PRACTICAL EXERCISES

Hosted by: Paula Toroi and Mika Kortesniemi

In action: Juha Peltonen, Anne-Mari Vitikainen, Touko Kaasalainen, Jenna Tarvonen, and Niko Kiiskinen

21 November 2024, TraMeXI workshop at HUS, Helsinki, Finland

PRESENTING

Measurement team:

- Jenna Tarvonen (all modalities and dosimeter responsible)
- Modality experts: Juha Peltonen, Anne-Mari Vitikainen, Touko Kaasalainan

Video editing:

- Juha Peltonen, Anne-Mari Vitikainen (mammography)

Live video recording:

- Niko Kiiskinen

Moderator at site:

- Mika Kortesniemi

Moderator at lecture room:

- Paula Toroi
- Support: Mirja Kemppi-Pfleger

TIME SCHEDULE GENERIC

- 14:30 start and introduction
- 14:40 – 16:50: 3 Modalities (á 40 min)
  - **0 – 12 min** PP-slides+video (Paula, Ullanlinna)
    - Modality slide 1-2 min, Overview video 5 min, Few intro slides 5-6 min(X-ray system used, typical measurements, measurements of today)
  - **12 min -25 min** live broadcast video from site
  - **25 min – 30 min** results (Paula, Ullanlinna)
  - **30 – 40 min** analysis (Paula, Ullanlinna)

TIME SCHEDULE: LIVE VIDEO TIMING

- 14:40 – 15:20 Conventional
  - **Live 14:52 – 15:05 (Juha, Jenna, Niko and Mika)**
- 15:25 – 16:05 Mammography
  - **Live 15:37 – 15:50 (Anne-Mari, Jenna, Niko and Mika)**
- 16:10 – 16:50 Interventional
  - **Live 16:22 – 16:35 (Touko, Jenna, Niko and Mika)**

Practical exercises:

GENERAL THINGS ABOUT DOSIMETRY

21 November 2024, TraMeXI workshop at HUS, Helsinki, Finland

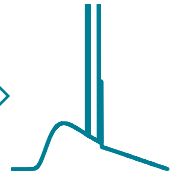
X-RAY IMAGING DOSIMETRY

Measurements

KAP
Air kerma-area product meter

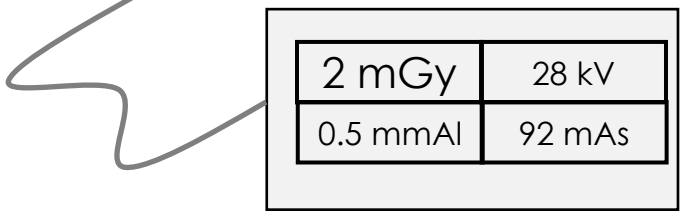
- Anode
- Tube voltage
- Filtration

- Tube current
- Time



Dose

Measurable quantities



X-ray multimeters (XMMs)

INTERNATIONAL GUIDANCE

IAEA: INTERNATIONAL ATOMIC ENERGY AGENCY

Dosimetry in Diagnostic Radiology: An International Code of Practice, Technical Reports Series No. 457, IAEA, Vienna (2007)

ICRU: INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

Patient Dosimetry for X Rays Used in Medical Imaging, ICRU Rep. 74, ICRU, Oxford (2005).

Radiation dosimetry and image quality assessment in CT, ICRU Rep.87 (2021).

ICRP: INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

Managing Patient Dose in Digital Radiology, ICRP Publication 93. (2004)

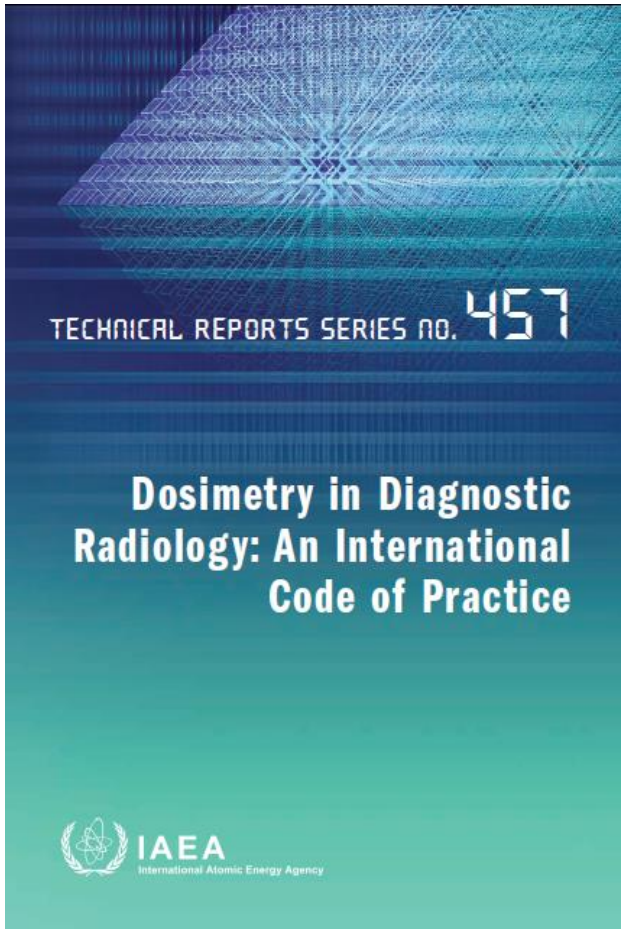
Optimisation of Radiological Protection in Digital Radiology Techniques for Medical Imaging (2023)

IEC: INTERNATIONAL ELECTROTECHNICAL COMMISSION

Medical Electrical Equipment — Dosimeters with Ionization Chambers and/or Semiconductor Detectors as Used in X-ray Diagnostic Imaging, IEC 61674:2012, IEC, Geneva (2012).

Medical Electrical Equipment — Dose Area Product Meters, IEC 60580:2000, IEC, Geneva (2000).

Medical Diagnostic X-ray Equipment — Radiation Conditions for Use in the Determination of Characteristics, IEC 61267:2005, IEC, Geneva (2005).



WHY WE NEED DOSIMETRY?

Technical performance

- Acceptance: system performs as specified
- QC: continuous performance

Validation of different dose displays and reports

- KAP meter, K at Interventional Reference Point (IRP)
- Dose in dicom header, Structured report (RDSR), dose mapping

Patient dose, generic

- Justification: benefit vs risk (averaged risk estimate)
- Optimization: ALARA
  - DRLs = a tool

Patient specific dose (e.g. pregnant woman)

- Individual risk?

The purpose will also impact on the target uncertainty!

- 100%
- 50%
- 25%
- 15%
- 10%
- 7%
- 5%
- 3%
- 1%

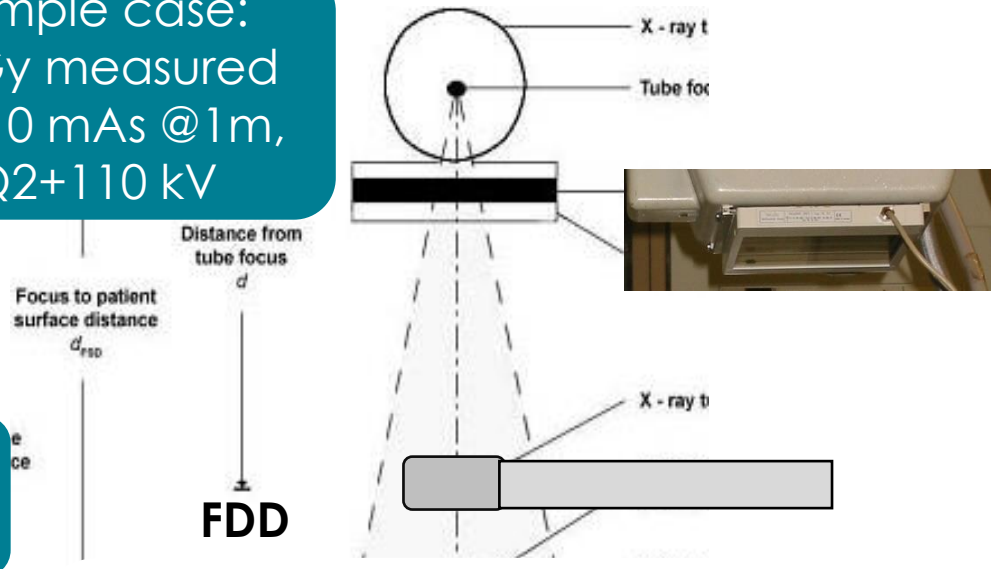
(95%, k=2)

QUANTITIES AND UNITS

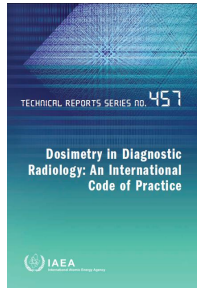
- Air kerma, K_a (≈ absorbed dose to air), mGy
  - Free in air
  - Entrance surface air kerma (ESAK)
- Tube current time product, Q, mAs
- Tube output, *Y*, mGy/mAs

$$Y(FDD) = \frac{K_a(FDD)}{Q} = \frac{1.00\ mGy}{10\ mAs} = 0.1\ mGy/mAs$$

Example case:
1 mGy measured with 10 mAs @1m, RQ2+110 kV



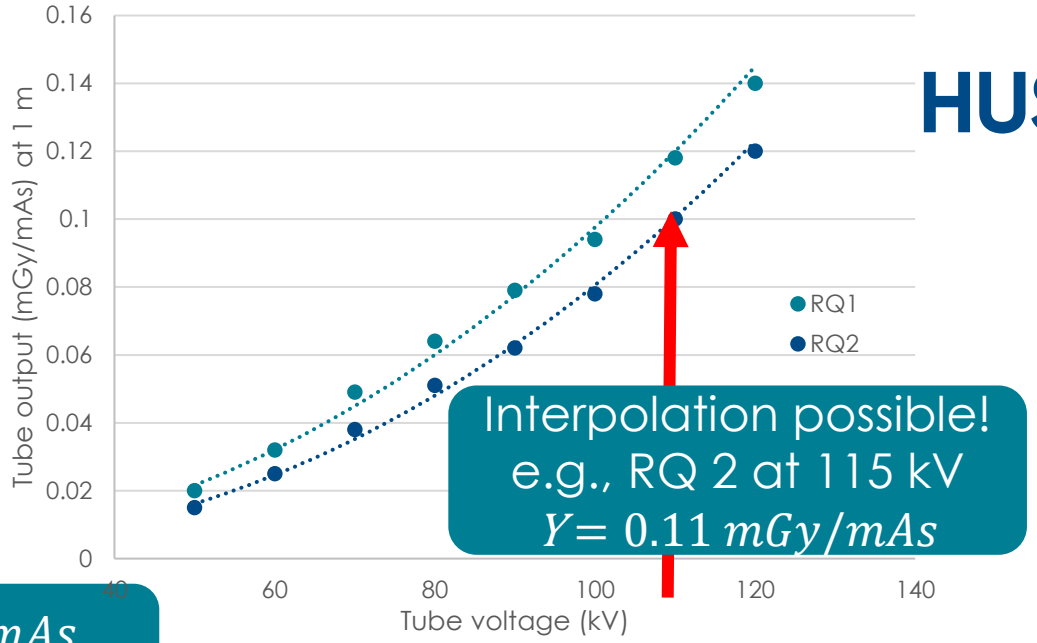
- Air kerma – area product (KAP), Gy ·m^2
  - $\int_A K_a(A)dA \approx K_a \cdot A_F$
  - X-ray beam/field area A_F
- Irradiation time t_R, s



Dosimetry in Diagnostic Radiology: An International Code of Practice, Technical Reports Series No. 457, IAEA, Vienna (2007)

USE OF TUBE OUTPUT

- K_a for a patient? RQ2+115 kV, 23 mAs, @2 m
- Tube output Y_d measured or interpolated for the correct radiation quality (@FDD)
- Air kerma, K_a with tube current time product Q_p used for a patient *p*



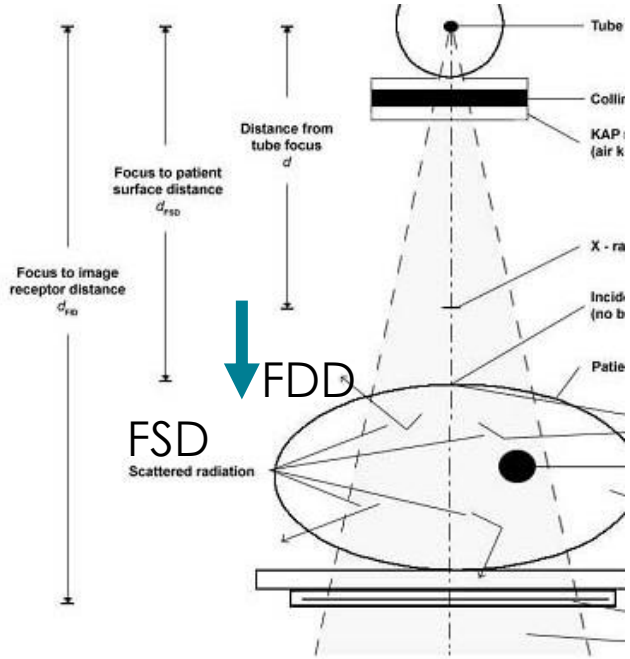
$$K_{a,Qp}(FDD) = Y_m(FDD) \cdot Q_p$$

$= 0.11 \frac{mGy}{mAs} \cdot 23 mAs$
=2.53 mGy

- Distance correction for the patient surface, *S* (or any other relevant distance)

$$K_{a,Qp,FSD} = K_{a,Qp,FDD} \cdot \left(\frac{FDD}{FSD}\right)^2$$

$= 2.53\ mGy \cdot \left(\frac{1\ m}{2\ m}\right)^2$
= 0.6325 mGy

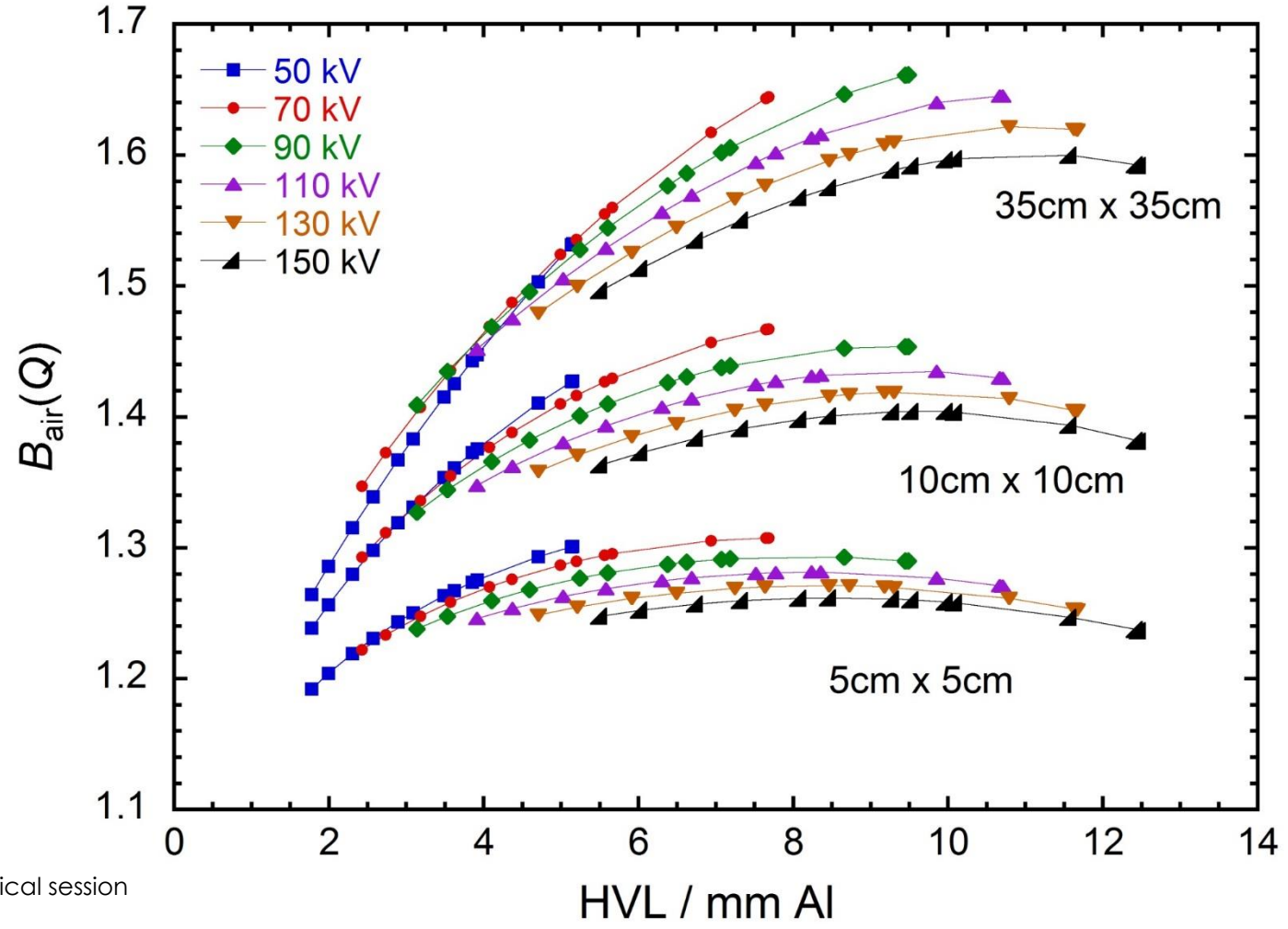


PATIENT DOSE

- Incident air kerma of an individual patient is still **not patient dose**.
- Calculation of e.g., organ doses requires information about **beam and patient properties**.
- Note: entrance surface air kerma cannot really be measured!!!
  (see the figure)
- Now we focus on measurements.

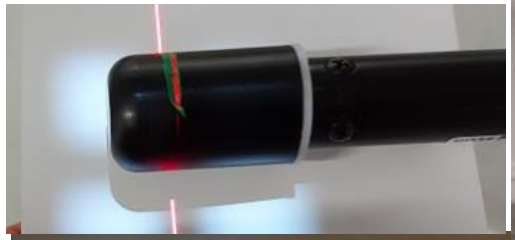
Back scatter factor, BSF

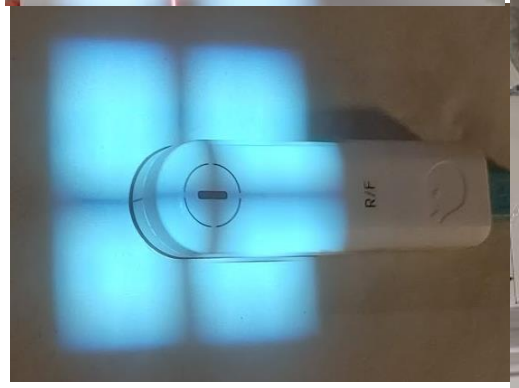
$$ESAK = K_{a,Qp,FSD} \cdot BSF(RQ, A)$$



MEASUREMENT CONDITIONS

- Measurement conditions will impact the uncertainty.
- Geometry
  - Positioning of dosimeter
    - Effective plane/point
  - Field size
  - Distance
- Scatter
- Radiation quality
- Environmental conditions
- Repetitions





$$K_m = M_m N_{ref} \sum k_{m,ref}$$

REFERENCE AND FIELD CLASS DOSIMETERS

- Dosimeters to measure X-ray beam output.
  - IAEA TRS-457 use the term reference class, but the requirements are not clear.
  - IEC 61674: **requirements for dosimeters** in specific conditions.
- Other dosimeter types can be used e.g., inside a phantom (TLD, Mosfet)
- Performance of dosimeter will impact the uncertainty (Niko's presentation).

Table A.1 – Estimation of COMBINED STANDARD UNCERTAINTY for dosimeter performance

PERFORMANCE CHARACTERISTIC	Subclause	Relative STANDARD UNCERTAINTY[a] %
Calibration factor[b]		±2,89
Linearity	5.1	±1,15
Repeatability	5.2	±0,58
RESOLUTION of reading	5.3	±0,58
STABILIZATION TIME	5.4	±1,15
Long term stability	5.6.1	±1,15
Accumulated dose stability	5.6.2	±0,58
RADIATION QUALITY	6.2	±2,89
AIR KERMA RATE	6.3	±1,15
Incidence of radiation	6.4	±1,73
Operating voltage	6.5	±1,15
Air pressure	6.6	±1,15
Temperature and humidity	6.8	±1,73
Electromagnetic compatibility	6.9	±2,89
Field size	6.10	±1,73
COMBINED STANDARD UNCERTAINTY		±6,6

[a] Relative STANDARD UNCERTAINTY assuming that there is no additional information about the PROBABILITY DISTRIBUTION of the PERFORMANCE CHARACTERISTIC within the allowed interval other than it has an uniform distribution, i.e. 0,577 *L* for symmetric limits.

[b] Although no requirement on the accuracy of the calibration factor is laid down in this document, a maximum error of the calibration factor is included here and assumed to be ±5 %. A uniform distribution is also assumed.

