Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Prüfschein
Test Certificate

Ausgestellt für: *Issued to:*	Radi Teknoloji Medikal San.ve Tic.AS Kocavezir Mah.Karacaoglan Cad.5/1007 Seyhan/Adana/ Turkey
Prüfgrundlage: *In accordance with:*	EN 61331-1:2014 and EN 61331-3:2014
Gegenstand: *Object:*	X-ray shielding material
Typ: *Type:*	LEAD 0.25 mm Pb, 0.35 mm Pb, 0.50 mm Pb
Kennnummer: *Serial No.:*	ID see page 2
Prüfscheinnummer: *Test Certificate No.:*	6256117-2
Datum der Prüfung: *Date of test:*	2019-03
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Geschäftszeichen: *Reference No.:*	6.25-13-21 P

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Im Auftrag
On behalf of PTB

Braunschweig 2019-03 21

Im Auftrag
On behalf of PTB

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Nationales Metrologieinstitut PTB

Dr. Ludwig Büermann

Pavel Galimov

Digitally signed by Matei Vasile
Date: 2021.06.23 12:29:19 EEST
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Location: Moldova

1 Scope

Determination of the lead equivalent class for a specified range of radiation qualities according to EN 61331-1 clause 5.5. The range of qualities is specified as 50 kV, 70 kV, 90 kV and 110 kV according to EN 61331-3 clause 5.3.

2 Description of the material and samples:

2.1 Product Description

Material Type	Protection in mm Pb
LEAD	0.25, 0.35 & 0.50

2.2 Sample description

Material type	Nominal lead-equivalent	Identification #	Area density Measured *)
10 cm x 10 cm	mm		kg/m^2
LEAD	0,25	none	3,33
LEAD	0,35	none	4,78
LEAD	0,50	none	6,78

*) Relative standard uncertainty: 1,0 %

3 Results

3.1 Assignment of lead equivalent class

Material type	Nominal lead-equivalent / mm	Lead equivalent class according to 5.5 of EN 61331-1	Range of class
LEAD	0,25	Yes	50 kV – 110 kV
LEAD	0,35	Yes	50 kV – 110 kV
LEAD	0,50	Yes	50 kV – 110 kV

3.2 Statement of compliance

Material type	Statement of compliance
LEAD	Lead equivalent 0,25 mm Pb: inverse broad beam 50 -110 kV EN 61331-1:2014
LEAD	Lead equivalent 0,35 mm Pb: inverse broad beam 50 -110 kV EN 61331-1:2014
LEAD	Lead equivalent 0,50 mm Pb: inverse broad beam 50 -110 kV EN 61331-1:2014

4 Single results of attenuation ratios and lead equivalent values

The inverse broad beam attenuation ratio F_{IB} was evaluated as $F_{IB} = F_N / B$, where F_N is the attenuation ratio measured with narrow beam condition and B is the build-up factor according to clause 5.2 of EN 61331-1. In clause 4.1 single results of F_N are presented and in clause 4.2 those of F_{IB}.

4.1 Narrow beam condition according to EN 61331-1 clause 4.2

F_N	Attenuation ratio measured with narrow beam condition
δ_N	Lead equivalent determined with narrow beam condition
R_N	Ratio δ_N / nominal lead thickness
ALXX	Radiation Qualities according to EN 61331-1 Table 1
XX	x-ray tube high voltage in kV

Lead 0.25			250
Quality	F_N	δ_N / µm	R_N
AL50	158,68	239,3	0,96
AL70	31,30	245,5	0,98
AL90	13,51	248,2	0,99
AL110	9,70	249,1	1,00
Lead 0.35			350
Quality	F_N	δ_N / µm	R_N
AL50	670,66	338,9	0,97
AL70	71,59	348,2	0,99
AL90	23,99	352,2	1,01
AL110	16,57	354,6	1,01
Lead 0.5			500
Quality	F_N	δ_N / µm	R_N
AL50	4007,83	485,5	0,97
AL70	191,95	498,4	1,00
AL90	46,98	503,2	1,01
AL110	31,25	503,5	1,01

Note that the lead equivalent values δ_N and the ratios R_N are given only for the purpose of comparison with the corresponding values δ_{IB} and R_{IB}. The testing results are only obtained from δ_{IB} and R_{IB} given in 4.2.

