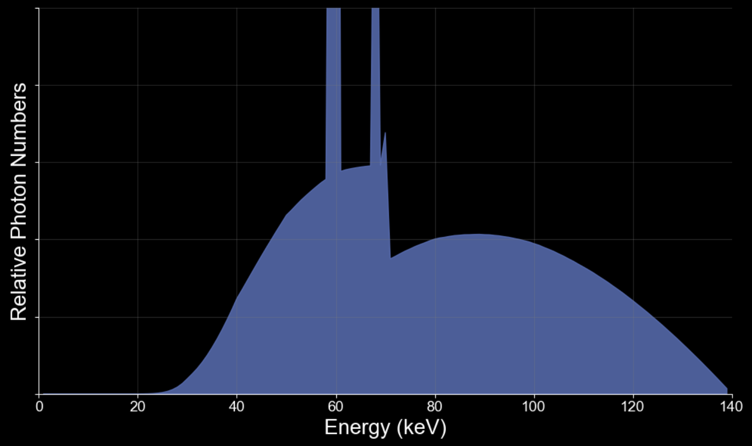
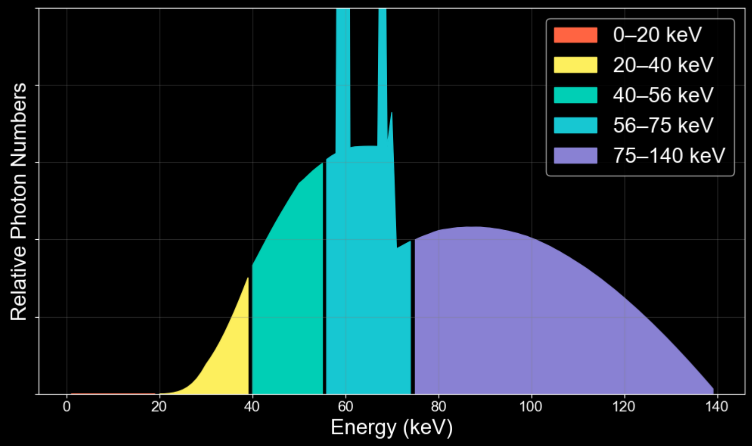




From conventional CT to Virtual Monoenergetic Imaging: A clinical guide with mean energy lookup tables for different scanners – Preliminary results

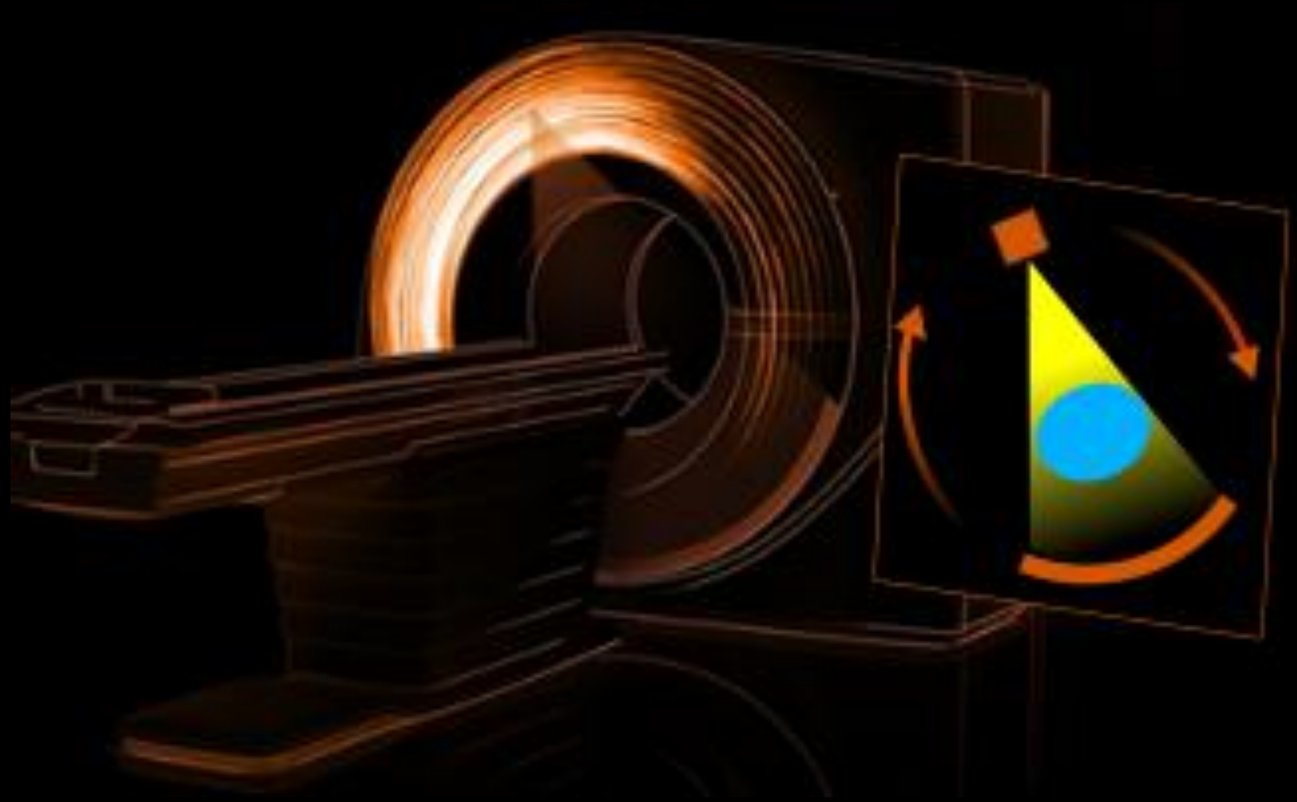
Gardermoen
Diagnostikk fysikere
November 2025