DOSIMETER USED FOR THE MEASUREMENT

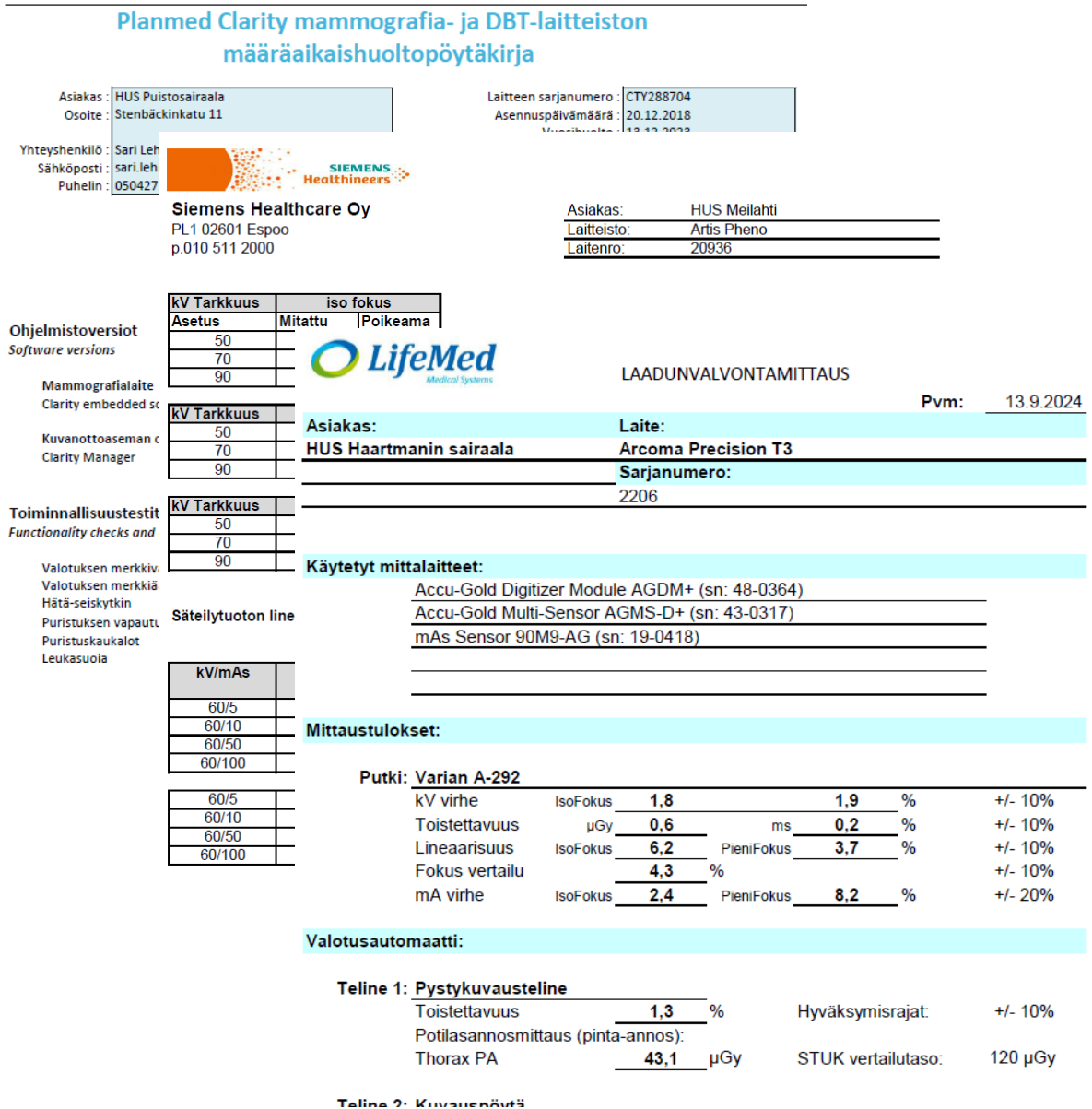
Selection based on availability, not to prefer one manufacturer.

- Radcal Accu-Gold
  - Digitizer module AGDM+
  - 10X6-6: general purpose IC
  - 10X6-6M: mammography IC
  - AGMS-DM+: diagnostic and mammographic range XMM

ROLE OF MEDICAL PHYSICIST

- Companies perform all the measurements, so why should we be interested in dosimetry ?

- Medical physicist has the responsibility to at least understand
  - what is in the reports?
  - what are uncertainties?
  - what are the measurement conditions?
  - how they impact on patient dose data?
  - can they be used e.g., for optimization?
- It is recommended to keep the capability for independent measurements.



Planmed Clarity mammografia- ja DBT-laitteiston määräaikaishuoltopöytäkirja

Asiakas : HUS Puistosairaala
Osoite : Stenbäckinkatu 11
Yhteyshenkilö : Sari Leh
Sähköposti : sari.lehi
Puhelin : 050427

Laitteen sarjanumero : CTY288704
Asennuspäivämäärä : 20.12.2018

SIEMENS Healthineers

Siemens Healthcare Oy
PL1 02601 Espoo
p.010 511 2000

Asiakas: HUS Meilahti
Laitteisto: Artis Pheno
Laitenro: 20936

Ohjelmistoversiot *Software versions*	kV Tarkkuus Asetus	iso fokus Mitattu	Poikeama
	50		
	70		
	90		

Mammografialaite
Clarity embedded sc

Kuvanottoaseman c Clarity Manager	kV Tarkkuus
	50
	70
	90

Toiminnallisuustestit *Functionality checks and*	kV Tarkkuus
	50
	70
	90

Valotuksen merkkiv
Valotuksen merkkiä
Hätä-seiskytkin
Puristuksen vapautu
Puristuskaukalot
Leukasuoja

Säteilytuoton line

kV/mAs		
60/5		
60/10		
60/50		
60/100		

60/5		
60/10		
60/50		
60/100		

LifeMed Medical Systems

LAADUNVALVONTAMITTAUS

Pvm: 13.9.2024

Asiakas:	Laite:
HUS Haartmanin sairaala	Arcoma Precision T3
	Sarjanumero:
	2206

Käytetyt mittalaitteet:

Accu-Gold Digitizer Module AGDM+ (sn: 48-0364)
Accu-Gold Multi-Sensor AGMS-D+ (sn: 43-0317)
mAs Sensor 90M9-AG (sn: 19-0418)

Mittaustulokset:

Putki: Varian A-292

kV virhe	IsoFokus	1,8		1,9	%	+/- 10%
Toistettavuus	µGy	0,6	ms	0,2	%	+/- 10%
Lineaarisuus	IsoFokus	6,2	PieniFokus	3,7	%	+/- 10%
Fokus vertailu		4,3	%			+/- 10%
mA virhe	IsoFokus	2,4	PieniFokus	8,2	%	+/- 20%

Valotusautomaatti:

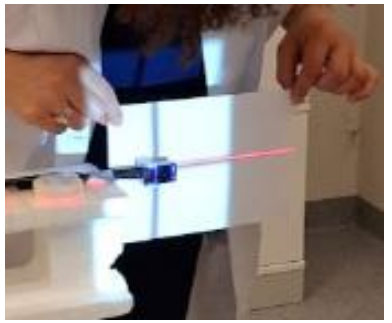
Teline 1: Pystykuvausteline

Toistettavuus	1,3	%	Hyväksymisrajat:	+/- 10%
Potilasannosmittaus (pinta-annos):				
Thorax PA	43,1	µGy	STUK vertailutaso:	120 µGy

Teline 2: Kuvauspöytä

AIM OF THE PRACTICAL SESSION

- Not to repeat tube output measurements.
- **Study impact of measurement conditions**.
  - How selected influence quantities will impact the results and patient dosimetry
  - Should we consider them in measurements or calculations?
  - For all modalities: impact of RQ and dosimeter used.
- Specifically:
  - Conventional projection radiography:
    - **Impact of field size and dosimeter positioning**
  - Mammography:
    - **Impact of compression paddle**
  - Interventional X-ray system
    - **Impact of patient table**



Practical exercises:

CONVENTIONAL RADIOGRAPHY

Juha Peltonen, Jenna Tarvonen (+Niko, Mika, Paula)

21 November 2024, TraMeXI workshop at HUS, Helsinki, Finland

CONVENTIONAL PROJETION RADIOGRAPHY

- Widely used due to its efficiency, accessibility, and ability to reveal a broad range of anatomical features and pathologies.

OVERVIEW VIDEO:

VIDEO link

X-RAY SYSTEM USED FOR THE MEASUREMENTS

- Powered by Canon DR: Arcoma Precision T3
- Tungsten anode with angle 12°
- Inherent filtartion 2.8 mmAl
- Additional filters: 0.1, 0.2 and 0.3 mmCu
- Tube voltage range: 40 – 125 kV

TYPICAL MEASUREMENTS

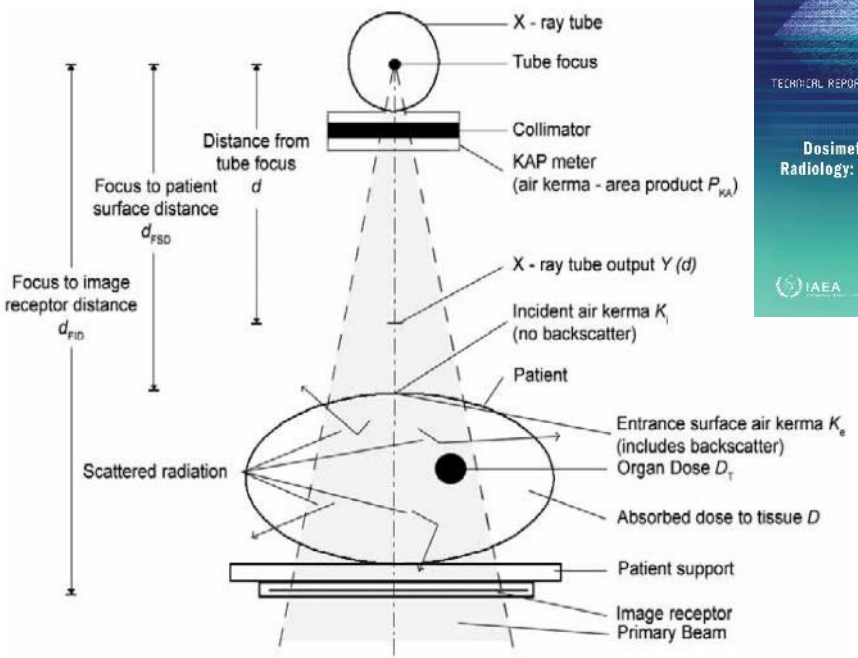
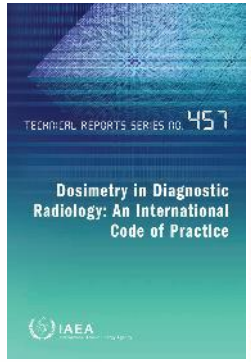


FIG. 3.2. Diagram of the measuring arrangement.



IAEA TRS No. 457 Dosimetry in Diagnostic Radiology: An International Code of Practice

FIG. 8.1. Experimental set-up for measurements using a CDRH abdomen/lumbar spine phantom on the table top with the ionization chamber positioned above the phantom.

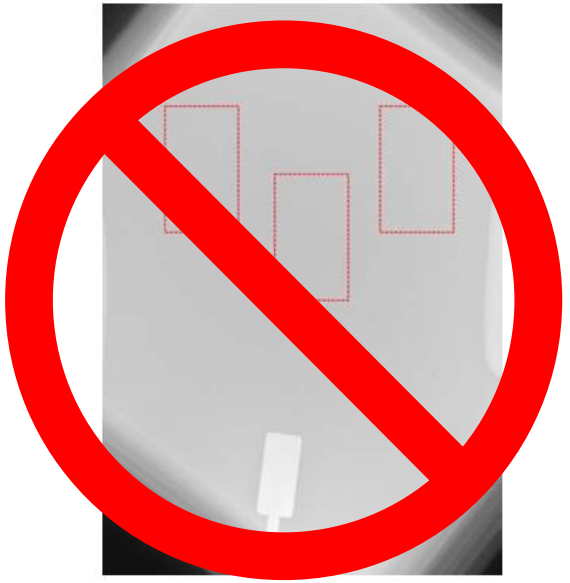


FIG. 12. X ray image showing the set-up for measuring the image receptor dose. A solid state detector and the AEC ionization chamber positions during a measurement under PMMA plates are indicated.

IAEA HHS No. 47 Handbook of Basic Quality Control Tests for Diagnostic Radiology

MEASUREMENTS

- 1 m distance from focus
- 100 mA, 100 ms, 10 mAs
- 6 RQ (table)
- IC, XMM and KAP measurements

Main aims today:

- Impact of field size
  - 10 cm*10 cm (ref)
  - 5 cm*5 cm and 50 cm*50 cm
- Impact of dosimeter position
  - Dosimeter in the centre (ref)
  - Dosimeter in the corner

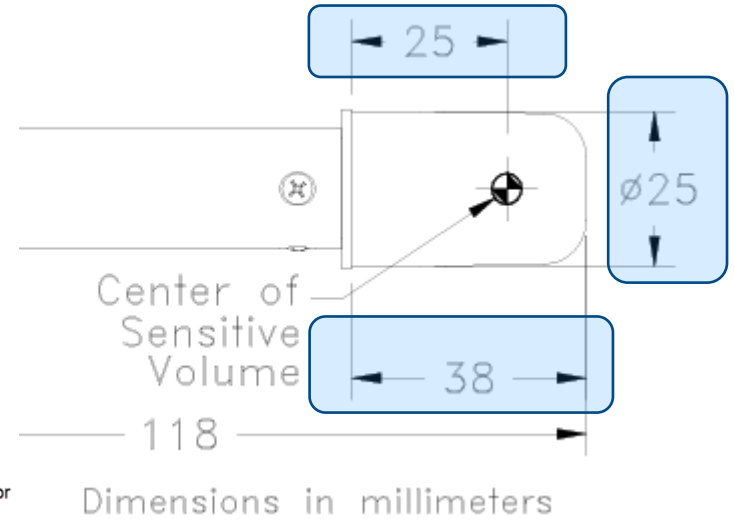
Tube voltage (kV)	Filtration (mmCu)
50	0
50	0.3
70	0
70	0.3
120	0
120	0.3

RADCAL IC FOR GENERAL RADIOLOGY

Performs automatic temperature and pressure correction.

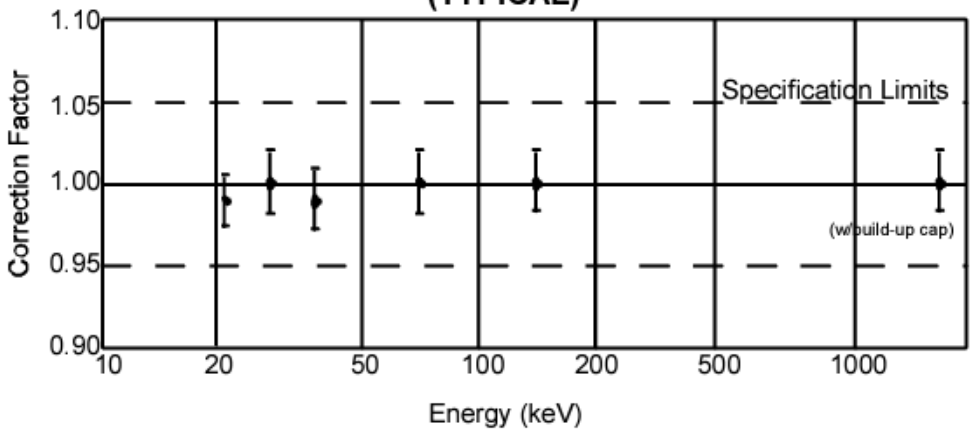
Specifications[1]

Rate Specifications	2 µR/s - 17 R/s 20 nGy/s - 149 mGy/s
Exposure Specifications	10 µR - 59 kR 100 nGy - 516 Gy
Cine Specifications:	0.1 µR/f - 1 R/f 1 nGy/fr - 10 mGy/f
Auto Dose Threshold	2 mR/s 19 µGy/s
Calibration Accuracy:	±4% using X-rays @ 60kVp & 2.8 mm Al HVL
Exposure Rate Dependence:	±5%, 0.4 mR/s to 80 R/s, up to 500 R/s for 50 us pulses
Energy Dependence	±5%, 30 keV to 1.33 MeV (with build-up material)
Construction:	Concentric cylinder. Polycarbonate walls and electrode. Conductive graphite interior coating. 6cm^3 active volume. 0.05kg
Environmental:	15° - 35° C working, 0° - 60° C storage, < 80% RH (non-condensing), 70-106 kPa
Minimum Field Size[2]:	25 mm x 38 mm



Chamber	10X6-6	
Min Rate	2 µR/s	20 nGy/s
Max Rate	17 R/s	149 mGy/s
Min Dose	10 µR	100 nGy
Max Dose	59 kR	516 Gy
Cine Specifications	0.1 µR/f - >1 R/f	1 nGy/f - >10 mGy/f
Calibration Accuracy	±4% using X-rays @ 60kVp and 2.8 mm AL HVL	
Exposure Rate Dependence	±5%, 0.4 mR/s to 80 R/s, up to 500 R/s for 50 us pulses	
Energy Dependence	±5%, 30 keV to 1.33 MeV (with build-up material)	
Construction	Polycarbonate walls and electrode conductive graphite interior coating; 6 cm3 active volume; 0.05kg	

-6 Ion Chamber
Energy Dependence
(TYPICAL)



RADCAL XMM FOR GENERAL RADIOLOGY

Reference conditions	**Mammo:** 2.2 mm thick polycarbonate compression paddle in beam for all measurements (kVp, dose, hvl). Calibrated using large focal spot. **Rad/Fluoro/Dental:** 12° Tungsten anode.
Size	35.6 mm x 20.0 mm x 11.8 mm
Reference point	Round marking 1 cm diameter midline – 3.2 mm from top surface.
Working temperature range	15°C - 35°C (Storage: 0°C / 32°F - 60°C / 140°F)
Humidity	< 80 % (without condensation)
Pressure	700 hPa – 1060 hPa

Note: The time range is different when using a Nugget. See Feat

Type	Anode / Filter	Tube	kV	Filt (um)	hvl (mm Al) ±10% or ±0.2 mm Al whichever is greater
Rad/Fluoro/Dental (AGMS-D)	W/Al	General	40-160 ±2% (2-24 mm Al, 40-160 kV) ±2.5% (25-40 mm Al, 50-160 kV)	2-40 mm	1.3-13.5

Rad/Flouro/Dental (AGMS-D)	Dose using AGDM	Dose Rate using AGDM	Dose using AGDM+	Dose Rate using AGDM+	Time
	150 nGy – >100 Gy, ±5% (17 µR – >11 kR, ±5%)	150 nGy/s – 350 mGy/s, ±5% (1.0 mR/min – 2.4 kR/min, ±5%)	80 nGy - >100 Gy, ±5% (9.1 uR - >11 kR, ±5%)	80 nGy/s - 150 mGy/s ±5% (0.55 mR/min - 1.0 kR/min, ±5%)	1 ms 0.1%

Reference condition: 12# Tungsten anode

LIVE BROADCAST

RESULTS

RAW RESULTS

- Repetitions:
  - 70 kV, 0 mmCu
  - 10 cm*10 cm
- Measured and displayed air kerma values (mGy) or KAP values.
- Calibration coefficients used and k_{tp} corrections applied.