Uncertainty of δ_N:
The relative expanded uncertainty of the measured lead equivalent δ_N is 4%.

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor $k = 2$. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement (GUM)". The value of the measurand then normally lies, with a probability of 95 %, within the attributed coverage interval.

4.2 Inverse broad beam condition according to EN 61331-1 clause 4.4

F_{IB}	Attenuation ratio measured with inverse broad beam condition
δ_{IB}	Lead equivalent determined with inverse broad beam condition
R_{IB}	Ratio δ_{IB} / nominal lead thickness
ALXX	Radiation Qualities according to EN 61331-1 Table 1
XX	x-ray tube high voltage in kV

Lead 0.25			250	
Quality	F_{IB}	δ_{IB} / µm	R_{IB}	$R_{IB} \geq 0{,}93$ or $F_{IB} \geq 250$?
AL50	115,55	234,4	0,94	Y
AL70	24,40	240,1	0,96	Y
AL90	10,99	242,2	0,97	Y
AL110	7,59	241,6	0,97	Y
Lead 0.35			350	
Quality	F_{IB}	δ_{IB} / µm	R_{IB}	$R_{IB} \geq 0{,}93$ or $F_{IB} \geq 250$?
AL50	510,73	341,3	0,98	Y
AL70	56,90	350,1	1,00	Y
AL90	19,76	353,9	1,01	Y
AL110	12,96	355,6	1,02	Y
Lead 0.5			500	
Quality	F_{IB}	δ_{IB} / µm	R_{IB}	$R_{IB} \geq 0{,}93$ or $F_{IB} \geq 250$?
AL70	2771,20	483,8	0,97	Y
AL90	143,18	497,4	0,99	Y
AL110	36,84	501,9	1,00	Y
AL130	23,05	500,9	1,00	Y

Uncertainty of δ_{IB}:
The relative expanded uncertainty of the measured lead equivalent δ_{IB} is 7 %.

The uncertainty stated is the expanded measurement uncertainty obtained by multiplying the standard measurement uncertainty by the coverage factor *k = 2.* It has been determined in accordance with the “Guide to the Expression of Uncertainty in Measurement (GUM)”. The value of the measurand then normally lies, with a probability of 95 %, within the attributed coverage interval.

5 Materials and methods used for testing

5.1 x-ray facility and radiation qualities

The x-ray facility named XG160 used for the attenuation measurements described in this test certificate is controlled by a unit of type MGC41, manufactured by YXLON International X-Ray GmbH. The converter-type generator is of type XGG which operates at a frequency of 40 kHz and yields a constant potential that can be varied between 10 kV and 160 kV in steps of 20 V. The high voltage ripple is 5 V/mA. The unipolar x-ray tube of type Comet MXR 165 has a tungsten anode with an angle of 30° and a 4 mm beryllium exit window. The maximum anode load is 6000 W but the maximum anode current is limited at about 90 mA at 60 kV. The tube current can be varied in steps of 0.1 mA. The emission angle is 45°. The high voltage is measured invasively with a frequency compensated voltage divider manufactured at the PTB and traceable to the PTB primary standard for dc high voltage. A high purity Ge spectrometer was used to measure the x-ray spectra from which the characteristic beam parameters shown in Table 1 were deduced. The radiation qualities according to EN 61331-1 were obtained by use of 2.50 mm Al (purity 99.99%) added filtration. The first half-value layers (HVL) in units of mm Al are listed in Table 1 and are compared with those published in Table 1 of EN 61331-1.

Table 1 Radiation qualities according to EN 61331-1 as realized at the PTB x-ray facility named XG 160.

