National Institute of Standards and Technology

REPORT OF AIR KERMA CALIBRATION

FOR

U.S. Department of Energy
Oak Ridge National Laboratory/ UT-Battelle LLC.
Bethel Valley Road
ATTN: James Bogard
Oak Ridge, TN 37831-6480

Radiation Detection Chamber: Thermo Electron, Model 2530/1C, SN 688

Calibrations performed by Ronaldo Minniti

Report reviewed by Michelle O'Brien

Report approved by Christopher G. Soares, Acting Group Leader

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 Ronaldo Minniti, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460,Gaithersburg, MD 20899, (301)975-5586, ronnie.minniti@nist.gov. 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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National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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Radiation Detection Chamber: Thermo Electron, Model 2530/1C, SN 688

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.
Chamber rotation: The model number faced the source of radiation.
Environmental conditions: The chamber is assumed to be open to the atmosphere.
Average leakage: 0.01 % of collector current.
Current ratio at full to half collection potential: 1.002 for an air-kerma rate of 2.89 E-5 Gy/s.
A detailed study of the ion 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				
^{137}Cs		10.8	YES	8.492 E+5	2.89 E-5	195
^{60}Co		14.9	YES	8.461 E+5	2.61 E-6	120

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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	1.64	94	68	
M250	5.25	3.2			18.3	3.2	98	85	
M300	4.25		6.5		21.7	5.3	100	97	
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. *revision 1/12/03*

ISO X-Ray Beam Quality Parameters Offered at NIST

Beam Code	Additional Filtration (mm)[a]				First HVL[b]		Second HVL[b]	
	Al	Cu	Sn	Pb	mmAl	mmCu	mmAl	mmCu
HK10					0.042		0.045	
HK20	0.15				0.128		0.170	
HK30	0.52				0.408		0.596	
HK60	3.19					0.079		0.113
HK100	3.90	0.15				0.298		0.463
HK200		1.15				1.669		2.447
HK250		1.60				2.463		3.37
HK280		3.06				3.493		4.089
HK300		2.51				3.474		4.205
WS60		0.3				0.179		0.206
WS80[c]		0.529				0.337		0.44
WS110[c]		2.029				0.97		1.13
WS150[c]			1.03			1.88		2.13
WS200[c]			2.01			3.09		3.35
WS250[c]			4.01			4.30		4.50
WS300[c]			6.54			5.23		5.38
NS10	0.095				0.049		0.061	
NS15	0.49				0.153		0.167	
NS20	0.90				0.324		0.351	
NS25	2.04				0.691		0.762	
NS30	4.02				1.154		1.396	
NS40		0.21				0.082		0.094
NS60		0.6				0.241		0.271
NS80[c]		2.0				0.59		0.62
NS100		5.0				1.14		1.24
NS120		4.99	1.04			1.76		1.84
NS150			2.50			2.41		2.57
NS200[c]		2.04	2.98			4.09		4.20
NS250			2.01	2.97		5.34		5.40
NS300[c]			2.99	4.99		6.17		6.30
LK10	0.30				0.061			
LK20	2.04				0.441			
LK30	3.98	0.18			1.492			
LK35		0.25			2.21			
LK55		1.19				0.260		
LK70[d]		2.64				0.509		
LK100[d]		0.52	2.0			1.27		
LK125		1.0	4.0			2.107		2.094
LK170		1.0	3.0	1.5		3.565		3.592
LK210		0.5	2.0	3.5		4.726		4.733
LK240		0.5	2.0	5.5		5.515		5.542

[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] Previous HVL values; need to be measured on the new MXR-321 tube. [d] Might be redeveloped using the Wyckoff-Attix rather than the Ritz FAC.

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 $W_{air}/e = 33.97$ 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 1.4%. 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 a typical uncertainty analysis are given in: P. J. Lamperti and M. O'Brien, "Calibration of X-Ray and Gamma-Ray Measuring Instruments", NIST Special Publication 250-58 (2001).

Change in Terminology:

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.

Stephen M. Seltzer
Leader, Radiation Interactions and Dosimetry Group

Changes in NIST Air-Kerma Primary Standards for Gamma-Ray Beams

The National Institute of Standards and Technology (NIST) has revised the primary standards for air-kerma (and exposure) from ^{60}Co and ^{137}Cs gamma-ray beams. ***The new standards are effective 1 July 2003***. The changes are mainly due to the implementation of new wall corrections for the graphite-wall air-ionization chambers that serve as our primary standards for gamma-ray air kerma. A complete description of these changes can be found in reference [1]. In addition, the air-kerma rates in our two therapy-level ^{60}Co gamma-ray beam facilities have been re-characterized through recent measurements using NIST primary-standard instruments. The result of these changes in standards is that the air-kerma rates delivered by our various ^{60}Co and ^{137}Cs sources now have values roughly **1%** higher than before.