Ivar Steen …, …. , .., … & Bente Konst

VESTFOLD HOSPITAL
OSLO UNIVERSITETSSYKEHUS
SØRLANDET SYKEHUS
AKERSHUS UNIVERSITETSSYKEHUS
SYKEHUSET ØSTFOLD
SYKEHUSET INNLANDET

LINKÖPING UNIVERSITY
CMIV

Background CT scanning



$$\frac{I}{I_0} = e^{-\mu d}$$

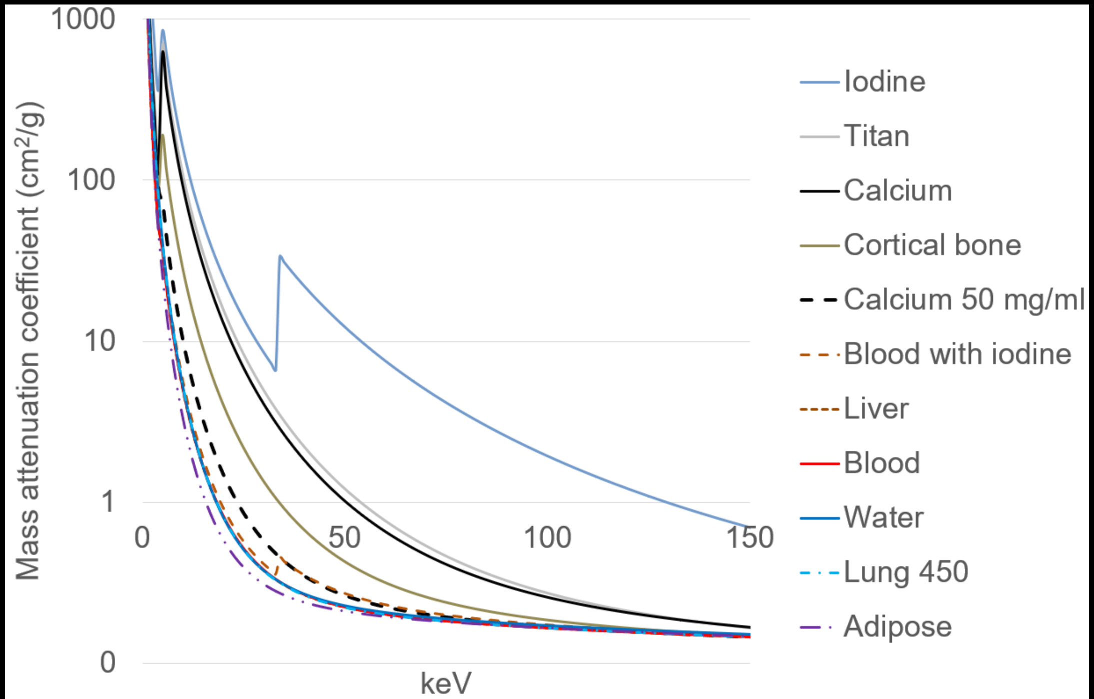
Monoenergetic parallel beam
by a uniform attenuator