PTB code	Tube voltage nominal	Added filtration	1st HVL	1st HVL (EN)	ratio	Mean Energy
	kV	mm Al	mm Al	mm Al		keV
Al 30	30	2,5	0.99	0,99	1.00	23.6
Al 40	40	2,5	1.41	1.44	0.98	28.4
Al 50	50	2,5	1.76	1,81	0.97	32.5
Al 60	60	2,5	2.06	2,14	0.96	36.1
Al 70	70	2,5	2.43	2.44	1.00	39.7
Al 80	80	2,5	2.73	2,77	0.99	43.1
Al 90	90	2,5	3.05	3.10	0.98	46.2
Al 100	100	2,5	3.37	3,44	0.98	49.0
Al 120	110	2,5	3.70	3.79	0.98	51.6
Al 120	120	2,5	4.01	4,13	0.97	54.0
Al 130	130	2,5	4.33	4.48	0.97	56.2
Al 140	140	2,5	4.65	4.82	0.96	58.3
Al 150	150	2,5	4.98	5,17	0.96	60.4

5.2 Set-up for narrow beam condition

The narrow beam condition set-up according to clause 4.2 of the EN 61331-1 standard was realized at the XG160 x-ray facility as shown in Figure 1. A plane parallel transmission ionization chamber manufactured at the PTB with very thin graphitized Polyethylen windows is used as a monitor chamber. The aperture a_2 limits the size of the circular shaped beam cross section whereas a_3 is not beam limiting but protects the monitor chamber against backscattered radiations. At 1 m distance from the focal spot a beam diameter of 8 cm was realized. The test object attenuating the beam is located at a distance of about 55 cm from the focal spot and aperture a_4 protects the air kerma detector which is positioned at 1 m distance from the focus against photons scattered from the test object. The sensitive cross sectional area of the air kerma detector is fully covered by the x-ray beam.

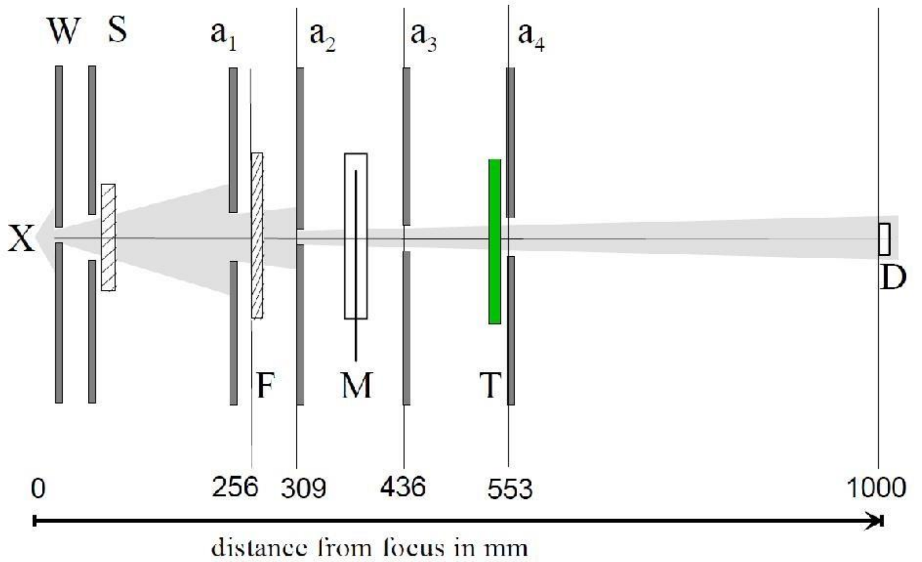

Figure 1: Schematic drawing of the narrow-beam-condition set-up as realized at the x-ray facility XG160 at the PTB. W: x-ray tube window; S: shutter; a_1 – a_4: apertures, a_2 is beam limiting; F: added filtration; M: monitor chamber; T: test object

