AAPM 60th. Annual Meeting

History of Calibration Protocols and Laboratories

Calibration Protocols-A Proud History of the AAPM

by

Peter R Almond

August 1 2018

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.

* Journal of Clinical Oncology 28 no. 35 2010

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

"The calibration protocol entitled, "Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams," Task Group 51, Radiation Therapy Committee, American Association of Physicists in Medicine, Medical Physics 26(9): 1847-1870, September 1999, would be accepted as an established protocol."

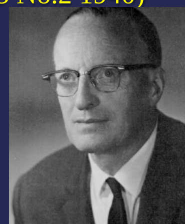
Texas Administrative Code: Radiation Safety Requirements for Accelerators, Therapeutic Radiation Machines, Simulators and Electronic Brachtherapy Devices §289.229

But that was not always the case!

One of the first calibration protocols in the United States preceded the founding of the AAPM by 20years.

RSNA Standardization Committee
Technical Bulletin No.1
The Measurement of Dose in Roentgen Therapy(Radiology 35 No.2 1940)

Edith Quimby 1891-1982



G. Laurence 1905-1987

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."

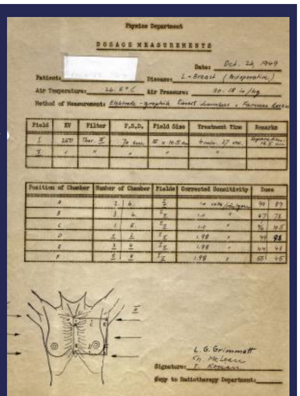
Lauritson Taylor
1902-2004
Chief of the Atomic and Radiation Division. NBS

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 %


Physics Department

DOSAGE MEASUREMENTS

Date: Oct. 24, 1949
Patient:
Disease: L-Breast (Postoperative)
Air Temperature: 24.6°C
Air Pressure: 30.18 in/Hg
Method of Measurement: Elektrode-graphite Correct chambers + Farmer dose...

Field	KV	Filter	F.S.D.	Field Size	Treatment Time	Remarks
I	250	Ther. II	70 cm	15 x 10.5 cm	4 min. 27 sec.	Separation 14.5 cm
II	"	"	"	"	"	

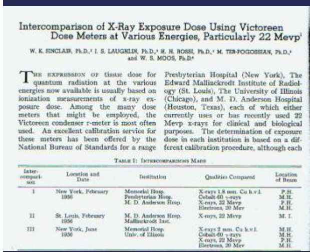
Position of Chamber	Number of Chamber		Fields	Corrected Sensitivity	Dose	
A	2	6	I	1.0 volts/röntgen	99	89
B	3	4	I II	1.0 "	67	78
C	1	5	I II	1.0 "	96	105
D	4	2	I II	1.98 "	99	98
E	3	4	I II	1.98 "	44	48
F	5	6	I II	1.98 "	55	45

L. G. Grimmett
Ch. McLean
Signature: F. Kossman
Copy to Radiotherapy Department:

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 γ-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 γ-rays and 2 MV x-rays respectively



Intercomparison of X-Ray Exposure Dose Using Victoreen Dose Meters at Various Energies, Particularly 22 Mevp[1]

W. K. SINCLAIR, Ph.D.,[2] J. S. LAUGHLIN, Ph.D.,[3] H. H. ROSSI, Ph.D.,[4] M. TER-POGOSSIAN, Ph.D.,[5] and W. S. MOOS, Ph.D.[6]

The expression of tissue dose for quantum radiation at the various energies now available is usually based on ionization measurements of x-ray exposure dose. Among the many dose meters that might be employed, the Victoreen condenser r-meter is most often used. An excellent calibration service for these meters has been offered by the National Bureau of Standards for a range

Presbyterian Hospital (New York), The Edward Mallinckrodt Institute of Radiology (St. Louis), The University of Illinois (Chicago), and M. D. Anderson Hospital (Houston, Texas), each of which either currently uses or has recently used 22 Mevp x-rays for clinical and biological purposes. The determination of exposure dose in each institution is based on a different calibration procedure, although each

TABLE I: INTERCOMPARISONS MADE

Inter-comparison	Location and Date	Institution	Qualities Compared	Location of Beam
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II	St. Louis, February 1956	M. D. Anderson Hosp. Mallinckrodt Inst.	X-rays, 22 Mevp	M. I.
III	New York, June 1956	Memorial Hosp. Univ. of Illinois	X-rays 2 mm. Cu h.v.l. Cobalt-60 γ-rays X-rays, 22 Mevp Electrons, 20 Mev	M.H. M.H. P.H. M.H.