Imaging/measurement using CT

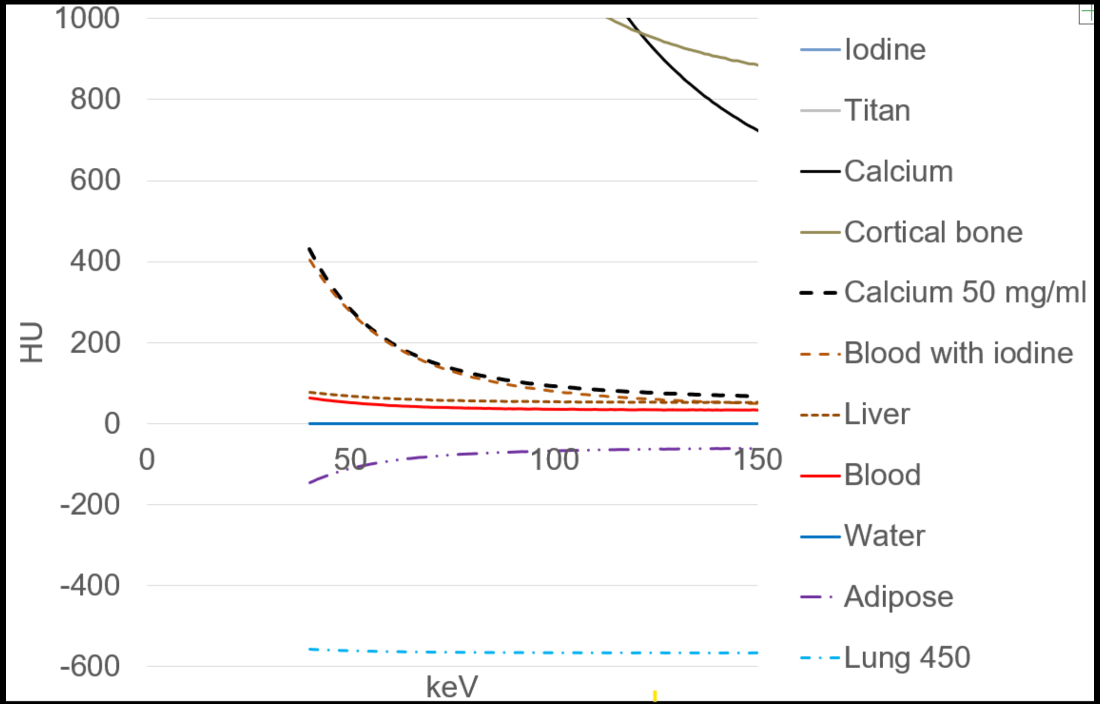
$$\frac{I}{I_0} = e^{-\mu d}$$

$$\boxed{CT - number = \frac{\mu_{tissue} - \mu_{water}}{\mu_{water}}}$$

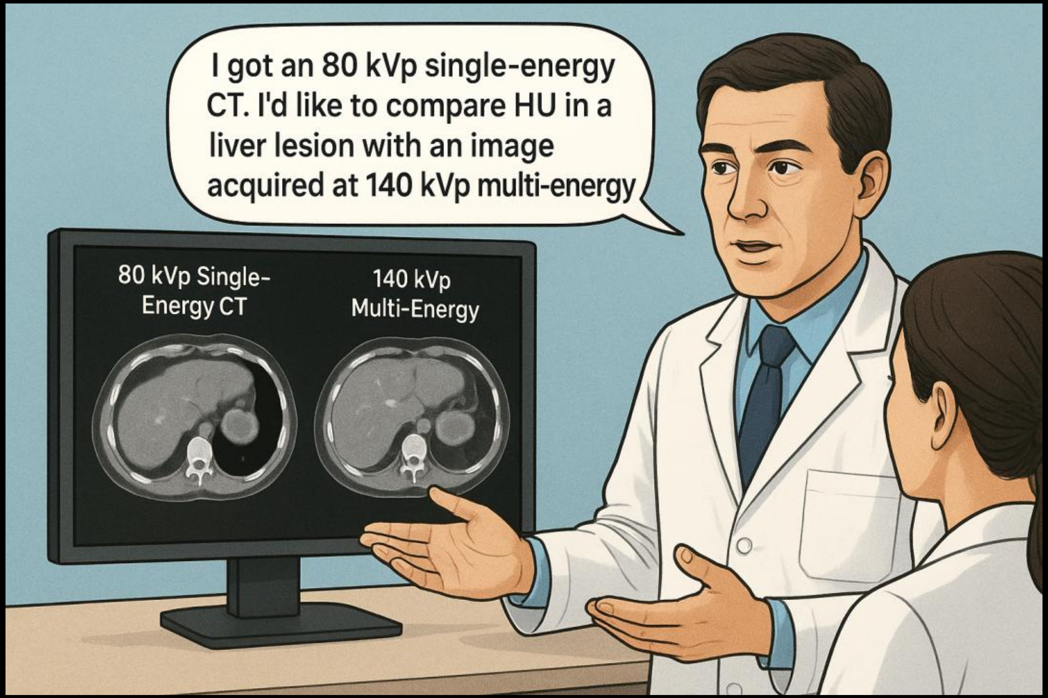
Mass attenuation coefficient (μ/ρ)



CT number (HU)



Motivation



Radiologists face significant variation in the CT images they are asked to evaluate, due to the diversity of CT scanners and reconstruction options.

Which scan parameters provide comparable keV across manufacturers?

Which virtual monoenergetic image can we use for comparison?

Lookup table based on mean energies.

CT values varies across vendors for same kVp

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 14, NUMBER 6, 2013

Scanner and kVp dependence of measured CT numbers in the ACR CT phantom

Robert J. Cropp,[1a] Petar Seslija,[1] David Tso,[2] Yogesh Thakur[1,2]
Integrated Medical Imaging,[1] Vancouver Coastal Health, Vancouver, British Columbia, Canada; Department of Radiology,[2] Faculty of Medicine, University of British Columbia, Vancouver, British Columbia, Canada
robert.cropp@vch.ca