5.3 Set-up for inverse broad beam condition

The inverse broad beam condition set-up according to clause 4.4 of the EN standard was realized at the XG160 x-ray facility as shown in Figure 2. The set-up is exactly the same as shown in Figure 1 except for the additional aperture a_5 in front of the air kerma detector which limits the beam size close to the entrance window of the plane parallel shaped air kerma detector in a way that the cross sectional area of the sensitive volume of the detector is only partly irradiated according to the conditions described in the standard. The lower drawing in Figure 2 complies with the description in the standard whereas the upper drawing shows the test object positioned far away from the air kerma detector behind aperture a_4. The reason for this additional set-up option for the test object is to allow a measurement of the build-up factor B. B is obtained from the ratio of the air kerma rate measurements when the test object is close to the detector (as shown in the lower picture and denoted as IBG-AT) and when the test object is positioned far away from the detector (as shown in the upper picture and denoted as IBG-AP).

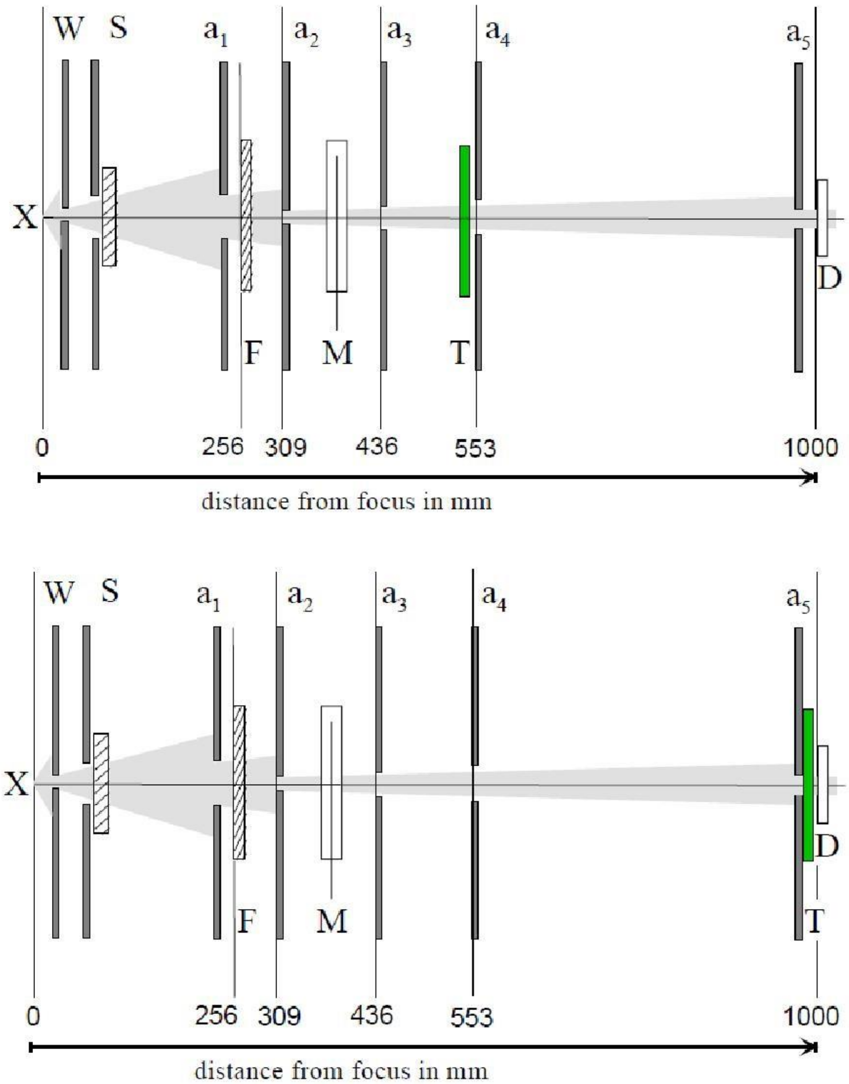

Figure 2: Schematic drawing of the inverse-broad-beam-condition set-up as realized at the x-ray facility XG160 at the PTB. W: x-ray tube window; S: shutter; a_1 – a_4: apertures, a_5 is beam limiting; F: added filtration; M: monitor chamber; T: test object. The set-up as shown in the upper and lower part are referred to as IBG-AP and IBG-AT, respectively, where IBG is an abbreviation of inverse broad beam geometry, AP for attenuated primary and AT attenuated total.

