Update on NIST X-Ray Air-Kerma Standards and Calibrations

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Beginning in November of 2001 the 100 kV x-ray tube was replaced, and all the NIST and ISO reference radiation qualities have been reestablished. The beam uniformity remains the same, and all x-ray beam half-value layers were reproduced. In May of 2002 the 320 kV x-ray tube was replaced. The new 320 kV tube is a different design than the previous tube, featuring less inherent filtration and a slightly larger focal spot. All NIST reference radiation qualities have been redeveloped, without changing the additional filtration appreciably or the operating tube potential. Most of the ISO reference radiation qualities have been reestablished, with the others to be reestablished in the near future. The four BIPM reference beam qualities produced at 100, 135, 180 and 250 kV have now been developed at NIST. These are being used for an indirect comparison with the BIPM, which should conclude in April of 2003. Since November of 2001, two voltage dividers have been acquired for use on all three x-ray ranges. Both voltage dividers are in the process of being calibrated by NIST Electronics and Electrical Engineering Laboratory and will be used to verify the operating voltage of the x-ray generators. The recent acquisition of the second divider will allow the measurement of voltage on both the cathode and anode of the 320 kV system. These calibrated dividers will allow a more accurate determination of voltage and possibly permit the calibration of non-invasive kVp meters. The design process for a replacement of the Wyckoff-Attix free-air ionization chamber, which is the 300 kV primary standard, has begun.

Monte Carlo calculations of correction factors for free-air chambers, by David Burns of the BIPM, were reported at the last two meetings of the CCRI(I) [1,2]. He obtained these data as a function of incident photon energy from 10 keV to 250 keV. Those pertaining to the three NIST standards, the Lamperti (up to 50 keV), Ritz (up to 100 keV) and Wyckoff-Attix (up to 250 keV) free-air chambers, were given to NIST and later augmented by additional calculations between 250 keV and 300 keV for the Wyckoff-Attix chamber. These data include results for the photon-scatter correction k_{sc}, the electron-loss correction k_e, and the new fluorescence correction k_{fl} introduced at the CCRI(I) 2001 [2]. Using a library of photon spectra derived by others [3] from measurements, the corrections for our standard free-air chambers were calculated for the beam qualities maintained by NIST. In this work, we included also the calculation for the attenuation correction k_{att}. As described in references [4, 5], previously at NIST k_e and k_{sc} were derived from the data in references [6-9], and k_{att} was derived from

measurements. The final determinations of theses factors depended to varying degrees on skillful curve fitting and interpolation. NIST is now in the process of adopting the Monte Carlo database provided by the BIPM and available x-ray beam spectra for the determination of k_{sc}, k_e, and k_{fl}, along with a blend of measured and calculated values for k_{att}. The current changes in NIST standards are indicated in Tables 1 and 2. Although most of these data are not expected to change significantly, note that the work is ongoing and some of these results could be revised.

References

[1] D.T. Burns, "Consistent set of calculated values for electron-loss and photon-scatter corrections for parallel-plate free-air chambers," CCRI(I)/99-4 (1999).

[2] D.T. Burns, "The re-absorption of fluorescence photons in free-air chambers," CCRI(I)/01-32 (2001).

[3] See, *e.g.*, W.W.Seelentag, W. Panzer, G. Drexler, L. Platz and F. Santner, A Catologue of Spectra for the Calibration of Dosimeters, GSF Report 560 (1979). Electronic files provided by C.G. Soares (private communication).

[4] P.J. Lamperti, T.P. Loftus and R. Loevinger, *Calibration of X-Ray and Gamma-Ray Measuring Instruments*, NBS Special Publication 250-16 (1988).

[5] P.J. Lamperti and M. O'Brien, *Calibration of X-Ray and Gamma-Ray Measuring Instruments,* NIST Special Publication 250-58 (2001).

[6] V.H. Ritz, "Standard free-air chamber for the measurement of Low-energy x rays (20-100 kilovolts-constant-potential)." J. Res. NBS **64C**, 49-53 (1960).

[7] H.O. Wyckoff and F.H. Attix, *Design of free-air ionization chambers*, NBS Handbook 64 (1957).

[8] A. Allisy and A.M. Roux, "Contribution a la mesure des rayons roentgen dans le domaines de 5 a 50 kV," Acta Radiologica **55**, 57-74 (1961).

[9] V.H. Ritz, "Design of free-air ionization chambers for the soft x-ray region (20-100 kV)," Radiology **73**, 911-922 (1959).

Table 1. NIST Calibration Conditions for X-Ray Measuring Instruments, 2003.