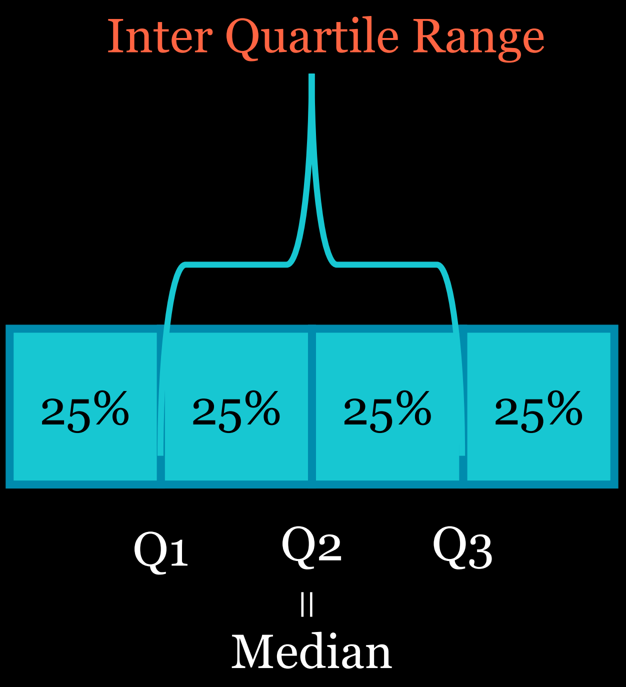


TABLE 7. Acrylic CT number measurements in HU. Data are from 24 GE, 7 Siemens, 3 Siemens SPECT-CT, and 1 Toshiba scanners. For each entry, the first value is the median and the second value (in parentheses) is the inter-quartile range.

	80 kVp	*100/110[a] kVp*	*120/130[a] kVp*	*135[b]/140 kVp*
GE	98 (8.1)	114 (5.3)	123 (5.2)	129 (4.3)
Siemens	111 (7.1)	125 (6.3)	132 (5.3)	137 (4.9)
Siemens SPECT-CT	103 (-)	121 (-)	127 (-)	-
Toshiba	109 (-)	121 (-)	125 (-)	127 (-)

[a] The available kVp values on the Siemens SPECT-CT scanners are 80, 110, and 130 kVp.
[b] The Toshiba scanner uses 135 kVp instead of 140.

TABLE 8. "Bone" CT number measurements in HU. Data are from 24 GE, 7 Siemens, 3 Siemens SPECT-CT, and 1 Toshiba scanners. For each entry, the first value is the median and the second value (in parentheses) is the inter-quartile range.

	80 kVp	*100/110[a] kVp*	*120/130[a] kVp*	*135[b]/140 kVp*
GE	1326 (18)	1121 (18)	988 (20)	907 (15)
Siemens	1192 (17)	989 (16)	880 (16)	821 (28)
Siemens SPECT-CT	1216 (-)	961 (-)	873 (-)	-
Toshiba	945 (-)	902 (-)	933 (-)	949 (-)

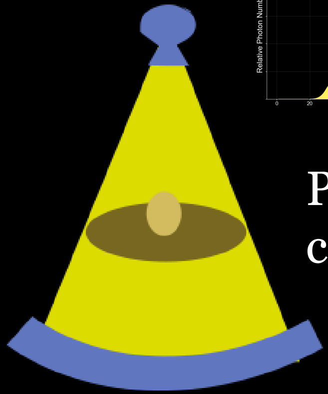
[a] The available kVp values on the Siemens SPECT-CT scanners are 80, 110 and 130 kVp.
[b] The Toshiba scanner uses 135 kVp instead of 140.

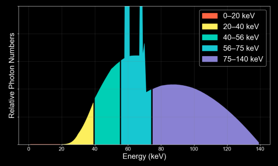
TABLE 9. Defined QC tolerance ranges for CT numbers of each material, based on collected data, taking manufacturer and kVp dependence into account. All CT numbers are in HU. For Siemens SPECT-CT and Toshiba, not enough scanners were surveyed to allow ranges to be defined.

	80 kVp	*100 kVp*	*120 kVp*	*140 kVp*
Solid water: GE	-5 to 7			
Solid water: Siemens	-5 to 5			
Air: GE	-1005 to -965			
Air: Siemens	-1005 to -980			
Polyethylene: GE & Siemens	-135 to -115	-115 to -100	-100 to -85	-90 to -75
Acrylic: GE & Siemens	90 to 120	110 to 130	120 to 135	125 to 140
"Bone": GE	1280 to 1340	1080 to 1140	940 to 1000	870 to 920
"Bone": Siemens	1160 to 1210	970 to 1010	860 to 900	790 to 830

Spectral imaging systems

Detector based

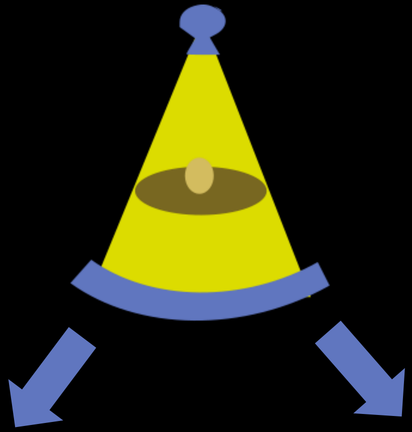




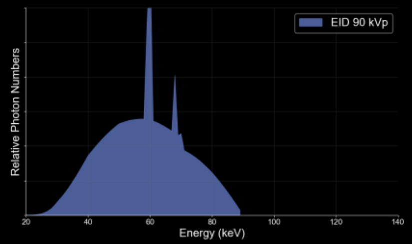
Photon counting

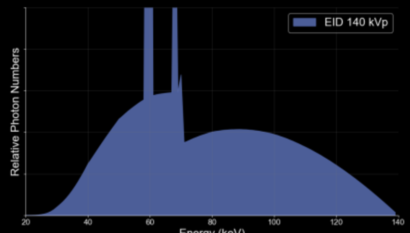
Dual layer

“Conventional CT”