5.4 Radiation detector used at narrow beam condition to measure F_N

The ionization chamber used was of type 34069-SN162 manufactured by the Physikalisch-Technische Werkstätten (PTW) in Freiburg, Germany. This chamber is a shadow-free plane parallel chamber used for absolute dosimetry in diagnostic radiology and mammography. The diameter of the sensitive volume is 30.4 mm and the walls consist of graphitized PMMA of thickness 0.32 mm and area density of 38 mg/cm^2. The air kerma response of this chamber was measured at the calibration facilities of the PTB as a function of the ISO 4037 narrow-spectrum series for tube potentials between 10 kV and 200 kV (coded N 10 to N 200). The result is shown in Figure 3 where the relative response is plotted as a function of the air-kerma-weighted mean energy ranging from 8 keV (N 10) to 166 keV (N 200). Note that this is equivalent with the Al-HVL range from about 0.05 mm to 19.4 mm.

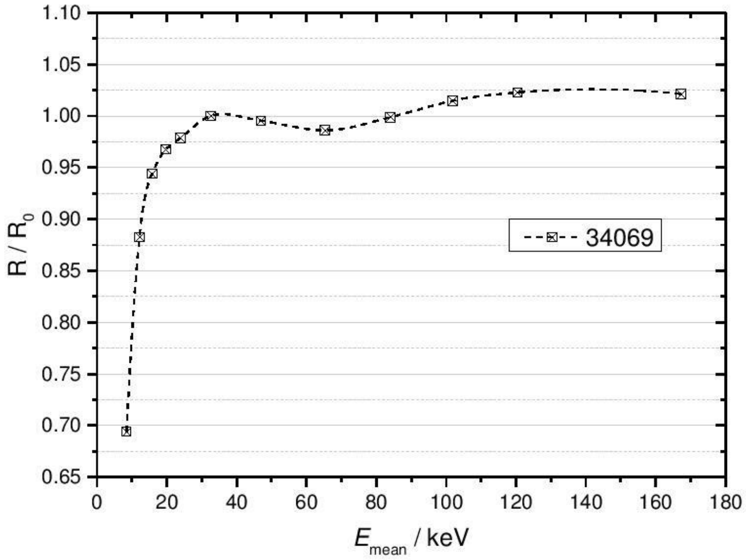

Figure 3: Relative response R/R_0 of the ionization chamber type PTW 34069 plotted as a function of the mean energy of the ISO 4037 narrow-spectrum series N 10 to N 200. R_0 is the response at N 100.

5.5 Radiation detector used at inverse broad beam condition to measure *B*

According to clause 4.4.3 of the EN 61331-1 standard flat ionization chambers shall be used for measurements under the inverse broad beam condition. The flat ionization chamber shall be calibrated in terms of air kerma under the same irradiation conditions. For the measurements of this test certificate the chamber type 34060 manufactured by the Physikalisch-Technische Werkstätten (PTW) in Freiburg, Germany, was used. This chamber is a shadow-free plane parallel chamber used for absolute dosimetry in diagnostic radiology. The diameter of the sensitive volume is 91.4 mm and the walls consist of graphitized PMMA of thickness 0.52 mm and area density of 62 mg/cm^2. The air kerma response of this chamber was measured at the calibration facilities of the PTB as a function of the ISO 4037 narrow-spectrum series for tube potentials between 20 kV and 200 kV (coded N 20 to N 200). Measurements were done under narrow beam conditions (as shown in Figure 1) and under inverse broad beam conditions (as shown in Figure 2). The results are shown in Figure 4 where the relative responses are plotted as a function of the air-kerma-weighted mean energy ranging from 15.8 keV (N 20) to 166 keV (N 200). From Figure 4 it is obvious that the energy response under usual conditions when the whole chamber is fully irradiated is significantly different from the response measured under inverse broad beam conditions when only the inner part of the sensitive volume is irradiated. Therefore at this condition only the build-up factor B is measured resulting from the ratio of the normalized chamber signals measured in IBG-AT (total attenuated radiation including scattered photons) and IBG-AP (attenuated primaries only). This procedure minimizes the influence of the non-negligible variation of the energy response of the chamber because both measurements are performed at the attenuated beam.

