Report on the Uncertainty Estimation
DIAGNOSTIC RADIOLOGY

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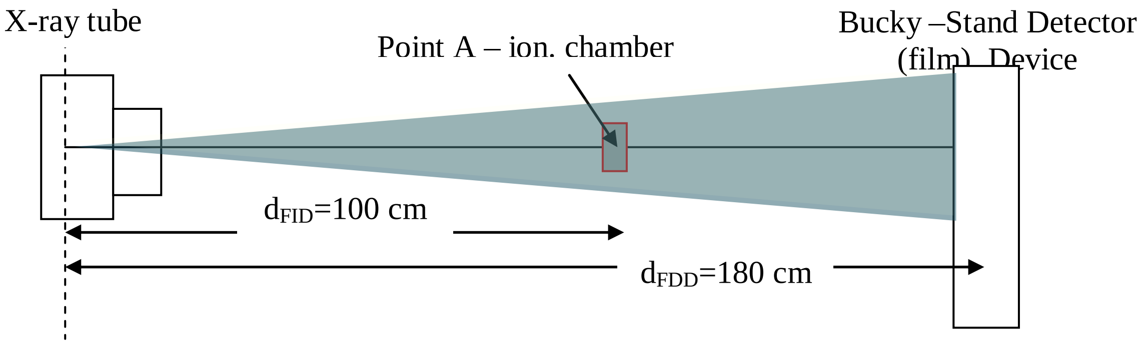
A. X-ray tube output, expressed as the air kerma at 1 m for 100 mAs



$$K_{i,100mAs} = R_{100mAs}\, k_{PT}\, N_{Q0}\, k_Q$$

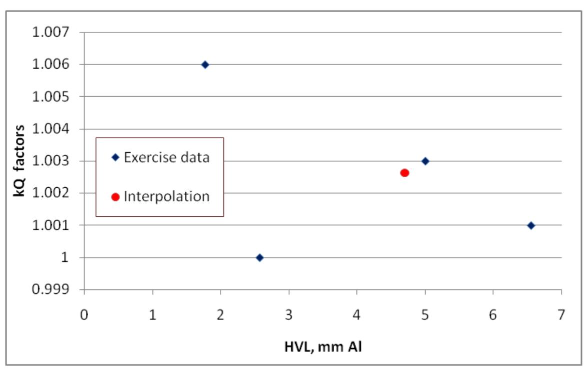
A.1 Calibration coefficient

The calibration coefficient N_{Q0} at RQR-5 quality as derived from calibration certificate (upper left value of certificate table) is N_{Q0} = 8.002 mGy / nC (8.002 10^6 Gy/C).

A.2 Correction for the beam quality

The correction factor, k_Q for the actual beam quality (HVL 4.7 mm Al) is derived from interpolation of data reported in the calibration certificate. kQ = 1.0026.

kQ Interpolation		
HVL	**kQ**	
1.77	1.006	Exercise data
2.57	1	Exercise data
5.00	1.003	Exercise data
6.55	1.001	Exercise data
4.7	1.00262963	Interpolation



A simplified method to estimate the uncertainty due to the interpolation is to consider the difference of the kQ values used for the interpolation, i.e. 1.000 (at 2.57 mm Al) and 1.003 (at 5 mm Al). Rectangular distribution is assumed. $u_{interpolation} = (1.003 – 1.000) /1.0026 / \sqrt{3} *100\% =$ 0.17 %. Other more accurate (although complex) methodologies for the uncertainty estimation due to interpolation of data could also be applied.

A.3 Correction for temperature and pressure

k_{PT} = Po x T / (P x To) = 1.01418 corrects for temperature and pressure.
All temperature values must be in Kelvin (^oK). The temperature absolute uncertainties in terms of ^oC or ^oK are numerically equal, e.g. ± 0.5 ^oC = ± 0.5 ^oK (*Note that* the relevant ^oC and ^oK uncertainties are NOT equal).
Temperature readings are multiplied with the calibration coefficient of the thermometer (=1.00) and pressure readings with the calibration coefficient of the barometer (=1.02, i.e. 98.5 x 1.02 = 100.47 kPa).