Radiology70(5) 1958
Presented at RSNA
December 1956

Warren Sinclair
1924-2014

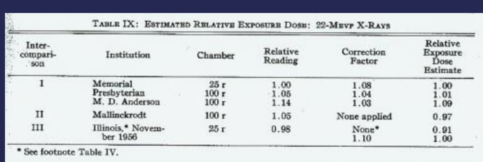


TABLE IX: ESTIMATED RELATIVE EXPOSURE DOSE: 22-MEVP X-RAYS

Inter-comparison	Institution	Chamber	Relative Reading	Correction Factor	Relative Exposure Dose Estimate
I	Memorial Presbyterian M. D. Anderson	25 r 100 r 100 r	1.00 1.05 1.14	1.08 1.04 1.03	1.00 1.01 1.09
II	Mallinckrodt	100 r	1.05	None applied	0.97
III	Illinois,* November 1956	25 r	0.98	None* 1.10	0.91 1.00

* See footnote Table IV.

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.

1. **Protocol for the Dosimetry of High Energy Electrons**
The Sub- Committee on Radiation Dosimetry (SCRAD) of the American Association of Physicists in Medicine
Phys. Med. Biol., 1966, vol., 11, No, 4, 505-520

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
Phys. Med. Biol., 1971, vol., 16, No 3, 379-396

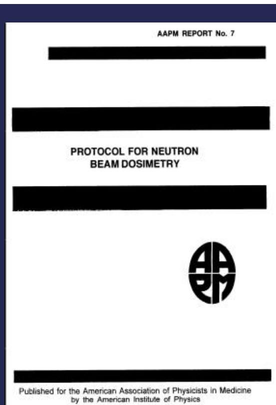
3. **A protocol for the determination of absorbed dose from high—energy photon and electron beams**
Task Group 21, Radiation Therapy Committee, American Association of Physicists in Medicine
Med. Phys. 10 (6), Nov/Dec 1983
(4. **The calibration and use of plane-parallel ionization chambers for the dosimetry 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



AAPM REPORT No. 7

PROTOCOL FOR NEUTRON BEAM DOSIMETRY

Published for the American Association of Physicists in Medicine by the American Institute of Physics

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 Dosimetery 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

$D = R.\ N.\ C_{\lambda}$

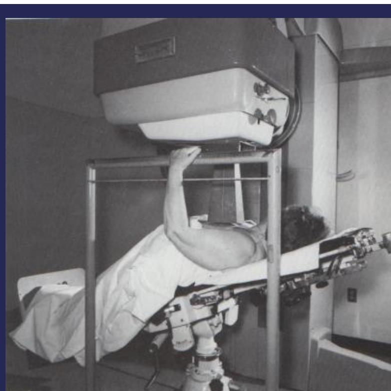
D = the dose in water at the chamber center
R = corrected chamber reading
N = the chamber exposure factor
C_{λ} = overall conversion factor

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



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PMB 11 No.4, 505-520 1966

Protocol for Dosimetry of High Energy Electrons 513

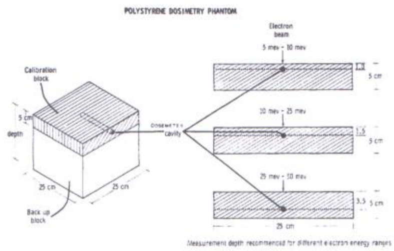


Fig. 3. Polystyrene Intercomparison Phantom for absorbed dose and 'output' measurements.

A similar expression for electrons, to the C_λ formula, was derived by Almond 1967 (C_F)*, Svensson and Pettersson 1967 (k) and the ICRU Report 21 1972 (C_E)

$$D = R.N.\ C_E$$

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)

*Phys. Med. Biol. 12 1967

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)
Phys. Med. Biol. 16 No 3 1971
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_λ 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_λ and C_E : the chamber wall for C_λ were assumed to be air-equivalent. The chamber wall for C_E the chamber wall was required to be water-equivalent.