IC (mGy)	XMM (mGy)	KAP (mGy*cm^2)
0.4263	0.3917	57
0.4269	0.3916	56
0.4271	0.3913	57
0.4273	0.3920	56
0.4261	0.3916	58
0.4265	0.3917	56
0.4269	0.3918	57
0.4271	0.3912	56
0.4274	0.3922	57
0.4270	0.3916	56
Mean (mGy)	**0.4269**	**0.3917**	**56.6**
SD (%)	**0.1**	**0.08**	**1.2**

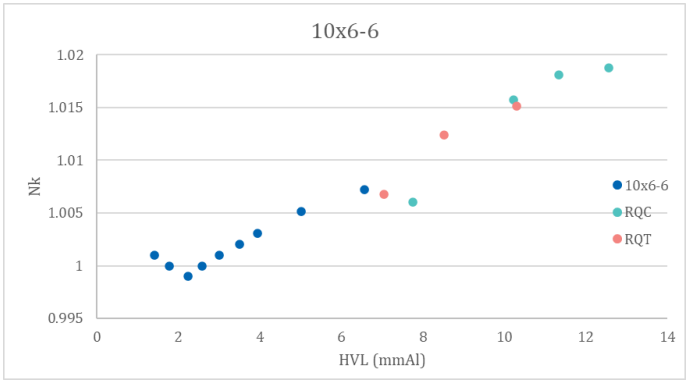
SELECTION OF CALIBRATION COEFFICIENTS

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	N_K_IC	N_K_XMM
50	0	1.95	**0.97**	**1.034**
50	0.3	3.86	0.973	1.025
70	0	2.73	**0.97**	**1.**
70	0.3	5.66	0.976	1.0
120	0	4.91	**0.975**	**1.026**
120	0.3	8.88	0.977	1.025

Radiation quality	Tube voltage	Filtration	HVL	Calibration coefficient	
	kV	mmAl	mmAl	10x6-6	AGMS-DM+
RQR 2	40	2.48	1.43	0.971	1.042
RQR 3	50	2.48	1.79	**0.97**	**1.034**
RQR 4	60	2.78	2.24	0.969	1.027
RQR 5	70	2.86	2.59	**0.97**	**1.**
RQR 6	80	3.02	3.01	0.971	
RQR 7	90	3.25	3.51		
RQR 8	100	3.37			
RQR 9	120	3.8			
RQR 10	150				1.023

Radiation qu			HVL	Calibration coefficient	
		mmCu	mmAl	10x6-6	AGMS-DM+
		.87	0.2	7.05	0.977	1.029
		3.82	0.25	8.53	0.982	1.027
	150	4.45	0.3	10.3	0.985	1.013
CX5	70	2.86	0.9	7.75	0.976	1.037
RQCX8	100	3.37	0.9	10.22	0.985	1.014
RQCX 9	120	3.82	0.9	11.33	0.988	1.012
RQCX10	150	4.45	0.9	12.56	0.988	1.014

Presented in the morning



IMPACT OF FIELD SIZE

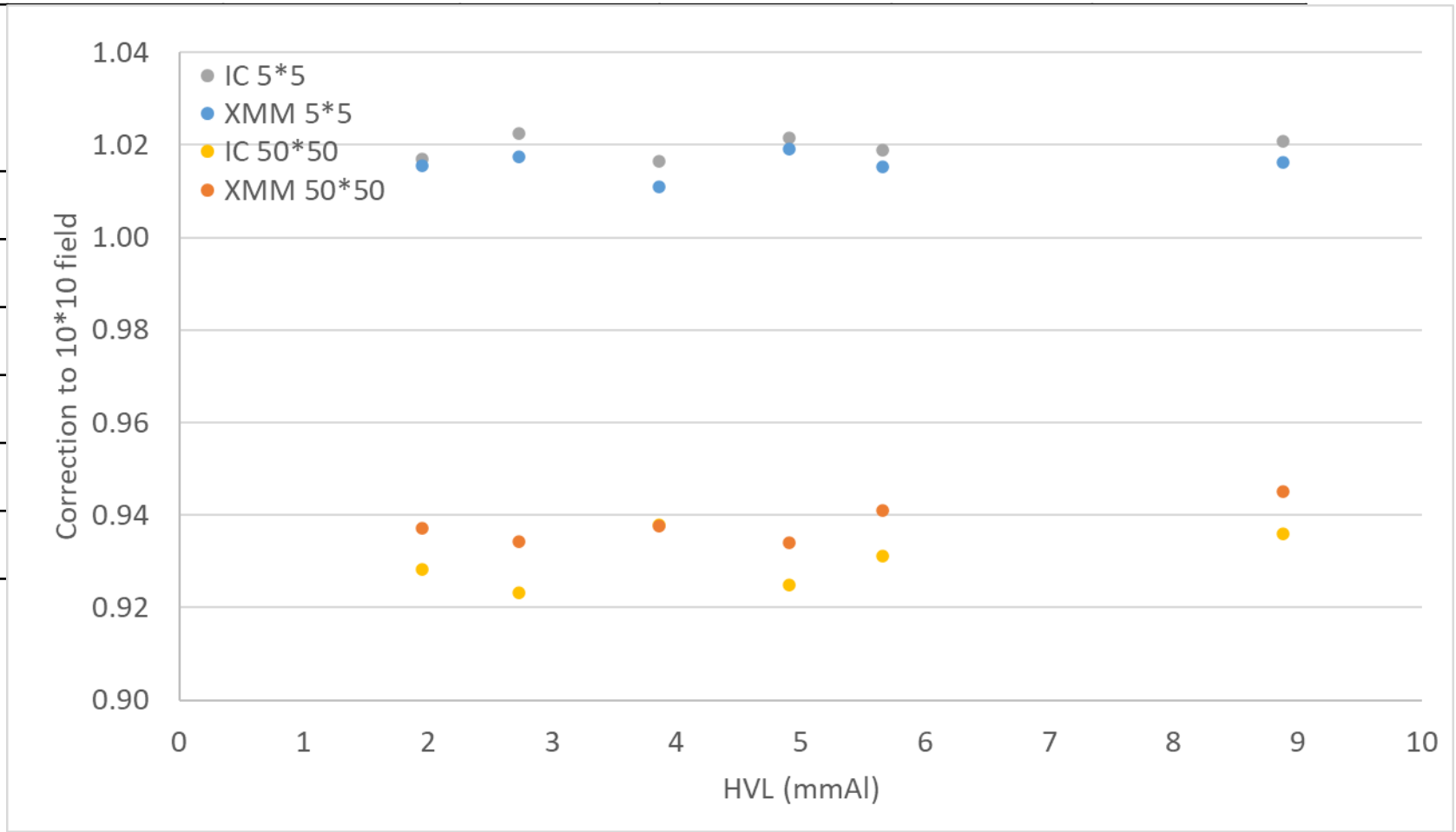
Tube voltage (kV)	**Filtration (mmCu)**	**HVL (mmAl)**	Ka_IC (mGy) **10x10**	Ka_XMM (mGy) 10x10	Ka_IC (mGy) **5x5**	Ka_XMM (mGy) 5x5	Ka_IC (mGy) **50x50**	Ka_XMM (mGy) 50x50
50	0	1.95						
50	0.3	3.86						
70	0	2.73						
70	0.3	5.66						
120	0	4.91						
120	0.3	8.88	**0.4627**		**0.4532**		**0.4943**	

2% smaller

6.4% larger

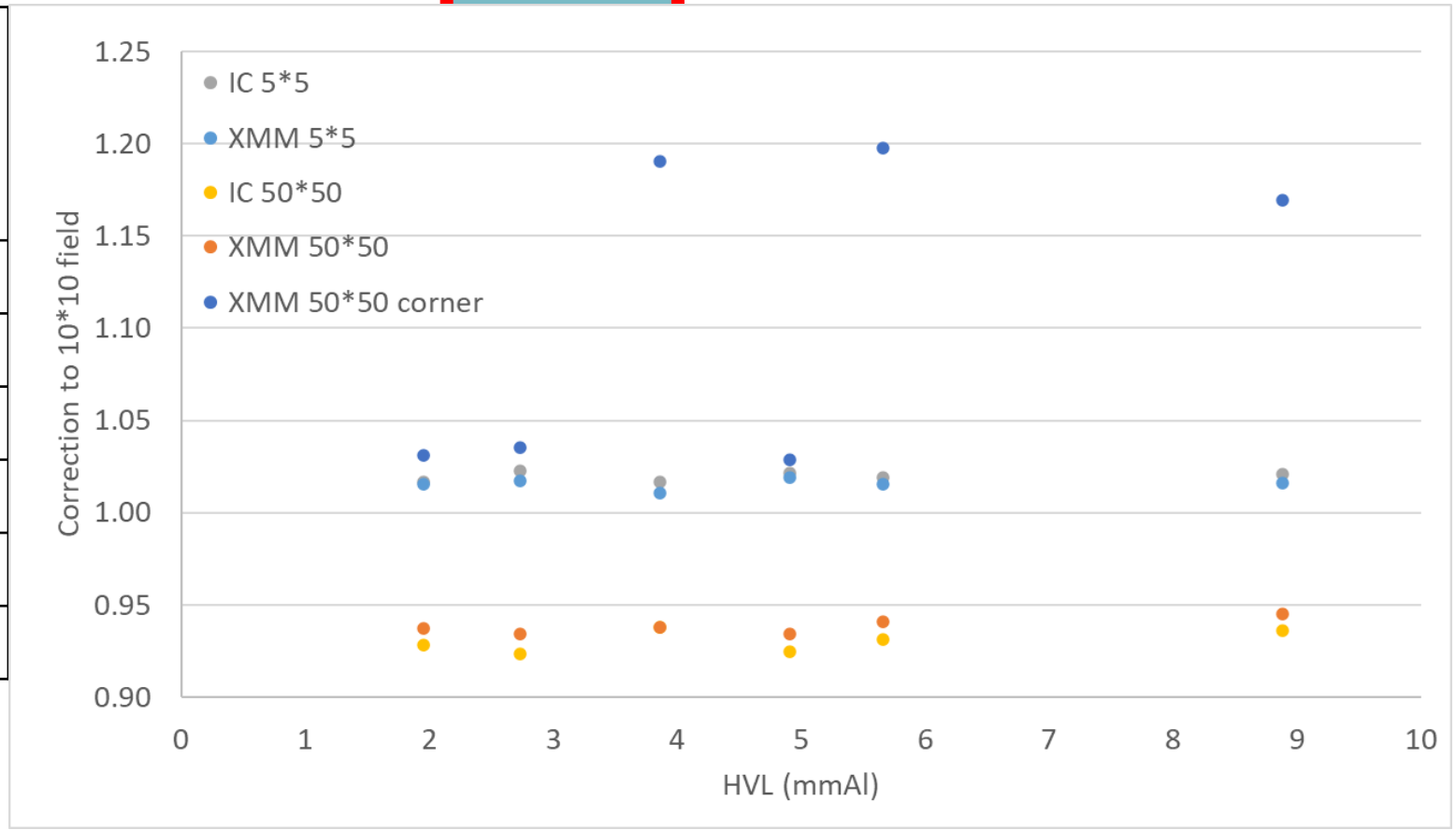
IMPACT OF FIELD SIZE

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)
50	0	1.95
50	0.3	3.86
70	0	2.73
70	0.3	5.66
120	0	4.91
120	0.3	8.88



IMPACT OF DOSIMETER POSITION

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)
50	0	1.95
50	0.3	3.86
70	0	2.73
70	0.3	5.66
120	0	4.91
120	0.3	8.88



OTHER QUANTITIES

10 cm*10 cm

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	Ka_IC (mGy) 10x10	Ka_XMM (mGy) 10x10	IC_XMM diff. (%)	PPV (kV)	HVL (mmAl)	TF (mmAl)
50	0	1.95	0.1913	0.1874	2.0	50.07	2.08	3.40
50	0.3	3.86	0.0194	0.0186	4.1	49.40	3.98	14.80
70	0	2.73	0.4141	0.4034	2.6	69.83	2.86	3.38
70	0.3	5.66	0.0839	0.0806	3.9	69.73	5.84	15.00
120	0	4.91	1.1525	1.1248	2.4	122.60	4.84	3.30
120	0.3	8.88	0.4627	0.4546	1.8	122.90	9.14	14.72

IC ja XMM difference 2% - 4%

Other XMM quantities differences to nominal:
PPV: 2.4%
HVL: 6.2%
TF:18%

IMPACT OF DOSIMETER POSITION: OTHER

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	Ka_IC (mGy) 50x50	Ka_XMM (mGy) 50x50	Ka_XMM (mGy) 50x50 corner
50	0	1.95	0.2060	0.1999	0.1817
50	0.3	3.86	0.0206	0.0198	0.0156
70	0	2.73	0.4485	0.4317	0.3896
70	0.3	5.66	0.0901	0.0857	0.0673
120	0	4.91	1.2461	1.2042	1.0937
120	0.3	8.88	0.4943	0.4810	0.3887

10 cm * 10 cm
Other XMM quantities differences to nominal:
TV: 1.9% - 2.5%
HVL: 6.2%
TF:18%

Corner
Other XMM quantities Difference to nominal:
TV: 6.7% - 7.7%
HVL: 29%
TF:88%

Practical exercises:

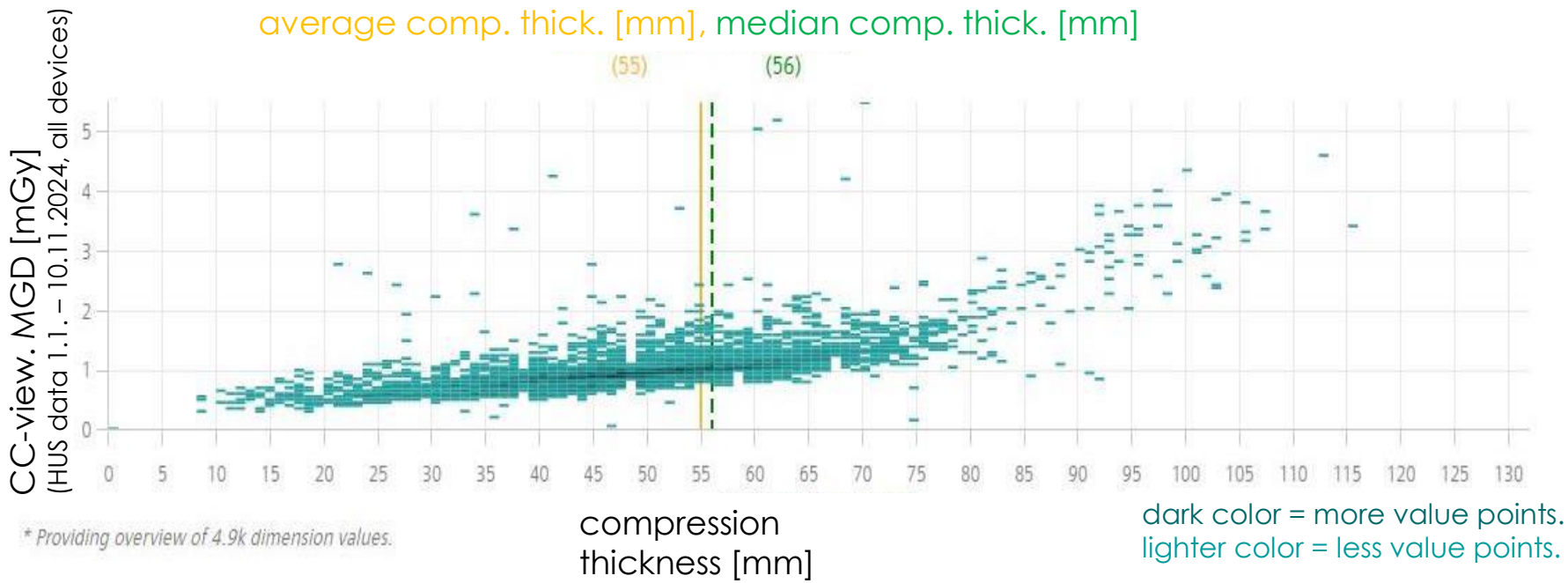
MAMMOGRAPHY

Anne-Mari Vitikainen, Jenna Tarvonen (+Niko, Mika, Paula)

21 November 2024, TraMeXI workshop at HUS, Helsinki, Finland

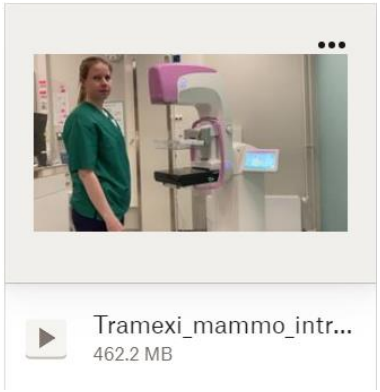
CLINICAL USAGE OF MAMMOGRAPHY

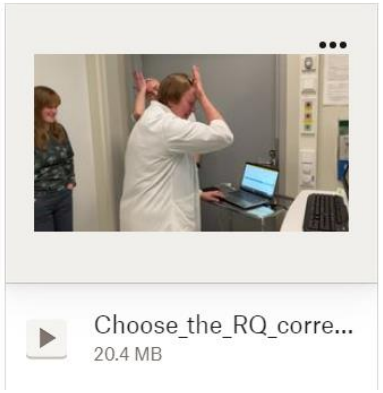
- medical imaging technique specialized in **breast** imaging
- aids in the early detection and diagnosis of **breast diseases** in women
  - widely used in breast cancer screening.
- dose quantity is mean/average **glandular dose** (MGD/AGD/D_g).
  - depends on technical factors, models used, breast thickness and density.



OVERVIEW VIDEO:

[Run the video prepared by Anne-Mari]

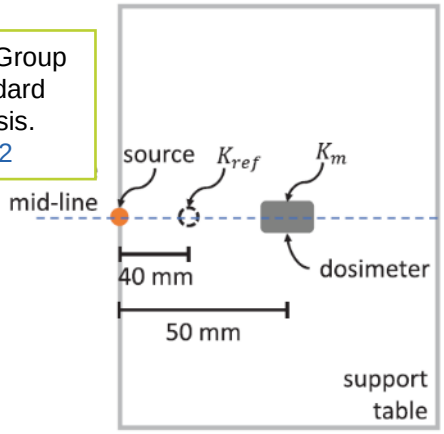




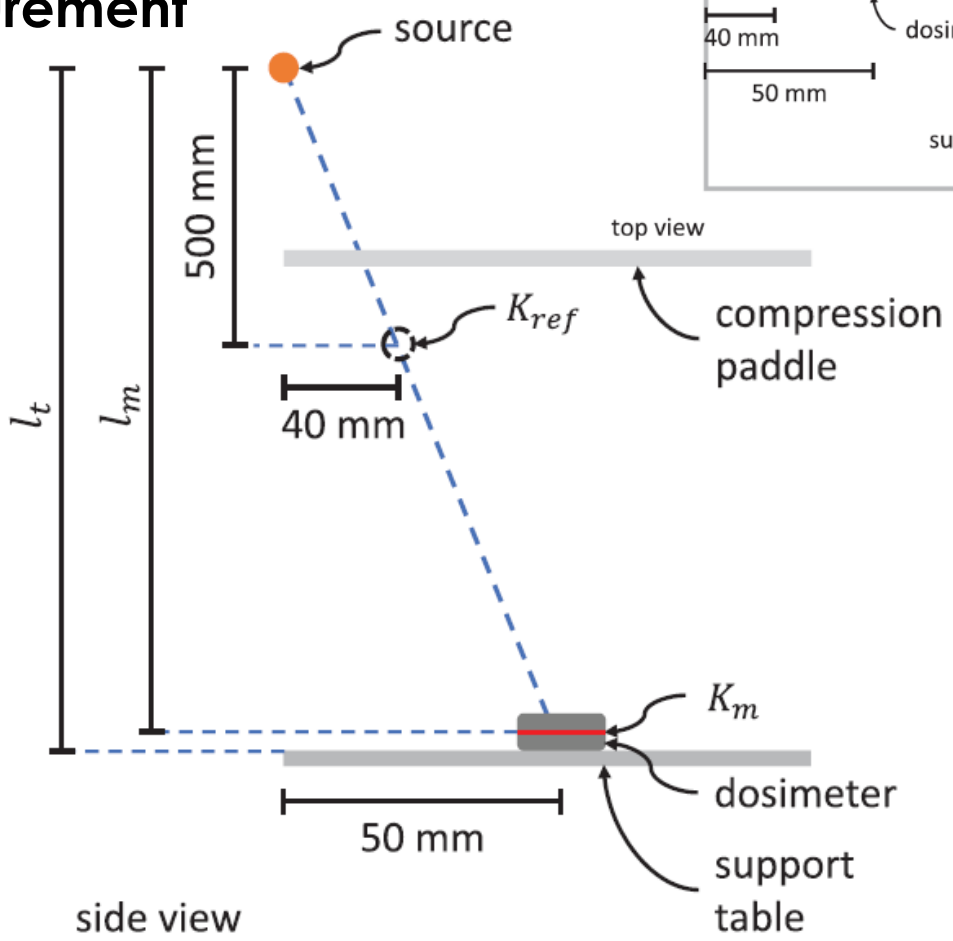
RECOMMENDED MEASUREMENT GEOMETRY

Sechopoulos I, Dance DR, Boone JM, et al. Joint AAPM Task Group 282/EFOMP Working Group Report: Breast dosimetry for standard and contrast-enhanced mammography and breast tomosynthesis. *Med. Phys*. 2024;51:712–739. https://doi.org/10.1002/mp.16842

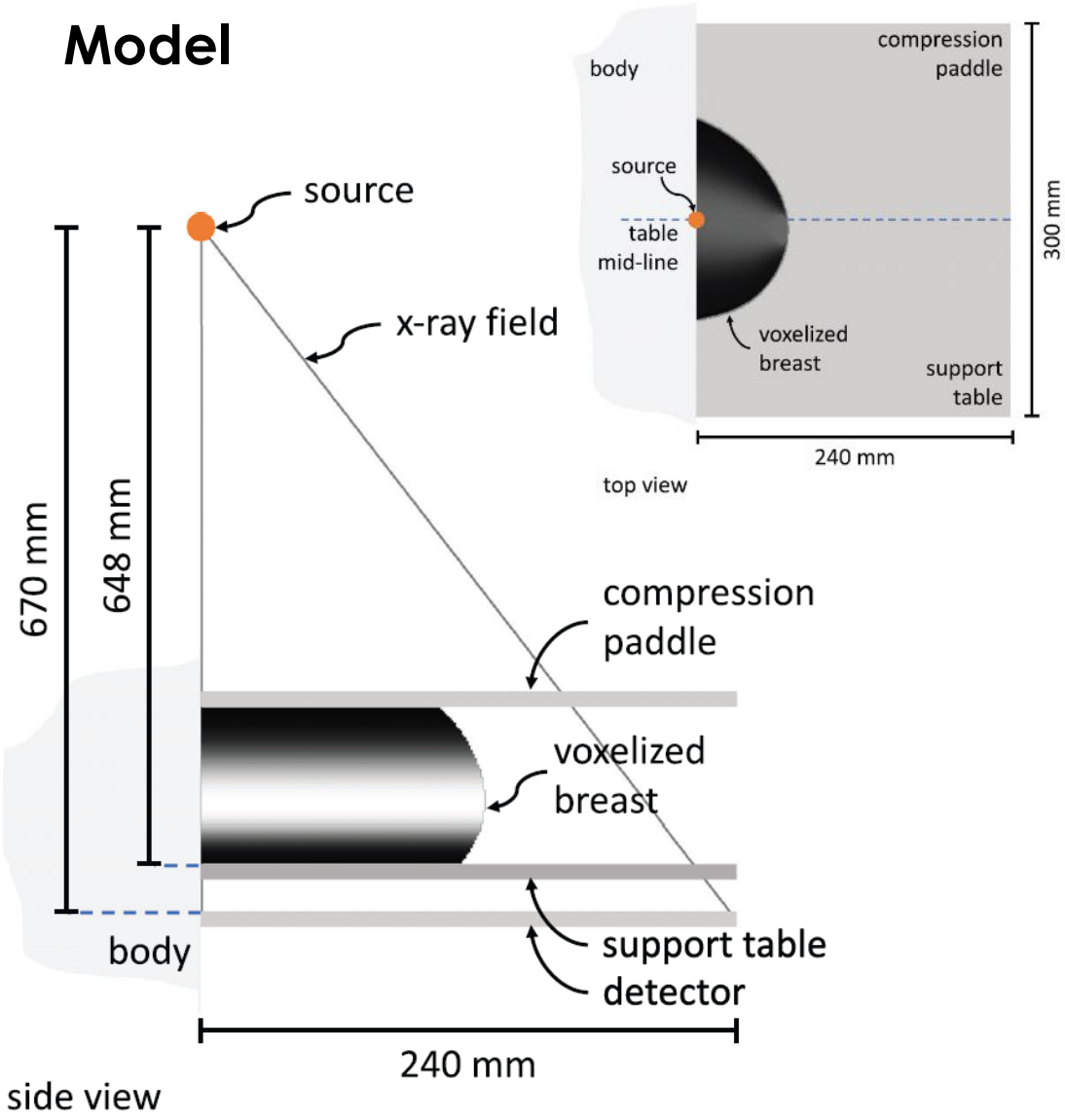
Measurement



Today
l_t = ?
l_m = ?