TYPE A	Data o C	oK
	21.6	294.6
	21.8	294.8
	22.0	295.0
	21.7	294.7
	21.5	294.5
Mean	**21.72**	294.72
SD	**0.19**	0.19
sample size	**5**	5
SD of the mean, s	**0.09**	0.09
		%
u% = s%	**0.40**	**0.03**

Po	101.3
To	293
P	100.47
T	294.72
kPT	**1.01418**

The uncertainty of the k_{PT} is estimated as,

kPT	**Value**	**Type A**	**Type B**	**Distribution**	**Comments**
		%	**%**		
Average temperature	294.72	**0.03**		Gaussian	Experimental SD% of the mean
Calibration Coefficient Thermometer	1.00		**1.00**	Gaussian	From Calibration cerificate : 0.02/2/1.00*100
Scale resolution thermometer			**0.01**	Rectangular	Half of the last digit : 0.05/294.7/sqrt(3)*100
Difference of oC : chamber - thermometer			**0.10**	Rectangular	0..5oC is ssumed : 0.5/294.7/sqrt(3)*100
Calibration Coefficient Barometer	1.02		**0.98**	Gaussian	From Calibration cerificate
Scale resolution Barometer			**0.03**	Rectangular	Half of the last digit : 0.05/98.5/sqrt(3)*100
SQRT of QUADRATIC SUM		**0.03**	**1.40**		Square root of the Quadritic Sum
Combined standtad uncertainty, k=1		**1.40**	**%**		Square root of the Quadritic Sum Type A and B
EXPANDED UNCERTAINTY, k=2		**2.81**	**%**		

A.4 Dosimeter readings

Readings		
TYPE A		
	2.96	**nC/100mAs**
	3.07	
	2.91	
	3.06	
	2.98	
Mean	**2.996**	**nC/100mAs**
Experimental Stand. Deviation	**0.07**	**nC/100mAs**
sample size	**5**	
ental Stand. Deviation of the mean, s (= u)	**0.03**	**nC/100mAs**
u% = s%	**1.02**	**%**

A.5 Long term stability of chamber – dosimeter

	Stability	
TYPE A		
	126.0	pC/min
	122.0	
	121.0	
	125.0	
	119.0	
	117.0	
	118.0	
	120.0	
	116.0	
	124.0	
Mean	120.80	pC/min
Experimental Stand. Deviation	3.43	pC/min
sample size	10	
Experimental Stand. Deviation of the mean, s (= u)	1.08	pC/min
u% = s%	0.90	%

A.6 X-ray tube output, $K_{i,100mAs}$ at 1 m

$K_{i,100mAs} = R_{100mAs}\, k_{PT}\, N_{Q0}\, k_Q$ = 2.996 x 1.014 x 8.002 x 1.0026 = 24.3869 mGy/100 mAs

A.7 Uncertainties due to distances

The uncertainty, u_d of the focus to the point of measurement (or interest) distance, d, influences the uncertainty of the air kerma by

$$K_d \propto \left(\frac{1}{d}\right)^2 \Rightarrow K_d = K_0 \cdot \left(\frac{1}{d}\right)^2$$

$$u_{K_d} = \sqrt{\left(\frac{\partial K_d}{\partial d} u_d\right)^2} = -2 \cdot \frac{K_0}{d^3} u_d = -2 \cdot \frac{K_0}{d^2} \cdot \left(\frac{u_d}{d}\right) = -2 \cdot K_d \cdot \left(\frac{u_d}{d}\right)$$

$$\left(\frac{u_{K_d}}{K_d}\right) = -2 \cdot \left(\frac{u_d}{d}\right)$$

Therefore, the relative uncertainty of the air kerma due to the distances (FID, FSD, etc) is twice the relative uncertainty of the distance. This formula is used to the uncertainty budges below.

