National Institute of Standards and Technology

REPORT OF AIR KERMA CALIBRATION

for

Oak Ridge National Laboratory
Contact: Jim Bogard

Radiation Detection Chamber: Exradin A3, SNXR021761

Calibrations performed by Michelle O'Brien CMO

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For the Director
National Institute of Standards and Technology
by

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Information on technical aspects of this report may be obtained from Michelle O'Brien, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460,Gaithersburg, MD 20899, (301)975-2014. The results provided herein were obtained under the authority granted by Title 15 United States Code Section 3710a. As such, they are considered confidential and privileged information, and to the extent permitted by law, NIST will protect them from disclosure for a period of five years, pursuant to Title 15 USC 3710a(c)(7)(A) and (7)(B).

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Chamber orientation: the cavity was positioned in the center of the beam with the stem of the chamber perpendicular to the beam direction
Chamber collection potential: -300 volts with respect to the inner electrode (- charge was collected)
Chamber rotation: the high voltage wire faced the source of radiation
Environmental conditions: the chamber is assumed to be open to the atmosphere
Average leakage: less than 0.003% of signal

A detailed study of ionization recombination was not performed and no correction was applied to the calibration coefficient(s). If the chamber is used to measure an air-kerma rate significantly different from that used for the calibration, it may be necessary to correct for recombination loss.

Beam Code	Half –Value Layer		Equilibrium Shell Added	Calibration Coefficient (Gy/C) 295.15 K (22 °C) and 101.325 KPa (1 Atm)	Air- Kerma Rate (Gy/s)	Calibration Distance (cm)
	mm Al	mm Cu				
M30	0.36		NO	9.151E+06	2.90E-03	50
M60	1.64	0.05	NO	8.099E+06	4.18E-04	100
M100	5.00	0.20	NO	7.989E+06	3.74E-04	100
S60	2.79		NO	7.935E+06	1.36E-04	100

NIST Calibration Conditions for X- and Gamma-Ray Measuring Instruments

Beam code	Additional Filtration [a]				Half-value layer[b] (HVL)		Homogeneity coefficient (HC)		Effective energy
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu	(keV)
X-Ray Beam Qualities									
L10					0.037		86		
L15					0.059		70		
L20					0.070		72		
L30	0.30				0.23		60		
L40	0.53				0.52		61		
L50	0.71				0.79		63		
L80	1.45				1.81		56		
L100	1.98				2.80		58		
M20	0.27				0.15		72		
M30	0.5				0.36		65		
M40	0.89				0.74		67		
M50	1.07				1.04		68		
M60	1.81				1.64	0.052	63	60	
M80	2.86				2.98	0.10	68	61	
M100	5.25				5.00	0.20	74	55	
M120	7.12				6.72	0.31	77	53	
M150	5.25	0.25			10.1	0.66	88	63	
M200	4.35	1.12			14.7		94		
M250	5.25	3.2			18.3		98		
M300	4.25		6.5		21.7		100		
H10	0.105				0.051		77		
H15	0.5				0.16		87		
H20	1.01				0.36		89		
H30	4.50				1.20		86		
H40	4.53	0.26			2.93		94		
H50	4.0			0.1	4.2	0.14	93	93	38
H60	4.0	0.61			6.0	0.25	94	94	46
H100	4.0	5.2			13.4	1.15	97	92	80
H150	4.0	4.0	1.51		16.9	2.43	100	96	120
H200	4.0	0.6	4.16	0.77	19.7	4.10	99	99	166
H250	4.0	0.6	1.04	2.72	22	5.19	99	98	211
H300	4.1		3.0	5.0	23	6.19	99	98	252
S60	4.35				2.79	0.09	76	66	
S75	1.50				1.81		58		
Gamma-Ray Beam Qualities									
^{137}Cs						10.8			662
^{60}Co						14.9			1250

[a]The additional filtration value does not include the inherent filtration. The inherent filtration is approximately 1.0 mm Be for beam codes L10-L100, M20-M50, H10-H40 and S75; and 3.0 mm Be for beam codes M60-M300, H50-H300 and S60.[b]The HVL values were measured directly using the two new x-ray tubes installed in November of 2001 and May of 2002.