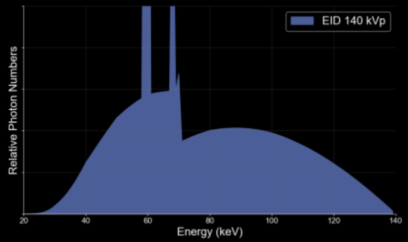


Sequenced





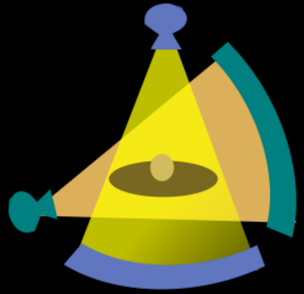
AI based



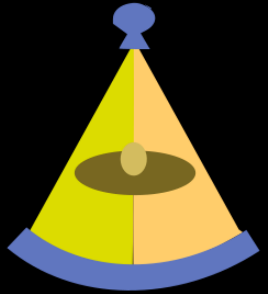
X-ray tubes

Dual source
dual detector

EID & PCCT



Split beam

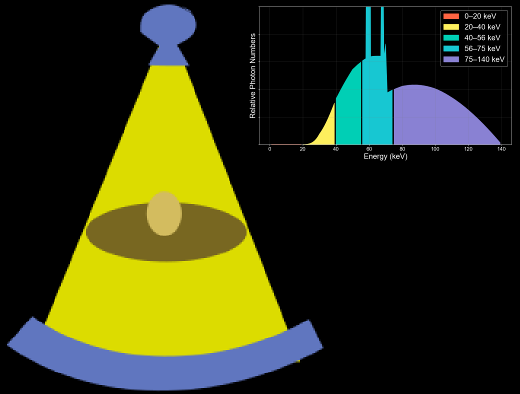


Rapid kV
Switching

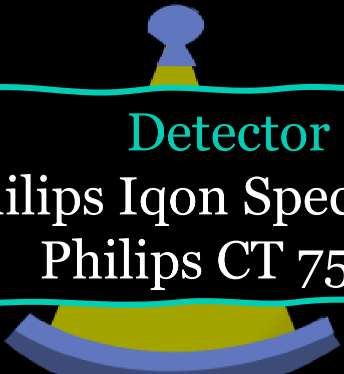
Spectral imaging systems

Detector based

Photon counting



Dual layer



Detector
Philips Iqon Spectral CT
Philips CT 7500

"Conventional CT"

Sequenced

Sequence /Twin spiral
Philips Ingenuity
Philips CT5000
Philips iCT Elite
Philips Incisive CT
Philips big bore
Siemens SOMATOM go.Open Pro
Siemens On site (mobile)

AI based

Singel specter + AI
Aquilion One Insight

X-ray tubes

Dual Source
Siemens SOMATOM Force
Siemens Definition Flash
Siemens SOMATOM Drive

Split beam / Twin beam
Siemens Definition Edge
Siemens Definition Edge+
Siemens X.Ceed

Rapid kV switching
Canon Aquilion Genesis
Canon Aquilion Genesis One
GE Revolution Frontier
GE Revolution CT Apex Edition (+AI)
GE Revolution CT ES (RT)

Project life

- Idea Linköping
  - Radiologist requested publication
- ECMP Sep-2024 München
  - Met head of physicist at OUS – shared idea
- April 2025 First and last author, invitation
  - TEAMS meeting: Kristin & Bente
- Response
  - YES
- TEAMS meeting
  - Need to do?
- Collect CT scanners specifications
  - Template (kV, filtration, angle, HVL)
- Simulate spectra Mean energy/HVL
  - Ivar use SPECTRUM
- Physical meeting Measurement
  - In Oslo – all participants
- Individual measurement
  - In all hospitals
- Publication Look up table?
  - Ivar gets all data