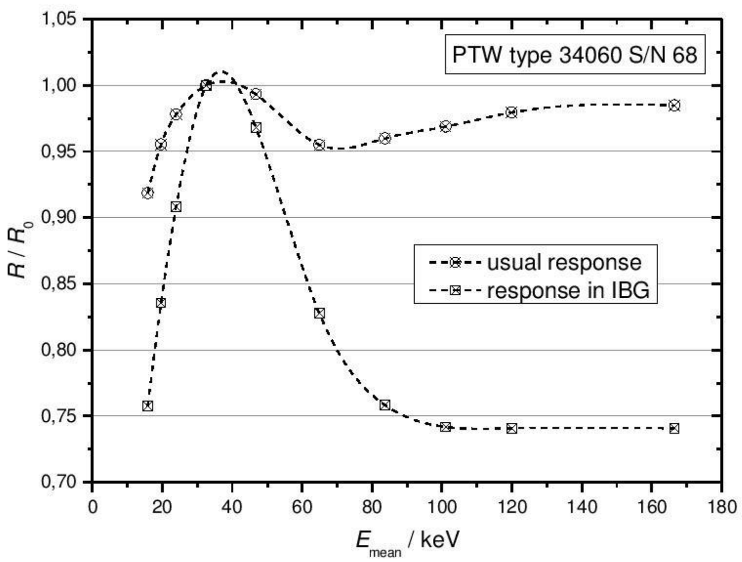

Figure 4: Relative response R/R_0 of the ionization chamber type PTW 34060 plotted as a function of the mean energy of the ISO 4037 narrow-spectrum series N 20 to N 200. R_0 is the response at N 100.

5.6 Reference lead sheets

High purity lead sheets produced by the company PLANSEE Composite Materials GmbH, Austria were used for the measurements. The thicknesses and their uncertainties are listed in Table 2. The sheets were square shaped with a size of about 5 cm x 5 cm.

Table 2 Thicknesses of the lead sheets and their uncertainties

Thickness / µm	Uncertainty /µm
100	1
147	2
187	3
244	5
297	4
332	5
531	7
710	20
810	20
1454	20
2015	50

5.7 Results of the attenuation factor F_N for the reference lead sheets

F_N values of the reference lead sheets were measured at the XG160 x-ray facility and are listed in Table 3.

Table 3 F_N values of the reference lead sheets for radiation qualities 50 kV to 150 kV

t_{Pb}/µm	AL50	AL60	AL70	AL80	AL90	AL100	AL110	AL120	AL130	AL140	AL150
100	17.42	10.73	7.56	5.87	4.82	4.22	3.83	3.53	3.30	3.10	2.93
147	41.25	20.87	13.03	9.25	7.15	6.07	5.41	4.93	4.54	4.22	3.95
187	79.47	34.24	19.43	12.85	9.49	7.90	6.97	6.30	5.77	5.33	4.94
244	187.30	64.66	32.21	19.44	13.53	11.02	9.62	8.65	7.88	7.21	6.63
297	393.70	111.1	49.31	27.48	18.19	14.57	12.65	11.34	10.28	9.37	8.55
332	629.60	155.9	64.21	34.03	21.84	17.31	15.00	13.43	12.15	11.04	10.04
531	7448	895.3	245.8	100.1	54.59	41.28	35.46	31.78	28.68	25.80	23.03
710	57900	3700	717.1	235.0	111.60	81.29	69.51	62.57	56.68	50.84	44.82