Beam code	Additional Filtration[a]				Half-value layer[b] (HVL)		Homogeneity coefficient (HC)		Effective energy (keV)	Total percent change in standard[c]
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
L10					0.037		86			−0.32[d]
L15					0.059		70			−0.23[d]
L20					0.070		72			−0.49
L30	0.30				0.23		60			−0.49
L40	0.53				0.52		61			+0.17
L50	0.71				0.79		63			−0.27
L80	1.45				1.81		56			−0.32
L100	1.98				2.80		58			+0.08
M20	0.27				0.15		72			−0.80
M30	0.5				0.36		65			−0.17
M40	0.89				0.74		67			+0.01
M50	1.07				1.04		68			+0.08
M60	1.81				1.64	0.052	63	60		−0.14
M80	2.86				2.98	0.10	68	61		e
M100	5.25				5.00	0.20	74	55		+0.20
M120	7.12				6.72	0.31	77	53		e
M150	5.25	0.25			10.1	0.66	88	63		−0.14
M200	4.35	1.12			14.7	1.64	94	68		+0.03
M250	5.25	3.2			18.3	3.2	98	85		+0.25
M300	4.25		6.5		21.7	5.3	100	97		+0.77
H10	0.105				0.051		77			−0.32[d]
H15	0.5				0.16		87			−0.19[d]
H20	1.01				0.36		89			−0.38
H30	4.50				1.20		86			−0.04
H40	4.53	0.26			2.93		94			−0.13
H50	4.0			0.1	4.2	0.14	93	93	38	−0.14
H60	4.0	0.61			6.0	0.25	94	94	46	−0.17
H100	4.0	5.2			13.4	1.15	97	92	80	−0.05
H150	4.0	4.0	1.51		16.9	2.43	100	96	120	−0.03
H200	4.0	0.6	4.16	0.77	19.7	4.10	99	99	166	+0.12
H250	4.0	0.6	1.04	2.72	22	5.19	99	98	211	+0.56
H300	4.1		3.0	5.0	23	6.19	99	98	252	+1.86
S60	4.35				2.79	0.09	76	66		−0.09
S75	1.50				1.81		58			+0.03

[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.

[c] Subject to modification as work progresses.

[d] Total change includes only that due to $k_e \cdot k_{sc} \cdot k_{fl}$, *i.e.*, does not include k_{att}, which is determined at the time of calibration for these low-energy beams.

[e] New beam quality.

Table 2. ISO X-Ray Beam Quality Parameters Offered at NIST

Beam Code	Additional Filtration (mm)[a]				First HVL[b]		Second HVL[b]		Total percent change in standard[c]
	Al	Cu	Sn	Pb	Al (mm)	Cu (mm)	Al (mm)	Cu (mm)	
HK10					0.042		0.045		−0.56
HK20	0.15				0.128		0.170		−0.64
HK30	0.52				0.408		0.596		+0.35
HK60	3.19					0.079		0.113	+0.44
HK100	3.90	0.15				0.298		0.463	−0.06
HK200		1.15				1.669		2.447	−0.02
HK250		1.60				2.463		3.37	+0.05
HK280		3.06				3.493		4.089	+0.18
HK300		2.51				3.474		4.205	+0.33
WS60		0.3				0.179		0.206	+0.09
WS80		0.529				0.337		0.44	−0.12
WS110		2.0295				0.97		1.13	−0.06
WS150			1.03			1.88		2.13	−0.07
WS200			2.01			3.09		3.35	+0.20
WS250			4.01			4.30		4.50	+0.18
WS300			6.54			5.23		5.38	+0.76
NS10	0.095				0.049		0.061		−1.09
NS15	0.49				0.153		0.167		−0.78
NS20	0.90				0.324		0.351		−0.30
NS25	2.04				0.691		0.762		+0.00
NS30	4.02				1.154		1.396		−0.15
NS40		0.21				0.082		0.094	−0.05
NS60		0.6				0.241		0.271	+0.09
NS80		2.0				0.59		0.62	−0.14
NS100		5.0				1.15		1.19	−0.07
NS120		4.99	1.04			1.70		1.85	+0.17
NS150			2.50			2.40		2.52	−0.14
NS200		2.04	2.98			4.09		4.20	+0.00
NS250			2.01	2.97		5.26		5.32	+0.43
NS300			2.99	4.99		6.17		6.30	+1.75
LK10	0.30				0.061				−1.20
LK20	2.04				0.441				−0.31
LK30	3.98	0.18			1.492				−0.11
LK35		0.25			2.21				−0.06
LK55		1.19				0.260			−0.39
LK70[d]		2.64				0.509			+0.74
LK100[d]		0.52	2.0			1.27			+6.19
LK125		1.0	4.0			2.107		2.094	−0.25
LK170		1.0	3.0	1.5		3.565		3.592	+0.16
LK210		0.5	2.0	3.5		4.726		4.733	+0.72
LK240		0.5	2.0	5.5		5.515		5.542	+0.34

see next page for table notes

[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; for all other techniques the inherent filtration is adjusted to 4 mm Al.
[b] The HVL values were measured directly using the two new x-ray tubes installed in November of 2001 and May of 2002.
[c] Subject to modification as work progresses.
[d] Might be redeveloped using the Wyckoff-Attic rather than the Ritz FAC.