The vision

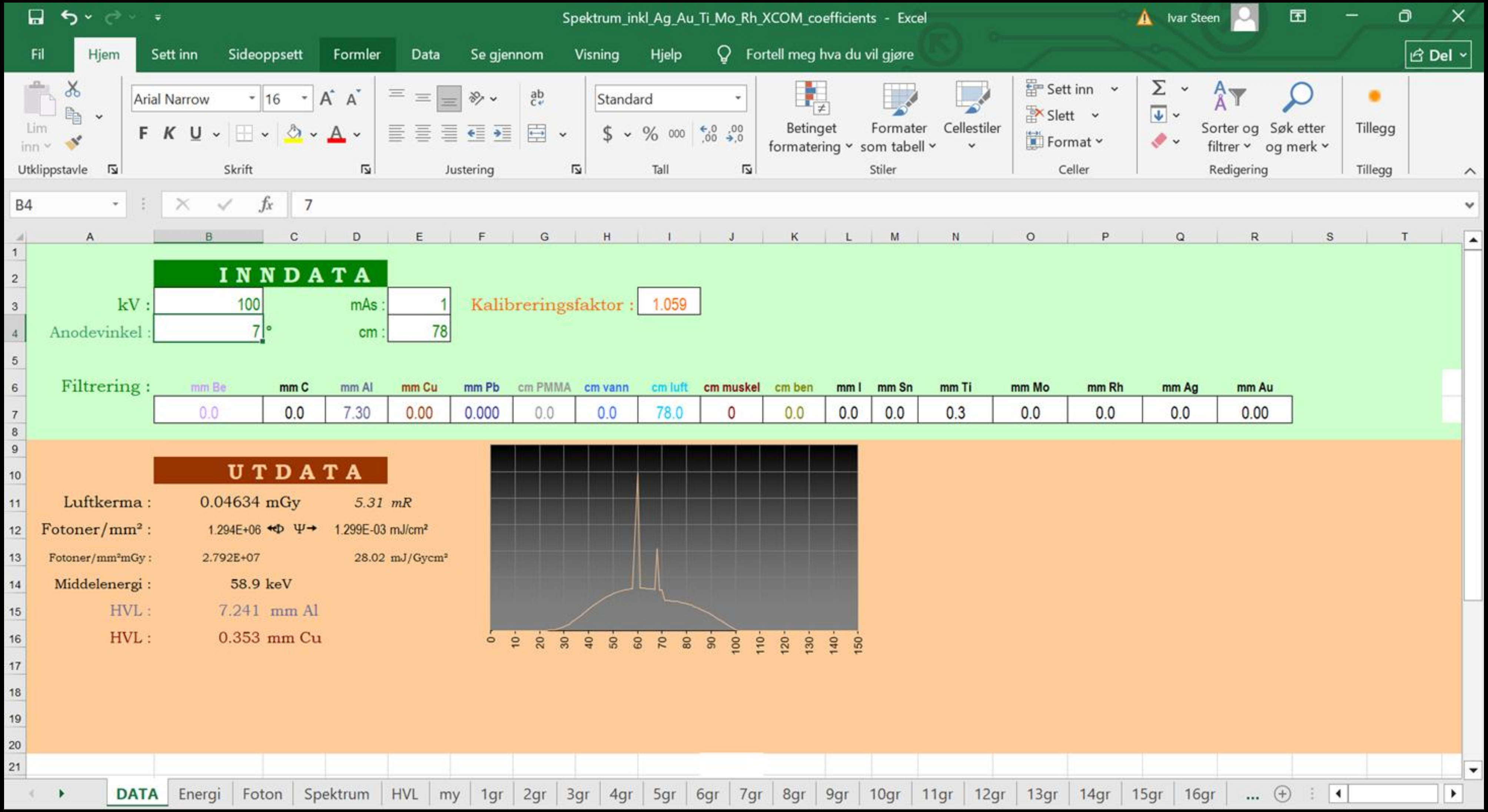
Scanner specs/ settings			Measured value	Simulated
Scanner model	kVp	Filtration	HVL [mm Al]	Mean energy
Siemens Force	100	6.2 mm Al + 0.3 mm Ti	7.4	59.4

Simulations

- Information about all scanners were collected from the documentation provided by the manufacturers.
- Expected spectra, HVLs and mean energies was simulated, using the Birch and Marshall calculation [1].
- The simulation results and documentation was used as a guideline when choosing the amount of Al needed for the measurements.

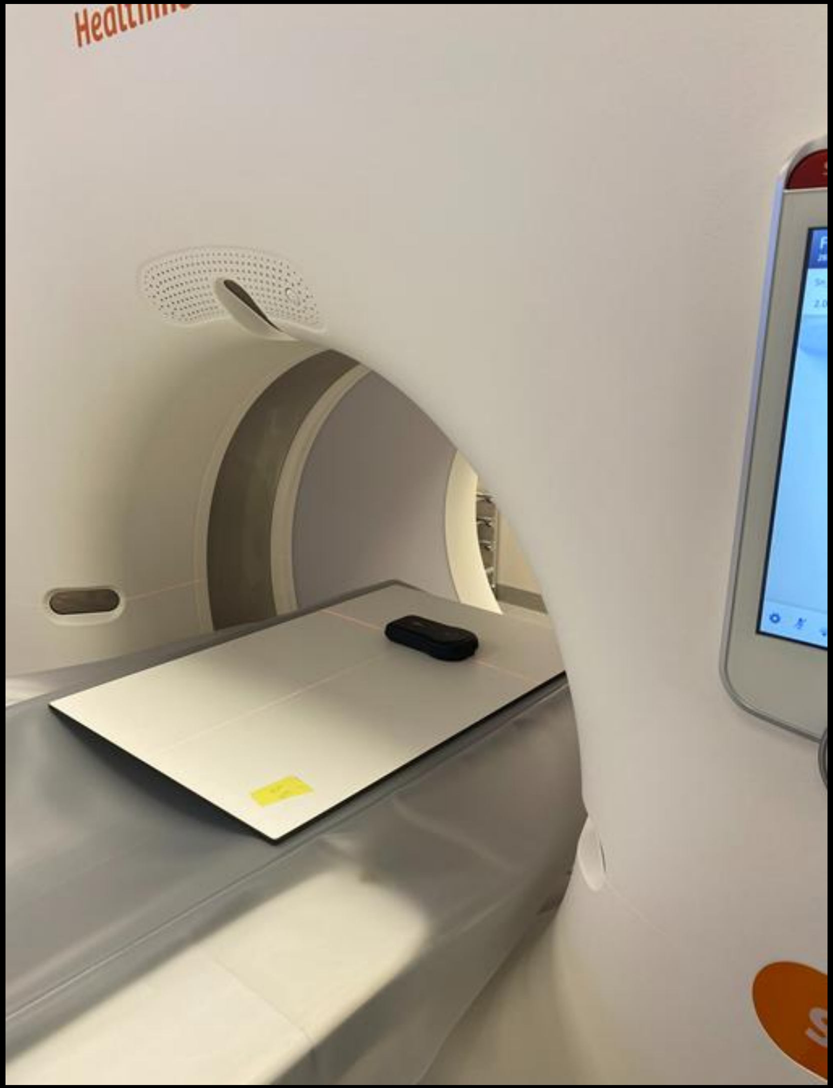
$$I(E) = \frac{\rho N}{A} \int_{T_0}^{E} \left(1 + \frac{T}{m_0 c^2}\right) Q \left(\frac{dT}{dx}\right)^{-1} \cdot \exp\left(\frac{-\mu(E)}{\rho C}\left(T_0^2 - T^2\right)\cot\theta\right) dT$$