Model

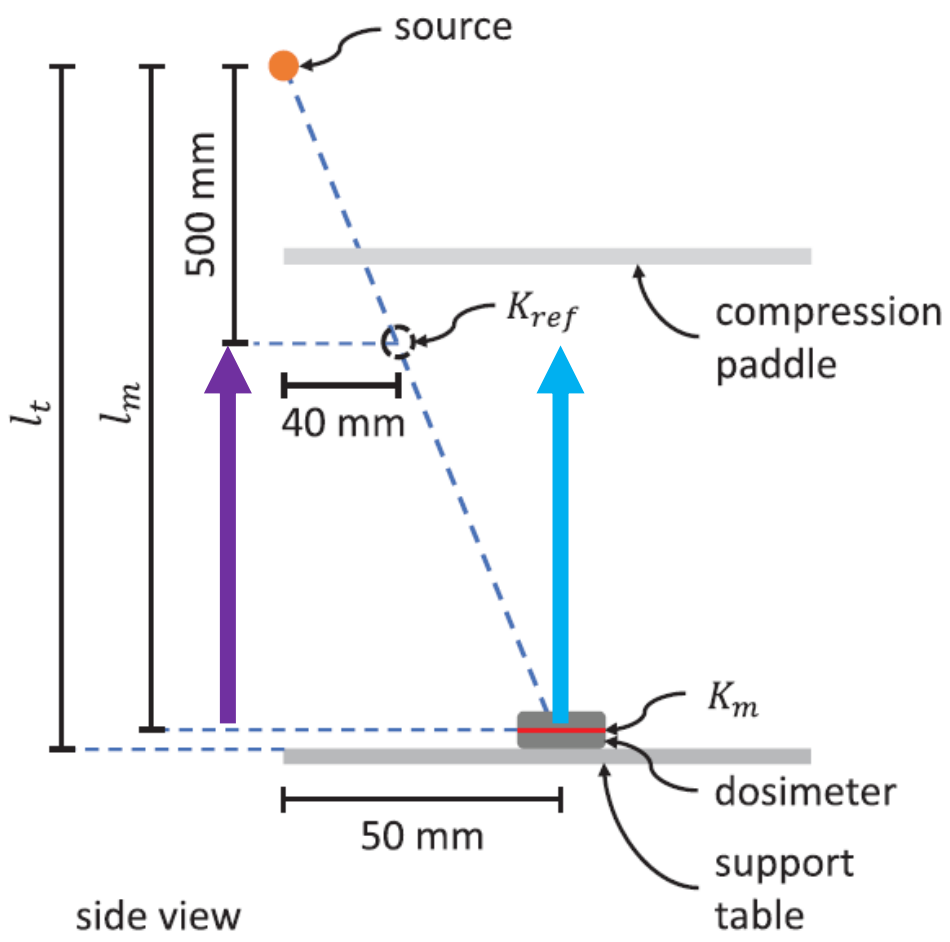


MEASUREMENT POSITION RELATED CORRECTIONS

HUS

Measurement

Today
l_t = ?
l_m = ?



Distance correction: square law

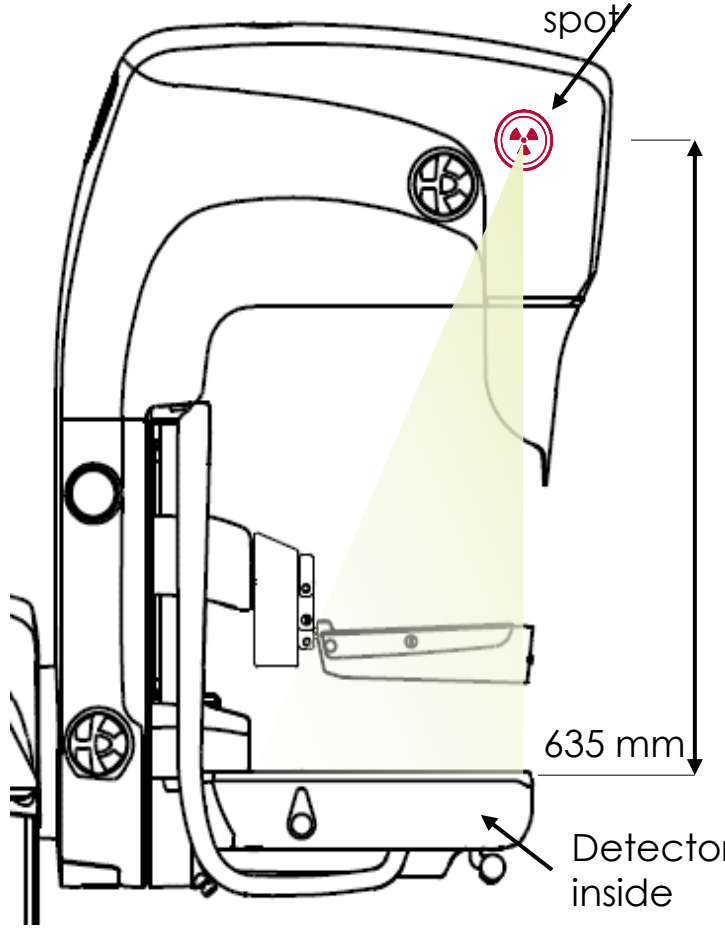
$$K_{ref} = K_m \left(\frac{l_m}{500\ mm} \right)^2 c_k$$

Forward scatter correction factor ~1.032

$$c_k = \frac{K_{ref}}{K_m} \left(\frac{500\ mm}{l_m} \right)^2$$

SYSTEM USED FOR THE MEASUREMENTS

- Manufacturer: Planmed Oy. Model: Clarity 3D full field digital mammography device, capable of tomosynthesis imaging.
- Tungsten (W) **anode**, with a rotating anode angle of 16° (large focus 0,3 mm) and 10 ° (small focus 0,1 mm used for magnification imaging).
- Device is equipped with a **60 µm** Rhodium (Rh) and a **75 µm** Silver (Ag) **filters** + 0,63 mm Beryllium tube port window.
  - With this device Rh-filter is used with compression thickness < 20 mm (@ 27 kV) and Ag-filter with compression thickness ≥ 20 mm (27-34 kV).
- X-ray **field size** is nominal 24x30 cm. Mammography devices in general use a fixed source to image distance and source to bucky distance.
  - source to image distance (650 mm),
  - source to bucky distance (635 mm).
- **Compression paddle** height can be adjusted according to the patient.
  - Maximum compression thickness is 16,5 cm.

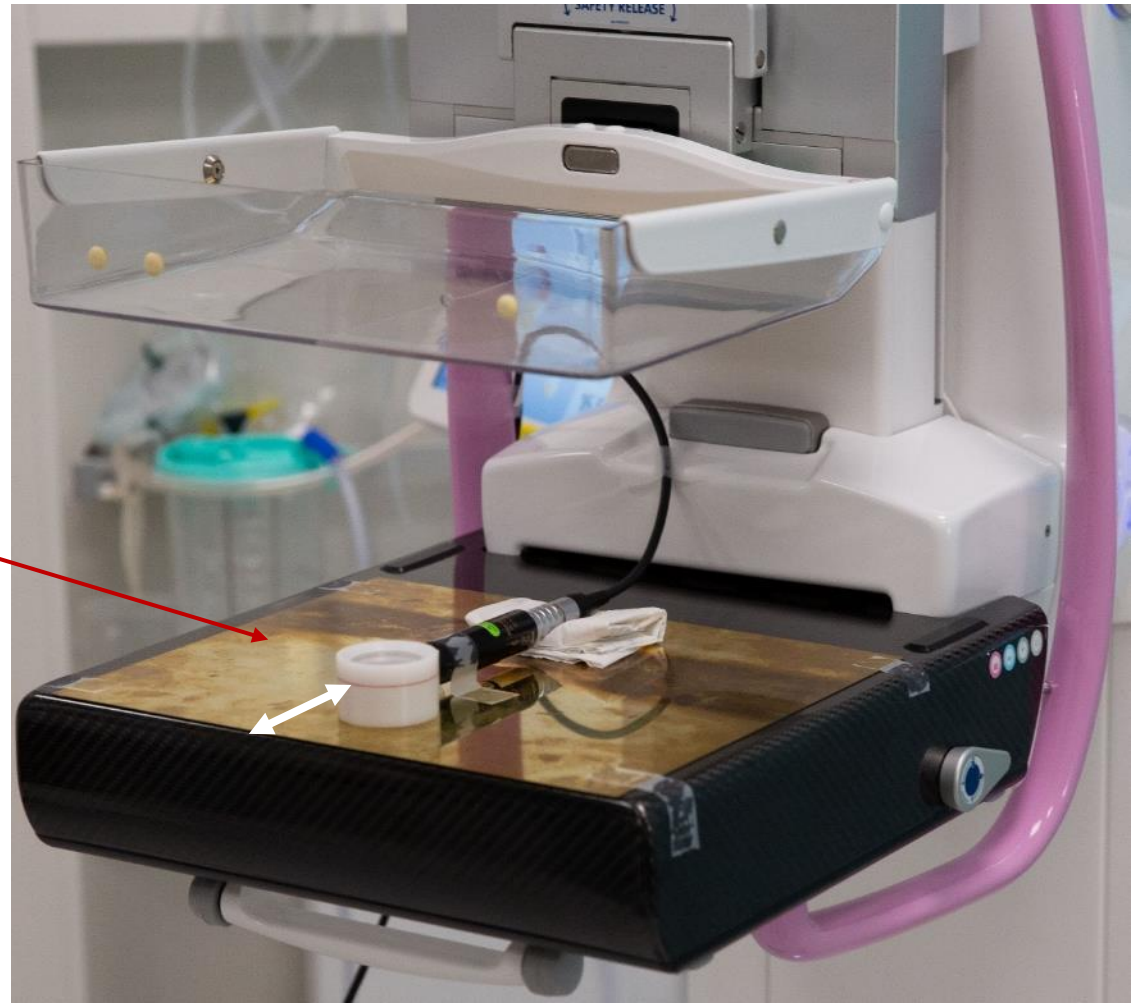


Today
l_t = 635 mm
l_m = ?

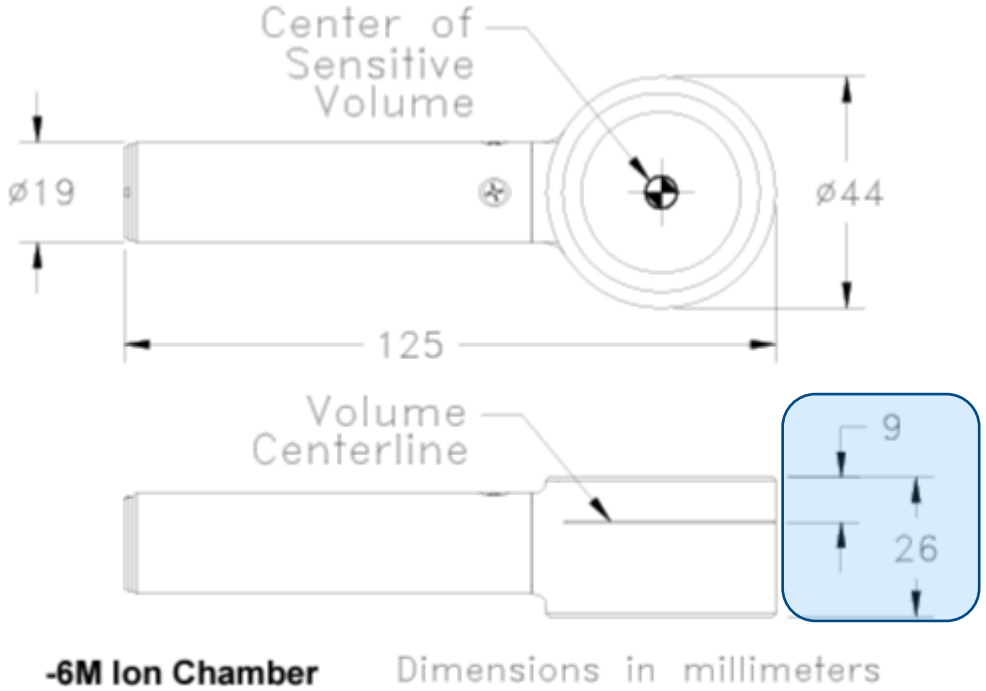
TODAYS MEASUREMENTS' SCHEMATICS

- Focus to bucky distance = 635 mm
- Positioning of dosimeter (IC/XMM)
  - Centered in left/right direction
  - Reference point 5 cm from chest wall side (white arrow)
- Detector shield plate thickness 0.54 mm.
- Compression paddle as far as possible: 165 mm
- 3 radiation qualities, 50 mAs

Radiation qualities
W/Rh 28kV
W/Ag 28 kV
W/Ag 32 kV



RADCAL IC FOR MAMMOGRAPHY



-6M Ion Chamber Dimensions in millimeters

Chamber	10X6-6M	
Min Rate	2 µR/s	20 nGy/s
Max Rate	10 R/s	88 mGy/s
Min Dose	10 µR	100 nGy
Max Dose	59 kR	516 Gy
Cine Specifications	N/A	
Calibration Accuracy	±4% using X-rays @ 30kVp and 0.50 mm AL HVL	
Exposure Rate Dependence	±5%, 0.02 R/min to 600 R/min	
Energy Dependence	±5%, 10 keV to 40 keV	
Construction	0.7 mg/cm2 metalized polyester window; polyacetal exterior; 6cm3 active volume; 0.08kg	

Reference point from bottom:
26 mm – 9 mm = 17 mm
l_m = 635 mm – 17 mm – 0.54 mm = **617.46 mm**

RADCAL XMM FOR MAMMOGRAPHY

Reference conditions	**Mammo:** 2.2 mm thick polycarbonate compression paddle in beam for all measurements (kVp, dose, hvl). Calibrated using large focal spot. **Rad/Fluoro/Dental:** 12° Tungsten anode.
Size	35.6 mm x 20.0 mm x 11.8 mm
Reference point	Round marking 1 cm diameter midline – 3.2 mm from top surface.
Working temperature range	15°C - 35°C (Storage: 0°C / 32°F - 60°C / 140°F)
Humidity	< 80 % (without condensation)
Pressure	700 hPa – 1060 hPa

Note: The time range is different when using a Nugget. See Feature Com

Type	Anode / Filter	Tube	kV ±2% or ±0.7kV whichever is greater	Filt (um)	hvl (mm Al) ±10% or ±0.05 mm Al whichever is greater
Mammo (AGMS-M)	Mo/Mo	General	21-49	16-44	0.21-0.50
	Mo/Rh	General	21-49	6-42	0.18-0.56
	Mo/Mo	GE	22-48	16-44	0.24-0.51
	Mo/Rh	GE	22-48	6-42	0.20-0.56
	Rh/Rh	GE	25-48	12-80	0.27-0.78
	W/Ag	General	20-38	12-80	0.17-0.78
	W/Rh	General	20-38	12-78	0.17-0.69
	W/Al	General	20-50	200-990	0.16-0.82

Mammo (AGMS-M)	Dose using AGDM	Dose Rate using AGDM	Dose using AGDM+	Dose Rate using AGDM+	Time
	150 nGy – >100 Gy, ±5% (17 µR – >11 kR, ±5%)	150 nGy/s – 350 mGy/s, ±5% (1.0 mR/min – 2.4 kR/min, ±5%)	80 nGy - >100 Gy, ±5% (9.1 uR - >11 kR, ±5%)	80 nGy/s - 150 mGy/s ±5% (0.55 mR/min - 1.0 kR/min, ±5%)	1 ms – 300 s ± 0.1% +0.2 ms

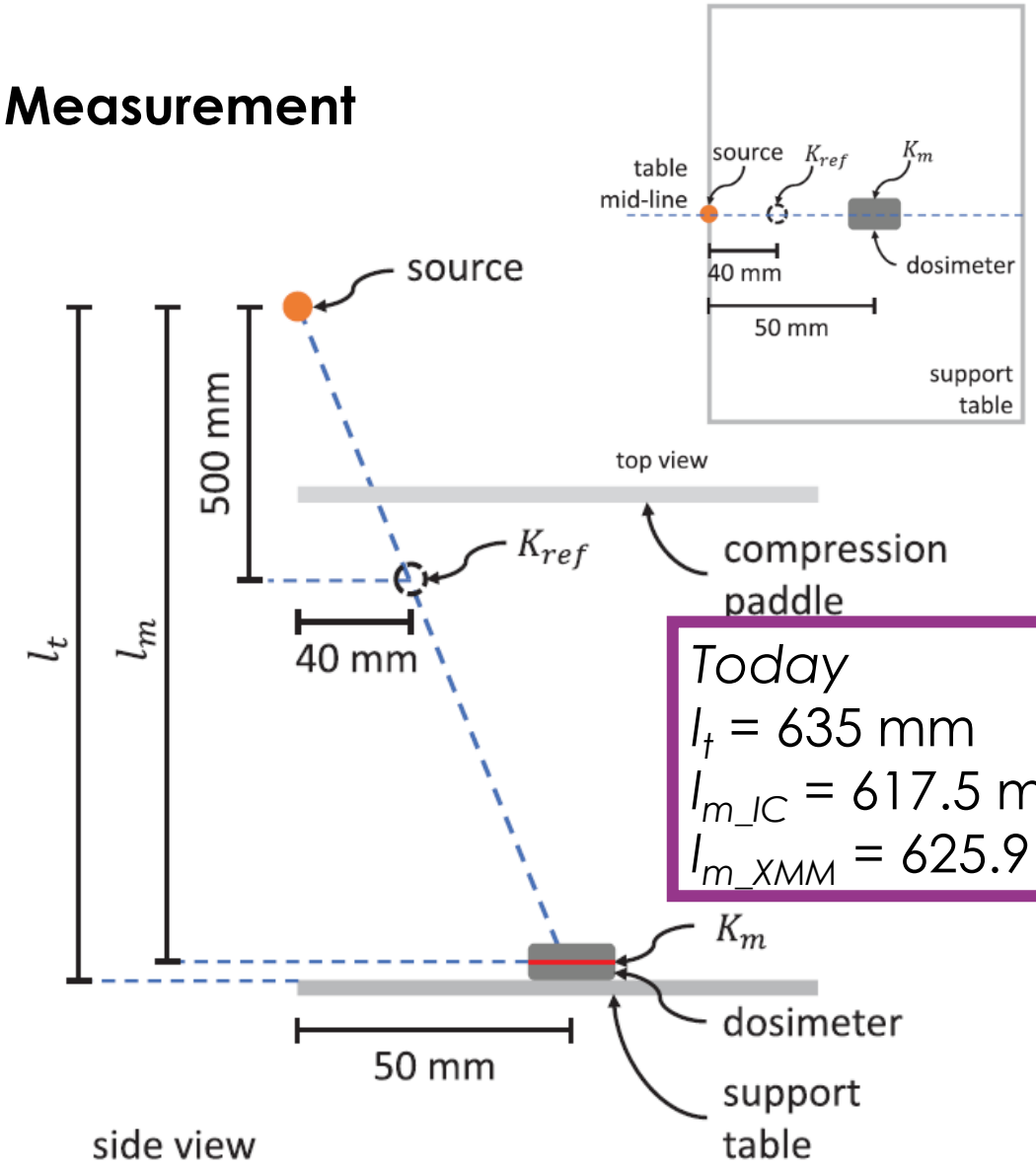
Reference Conditions:

