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

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The report of the indirect comparison between the NIST and the BIPM for x-ray energies between 100 and 250 kV is currently being completed. As a result of the comparison, the recombination correction for the NIST medium-energy x-ray standard, the Wyckoff-Attix chamber, is being verified through measurements. The magnitude of the correction is not expected to change, but the uncertainty assessment will be documented.

The NIST participation in the Euromet 545 was completed in January of 2005. Results were submitted for all three chambers for all of the requested ISO-NS reference beam qualities.

Five additional references-beam qualities were determined at NIST to represent the low-energy BIPM qualities. These will be used for future comparisons.

The design process for a replacement of the Wyckoff-Attix free-air ionization chamber, the measurement standard for air kerma from medium-energy x-ray beams, is ongoing. Drawings for the new standard are planned for completion by February of 2006.

The following correction regarding changes in NIST x-ray air-kerma standards was issued in May of 2004, and is repeated here for the record:

Corrected Note on Change of NIST X-Ray Beam Standards

14 May 2004

In the summer of 2003, we issued a number of tables indicating the changes in NIST standards for air kerma (exposure) for low-energy and medium-energy x-ray beams. The basis for the change is indicated below, in text similar to the earlier distributions. However, on careful review we found that some of the net changes reported earlier were in error, mainly because they were based on misquoted "previous" values. In order to consistently correct this information and to provide factors less subject to misunderstanding, new tables are given below. Note that these tables supersede all earlier versions.

The National Institute of Standards and Technology has revised its air-kerma (exposure) standards for x-ray beams, as of January 1, 2003. The changes are due to the implementation of correction factors for free-air chambers from Monte Carlo calculations, reported by David Burns of the Bureau International des Poids et Mesures (BIPM) at the 1999 and 2001 meetings of the Consultative Committee on Ionizing Radiation (Section I) [1,2]. These data, as a function of incident photon energy from 10 keV to 300 keV, pertain to the three NIST standards, the Lamperti (up to 50 keV), Ritz (up to 100 keV) and Wyckoff-Attix (up to 300 keV) free-air chambers. The values of the photon-scatter correction k_{sc} and the electron-loss correction k_e have been changed and a new fluorescence correction k_{fl} has been implemented. Using a library of photon spectra derived by others [3] from measurements, the corrections for our standard free-air chambers have been calculated for the beam qualities maintained by NIST, including also calculated attenuation corrections 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] (k_{att} was derived from measurements), with the final determinations depending to varying degrees on skillful curve fitting and interpolation. This old procedure was used to make some intermediate changes to correction factors during the last few years, occasioned by the reestablishment of calibration beam qualities after replacement of x-ray-generating equipment.

NIST adopts the Monte Carlo data provided by the BIPM in conjunction with the 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 changes to the NIST standards are indicated in the tables that follow. The air-kerma rates have been adjusted due to the implementation of the new correction factors for all reports of air-kerma issued after January 1, 2003.

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 x-ray beam quality parameters and *corrected* changes in standards, 1 January 2003.

Beam code	Additional filtration[a]				Half-value layer[b] (HVL)		Homogeneity coefficient (HC)		Effective energy (keV)	Total relative change[c] (%)
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
L10					0.037		86			−0.30
L15					0.059		70			−0.19
L20					0.070		72			−0.31
L30	0.30				0.23		60			+0.03
L40	0.53				0.52		61			+0.60
L50	0.71				0.79		63			+0.04
L80	1.45				1.81		56			+0.06
L100	1.98				2.80		58			+0.22
M20	0.27				0.15		72			−0.22
M30	0.5				0.36		65			−0.16
M40	0.89				0.74		67			+0.37
M50	1.07				1.04		68			+0.20
M60	1.81				1.64	0.052	63	60		−0.30
M80	2.86				2.98	0.10	68	61		−0.13
M100	5.25				5.00	0.20	74	55		−0.01
M120	7.12				6.72	0.31	77	53		−0.04
M150	5.25	0.25			10.1	0.66	88	63		−0.15
M200	4.35	1.12			14.7	1.64	94	68		+0.02
M250	5.25	3.2			18.3	3.2	98	85		+0.24
M300	4.25		6.5		21.7	5.3	100	97		+0.76
H10	0.105				0.051		77			−0.26
H15	0.5				0.16		87			−0.15
H20	1.01				0.36		89			−0.14
H30	4.50				1.20		86			−0.07
H40	4.53	0.26			2.93		94			−0.05
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	−0.06
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	+1.85
S60	4.35				2.79	0.09	76	66		−0.10
S75	1.50				1.81		58			+0.04