5.8 Determination of lead equivalent thicknesses δ_N for the test material

The F_N values of the reference lead sheets shown in Table 3 were fitted by a second order polynomial $y(x) = b_0 + b_1x + b_2x^2$, where $y = t_{Pb}$ is the thickness of lead and $x = \ln(F_N)$. An example of such a fit is shown in Figure 5. Lead equivalent values of materials under test were obtained by a single measurement of F_N and inserting $x = \ln(F_N)$ in the polynomial. This is graphically shown in Figure 5. Note that curves as shown in Figure 5 need to be measured for each reference radiation quality needed for the test. Such curves are specific for the used x-ray facility and may differ for other facilities. Therefore it is mandatory to use the same x-ray facility for the reference measurements with lead and for the material sheet under test.

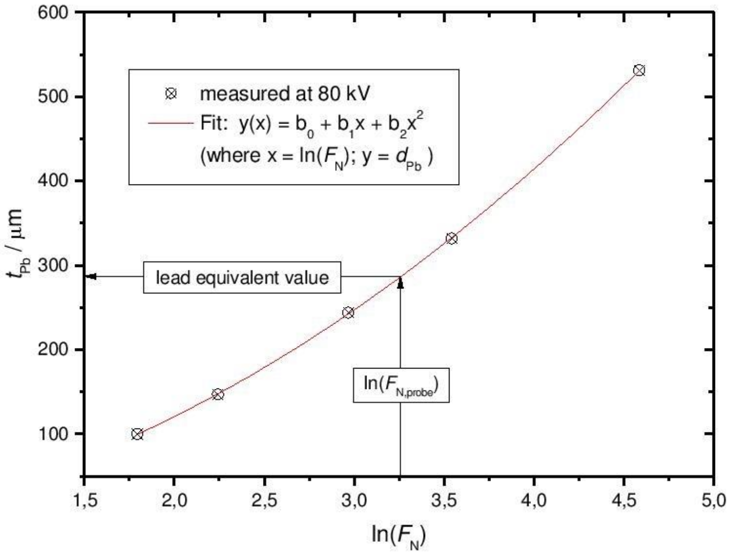

Figure 5: Polynomial fit to the $\ln(F_N)$ values for the 80 kV radiation quality. Lead equivalent values of a test object are obtained as shown in the figure.

5.9 Results of the attenuation factor F_{IB} for the reference lead sheets

The build-up factor B was measured as described in 5.5 for the reference lead sheets listed in Table 2 up to thicknesses of 710 µm and for the reference radiation qualities from 50 kV to 150 kV. Results are listed in Table 4.

Table 4 Measured build-up factors B for the reference lead sheets for radiation qualities 50 kV to 150 kV

t_{Pb}/µm	AL50	AL60	AL70	AL80	AL90	AL100	AL110	AL120	AL130	AL140	AL150
100	1.23	1.21	1.19	1.17	1.16	1.16	1.17	1.17	1.18	1.18	1.18
147	1.24	1.21	1.21	1.17	1.16	1.16	1.18	1.19	1.19	1.20	1.20
187	1.26	1.22	1.20	1.18	1.16	1.18	1.20	1.21	1.22	1.22	1.22
244	1.29	1.26	1.23	1.20	1.19	1.21	1.23	1.25	1.27	1.28	1.28
297	1.30	1.26	1.23	1.21	1.19	1.21	1.24	1.27	1.28	1.29	1.30
332	1.37	1.31	1.27	1.24	1.22	1.24	1.27	1.30	1.32	1.33	1.33
531	1.47	1.35	1.32	1.28	1.26	1.29	1.33	1.38	1.41	1.43	1.44
710		1.45	1.40	1.35	1.31	1.34	1.39	1.44	1.48	1.51	1.52

Values of the attenuation factor with respect to the inverse broad beam condition were calculated as $F_{IB} = F_N / B$ using the F_N values from Table 3 and the B values from Table 4. The results are listed in Table 5.

