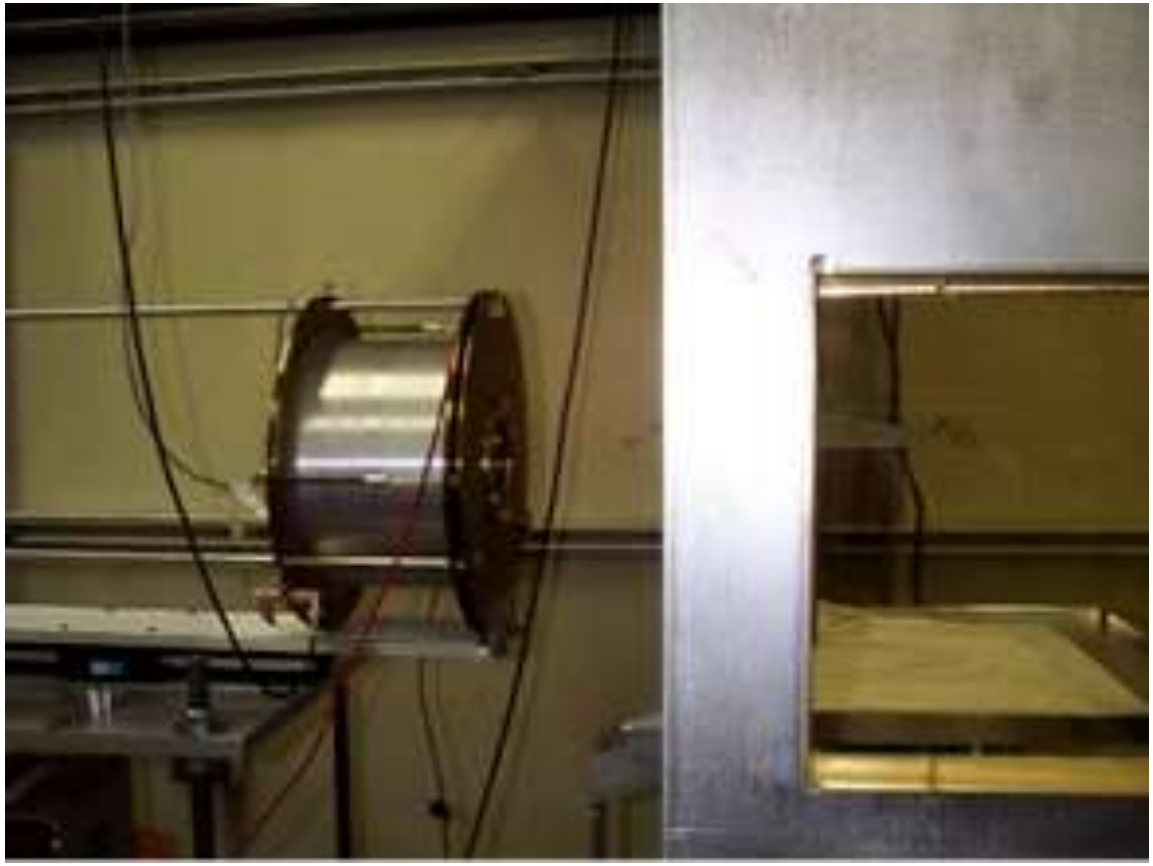
Calibration Quantities and Units

- **Air kerma strength ($\mu Gym^2/hr$)**
  - **Actual characterization of source *output* in terms of the *dose* delivered to air. Related to exposure primarily by W/e, which is the average energy required to produce an ion pair in dry air. Taken into vacuum**
- **Endorsed by the AAPM for use in treatment planning protocols, and adopted in TG 43.**

NIST Brachytherapy Standard

- **Based on the Wide Angle Free Air Chamber (WAFAC)**
- **The WAFAC has improved geometry for line sources, better sensitivity and filters the low energy contamination.**

NIST Wide Angle Free Air Chamber (WAFAC)