[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] Total change includes that due to changes in $k_{att} \cdot k_e \cdot k_{sc} \cdot k_{fl}$, assuming an air density of 0.0011965 g/cm^3 in the evaluation of k_{att}. The total relative change in % is $100(\Pi k_{new}/\Pi k_{old}-1)$, or $100(K_{new}/K_{old}-1)$, where K is the air kerma measured using the indicated standard.

Table 2. ISO x-ray beam quality parameters and *corrected* changes in standards, 1 January 2003.

Beam Code	Additional filtration (mm)[a]				First HVL[b]		Second HVL[b]		Total relative change[c] (%)
	Al	Cu	Sn	Pb	Al (mm)	Cu (mm)	Al (mm)	Cu (mm)	
HK10					0.042		0.045		−0.59
HK20	0.15				0.128		0.170		−0.43
HK30	0.52				0.408		0.596		−0.33
HK60	3.19					0.079		0.113	−0.23
HK100	3.90	0.15				0.298		0.463	−0.11
HK200		1.15				1.669		2.447	−0.02
HK250		1.60				2.463		3.37	−0.01
HK280		3.06				3.493		4.089	+0.00
HK300		2.51				3.474		4.205	−0.01
WS60		0.3				0.179		0.206	−0.12
WS80		0.529				0.337		0.44	−0.10
WS110		2.0295				0.97		1.13	−0.04
WS150			1.03			1.88		2.13	−0.02
WS200			2.01			3.09		3.35	+0.00
WS250			4.01			4.30		4.50	+0.00
WS300			6.54			5.23		5.38	+0.00
NS10	0.095				0.049		0.061		−0.56
NS15	0.49				0.153		0.167		−0.42
NS20	0.90				0.324		0.351		−0.34
NS25	2.04				0.691		0.762		−0.29
NS30	4.02				1.154		1.374		−0.23
NS40		0.21				0.082		0.094	−0.17
NS60		0.6				0.241		0.271	−0.10
NS80		2.0				0.59		0.62	−0.07
NS100		5.0				1.14		1.19	−0.03
NS120		4.99	1.04			1.76		1.84	−0.01
NS150			2.50			2.41		2.57	−0.01
NS200		2.04	2.98			4.09		4.20	+0.00
NS250			2.01	2.97		5.34		5.40	+0.00
NS300			2.99	4.99		6.17		6.30	+0.00
LK10	0.30				0.061				−0.53
LK20	2.04				0.441				−0.31
LK30	3.98	0.18			1.492				−0.22
LK35		0.25			2.21				−0.19
LK55		1.19				0.260			−0.10
LK70		2.64				0.509			−0.06
LK100		0.52	2.0			1.27			−0.02
LK125		1.0	4.0			2.107		2.094	−0.01
LK170		1.0	3.0	1.5		3.565		3.592	+0.00
LK210		0.5	2.0	3.5		4.726		4.733	+0.00
LK240		0.5	2.0	5.5		5.515		5.542	+0.00

[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 for the two new x-ray tubes installed in November 2001and in May 2002.

[c] New values of k_{att}, k_e, and k_{sc} have been used since July 2001, *i.e.*, for all calibrations; k_{fl} was introduced January 2003. Thus the relative change (in %) to disseminated standards is effectively 100(k_{fl}-1), values of which are listed in this column.