A.8 The uncertainty of the $K_{i,100mAs}$ is estimated as

Influence Quantity	Value	Type A %	Type B %	Distribution	Comments
$N_K = N_{K,RQR5}$ x kQ	8.026		0.40	Gaussian	from calibration certificate, Nk x kq uncertaimty = 0.8% @ k=2
Long term stability of chamber		0.90		Gaussian	Experimental SD% of the mean (measurements with check source)
Difference of beam qualities - kQ	1.0026		0.17	Rectangular	Interpolation of kQ for qualities = (1.003-1)/1.0026/sqrt(3)*100
Readings, nC/100mAs	2.996	1.02		Gaussian	Experimental SD% of the mean
k_{PT}	1.0142	0.03	1.40	see u_{kPT}	see next sheet
Readout scale resolution			0.10	Rectangular	Half of the last digit : 0.005/2.996/sqrt(3)*100
FID, Positioning of chamber, mm	1000		0.58	Rectangular	Assumed 5 mm distance accuracy : 2 x (5/1000/sqrt(3)*100)
X-ray mAs accuracy			2.89	Rectangular	Assumed 5% at 1 sd, as stated by the manufacturer
mAs display resolution			0.03	Rectangular	100.0 mAs Half of the last digit : 0.05/100/sqrt(3)*100
$K_{i,100mAs}$ in mGy/100mAs	24.3869				
SQRT of QUADRATIC SUM		1.36	3.29		Square root of the Quadritic Sum
Combined standtad uncertainty, k=1		3.56	%		Square root of the Quadritic Sum Type A and B
EXPANDED UNCERTAINTY, k=2		7.12	%		

The uncertainty of the X-ray tube output is 3.56 % (k=1) **or** 7.12% (k=2) **or** 0.868722 Gy/100mAs (k=1) **or** 1.737445 mGy/100mAs (k=2).
<u>All aforementioned uncertainties are equivalent.</u>

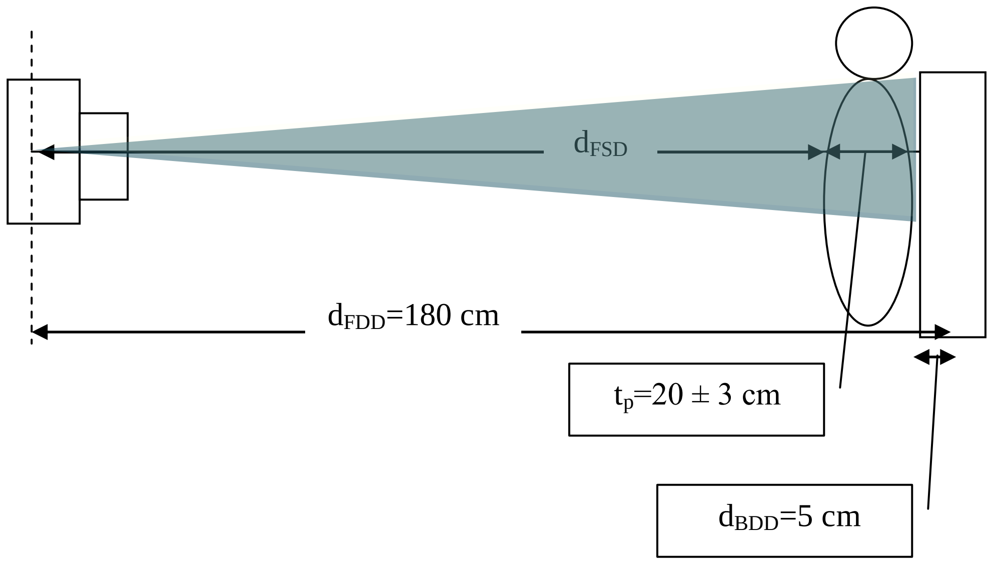
The final result of the X-ray tube output is $K_{i,100mAs}$ = (24.4 ± 0.9) mGy/100mAs (k=1).