Courtesy of Mike Mitch, PhD, NIST

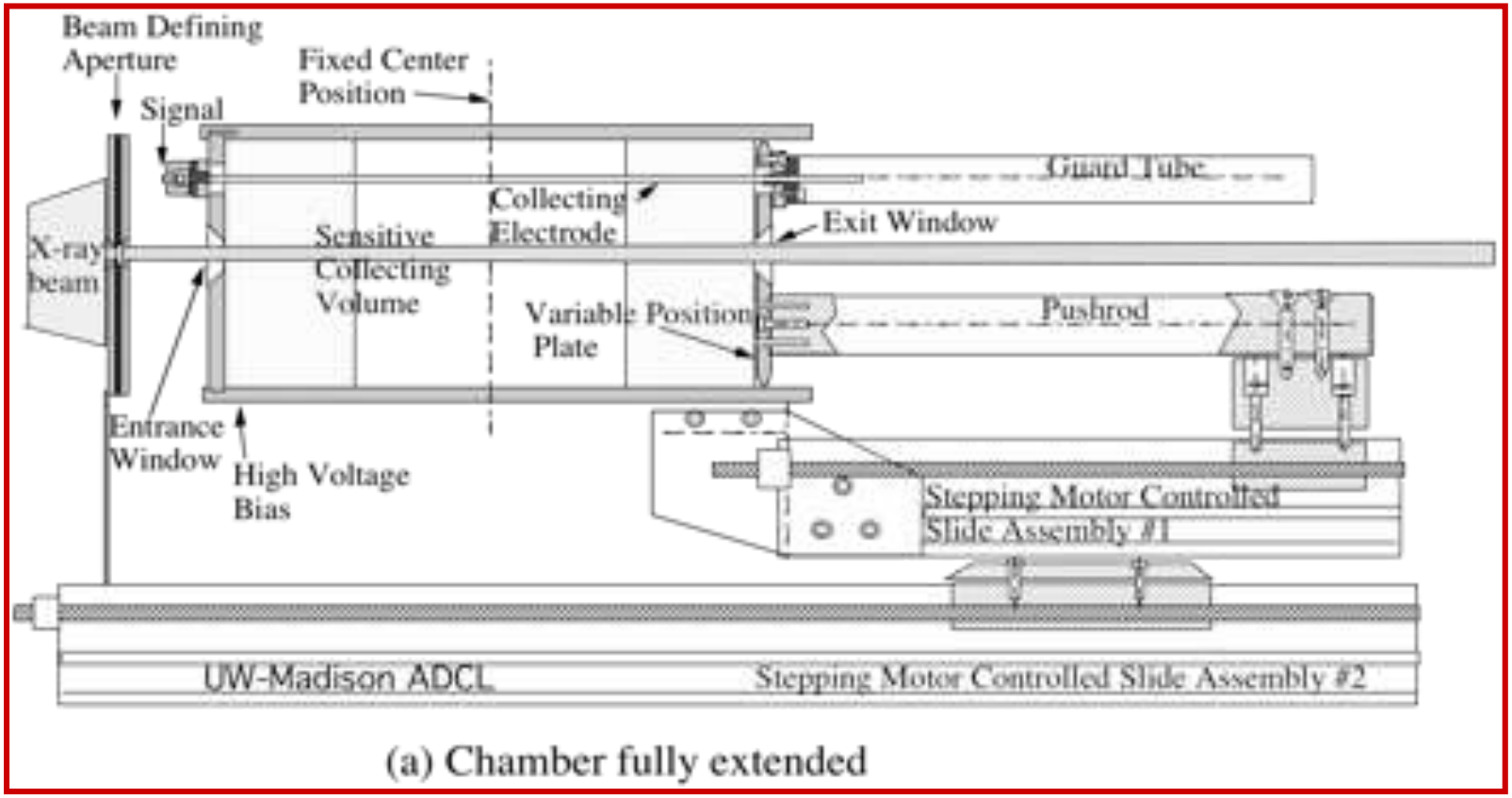
NIST/ADCL Brachytherapy Comparisons

- **Comparison of Brachytherapy sources at NIST for Low Dose Rate Sources must occur each year.**
- **NIST circulates sources through ADCLs**
- **Comparison between NIST and ADCLs are $\leq$ 1 %.**