Review Article

A formalism for calculation of absorbed dose to a medium from photon and electron beams

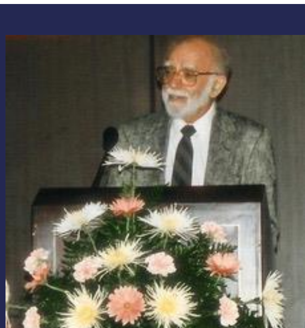
Robert Loevinger

Center for Radiation Research, National Bureau of Standards, Washington, DC 20234

(Received 2 May 1980; accepted for publication 17 July 1980)

A formalism is derived that relates the absorbed dose to a medium from photon and electron beams to the photon calibration factor of an ionization chamber. The formalism is applicable to the photon and electron beam energies that are currently of interest in radiation therapy. It is developed in terms of a cavity-gas calibration factor, a quantity characteristic of the chamber and independent of the energy of the calibration beam assuming the energy expended per ion pair is energy independent. The cavity – gas calibration factor can be obtained from a chamber calibration performed in terms of exposure,absorbed dose to water,or air kerma. The perturbation corrections due to replacement of the surrounding medium by the chamber wall and cavity are identified as ratios of the photon energy fluence,or the electron fluence, at the position of the chamber center. The unmanageable complexities of a theory that covers an ionization chamber made of several materials are avoided by limiting the development to a chamber made of a single material with the expectation that the inhomogeneities of real chambers can be treated as perturbations. Attention is called to certain theoretical aspects of this dosimetry development that do not appear to have been previously recognized.

Med. Phys. 8(1), Jan/Feb. 1981



Bob Loevinger

Introduced cavity-gas calibration factor N_{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 Dosimtery of the American Association pf Physicist 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_λ 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)

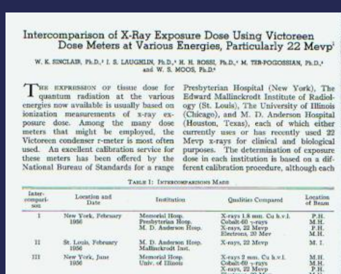
Overall average 5 year cancer survival rate for the 1950s was 30%
i.e. for 10 people diagnosed with cancer 3 would have been alive at 5 years after diagnosis and 7 would have died.

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.

AAPM 60th. Annual Meeting

Obviously many reasons for this improvement
But 54,000 times a day the AAPM calibration protocols play a part.

A proud history indeed!



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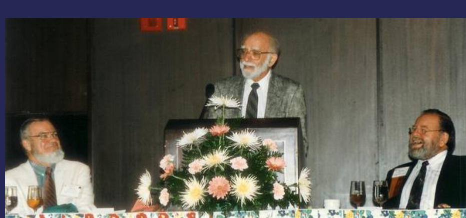

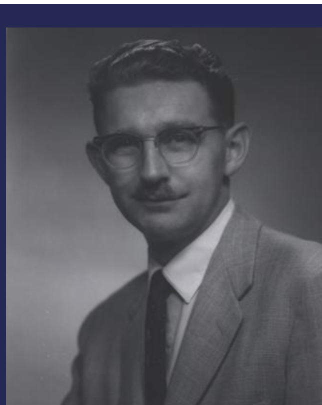

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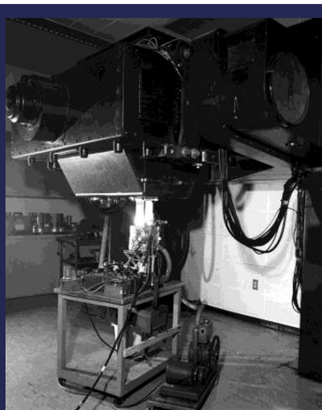

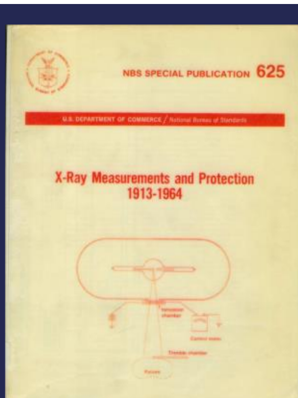

Clearly there was a need for calibration protocols.

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%,