B. Entrance surface air kerma for a typical – average patient

B.1 Focus to patient skin distance d_{FSD}

The focus to patient skin distance d_{FSD} is determined from the focus-to detector (film) distance d_{FFD}, the space between the bucky (stand device) and detector (film) d_{BDD} and the typical patient thickness, t_P. (Fig. b). Therefore,

$$d_{FSD} = d_{FDD} - d_{BDD} - t_P = 1800 - 50 - 200 = 1550 \text{ mm}$$



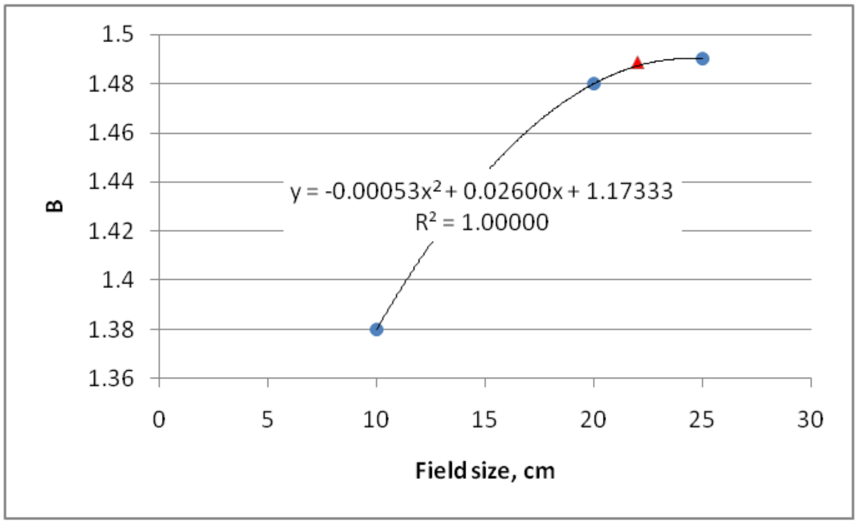
Note that in this case (**$d_{FSD} = d_{FDD} - d_{BDD} - t_P$**), the uncertainty propagation law concerns the absolute uncertainty of distances (not the relevant uncertainties of the distances).
Since all quantities in above formula refer to distance in mm, the standard absolute uncertainties (in mm) are combined. Therefore the uncertainty of the d_{FSD} is estimated from

Influence Quantity	Value	Type A	Type B	Distribution	Comments
	mm	mm	mm		
FDD, Indication accuracy	1800		5.77	Rectangular	10 mm accuracy : 10/sqrt(3)
BDD	50		2.89	Rectangular	5 mm accuracy= 5/sqrt(3)
tp, patient thickness	200	30.00		Gaussian	3cm = 30 mm
FSD	1550				
SQRT of QUADRATIC SUM, in mm		30.00	6.45		**in mm,** Square root of the Quadritic Sum
		%	%		
Relative standard uncertainty		1.94	0.42		
Combined standtad uncertainty, k=1		1.98			Square root of the Quadritic Sum Type A and B

The lower lines of the table convert the standard absolute uncertainties to relative % standard uncertainties, in order to be used and combined to the uncertainties for the air kerma (uncertainty budge).

B.2 Backscatter factor

The backscatter factor for the 22 x 22 cm^2 field size is derived from the interpolation of backscatter factor data, using a quadratic fitting curve. The B (at 22x22cm^2) = 1.4888.



Field	B
10	1.38
20	1.48
25	1.49
22	1.48881

The uncertainty of the interpolation result could be taken as the difference of the B values used for the interpolation. Rectangular distribution is assumed.
$u_{interpolation}$ = (1.49 – 1.48) / 1.4888 /√3 *100% = 0.39 %
Other more accurate (although complex) methodologies for the uncertainty estimation due to interpolation of data could also be applied.

In addition, a standard uncertainty of 5% to the backscatter values could be assumed.