Calibration coefficients and calibration factors reported prior to 1 July 2003 for instruments sent to NIST for calibration in these beams should be modified or re-determined to account for these changes as described below.

Therapy-Level ^{60}Co Beams: Instruments that are regularly calibrated in our therapy-level ^{60}Co beams will receive a calibration incorporating the change in the standard when next sent back to NIST for calibration. No precise adjustment can be applied to the calibration coefficients reported previously because the irradiation conditions have been modified. Calibrations of instruments are now performed at distance of 1.0 m from the source with a collimator setting for a field of 10.0 x 10.0 cm^2, as recommended in most protocols.

Radiation-Protection-Level ^{60}Co Beams: If an instrument was calibrated at NIST prior to 1 July 2003 in one of our radiation-protection-level ^{60}Co-beam facilities, that calibration coefficient or calibration factor should be multiplied by **1.0105** to account for the change in the standard. Customers can contact Dr. Ronaldo Minniti at NIST (phone: 301-975-5586, e-mail: ronnie.minniti@nist.gov) to verify that their instruments were calibrated in the radiation-protection-level ^{60}Co facility prior to applying this adjustment.

^{137}Cs Beams: If an instrument was calibrated at NIST prior to 1 July 2003 in one of our ^{137}Cs-beam facilities, that calibration coefficient or calibration factor should be multiplied by **1.009** to account for the change in the standard.

If there are any questions regarding the changes in NIST gamma-ray air-kerma standards or how they apply to your calibrations, please contact us at NIST.

References:

[1] S.M. Seltzer and P.M. Bergstrom, Jr., "Change in the US Primary Standards for the Air Kerma from Gamma-Ray Beams," NIST J. Res. (in press).

Changes in NIST Air-Kerma Primary Standards for X-Ray Beams

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 last two 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 now 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 which follow. Note that the work is ongoing and some of these results could be revised, although most of these data are not expected to change significantly. The air-kerma rates have been adjusted due to the implementation of 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 change in standards, 2003.

Beam code	Additional Filtration[a]				Half-value layer[b] (HVL)		Homogeneity coefficient (HC)		Effective energy (keV)	Total percent change[c]
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
L10					0.037		86			−0.21
L15					0.059		70			−0.66
L20					0.070		72			−3.39
L30	0.30				0.23		60			+0.04
L40	0.53				0.52		61			+0.61
L50	0.71				0.79		63			+0.05
L80	1.45				1.81		56			+0.07
L100	1.98				2.80		58			+0.23
M20	0.27				0.15		72			−0.19
M30	0.5				0.36		65			−0.16
M40	0.89				0.74		67			+0.38
M50	1.07				1.04		68			+0.65
M60	1.81				1.64	0.052	63	60		+0.64
M80	2.86				2.98	0.10	68	61		+0.13
M100	5.25				5.00	0.20	74	55		+0.81
M120	7.12				6.72	0.31	77	53		+0.03
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			+0.56
H15	0.5				0.16		87			+0.08
H20	1.01				0.36		89			+0.44
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	−0.05
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. 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}; for the Lamperti and the Ritz FACs, k_{att} is evaluated for the actual air density at the time of calibration.

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

Beam Code	Additional Filtration (mm)[a]				First HVL[b]		Second HVL[b]		Total percent change[c]
	Al	Cu	Sn	Pb	Al (mm)	Cu (mm)	Al (mm)	Cu (mm)	
HK10					0.042		0.045		−0.71
HK20	0.15				0.128		0.170		−0.64
HK30	0.52				0.408		0.596		+0.30
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		−1.18
NS15	0.49				0.153		0.167		−0.86
NS20	0.90				0.324		0.351		−0.30
NS25	2.04				0.691		0.762		−0.05
NS30	4.02				1.154		1.396		−0.14
NS40		0.21				0.082		0.094	−0.02
NS60		0.6				0.241		0.271	+0.10
NS80		2.0				0.59		0.62	−0.14
NS100		5.0				1.14		1.24	−0.07
NS120		4.99	1.04			1.76		1.84	+0.17
NS150			2.50			2.41		2.57	−0.14
NS200		2.04	2.98			4.09		4.20	+0.00
NS250			2.01	2.97		5.34		5.40	+0.43
NS300			2.99	4.99		6.17		6.30	+1.75
LK10	0.30				0.061				−1.32
LK20	2.04				0.441				−0.34
LK30	3.98	0.18			1.492				−0.07
LK35		0.25			2.21				−0.06
LK55		1.19				0.260			−0.32
LK70[d]		2.64				0.509			+0.75
LK100[d]		0.52	2.0			1.27			+6.24
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

[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 2001 and May 2002.

[c] Subject to modification as work progresses.

[d] Might be redeveloped using the Wyckoff-Attix rather than the Ritz FAC.