- 2.2 mm polycarbonate compression paddle in beam for all measurements (kVp, dose, hvl).
- Calibrated using large focal spot

Reference point from bottom:
11.8 mm – 3.2 mm = 8.6 mm
l_m= 635 mm – 8.6 mm - 0.54 mm= **625.86 mm**

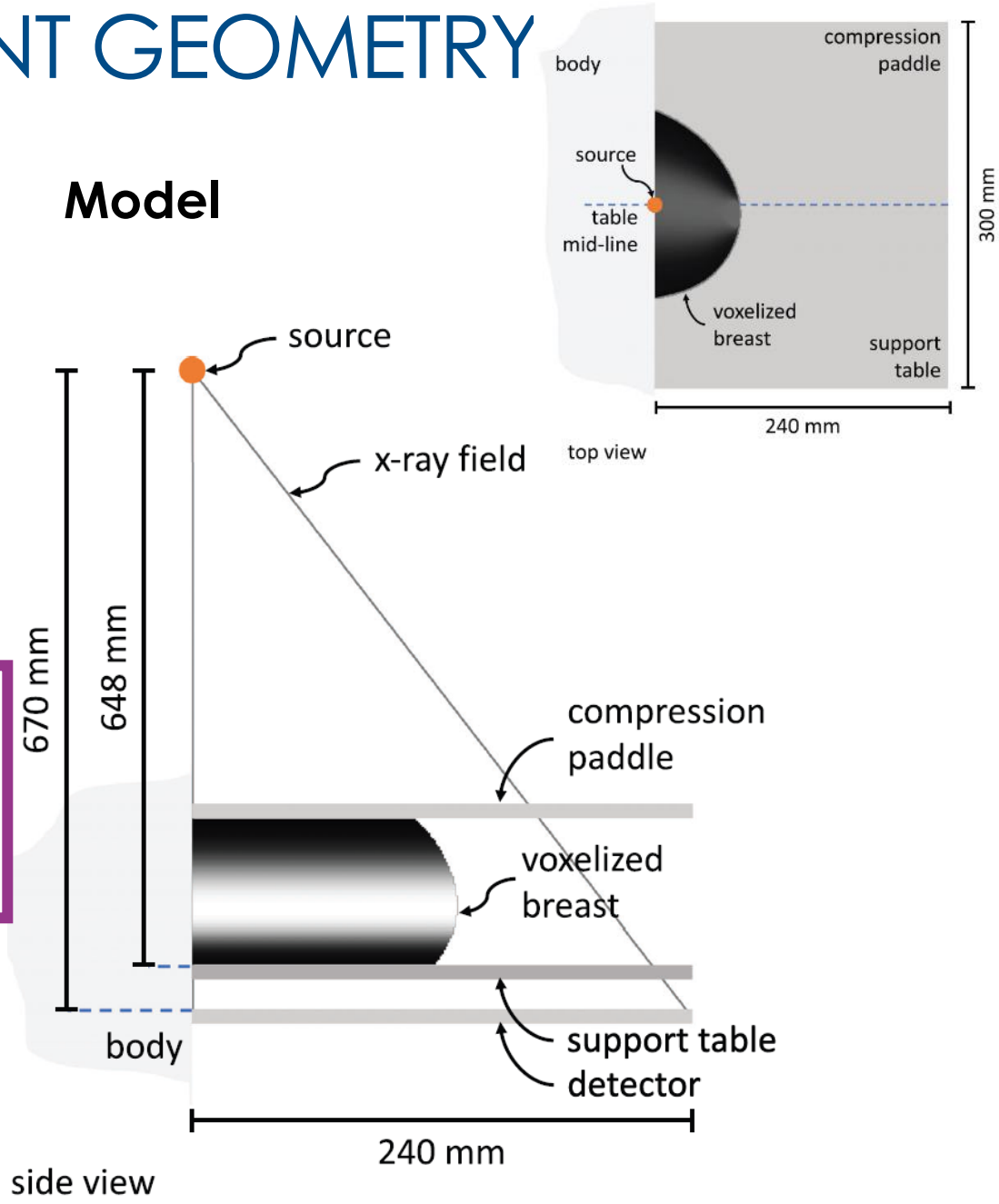
RECOMMENDED MEASUREMENT GEOMETRY

Measurement



Today
l_t = 635 mm
l_{m_IC} = 617.5 mm
l_{m_XMM} = 625.9 mm

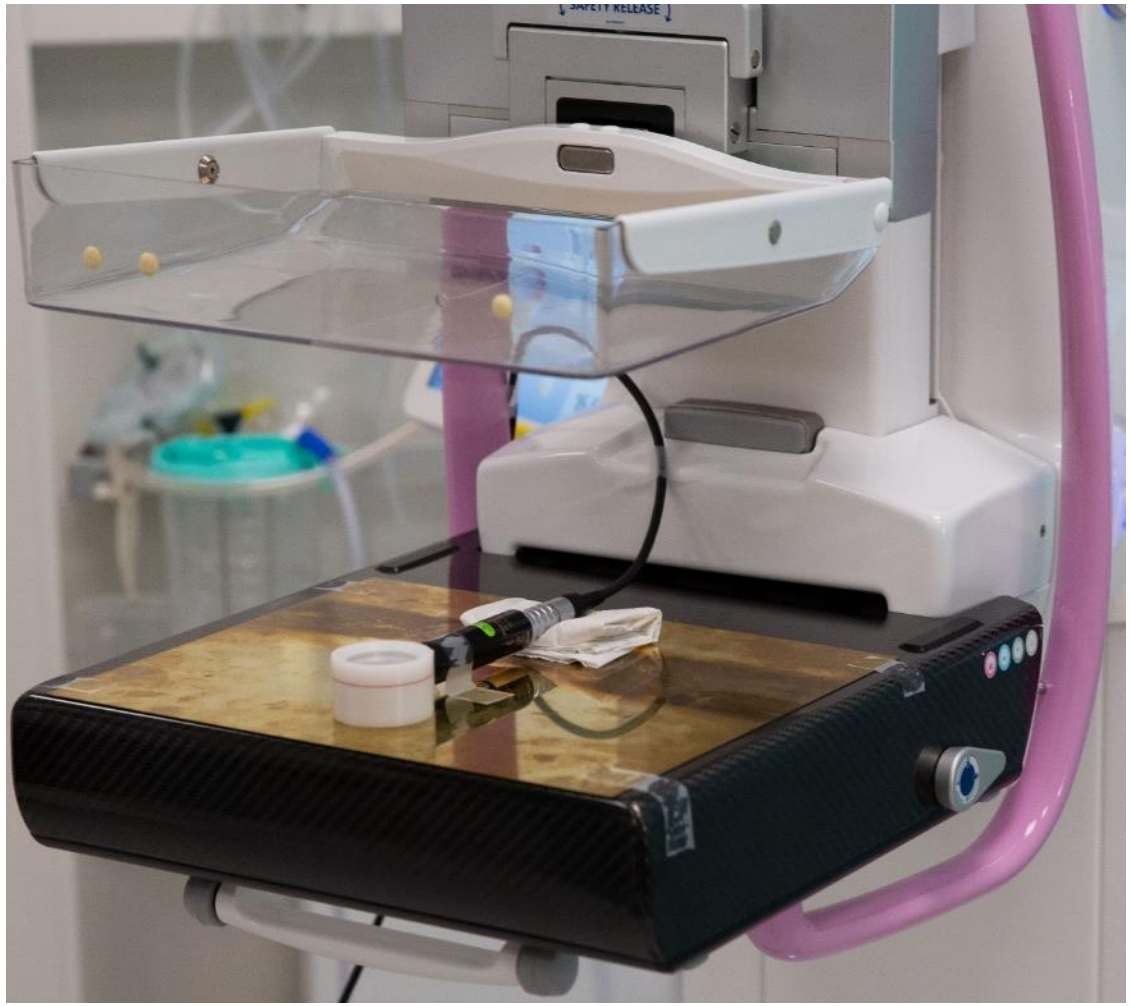
Model

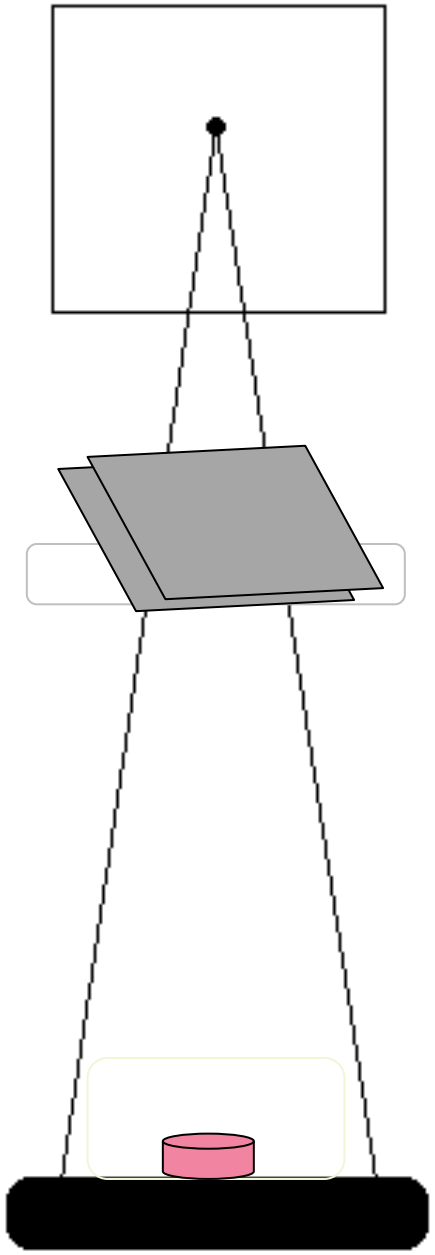


AIMS OF TODAY'S MEASUREMENTS

- Impact of compression paddle (CP)
  - CP positions
    - Far: 165 mm
    - Close: 3 cm distance from dosimeter
    - Contact: 0 cm from dosimeter
- Bonus
  - HVL measurement
  - Chamber positioning
- Extra
  - Other XMM quantities

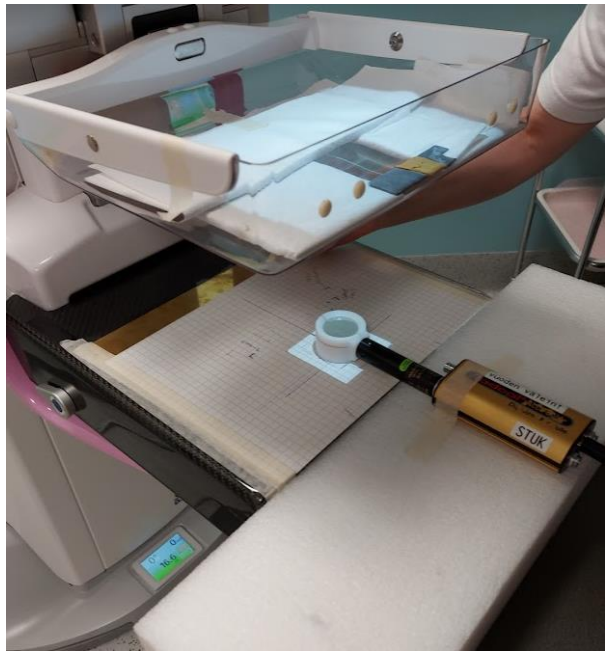
Radiation qualities
W/Rh 28kV
W/Ag 28 kV
W/Ag 32 kV





MEASUREMENT OF HVL

This method is only valid with ionization chambers



1. Narrow beam geometry?
2. Measure air kerma without HVL filters
3. Attenuate beam using HVL-filters
   a) Thickness slightly less than expected HVL
   b) Thickness slightly more that expected HVL
4. Calculate HVL.

HVL filters:

- Sheet of aluminium
- High purity (e.g., 99.9%)
- Accurately known thickness

What if you only have an XMM?

LIVE BROADCAST

RESULTS

RAW RESULTS

- Repetitions: W/Ag 28 kV
- Measured and displayed air kerma values (mGy).
- Temperature and air pressure correction done by the meter.
- Calibration coefficients used as show in the morning.

	IC	XMM
	1.443	1.452
	1.445	1.453
	1.443	1.454
	1.444	1.455
	1.445	1.454
	1.444	1.451
	1.445	1.453
	1.443	1.453
	1.443	1.452
	1.445	1.453
Mean (mGy)	**1.444**	**1.453**
SD (%)	**0.07**	**0.08**

CORRECTED RESULTS

	Ka_IC (mGy)	**Ka_XMM (mGy)**
W/Rh 28 kV	**1.773**	***1.811***
W/Ag 28 kV	**1.415**	***1.453***
W/Ag 32 kV	**2.068**	***2.125***

Can they be compared now?

What about the distance?

l_{m_IC} = 617.5 mm
l_{m_XMM} = 625.9 mm

CORRECTED RESULTS

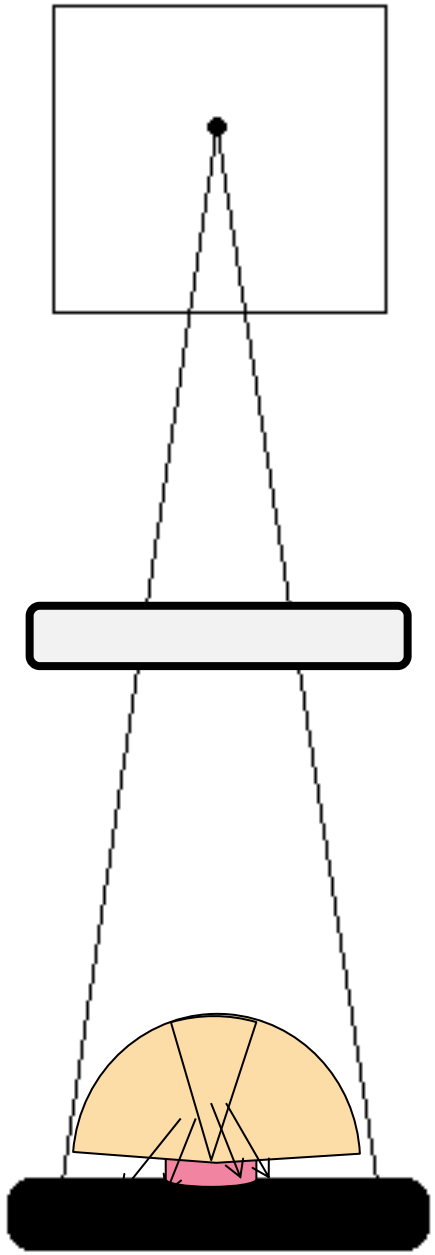
l_{m_IC} = 617.5 mm
l_{m_XMM} = 625.9 mm

- l_m=617.5 mm $\quad k_d = \frac{625.86^2}{617.46^2}$

	Ka_IC (mGy)	*Ka_XMM (mGy)*	k_d	**Ka_XMM (mGy)**
W/Rh 28 kV	**1.773**	*1.811*	*1.027*	***1.860***
W/Ag 28 kV	**1.415**	*1.453*	*1.027*	***1.493***
W/Ag 32 kV	**2.068**	*2.125*	*1.027*	***2.183***

FORWARD SCATTER FROM COMPRESSION PADDLE

	In **contact** (0 cm)		**Near** (3 cm)		**Far** (15 cm)		**Max. forward scatter**	
	IC	XMM	IC	XMM	IC	XMM	IC	XMM
W/Rh 28 kV								
W/Ag 28 kV	**1.468**	**1.524**			**1.415**	**1.493**		
W/Ag 32 kV								

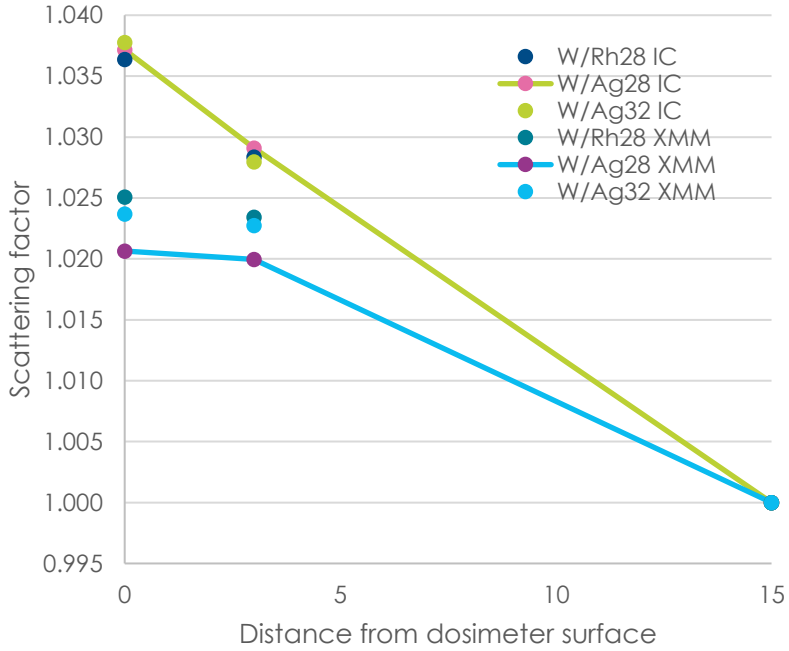


FORWARD SCATTER FROM COMPRESSION PADDLE

	In **contact** (0 cm)		**Near** (3 cm)		**Far** (15 cm)		**Max. forward scatter**	
	IC	XMM	IC	XMM	IC	XMM	IC	XMM
W/Rh 28 kV								
W/Ag 28 kV	1.468	1.524			1.415	1.493	**1.037**	**1.021**
W/Ag 32 kV								

FORWARD SCATTER FROM COMPRESSION PADDLE

	In **contact** (0 cm)		**Near** (3 cm)		**Far** (15 cm)		**Max. forward scatter**	
	IC	XMM	IC	XMM	IC	XMM	IC	XMM
W/Rh 28 kV	1.838	1.907	1.823	1.904	1.773	1.860	1.037	1.025
W/Ag 28 kV	**1.468**	**1.524**	1.456	1.523	**1.415**	**1.493**	**1.037**	**1.021**
W/Ag 32 kV	2.146	2.235	2.126	2.233	2.068	2.183	1.038	1.024