Table 5 F_{IB} values of the reference lead sheets for radiation qualities 50 kV to 150 kV

t_{Pb} /µm	AL50	AL60	AL70	AL80	AL90	AL100	AL110	AL120	AL130	AL140	AL150
100	14.18	8.86	6.36	5.01	4.16	3.63	3.26	2.99	2.79	2.62	2.47
147	32.88	17.01	10.83	7.82	6.11	5.15	4.53	4.09	3.75	3.48	3.25
187	62.25	27.59	15.99	10.77	8.05	6.64	5.77	5.16	4.69	4.31	4.00
244	143.16	51.28	26.14	16.09	11.35	9.13	7.83	6.93	6.24	5.68	5.21
297	294.30	86.85	39.51	22.48	15.11	11.92	10.12	8.90	7.96	7.20	6.56
332	463.90	120.72	51.02	27.63	18.02	14.04	11.87	10.40	9.27	8.36	7.58
531	5074	658	186.41	77.95	43.38	31.95	26.44	22.93	20.22	17.94	15.94
710	36944	2600	522.46	176.53	85.86	60.43	49.28	42.54	37.39	32.95	28.85

5.10 Determination of lead equivalent thicknesses δ_{IB} for the test material

Values of F_{IB} from table 5 were fitted by a second order polynomial $y(x) = b_0 + b_1x + b_2x^2$, where $y = t_{Pb}$ is the thickness of lead and $x = \ln(F_{IB})$. An example of such a fit is shown in Figure 6. Lead equivalent values of materials under test were obtained by a measurement of $F_{IB} = F_N B$ and inserting $x = \ln(F_{IB})$ in the polynomial. This is graphically shown in Figure 6. Note that curves as shown in Figure 6 need to be measured for each reference radiation quality needed for the test. Such curves are specific for the used x-ray facility and may differ for other facilities. Therefore it is mandatory to use the same x-ray facility for the reference measurements with lead and for the material sheet under test. It is recommended to use the same radiation detectors and geometrical set-up for the reference measurements with the lead layers and the material under test. This method reduces significantly the uncertainties resulting from the energy dependence of the radiation detectors and the special set-up chosen for the measurements.

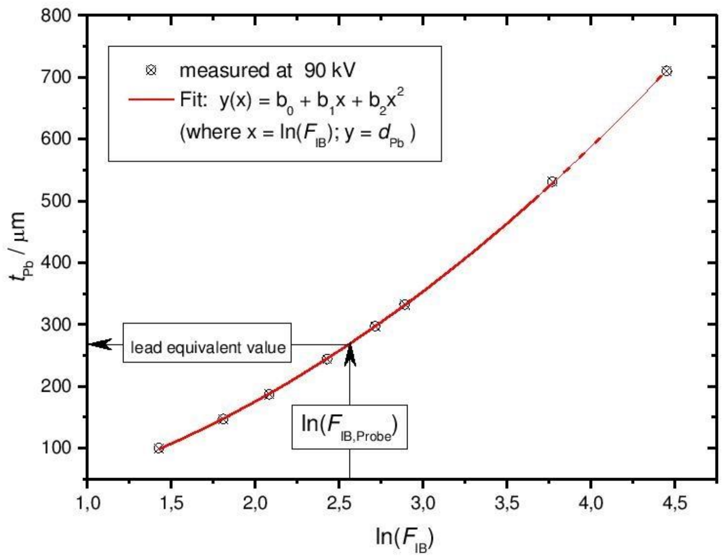

Figure 6: Polynomial fit to the $\ln(F_{IB})$ values for the 90 kV radiation quality. Lead equivalent values of a test object are obtained as shown in the figure.