It is estimated that in 2018, 554,000 cancer patients will receive radiation therapy during their initial treatment course. Assuming 20-30 fractions per treatment course, there will be 11 to 17 million individual treatment sessions each year or on average a machine is turned on to treat a patient 54,000 every week day.

The correctness and accuracy of the absorbed dose for each of the treatment sessions is initially guaranteed by the treatment machine calibration. In most cases the calibration protocol used will be an AAPM protocol.

Texas Administrative Code: Radiation Safety Requirements for Accelerators, Therapeutic Radiation Machines, Simulators and Electronic Brachtherapy Devices §289.229

But that was not always the case!

One of the first calibration protocols in the United States preceded the founding of the AAPM by 20 years.
Communication
The Tissue Dose
Lewis G. Jacobs, M.D.
Radiology Vol. 33 #4 October 1939
“There has been a great deal of material published of late by physicists who have attempted to solve the problem of tissue dose…While it is quite proper for the physicist to limit his work to the field in which he is skilled, the radiotherapist must give attention to all other phases of this subject in applying these measurements and recommendations to practical therapy.”

(continued)
“If the physical dose is calibrated with a degree of precision differing from the precision with which we can measure the biologic effect, the total precision of our measurement will be that of the less precise of the two…It is, therefore, not unfair to conclude that, even if our physical dose has a precision of +/- 10 per cent, our total precision is certainly not better than +/- 30 per cent, and probably not that good.”
“Quimby had suggested that clinical calibrations should have an error close to 5% but certainly not greater than 15%.”
This was the age of orthovoltage (kilovolt machines) where the skin dose was 100% and the treatment was monitored by the skin reaction. There were four degrees of reaction:
1. Threshold erythema, a distinct reddening
2. Dry desquamation, loss of superficial layers of the epidermis
3. Moist desquamation, loss of basal layer of the epidermis.
4. Necrosis, irreversible ulceration, dermal destruction

The generally accepted maximum level of skin reaction was early level 3-moist desquamation. Since the dose at which patients reached this level could vary by as much as 30% between patients, radiologists questioned what was the use of calibrating the output to 10%.
Precision in Dosimetry
R. R. Newell
(January 24, 1940)
“It will result in disaster if the radiologist in
narrowing his attention to catch a few roentgen
should slip into a blunder amounting to several
erythema doses…The conclusion is that the
physicists can’t do the radiologist’s dosimetry for
him, they can only provide him with the tools. In
using them he [the radiologist] has to watch
everything, but should not forget above all to watch
his patient.”
(Unpublished memo)

Physicists could be tolerated but never
regarded as professional colleagues. Let
them do their measurements even though
the results would have little or nothing to
do with the patient or treatment outcome.

Comment by Taylor on
Newell’s Memo

“Just because there may be a
large biologic uncertainty,
there is no excuse for
tolerating sloppy physical
measurements where little
effort will yield satisfactory
measurements. This will
lead eventually to complete
degradation in the whole
therapy technique.”

Lauritson Taylor
1902-2004
Chief of the Atomic and
Radiation Division. NBS
Calibrations were done with the ion-chamber “in-air” in roentgens /min.

Treatments were controlled by time.

Chambers were calibrated at NBS for specified HVLs
No build-up cap on the chambers

Dosimetry Measurements 1949
Treatment time: 4min 27s regardless of patient, field size, field separation and date. In phantom studies dosimeters were good to +/- 6%
15 sets of measurements between October and November 1949 on the same patient, the dose varied by +/- 23%
The basic reason for having calibration protocols.
“…sloppy physical measurements …will lead eventually to complete degradation in the whole therapy technique.”

After World War II new radiation therapy equipment became available:
- Cobalt 60 1.25 Mev $\gamma$-rays (0.5cm)
- Van de Graaff accelerators 2MV X-rays (~0.5cm)
- Linear accelerators 6MV X-rays (1.5cm)
- Betatrons 22MV X-rays (4cm)
- Skin reaction much less because of the dose build-up at depth

For the higher energies calibrations in terms of exposure were not viable. The highest energy for which the NBS and the NPL offered an exposure calibration for ionization chambers with the appropriate build up cap, was cobalt 60 $\gamma$-rays and 2 MV x-rays respectively
In response to a question by Rosalyn Yallow, Sinclair pointed out that “this is not a difference in measurement. This is a difference in the corrections believed necessary to the measurement after you have made it.”
1958 saw the beginning of the formation of the AAPM, in which Warren Sinclair played a significant part. The new organization was to be concerned primarily with the professional needs of its members. Medical physicists were not regarded as competent professionals by the medical profession, hospital administrations or government agencies.