Absolute Standards for Diagnostic

- Maintained at NIST for various x-ray energies
- As a example, look at Mammography – the first completed NEEDS report done in conjunction with UW, NIST and FDA.
- It used a free-air chamber for 50 keV or less called the Attix Free Air Chamber

Schematic of UW Free Air Chamber developed for Mammography



(a) Chamber fully extended

ADCL comparison Mammography

- **Generally the comparison between NIST and the ADCLs is ≤ 1 %.**

Future Devices

- New devices, sources are introduced to medical purposes in an attempt to improve patient care. Calibration may be questionable.
- When Manufacturers improvise, the patient becomes the dosimeter and there can be great variation.
- AAPM, CIRMS and FDA need to insist that there be a NIST traceable calibration to a standard
- This should be completed within a reasonable time period.

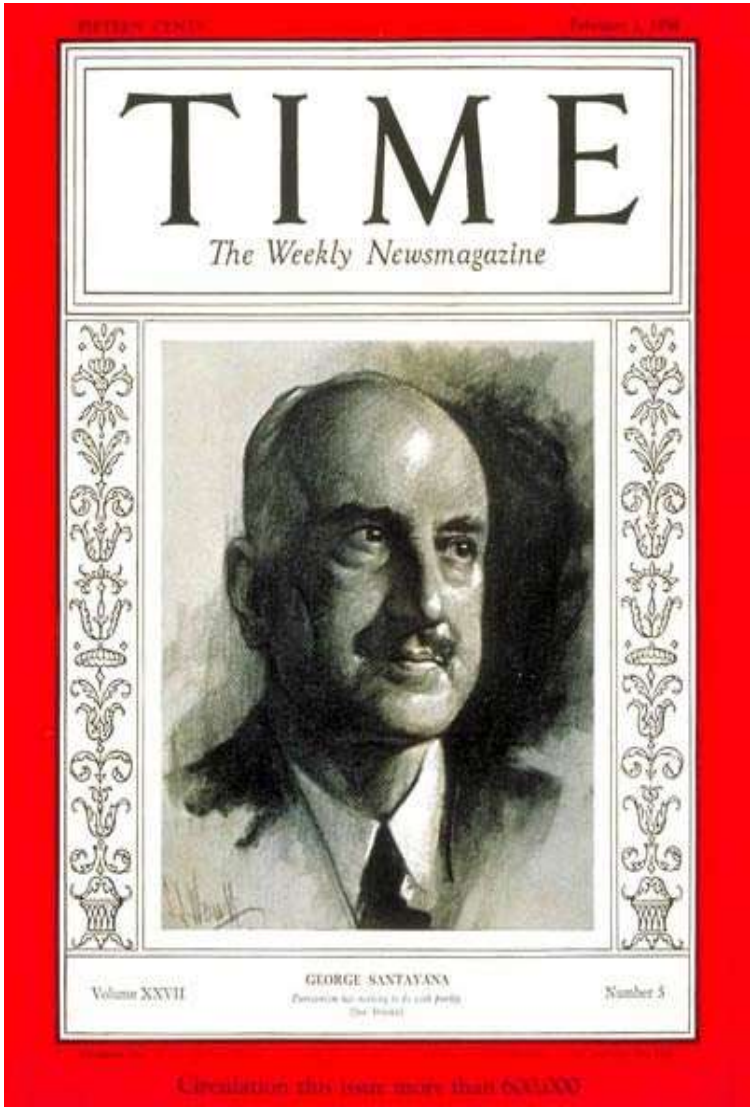
Future Standards

- **The procedure for new brachytherapy devices was given in AAPM guidelines.**
  - Guidelines by the AAPM and GEC-ESTRO on the use of innovative brachytherapy devices and applications: Report of Task Group 167, Med Phys 43: 3178 (2016)
- **Without these standards, there is a danger to the patient**

Lesson to ponder

"Those who do not remember the past are condemned to repeat it."

George Santayana, Harvard Professor and poet



Conclusions

- **Maintenance of accuracy and precision is very important for Medical Applications**
- **Knowledge of characteristics of chambers is very important**
- **Medical Applications rely heavily upon precise traceable calibrations.**

Conclusions

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

Acknowledgements

- All of my graduate students
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