ISO X-Ray Beam Quality Parameters Offered at NIST

Beam	Additional Filtration (mm)[a]				First HVL		Second HVL	
Code	Al	Cu	Sn	Pb	mmAl	mmCu	mmAl	mmCu
HK10					0.04		0.05	
HK20	0.15				0.13		0.16	
HK30	0.52				0.39		0.59	
HK60	3.19					0.08		0.11
HK100	3.90	0.15				0.31		0.46
HK200		1.15				1.72		2.43
HK250		1.60				2.52		3.37
HK280		3.06				3.45		4.07
HK300		2.51				3.46		4.21
WS60		0.3				0.177		0.23
WS80		0.529				0.337		0.44
WS110		2.029				0.97		1.13
WS150			1.03			1.88		2.13
WS200			2.01			3.09		3.35
WS250			4.01			4.30		4.50
WS300			6.54			5.23		5.38
NS10	0.095				0.051		0.060	
NS15	0.49				0.15		0.18	
NS20	0.90				0.32		0.33	
NS25	2.04				0.69		0.76	
NS30	4.02				1.16		1.35	
NS40		0.21				0.085		0.092
NS60		0.6				0.25		0.26
NS80		2.0				0.59		0.66
NS100		5.0				1.13		1.19
NS120		4.99	1.04			1.70		1.85
NS150			2.50			2.40		2.52
NS200		2.04	2.98			4.09		4.20
NS250			2.01	2.97		5.26		5.32
NS300			2.99	4.99		6.17		6.30
LK10	0.30				0.062			
LK20	2.04				0.43		0.43	
LK30	3.98	0.18			1.48			
LK35		0.25			2.16		2.16	
LK55		1.19				0.26		
LK70		2.64				0.51		
LK100		0.52	2.0			1.27		
LK125		1.0	4.0			1.94		
LK170		1.0	3.0	1.5		3.59		
LK210		0.5	2.0	3.5		4.68		
LK240		0.5	2.0	5.5		5.49		

a The additional filtration does not include the inherent filtration. The inherent filtration is a combination of the filtration due to the monitor chamber plus 1 mm Be for beam codes LK10-LK30, NS10-NS30, HK10-HK30 and for all other techniques the inherent filtration is adjusted to 4 mm Al.

Explanation of Terms Used in the Calibration Procedures and Tables

Air Kerma: The air–kerma rate at the calibration position is measured by a free-air ionization chamber for x radiation and by graphite cavity ionization chambers for ^{60}Co and ^{137}Cs gamma radiation, and is expressed in units of grays per second (Gy/s). The gamma-ray air-kerma rates are corrected to the date of calibration (from previously measured values) by decay corrections based on half-lives of 5.27 years for ^{60}Co and 30.0 years for ^{137}Cs. For a free-air ionization chamber with measuring volume V, the air-kerma rate is determined by the relation:

$$\dot{K} = \frac{I}{\rho_{\text{air}} V} \frac{W_{\text{air}}}{e} \frac{1}{1 - g_{\text{air}}} \prod_i k_i$$

where

$I / (\rho_{\text{air}} V)$ is the ionization current, measured by the standard, divided by the mass of air in the measuring volume

W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in dry air, the value used at NIST is $W_{\text{air}}/e = 33.97$ J/C

g_{air} is the fraction of the initial kinetic energy of secondary electrons dissipated in air through radiative processes, the values used at NIST are 0.0032 for ^{60}Co, 0.0016 for ^{137}Cs and 0.0 (negligible) for x rays with energies less than 300 keV, and

$\Pi \; k_i$ is the product of the correction factors to be applied to the standard.

Air kerma in grays (Gy) is related to exposure (X) in roentgens (R) by the equation:

$$X = \frac{K}{2.58E-4} \frac{1 - g_{\text{air}}}{W_{\text{air}}/e}$$

To obtain exposure in roentgens, divide air kerma in grays by 8.79E-3 for ^{60}Co gamma rays, 8.78E-3 for ^{137}Cs gamma rays, and 8.76E-03 for x rays with energies less than 300 keV.

Beam Code: The beam code identifies important beam parameters and describes the quality of the radiation field. NIST offers four types of reference beam qualities, as well as the ISO reference radiation qualities. NIST beam codes are referred to as L, M, H, and S beams, which stand for light, moderate, heavy, and special filtration, respectively. The number following the letter is the constant potential across the x-ray tube. For gamma radiation, the beam code identifies the radionuclide.

Calibration Distance: The calibration distance is that between the radiation source and the detector center or the reference line. For thin-window chambers with no reference line, the window surface is the plane of reference. The beam size at the stated distance is appropriate for the chamber dimensions.