FORWARD SCATTER

Selected forward scatter correction factor 1.032

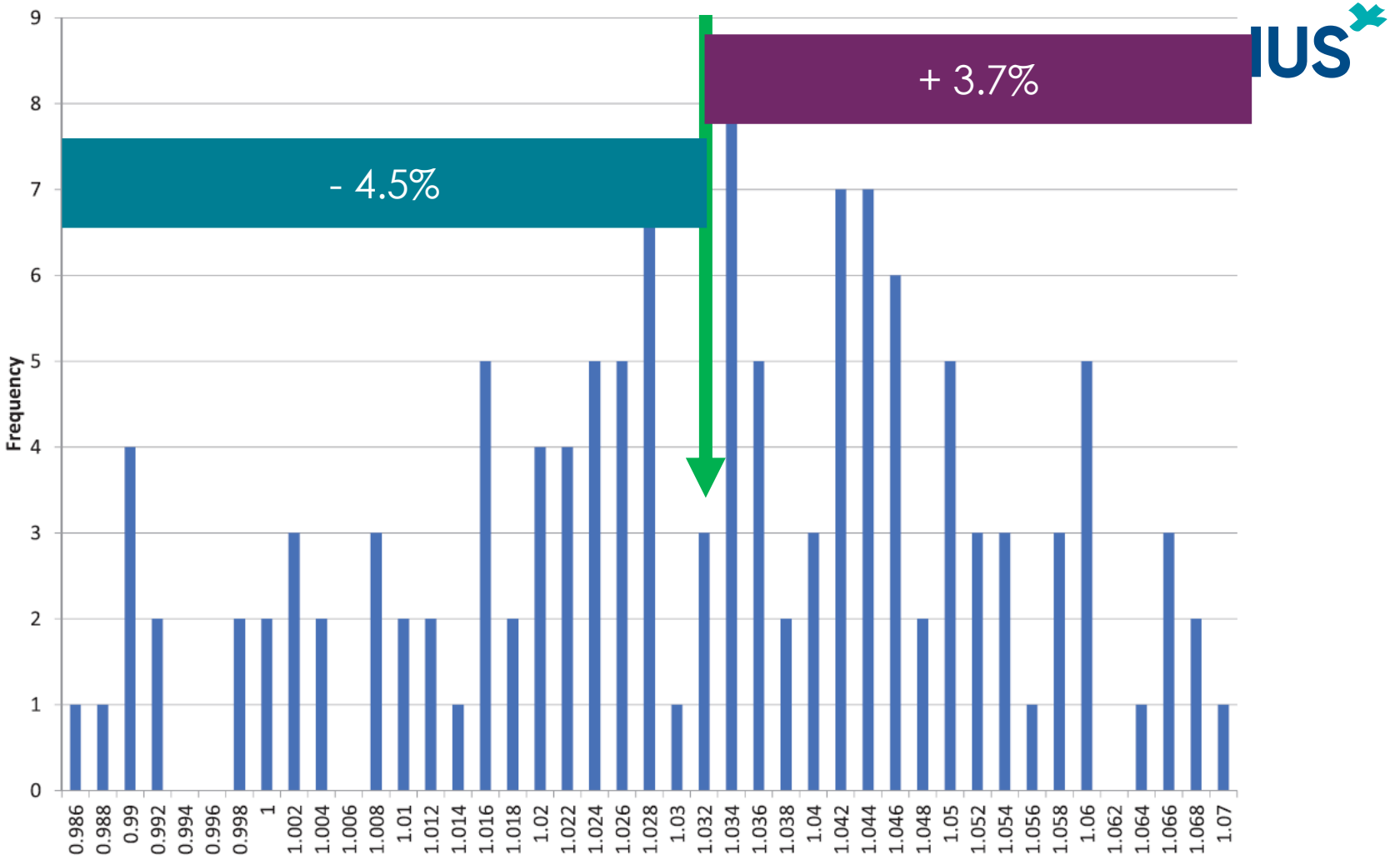
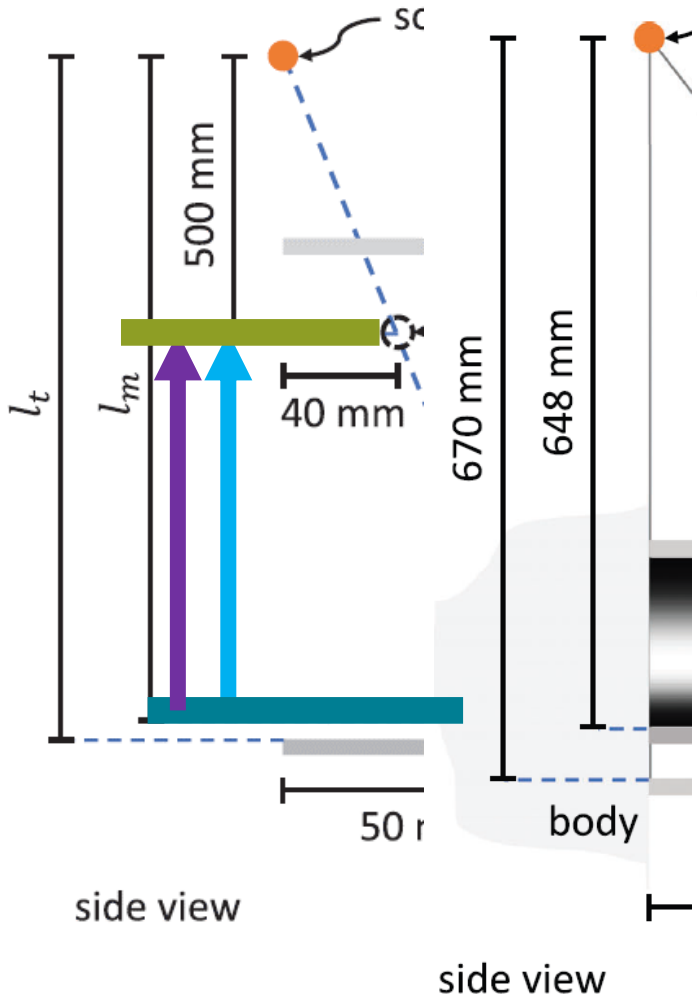
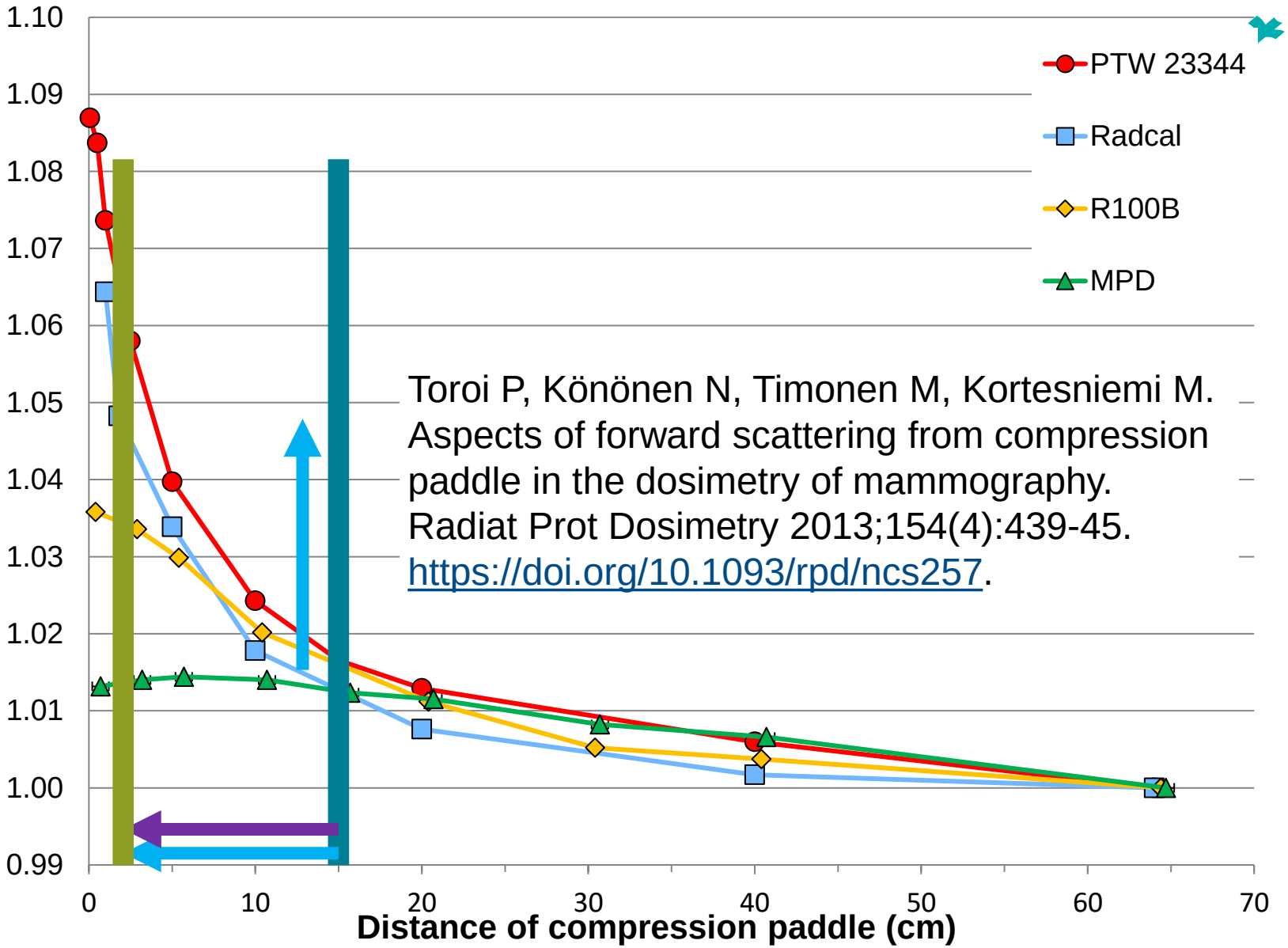


FIGURE A.1 Histogram of the c_k values obtained from 128 measurements on 28 different imaging systems. The median of the measurements is 1.032 (range = [0.985, 1.069], $25^{th}/75^{th}$ percentiles = [1.017, 1.045]), and hence the value set for c_k in the breast dosimetry software for Equation 2 is 1.032.

FORWARD SCATTER





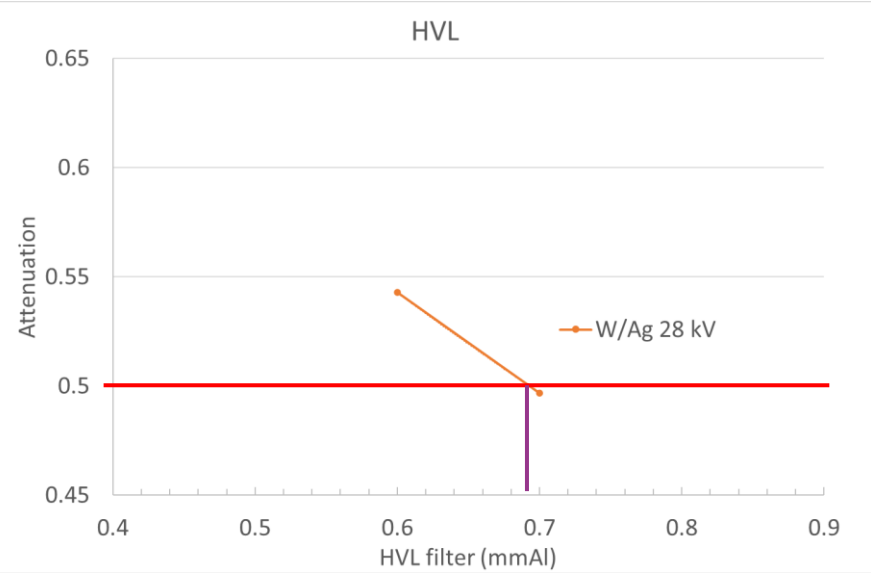
Toroi P, Könönen N, Timonen M, Kortesniemi M. Aspects of forward scattering from compression paddle in the dosimetry of mammography. Radiat Prot Dosimetry 2013;154(4):439-45. https://doi.org/10.1093/rpd/ncs257.

HVL

HVL filtration (mmAl)	Ka (mGy)			Ka ratio (attenuation)		
	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV
0		**1.415**				
0.4						
0.5						
0.6		**0.768**			**0.543**	
0.7		**0.703**			**0.497**	
0.8						
		IC HVL (mmAl)				
		XMM HVL (mmAl)				
		Difference (%)				

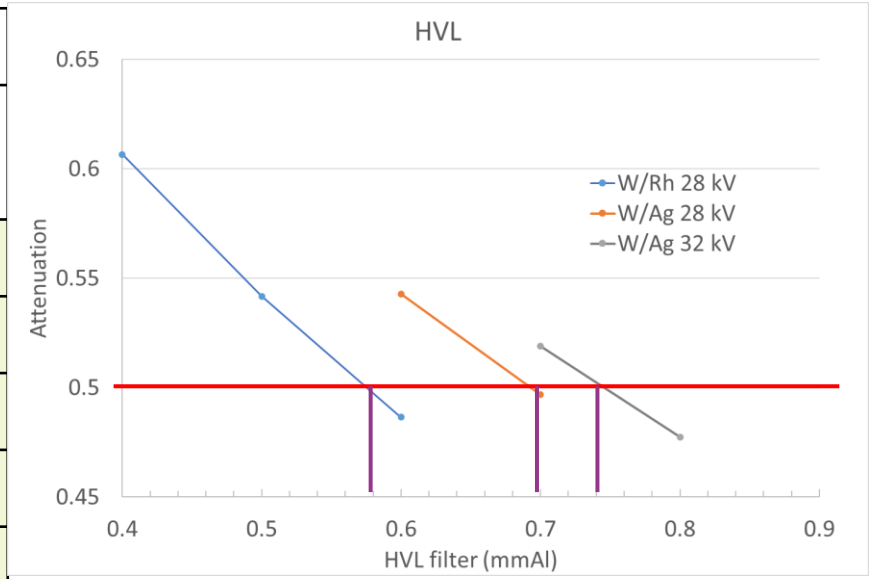
HVL

HVL filtration (mmAl)	Ka (mGy)			Ka ratio (attenuation)		
	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV
0		**1.415**				
0.4						
0.5						
0.6		**0.768**			**0.543**	
0.7		**0.703**			**0.497**	
0.8						
		IC HVL (mmAl)			**0.693**	
		XMM HVL (mmAl)			**0.655**	
		Difference (%)			**5%**	



HVL

HVL filtration (mmAl)	Ka (mGy)			Ka ratio (attenuation)		
	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV	W/Rh 28 kV	W/Ag 28 kV	W/Ag 32 kV
0	1.774	1.415	2.068			
0.4	1.076			0.607		
0.5	0.961			0.542		
0.6	0.863	0.768		0.486	0.543	
0.7		0.703	1.073		0.497	0.519
0.8			0.987			0.477
		IC HVL (mmAl)		0.574	0.693	0.744
		XMM HVL (mmAl)		0.551	0.655	0.714
		Difference (%)		4%	5%	4%



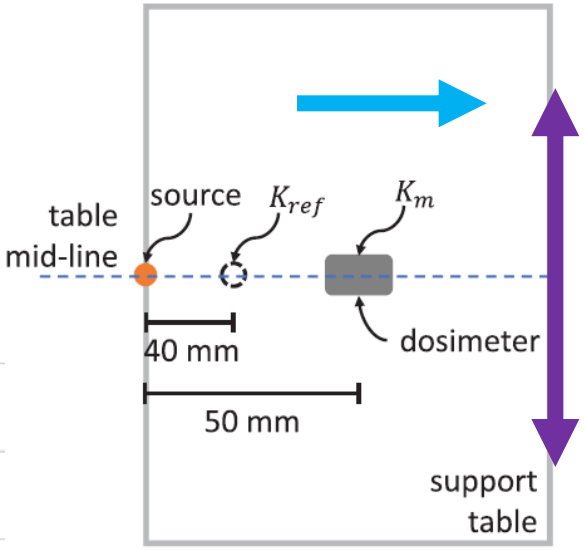
D_G CALCULATION

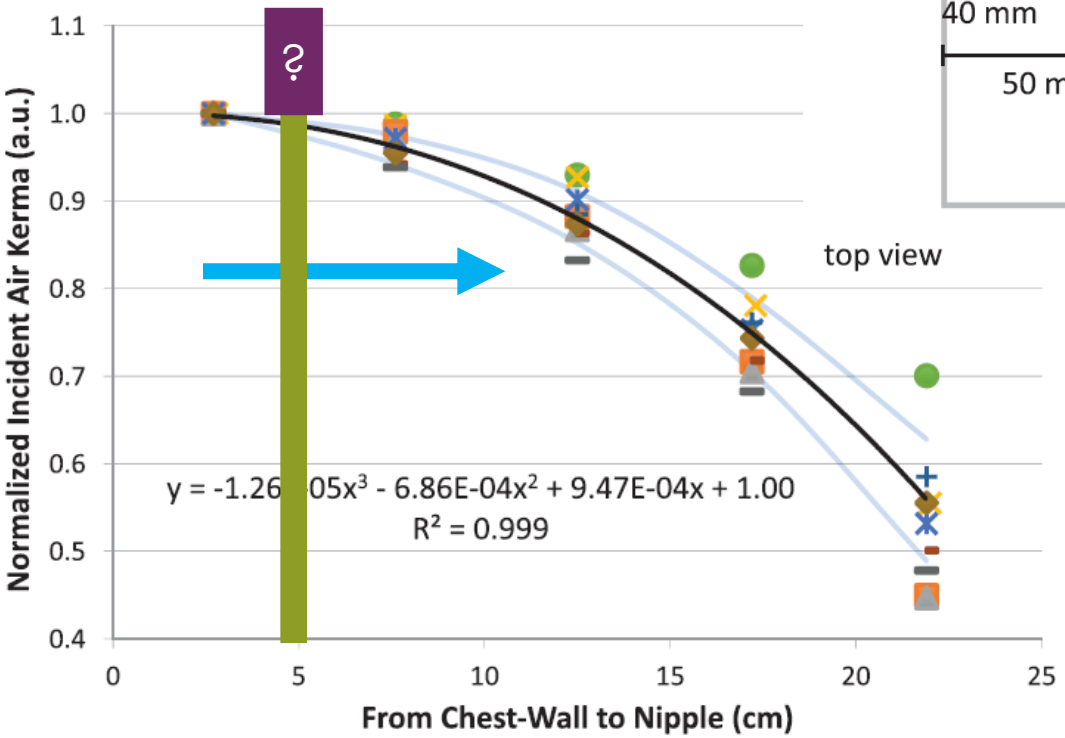
- Mammography of Finnish woman with 5 cm breast thickness
- Exposed in CC with W anode+ **75 µm** Silver (Ag) filter, 28 kV, 63 mAs
- Measured air kerma 1.415 mGy
- HVL
  - HVL_IC = 0.693 mmAl
  - HVL_XMM = 0.655 mmAl
- **Calculate D_G**

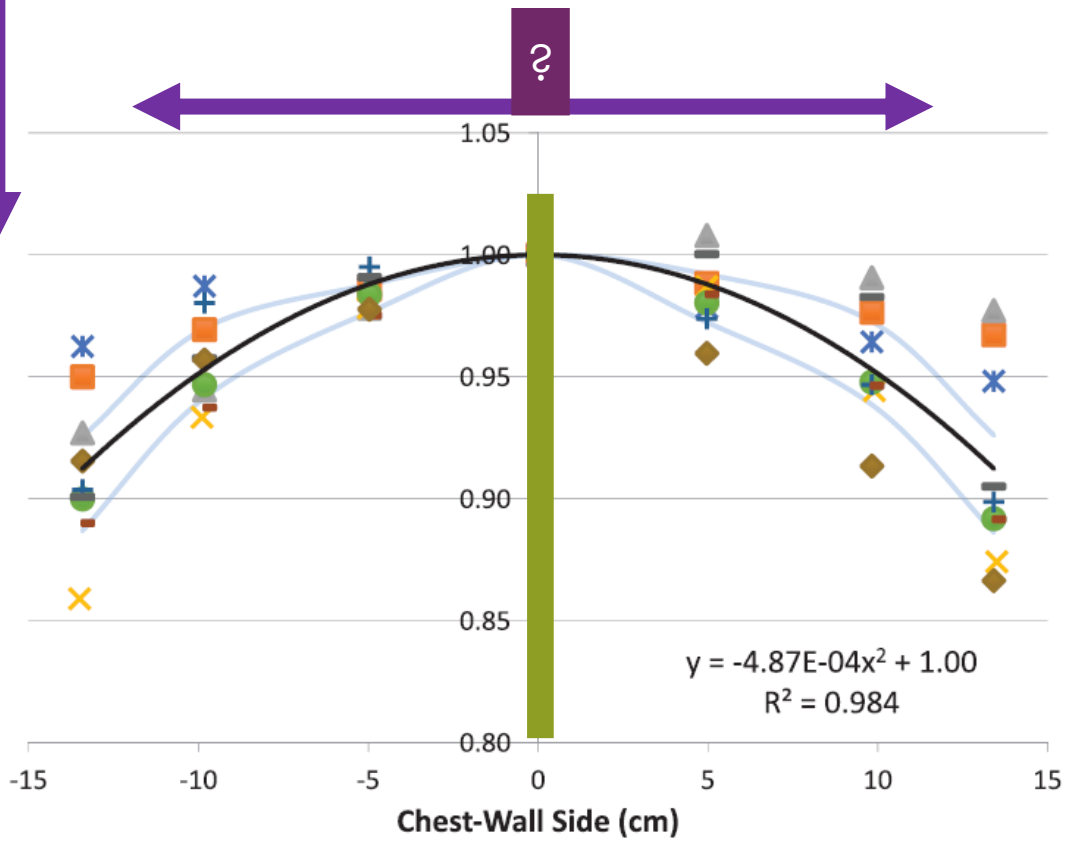
Today
l_t = 635 mm
l_{m_IC} = 617.5 mm
l_{m_XMM} = 625.9 mm

https://medphys.royalsurrey.nhs.uk/TG282doseCalculator

POSITIONING

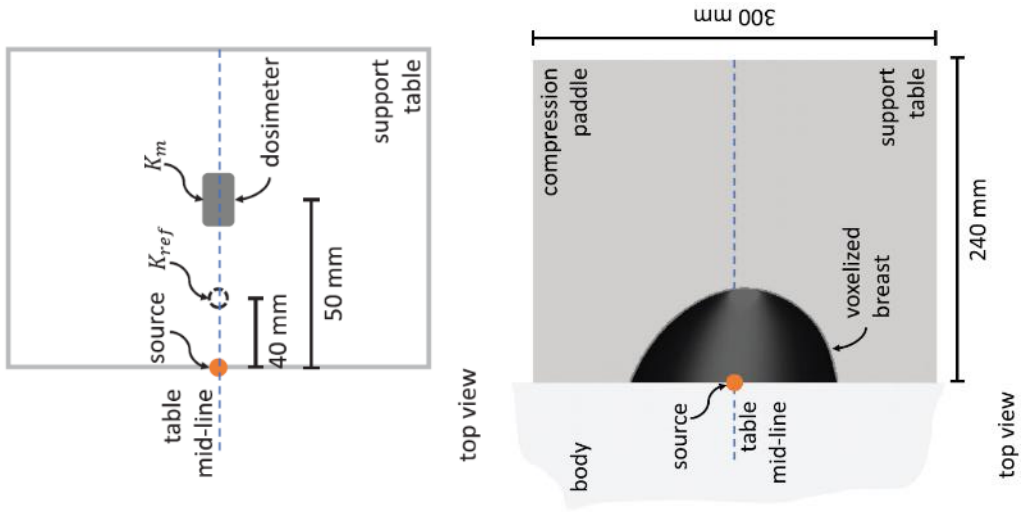






POSITIONING

- W/Ag 28 kV



	-1 cm	C	+1 cm
6 cm		1.395	
5 cm	1.408	**1.408**	1.404
4 cm		1.422	

	-1 cm	C	+1 cm
6 cm		-1%	
5 cm	~0%	**1.408**	-0.3%
4 cm		+1%	

EFOMP/AAPM

	-1 cm	C	+1 cm
6 cm		-0.8%	
5 cm	~0%	**1.408**	~0%
4 cm		+0.6%	

Practical exercises:

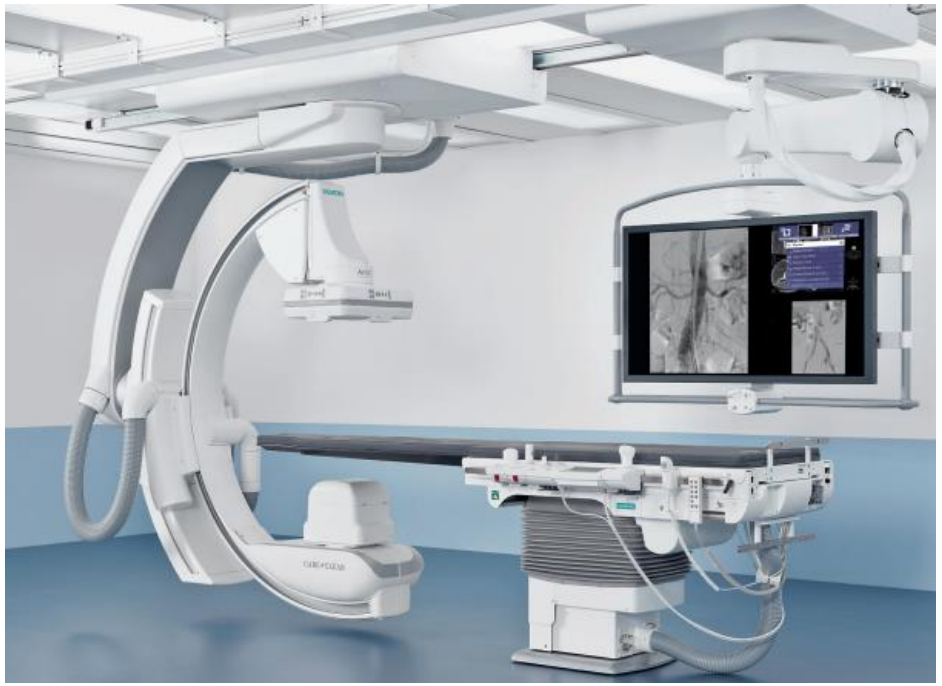
INTERVENTIONAL RADIOGRAPHY

Touko Kaasalainen, Jenna Tarvonen (+Juha, Jouni, Niko, Mika, Paula)

21 November 2024, TraMeXI workshop at HUS, Helsinki, Finland

FLUOROSCOPY

- Provides **real-time imaging**, enabling navigation of instruments precisely within the body.
- Primarily utilized in **minimally invasive medical procedures**: interventional radiology, cardiology, and surgery (angioplasty, stent placement, embolization etc…)
- Dose quantities:
  - Air kerma-area product (KAP) or DAP
  - air kerma at the reference point (K_r)
  - *entrance surface air kerma (ESAK)*
  - fluoroscopy time (complexity level).



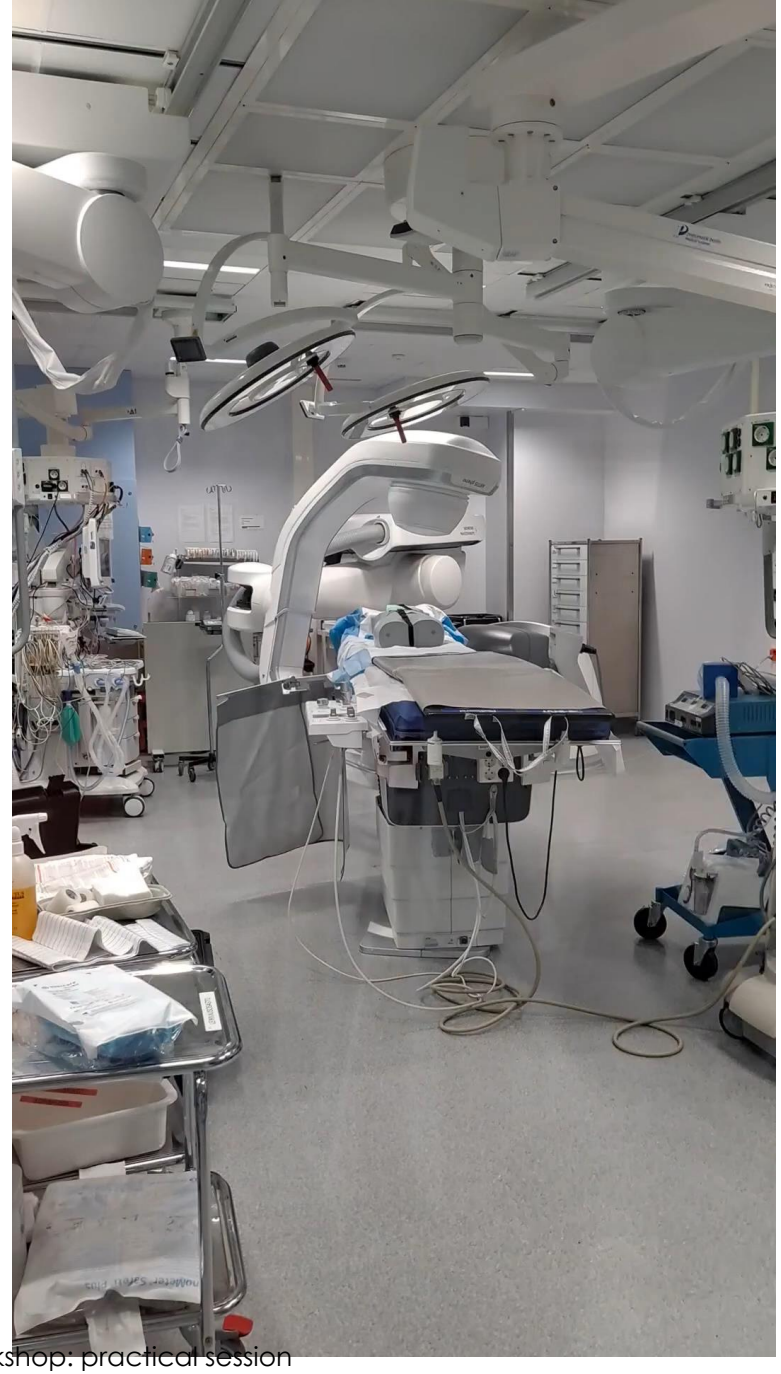
Interventional reference point 15 cm from iso center (IEC standard 60601-2-43)

OVERVIEW VIDEO:

VIDEO link

LARGE ANGULAR VARIATION

INTRAOPERATIVE CBCT



DOSIMETRY AND CHALLENGES

- Radiation qualities:
  - copper filtration (traceability challenge)
- AEC: How to get radiation and different RQs
- Geometry challenge for measurements
  - Angular variation
  - Limited space
    - Position of dosimeter, field size, distance
  - Patient couch attenuation and scatter
- Geometry challenge for patient dosimetry
  - Peak skin dose
  - Patient couch attenuation and scatter
- KAP meter calibration

PATIENT TABLE

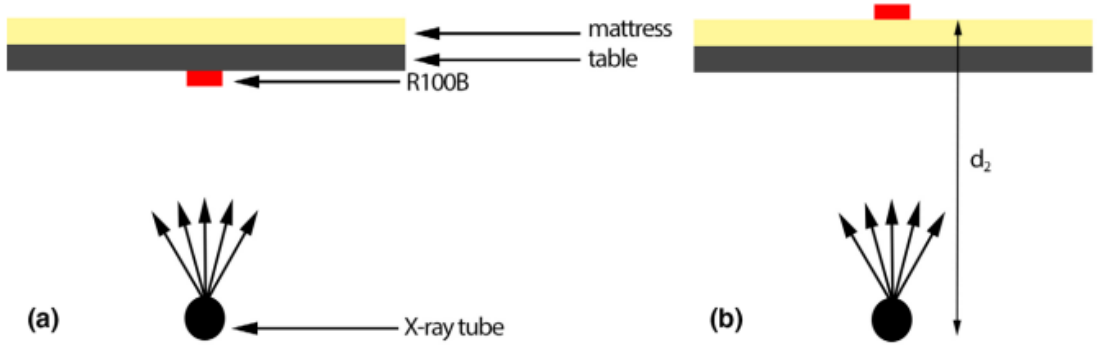
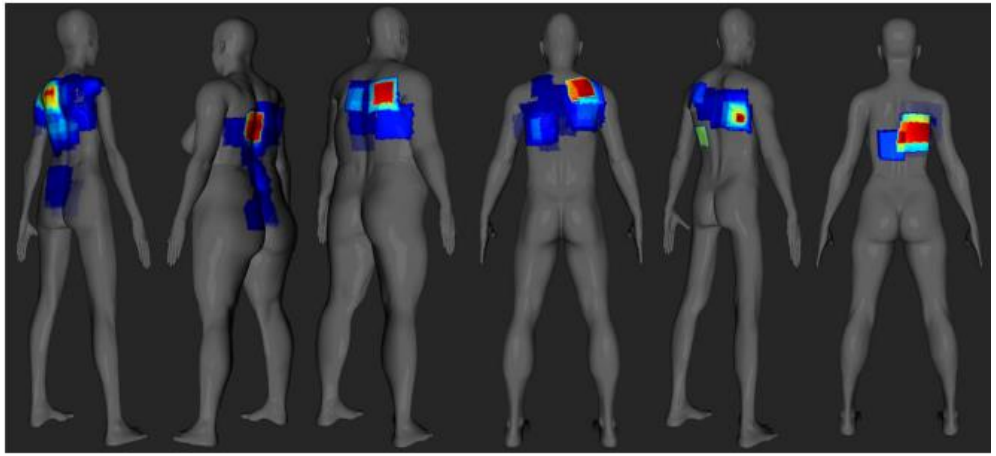


FIG. 2. Table attenuation factor measurements for (a) setup 1 and (b) setup 2. Setup 1 was used to measure air kerma rates when there was no influence of table, whereas setup 2 was used to measure air kerma rates when table and mattress were in the beam path.

- Table attenuation 0.69 – 0.88 depending on RQ and field size
- Table oblique factors (angluar impact) Max. 40° and low filtration => 0.894

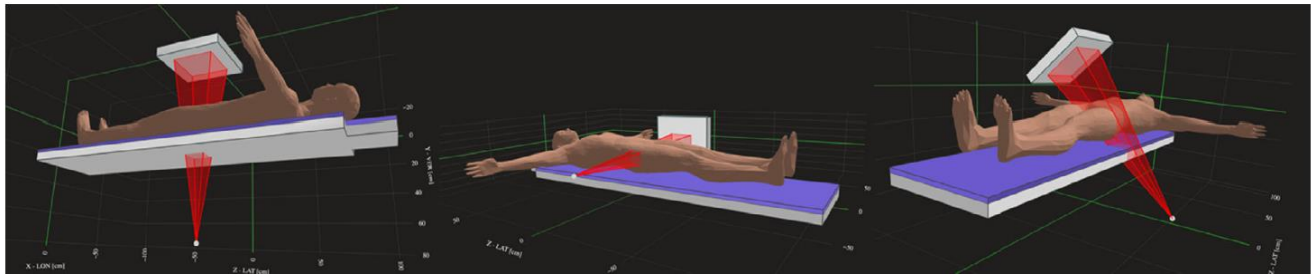
FIG. 4. Skin dose maps for different RDSRs. Color map is relative to the PSD for each individual patient.



Krajinović, Marko & Krzanovic, Nikola & Ciraj-Bjelac, Olivera. (2021). Vendor-independent skin dose mapping application for interventional radiology and cardiology. Journal of Applied Clinical Medical Physics. 22. 10.1002/acm2.13167.

AAPM TG357 & EFOMP JOINT REPORT (2021) ESTIMATION OF PATIENT SKIN DOSE IN FLUOROSCOPY

- Real-time skin dose monitoring systems are important tools for interventional radiology.
- Comprehensive recommendations for estimating patient skin dose.
- Promoting standardized approaches and technologies.
- Excellent uncertainty budget and discussion!



Andersson, Jonas & Bednarek, Daniel & Bolch, Wesley & Boltz, Thomas & Bosmans, Hilde & Gislason-Lee, Amber & Granberg, Christoffer & Hellström, Max & Kanal, Kalpana & McDonagh, Ed & Paden, Robert & Pavlicek, William & Khodadadegan, Yasaman & Torresin, Alberto & Trianni, Annalisa & Zamora, David. (2021). Estimation of patient skin dose in fluoroscopy: summary of a joint report by AAPM TG357 and EFOMP. Medical Physics. 48. 10.1002/mp.14910.

TYPICAL MEASUREMENTS

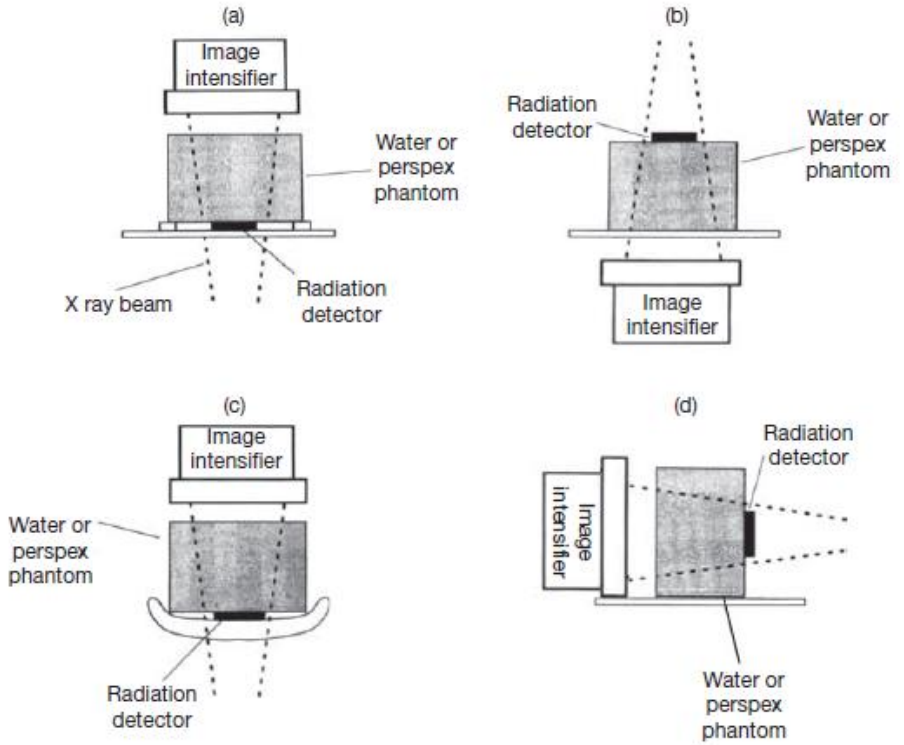


FIG. 8.4. Configuration for measurement of patient entrance surface air kerma: (a) an under couch installation, (b) an over couch installation, (c) a C-arm unit, (d) C-arm unit, lateral exposures or when a couch used clinically is not available (after Martin et al. [8.12]).

IAEA TRS No. 457 Dosimetry in Diagnostic Radiology: An International Code of Practice

FIG. 26. (a) Set-up used to test the air kerma rate at the entrance of the detector, showing the solid state detector positioned below the PMMA plates. (b) The obtained X ray image.

IAEA HHS No. 47 Handbook of Basic Quality Control Tests for Diagnostic Radiology

TYPICAL MEASUREMENTS

AAPM Report No. 125 (2012)
Functionality and Operation of Fluoroscopic Automatic Brightness Control/Automatic Dose Rate Control Logic in Modern Cardiovascular and Interventional Angiography Systems

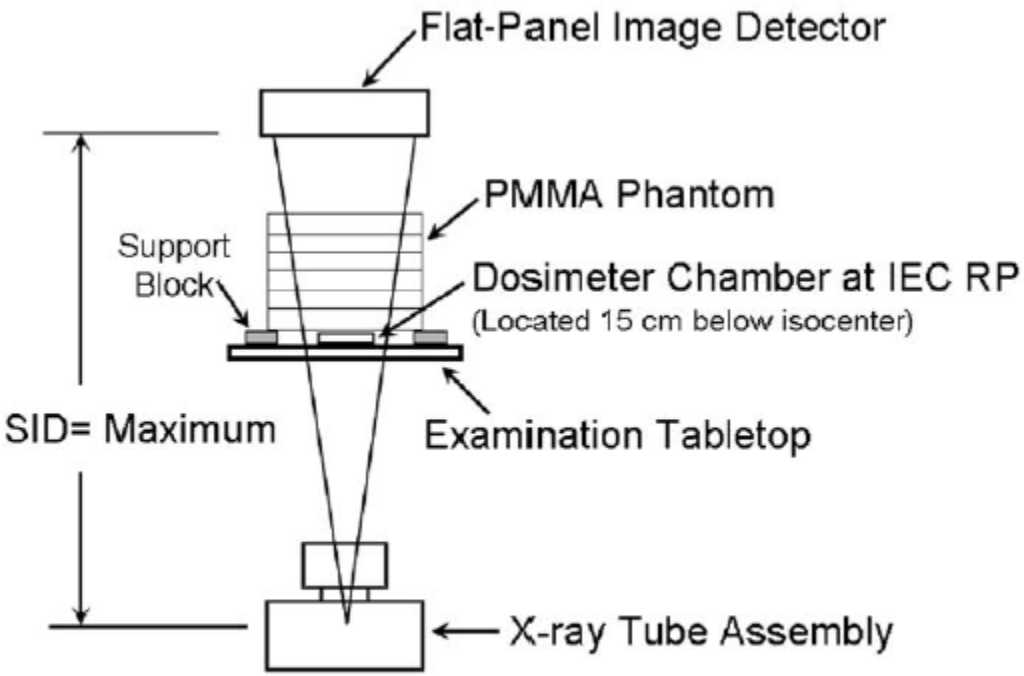
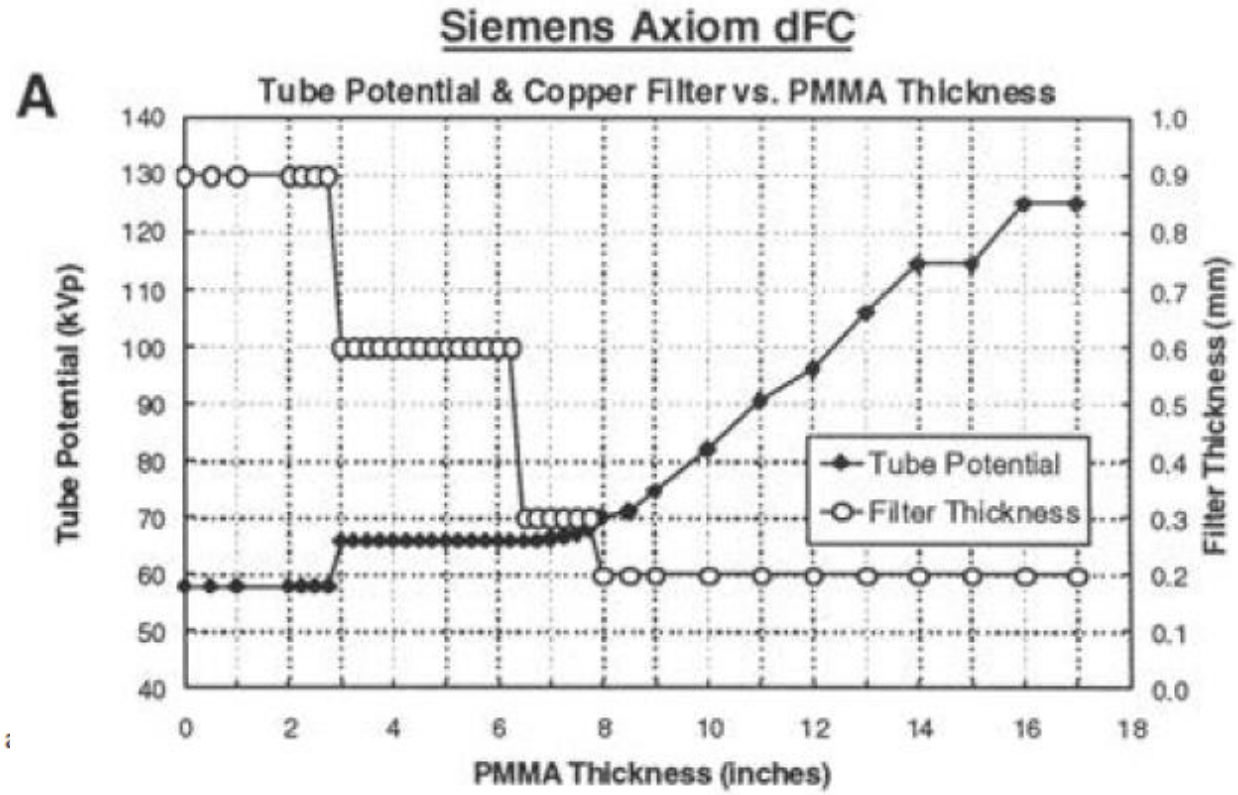
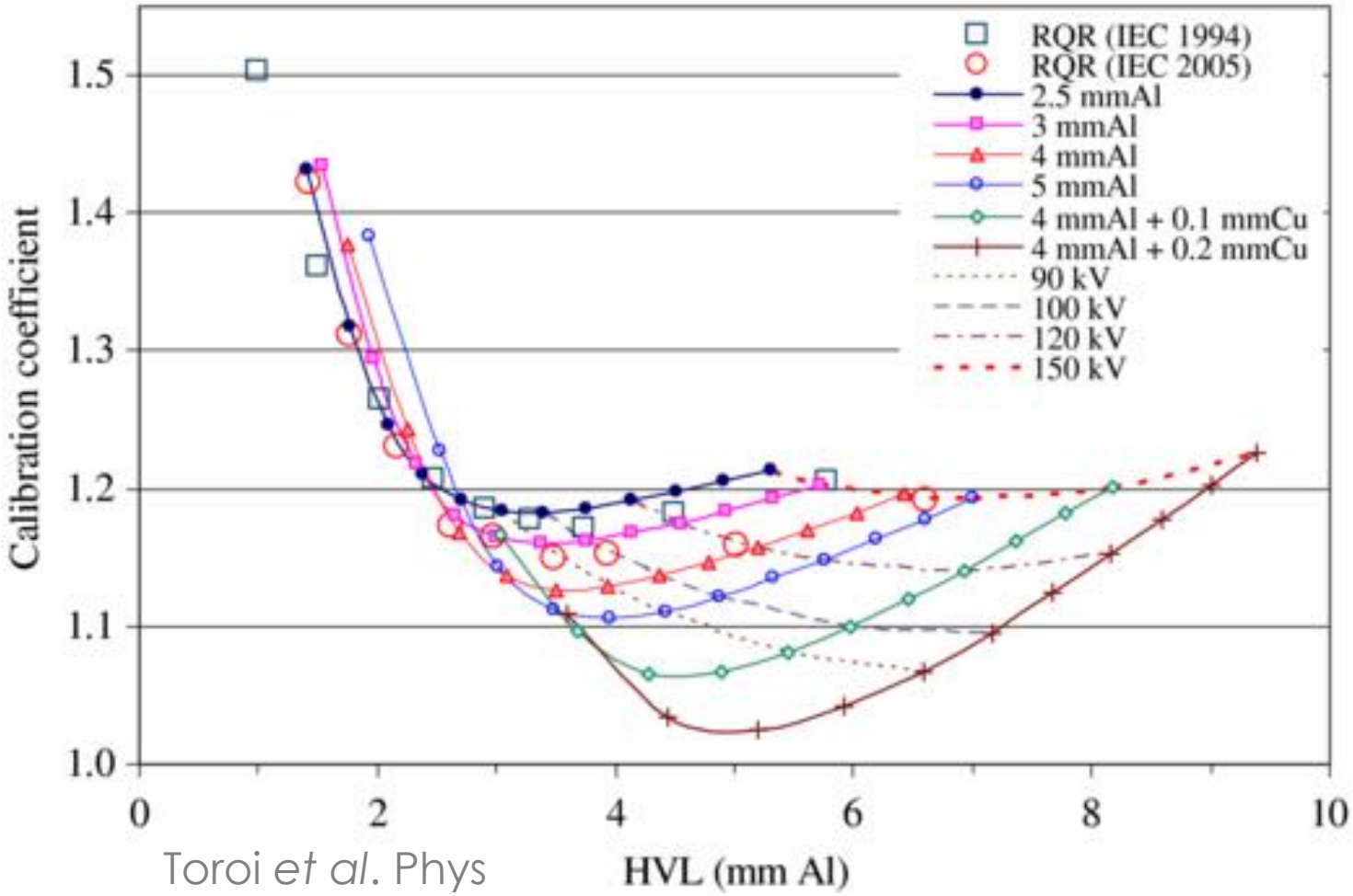