B.3 Incident air kerma (free in air) at the at d_{FSD}

The incident air kerma (free in air) at the at d_{FSD} i.e. at the point of skin entrance (with the absence of the patient) is determined from

$$K_{i,100mAs,dFSD} = K_{i,100mAs}\,(d_{FID} / d_{FSD})^2 = 24.3869\,(1000 / 1550)^2 \text{ mGy/100 mAs} =$$
$$K_{i,100mAs,dFSD} = 10.15062 \text{ mGy/100 mAs}$$

The incident air kerma at the d_{FSD} for average patient chest exposure settings is deduced from

$$K_i = K_{i,100mAs,dFSD} \text{ x } (mAs)_{av} = 10.15062 \text{ mGy/100 mAs} * 2.6 \text{ mAs} = 0.26392 \text{ mGy}$$

B.4 Entrance surface air kerma

The entrance surface air kerma at the point at the patient skin is $K_e = K_i \text{ x } B = 0.26392 \text{ x } 1.4888 =$ 0.39292 mGy

B5. Uncertainty of the Entrance surface air kerma Ke

Influence Quantity	Value	Type A %	Type B %	Distribution	Comments
$K_{i,100mAs}$	24.387	1.36	3.29	see respective table	
FID, Positioning of chamber	1000		--		Already considered in $K_{i,100mAs}$
FSD = FDD-BDD-tp	1550	3.64	0.78	see table for FSD	Twice the distance relevant uncertainty : see text
mAs average	2.6	2.60		Gaussian	
Backscatter interpolation	1.488		0.39	Rectangular	Due to Interpolation : 0.01 / 1.488 / sqrt(3) *100%
Backscatter values			2.89	Rectangular	5% is assumed
Ke in mGy	0.393				
SQRT of QUADRATIC SUM		4.67	4.46		Square root of the Quadritic Sum
Combined standtad uncertainty, k=1		6.46	%		Square root of the Quadritic Sum Type A and B
EXPANDED UNCERTAINTY, k=2		12.93	%		

<u>*Note:*</u> The uncertainty due to the FID, u_{FID}, has already been considered in the uncertainty of the $K_{i,100mAs}$.

The uncertainty of the ***Entrance surface air kerma*** is 6.46 % (k=1) **or** 12.93% (k=2) **or** 0.0253807 mGy (k=1) or 0.0507614 mGy (k=2)
<u>All aforementioned uncertainties are equivalent.</u>

The final result of the *Entrance surface air kerma* Ke **= (0.39 ± 0.03) mGy (k=1).**

C. Dose to thyroid

The thyroid dose is calculated by $D_{thyroid} = K_{i,100mAs,FSD}\ x\ c_{Ki,Dthyroid}$, = 0.26392 mGy x 0.28 = 0.073897 mGy
and its uncertainty

Influence Quantity	Value	Type A %	Type B %	Distribution	Comments
$K_{i,100mAs}$	24.387	**1.36**	**3.29**	see respective table	
FID, Positioning of chamber	1000		--		Included in u for $K_{i,100mAs}$
FSD = FDD-BDD-tp	1550	**3.64**	**0.78**	see table for FSD	Twice the distance relevant uncertainty : see text
mAs average	2.6	**2.60**		**Gaussian**	
Coversion factor,c	0.28		**2.89**	**Rectangular**	divide by 2 for k=1, 10/2/sqrt(3)
D thyroid, mGy	**0.073897**				
SQRT of QUADRATIC SUM		**4.67**	**4.45**		Square root of the Quadritic Sum
Combined standtad uncertainty, k=1		**6.45**	%		Square root of the Quadritic Sum Type A and B
EXPANDED UNCERTAINTY, k=2		**12.90**	%		

The uncertainty of the ***dose to thyroid*** is 6.45 % (k=1) **or** 12.90% (k=2) **or** 0.0047672 mGy (k=1) **or** 0.0095345 (k=2)
All aforementioned uncertainties are equivalent.

The final result of the dose to thyroid is D_{th} = (0.074 ± 0.005) mGy (k=1).