However there was a dissenting voice: “Of somewhat more than passing interest, Mr du(Sault of) Temple stated his belief that ‘the prestige and impact of a Society of specialists depend foremost on what it gives the scientific community. Thus we were in error to exclude scientific considerations from our purposes’. Nevertheless, we did not then believe that another scientific forum was needed.”
Gail Adams Med Phys Vol 5 No.4 1978

A list was made of the Seven Functions for the AAPM. Here are the first few:

1. Represent the membership in intercourse with government agencies and other organizations
2. Consider problems of professional competence, including certification.
3. To the extent that specific needs are not met elsewhere:
   a. Establish standards (e.g., dosimetry)
It took about three years for changes: 1961 First AAPM scientific sessions at RSNA meeting in November. 1962 First Scientific Committee at RSNA meeting in November. 1963 Enter SCRAD (Sub-Committee on Radiation Dosimetry) at RSNA meeting in November. Blackstone Hotel.

The Sub-Committee on Radiation Dosimetry (SCRAD) of the American Association of Physicists in Medicine

2. Protocol for the Dosimetry of X- and Gamma-Ray Beams with Maximum Energies Between 0.6 and 50 MeV
Scientific Committee on Radiation Dosimetry (SCRAD) of The American Association of Physicists in Medicine
3. A protocol for the determination of absorbed dose from high—energy photon and electron beams
Task Group 21, Radiation Therapy Committee, American Association of Physicists in Medicine
Med. Phys. 10 (6), Nov/Dec 1983
(4. The calibration and use of plane-parallel ionization chambers for the dosimetry of electron beams: An extension of of the 1983 AAPM protocol report of AAPM Radiation Therapy Committee Task Group No.39
Med. Phys. 21(8), August 1994 )

5. AAPM’s TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams
Med. Phys. 26 (8), September 1999
( Radiation Therapy Committee Task Group #51)
(6. Addendum to the AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon beams
Med. Phys. 41 (4), April 2014)

First published in 1974
For completeness need to add two other protocols that were not published in either journal but as AAPM Reports: -
(a) No.7 “Protocol for Neutron Beam Dosimetry” (1980)
Radiation Therapy Committee Task Group #18
(b) No. 16 “Protocol for Heavy Charged Particle Therapy Beam Dosimetry” (1986)
Radiation Therapy Committee Task Group #20

Today we will look at just the x-ray and electron beam protocols that span 48 years.
During that time significant changes took place.
megavoltage x-ray and electron beams machines were introduced
Calibration standard went from exposure to absorbed dose to water
The units went from cgs (centimeter, gram, second) to SI units. The rad replaced by the gray, mmHg by kPa
Digital Computers and Monte-Carlo simulations became available
Improvement in measuring equipment both in electrometers and ion chambers.
Quote from TG21, “It is inevitable that concepts change and data and instruments are refined.”
In addition the radiation oncology community was changing. At the same time the AAPM was being formed the radiation oncologists were starting ASTRO. The old guard of radiologists were being replaced by a new generation who were pushing for a more scientific approach to radiation oncology.

This group believed that advances in radiation oncology and patient survival could only come about with randomized clinical trials. But no single institution in the USA would see enough patients with the same diagnosis to mount such trials. Only with combined clinical trials would there be enough patients to produce data that would be statistically meaningful, and the Radiation Therapy Oncology Group (RTOG) was formed.

For combined clinical trials the dosimetry has to be uniform at all participating institutions and to ensure that it is the Radiological Physics Center (RPC) was created. Such uniformity starts with the accuracy of the treatment machine calibration.
The development of protocols preceded the RTOG and the RPC and was undertaken as a sub-committee on radiation dosimetry (SCRAD) and later as task groups of the Radiation Therapy Committee.

Protocol for the Dosimetry of High Energy Electrons

PMB 11 No.4, 505-520 1966

Why a protocol for high energy electrons and not one for high energy photons?

A Code of Practice for the Dosimetry of 2 to 8 MV X-ray and Caesium-137 and Cobalt-60 γ-ray Beams (HPA 1964)

Phys. Med. Biol. 9 No.4 1964

\[ D = R \times N \times C_\lambda \]

- \( D \) = the dose in water at the chamber center
- \( R \) = corrected chamber reading
- \( N \) = the chamber exposure factor
- \( C_\lambda \) = overall conversion factor

First protocols to recommend calibration using a water phantom.
Protocol for the Dosimetry of High Energy Electrons

“The increasing number of high energy electron beam installations in the United States makes it highly desirable that standard methods for the measurement of output and absorbed dose be explicitly described in order to facilitate uniformity of dosimetry...