Figure 8. The experimental setup for the evaluation of fluoroscopic ABC/ADRIQ control logic of a system.



ENERGY DEPENDENCY OF KAP METERS



Toroi *et al*. Phys Med Biol 2008

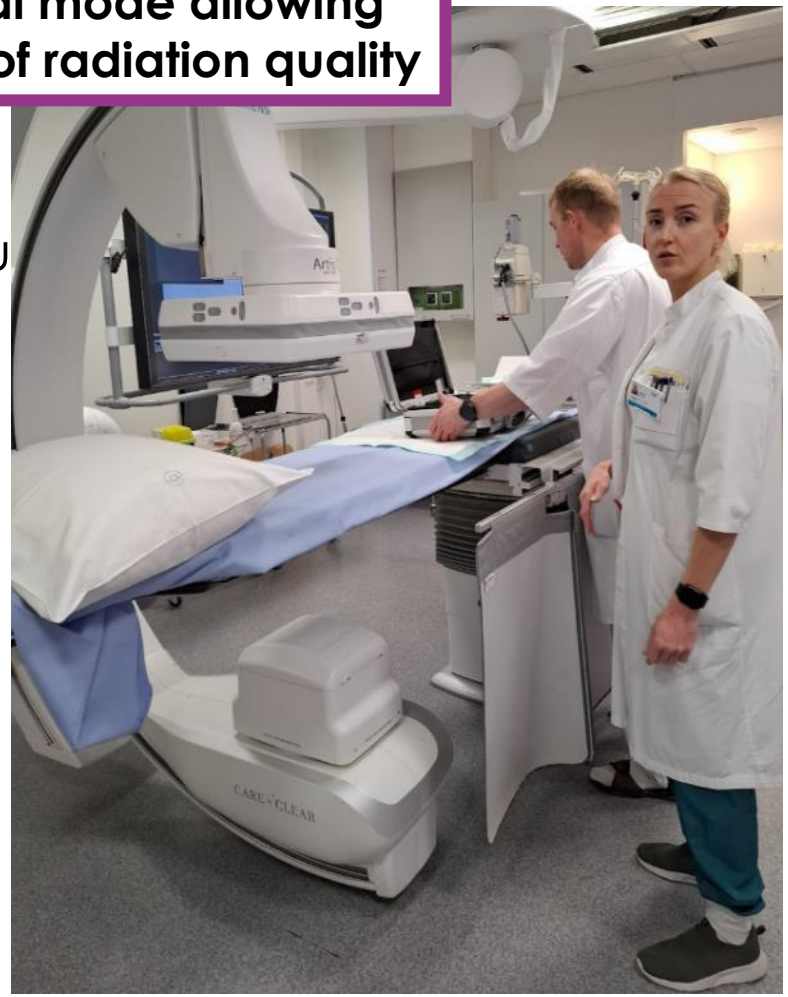
- IEC 60580:2019 standard for KAP meters: limits of variation related to radiation quality is **±8% 50 - 150 kV (IEC RQR)**. With aluminium filter 2.5 – 4.5 mmAl
- For other filtrations, no requirements are stated.

X-RAY SYSTEM USED FOR THE MEASUREMENTS

Siemens Artis Q

Technical mode allowing selection of radiation quality

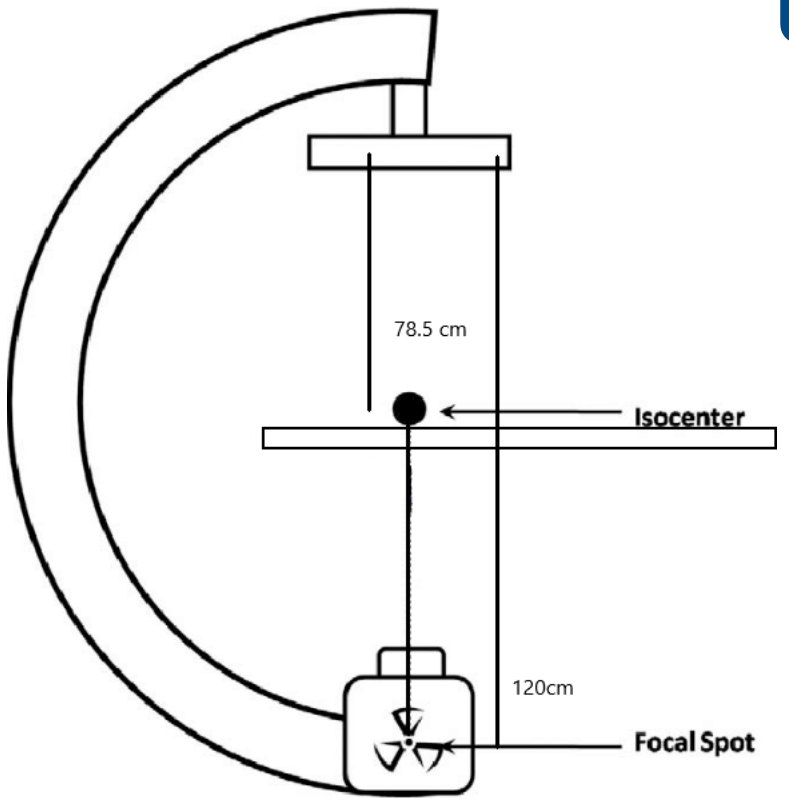
- Tube voltage: 40-125 kV in 0.1 kV increments
  → 70, 90, 125 kV
- Inherent filtration 2.5 mmAl + 0.1, 0.2, 0.3, 0.6, 0.9 mm Cu
  → 0 mmCu and 0.9 mmCu
- Tube current:
  - Acquisition Mode: 15 to 1000 mA in 0.01 mA steps
    → 200 mA
  - Continuous Fluoroscopy: 0.5 to 50 mA
  - Pulsed Fluoroscopy: 15 to 250 mA
- Pulse frequency: 0.5 ms to 100 p/s or continuous mode
- Pulse time: 0.5 ms to unlimited (continuous mode)
  → 50 ms



MEASUREMENT GEOMETRY

- Focal Spot-to-Detector Distance: Adjustable from 90 to 120 cm

  → 120 cm used
- Ionization chamber and XMM
  - Placed in the isosenter (Focus-to-Isocenter Distance 78.5 cm)
  - ”Free in air”
- Fielz size: 10 cm * 10 cm at isocenter



RADCAL XMM FOR GENERAL RADIOLOGY

Reference conditions	**Mammo:** 2.2 mm thick polycarbonate compression paddle in beam for all measurements (kVp, dose, hvl). Calibrated using large focal spot. **Rad/Fluoro/Dental:** 12° Tungsten anode.
Size	35.6 mm x 20.0 mm x 11.8 mm
Reference point	Round marking 1 cm diameter midline – 3.2 mm from top surface.
Working temperature range	15°C - 35°C (Storage: 0°C / 32°F - 60°C / 140°F)
Humidity	< 80 % (without condensation)
Pressure	700 hPa – 1060 hPa

Note: The time range is different when using a Nugget. See Feat

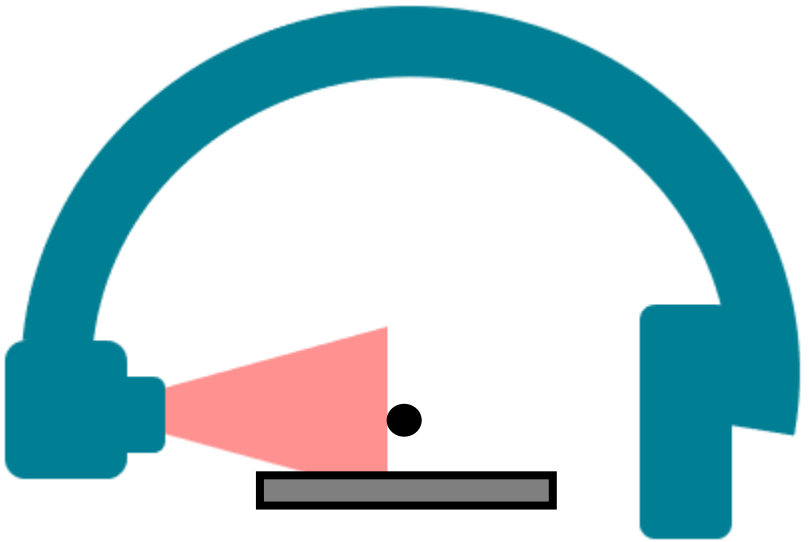
Type	Anode / Filter	Tube	kV	Filt (um)	hvl (mm Al) ±10% or ±0.2 mm Al whichever is greater
Rad/Fluoro/Dental (AGMS-D)	W/Al	General	40-160 ±2% (2-24 mm Al, 40-160 kV) ±2.5% (25-40 mm Al, 50-160 kV)	2-40 mm	1.3-13.5

Rad/Flouro/Dental (AGMS-D)	Dose using AGDM	Dose Rate using AGDM	Dose using AGDM+	Dose Rate using AGDM+	Time
	150 nGy – >100 Gy, ±5% (17 µR – >11 kR, ±5%)	150 nGy/s – 350 mGy/s, ±5% (1.0 mR/min – 2.4 kR/min, ±5%)	80 nGy - >100 Gy, ±5% (9.1 uR - >11 kR, ±5%)	80 nGy/s - 150 mGy/s ±5% (0.55 mR/min - 1.0 kR/min, ±5%)	1 ms 0.1%

Reference condition: 12# Tungsten anode

TABLE ATTENUATION

- Table attenuation
  - Tabletop Material: Carbon-fiber
  - Aluminum Equivalency:
    - Tabletop Carbon-fiber
      - ≤ 1.4 mm Al at 100 kV
    - Mattress
      - standard ≤ 0.6 mm Al
      - thick mattress ≤ 1.0 mm Al
- Different irradiation geometries
  - Under-couch 0 degree
  - Tilted 30 degrees (table
  - Right anterior 90 degrees (no table)



LIVE BROADCAST

RESULTS

RAW RESULTS

- Repetitions:
  - 70 kV 0 mmCu
  - No couch
- Measured and displayed air kerma values (mGy).

	IC	XMM
	0.6745	0.6354
	0.6737	0.6352
	0.6737	0.6350
	0.6731	0.6353
	0.6740	0.6351
	0.6742	0.6356
	0.6734	0.6353
	0.6737	0.6352
	0.6731	0.6351
	0.6743	0.6354
Mean (mGy)	**0.6738**	**0.6353**
SD (%)	**0.07**	**0.03**

MEAN VALUES

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	Ka_IC (mGy) 0°	Ka_XMM (mGy) 0°	Ka_IC (mGy) 30°	Ka_IC (mGy) 90°	Ka_XMM (mGy) 90°	KAP (µGym^2)
70	0	2.68	**0.447**			**0.674**		**6.17**
125	0.9	9.17	**0.306**			**0.390**		**3.98**

KAP CALIBRATION COEFFICIENTS

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	N_KAP Ka_IC (mGy) 0°	N_KAP Ka_XMM (mGy) 0°	N_KAP Ka_IC (mGy) 30°	N_KAP Ka_IC (mGy) 90°	N_KAP Ka_XMM (mGy) 90°	KAP (µGym^2)
70	0	2.68	0.72			1.09		0.72
125	0.9	9.17	0.77			0.98		0.77

MEAN VALUES

IC ja XMM erot 2% - 6%

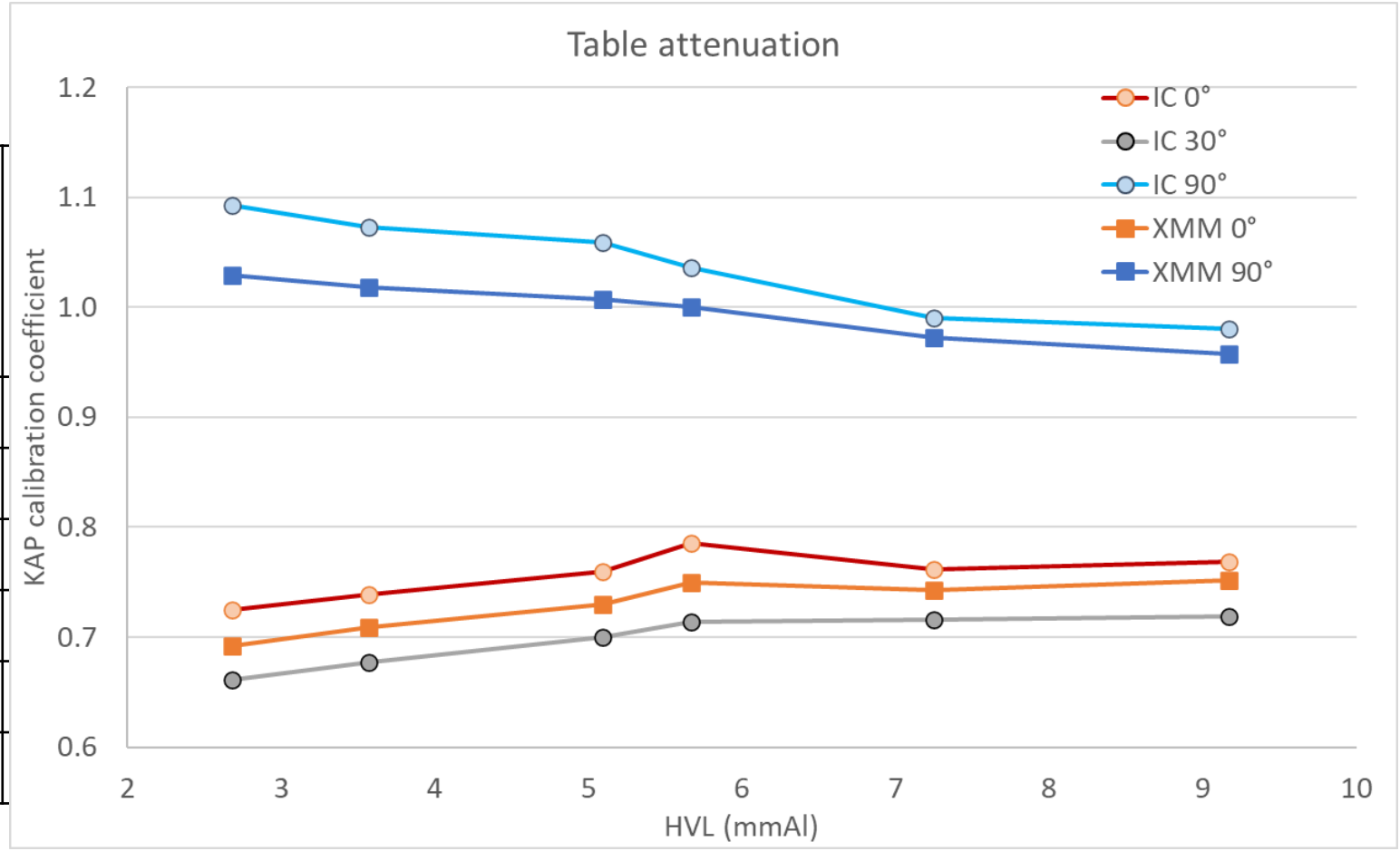
Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	Ka_IC (mGy) 0°	Ka_XMM (mGy) 0°	Ka_IC (mGy) 30°	Ka_IC (mGy) 90°	Ka_XMM (mGy) 90°	KAP (µGym^2)
70	0	2.68	0.447	0.427	0.408	0.674	0.635	6.17
70	0.9	5.67	0.022	0.021	0.020	0.029	0.028	0.28
90	0	3.57	0.769	0.738	0.705	1.117	1.060	10.41
90	0.9	7.25	0.083	0.081	0.078	0.108	0.106	1.09
125	0	5.09	1.466	1.410	1.351	2.044	1.945	19.31
125	0.9	9.17	0.306	0.299	0.286	0.390	0.381	3.98

KAP CALIBRATION COEFFICIENTS

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)	N_KAP Ka_IC (mGy) 0°	N_KAP Ka_XMM (mGy) 0°	N_KAP Ka_IC (mGy) 30°	N_KAP Ka_IC (mGy) 90°	N_KAP Ka_XMM (mGy) 90°	KAP (µGym^2)
70	0	2.68	0.72	0.69	0.66	1.09	1.03	0.72
70	0.9	5.67	0.79	0.75	0.71	1.04	1.00	0.79
90	0	3.57	0.74	0.71	0.68	1.07	1.02	0.74
90	0.9	7.25	0.76	0.74	0.72	0.99	0.97	0.76
125	0	5.09	0.76	0.73	0.70	1.06	1.01	0.76
125	0.9	9.17	0.77	0.75	0.72	0.98	0.96	0.77

TABLE ATTENUATION

Tube voltage (kV)	Filtration (mmCu)	HVL (mmAl)
70	0	2.68
70	0.9	5.67
90	0	3.57
90	0.9	7.25
125	0	5.09
125	0.9	9.17



Thank you!

The projects (22NRM01 TraMeXI) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.
Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

THANKS!