Calibration Coefficient: The calibration coefficients given in this report are quotients of the air kerma and the charge generated by the radiation in the ionization chamber. The average charge used to compute the calibration coefficient is based on measurements with the wall of the ionization chamber at the stated polarity and potential. With the assumption that the chamber is open to the atmosphere, the measurements are normalized to a pressure of one standard atmosphere (101.325 kPa) and a temperature of 295.15 K (22 °C). Use of the chamber at other pressures and temperatures requires normalization of the ion currents to these reference conditions using the normalizing factor F (see below).

Effective Energy: The effective energy is shown for those beams where it is considered a meaningful characterization of the beam quality. The effective energy for gamma radiation is the mean photon energy emitted by the radionuclide, and for x radiation it is computed from good-geometry copper attenuation data. The initial slope of the attenuation curve is used to determine the attenuation coefficient, and the photon energy associated with this coefficient is given as the "effective energy." The energy vs attenuation-coefficient data used for this purpose were taken from J. H. Hubbell, Int. J. Appl. Radiat. Isot. 33, 1269 (1982). For beam codes H50-H300, the effective energy is well represented by the equation: effective energy = $0.861V$ - 6.1 keV where V is the constant potential in kilovolts.

Equilibrium Shell: Material added to the nominal wall thickness of the chamber to ensure electronic equilibrium.

Half-Value Layer: The half-value layers (HVL) in aluminum and in copper have been determined by measurements with a free-air chamber for x radiation, and have been calculated for the copper HVLs of ^{60}Co and ^{137}Cs.

Homogeneity Coefficient: The homogeneity coefficient is the quotient of the first HVL and the second HVL, generally expressed as a percent.

Humidity: No correction is made for the effect of water vapor on the instrument being calibrated. It is assumed that both the calibration and the use of that instrument take place in air with a relative humidity between 10% and 70%, where the humidity correction is nearly constant.

Normalizing Factor F: The normalizing factor F is computed from the following expression: $F = (273.15 + T)/(295.15H)$ where T is the temperature in degrees Celsius, and H is the pressure expressed as a fraction of a standard atmosphere. (1 standard atmosphere = 101.325 kilopascals = 1013.25 millibars = 760 millimeters of mercury)

Uncertainty: The expanded, combined uncertainty of the calibration described in this report is 1%, of which 0.8% is assigned to the uncertainty in the air-kerma rate of the NIST beam. The expanded, combined uncertainty is formed by taking two times the square root of the sum of the squares of the standard deviations of the mean for component uncertainties obtained from replicate determinations, and assumed approximations of standard deviations for all other uncertainty components; it is considered to have the approximate significance of a 95% confidence limit. Details of the uncertainty analysis are given in: Lamperti, P.J., O'Brien,M., "Calibration of X-Ray and Gamma-Ray Measuring Instruments ", NIST Special Publication 250-58 (2001).

The Radiation Interactions and Dosimetry Group of the NIST Ionizing Radiation Division has made a change in its terminology in calibration and special test reports pertaining to photon and electron dosimetry. This change in terminology is in effect as of 1 May 2002. The proposed changes are based on recommendations in ISO 31-0 (1992) that have been followed for some years now by a number of other international organizations: a quantity with dimensions should be termed a "coefficient," and a quantity that is dimensionless should be termed a "factor."

In this revised terminology, the calibration quantity is defined as the conventional true value of the quantity the instrument is intended to measure, divided by the instrument's reading; this calibration ratio is termed a *coefficient* if it has dimensions or a *factor* if it is dimensionless.

Thus: (a) For our x-ray and gamma-ray calibrations of ionization chambers, for which the calibration ratio has dimensions of gray (or roentgen) per coulomb, the reported quantity is a *calibration coefficient*, rather than the old calibration factor.

(b) For calibrations of instruments that read directly in absorbed dose, kerma or exposure, or their rates, for which the calibration ratio is dimensionless, the reported quantity is a *calibration factor*, rather than the old correction factor.

(c) Other similar calibrations, such as for well-chambers used in brachytherapy dosimetry, will also incorporate these changes.

This change should provide improved clarity in our calibration reports, removing any possible confusion between a reported calibration correction factor (using the old terminology) and those correction factors (*e.g.*, for pressure, temperature, saturation) used in the calibration procedures.

The change in terminology is intended to be benign. *The meaning of the reported calibration quantity has not changed.* The correspondence with the older terminology is outlined above to establish the equivalence of the new terms for those concerned with satisfying, to the letter, documentary standards and protocols.

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