This protocol presents recommendations of SCRAD for a uniform dosimetry for high energy electron beams.”

PMB 11 No.4, 505-520 1966
A similar expression for electrons, to the $C_\lambda$ formula, was derived by Almond 1967 ($C_\Phi^*$), Svensson and Pettersson 1967 (k) and the ICRU Report 21 1972 ($C_E$)

$$D = R \cdot N \cdot C_E$$

$D$ = the dose in water at the chamber center
$R$ = corrected chamber reading
$N$ = the chamber exposure factor
$C_E$ = overall conversion factor (function of energy)


The next protocol from the AAPM was for photon beams.

Protocol for the Dosimetry of X- and Gamma-Ray Beams with Maximum Energies Between 0.6 and 50 MeV

Science Committee on Radiation Dosimetry (SCRAD)


First protocol to give uncertainties for the beam calibrations, 2.5%(Co-60) and 3.4%(30MV), and the last until the addendum for TG 51(2014)
$C_\lambda$ and $C_E$ (1960s and 1970s) were the first generation of protocols and were based on chamber exposure calibration factor. It had tables of dose conversion factors versus nominal energy for photons and electrons respectively, generally for Farmer and Victoreen chambers. Not much attention paid to the actual quality of the beam. This could lead to errors of up to 5%. There were separate protocols for photons and electrons.
There was one significant difference between the concept of $C_\lambda$ and $C_E$: the chamber wall for $C_\lambda$ were assumed to be air-equivalent. The chamber wall for $C_E$ the chamber wall was required to be water-equivalent.
Introduced cavity-gas calibration factor $N_{\text{gas}}$, which can be obtained from the chamber’s exposure, absorbed dose to water or air-kerma factors.

“This paper has been prepared in support of the Task Group 21 on High Energy Dosimetry of the American Association of Physicists in Medicine.”

‘A protocol for the determination of absorbed dose from high—energy photon and electron beams.’ Task Group 21, Radiation Therapy Committee, American Association of Physicists in Medicine Med. Phys. 10 (6), Nov/Dec 1983

TG 21(1983) was the second generation of calibration protocols combining photon and electron, that addressed the problems in the $C_\lambda$ and $C_E$ approach, at the expense of complexity, especially for the chamber specific factors and their variation with beam quality. With complexity came the potential for increased errors. It was based upon the chambers exposure calibration factor although absorbed dose to water calibration factor could be used. Although a water phantom was recommended for measurements, plastic phantoms were allowed. Gave parameters for a number of chambers This was a transition protocol

. AAPM’s TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams
Med. Phys. 26 (8), September 1999
(Radiation Therapy Committee Task Group #51)
Dave Rogers developed the formalism for TG51

TG51(1999) is a third generation protocol and is based upon the chamber’s absorbed dose to water calibration factor. It is a prescriptive protocol, that is it is a “how to” document that describes the steps necessary to perform the calibration for a given photon or electron beam. It is more simple than TG21 and therefore less prone to error.

Summary

The basic reason for having calibration protocols. “…sloppy physical measurements …will lead eventually to complete degradation in the whole therapy technique.”
Clearly there was a need for calibration protocols.

The calibration of treatment machines in terms of absorbed dose to water at the reference depth can be carried, under ideal conditions, with an uncertainty of 0.9%, and for less than ideal conditions, with an uncertainty of 2.1% (TG51 Addendum 2014)

Overall average 5 year cancer survival rate for the 1950s was 30% i.e. for 10 people diagnosed with cancer 3 would have been alive at 5 years after diagnosis and 7 would have died.

Current overall average 5 year cancer survival rate is 70% i.e. for 10 people diagnosed with cancer 7 will be alive at 5 years after diagnosis and 3 will die.
Obviously many reasons for this improvement
But 54,000 times a day the AAPM calibration protocols play a part.

A proud history indeed!
In response to a question by Rosalyn Yallow Sinclair pointed out that “this is not a difference in measurement. This is difference in the corrections believed necessary to the measurement after you have made it.”
Clearly there was a need for calibration protocols.

The calibration of treatment machines in terms of absorbed dose can be carried out with a precision of +/- 1% and an accuracy of +/- 2% traceable to NIST.

The mean dose to the tumor can be determined with an accuracy of +/- 5%.