Simulations



Measurements

- Dosimeter was placed in the ISO-center of the scanner.
- Exposures was done with a stationary x-ray tube.
- Dose was measured with increasing amounts of Al, until it was halved.
- The HVL was interpolated from these measurements.

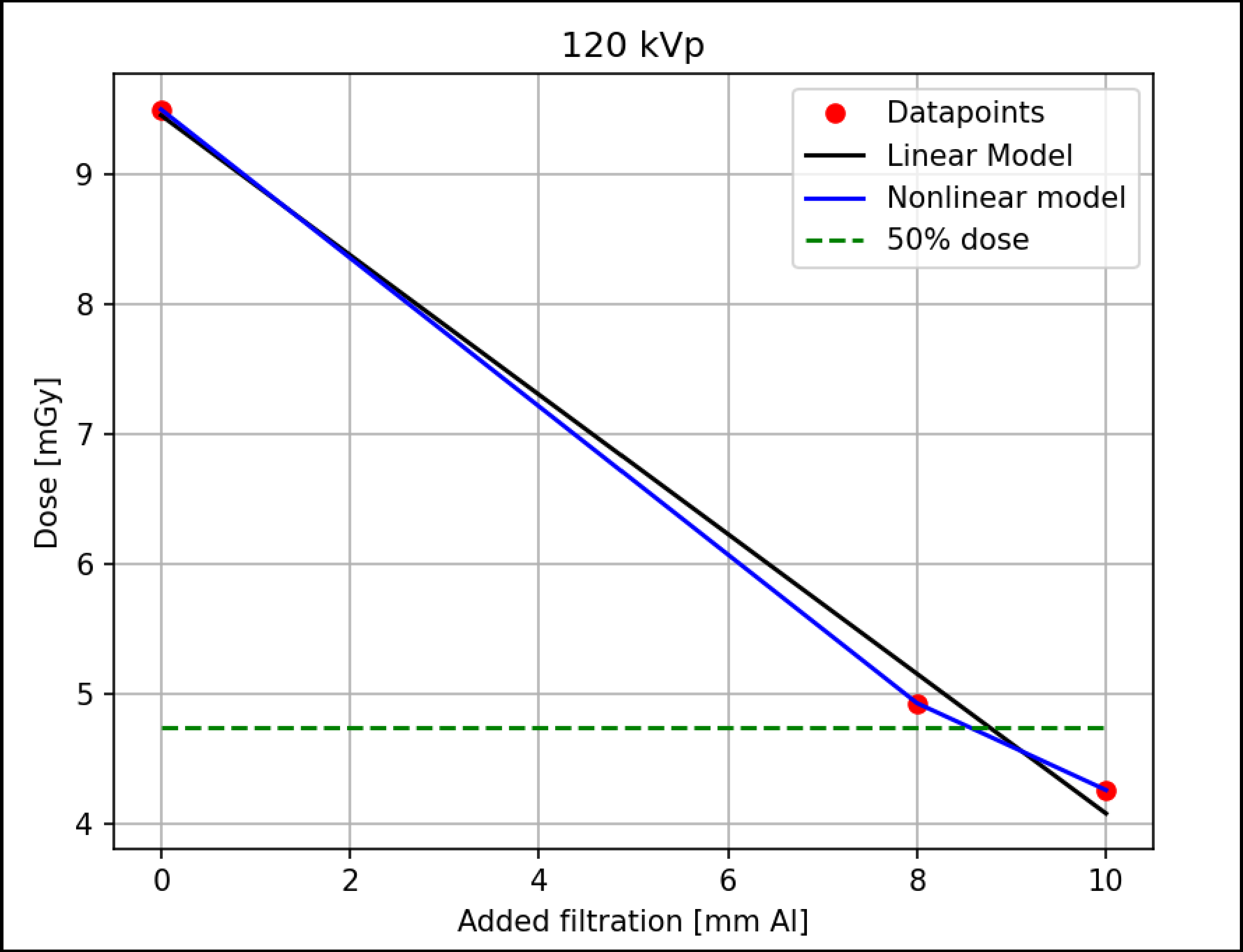


Linear vs non-linear HVL calculation

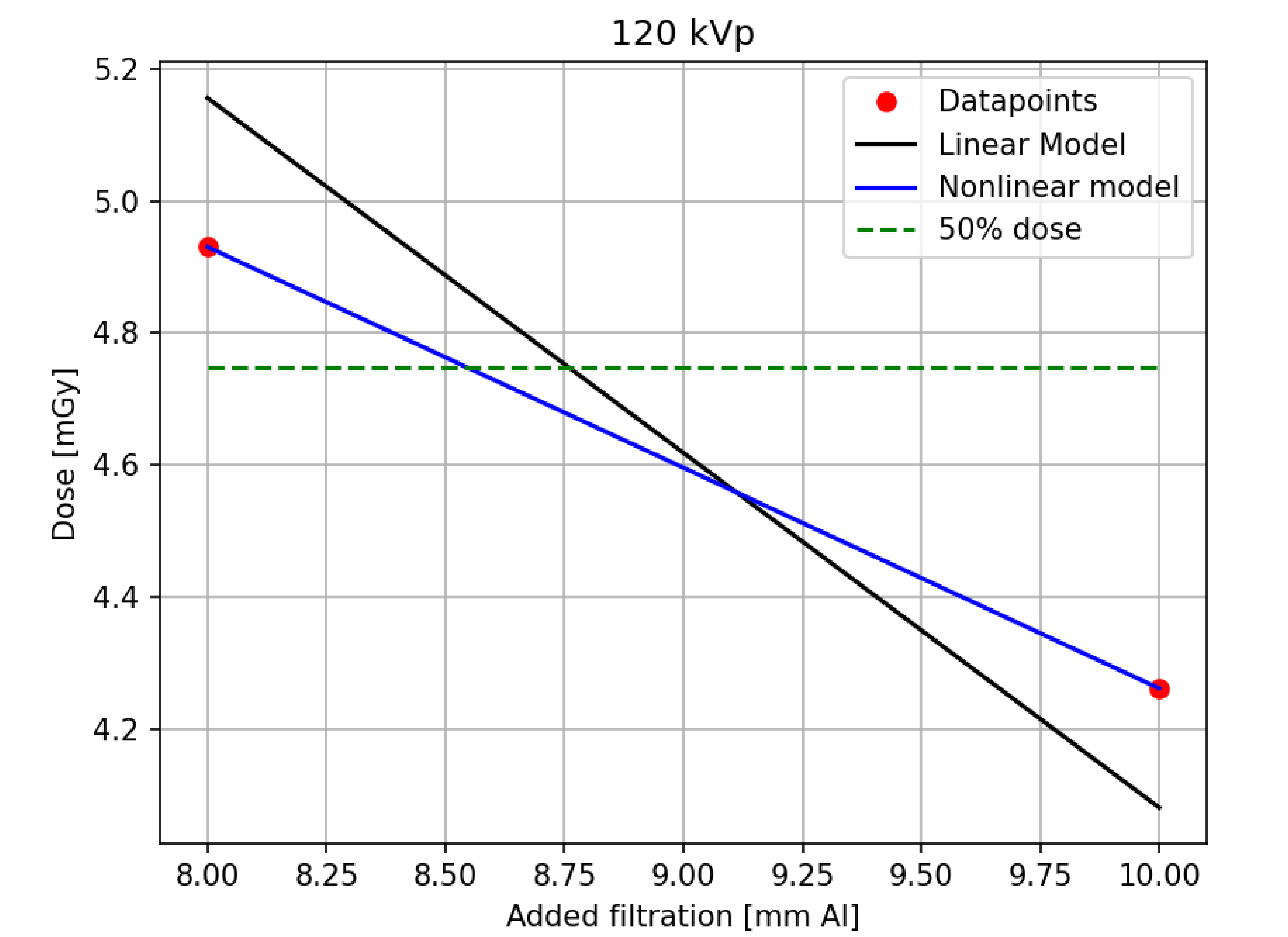
- The HVL is determined through interpolation of the measurements.
- This can be done with a linear or exponential model [4].
- Both models fit the data with a coefficient of determination >0.99

$$Dose = a \cdot Al + b$$

$$Dose = Dose_0 \cdot e^{-\frac{a^2-(a-2b\cdot Al)^2}{4b}}$$



120 kVp
Datapoints
Linear Model
Nonlinear model
50% dose
Dose [mGy]
Added filtration [mm Al]
0
2
4
6
8
10
4
5
6
7
8
9



120 kVp
Datapoints
Linear Model
Nonlinear model
50% dose
Dose [mGy]
Added filtration [mm Al]
5.2
5.0
4.8
4.6
4.4
4.2
8.00
8.25
8.50
8.75
9.00
9.25
9.50
9.75
10.00

Preliminary Results

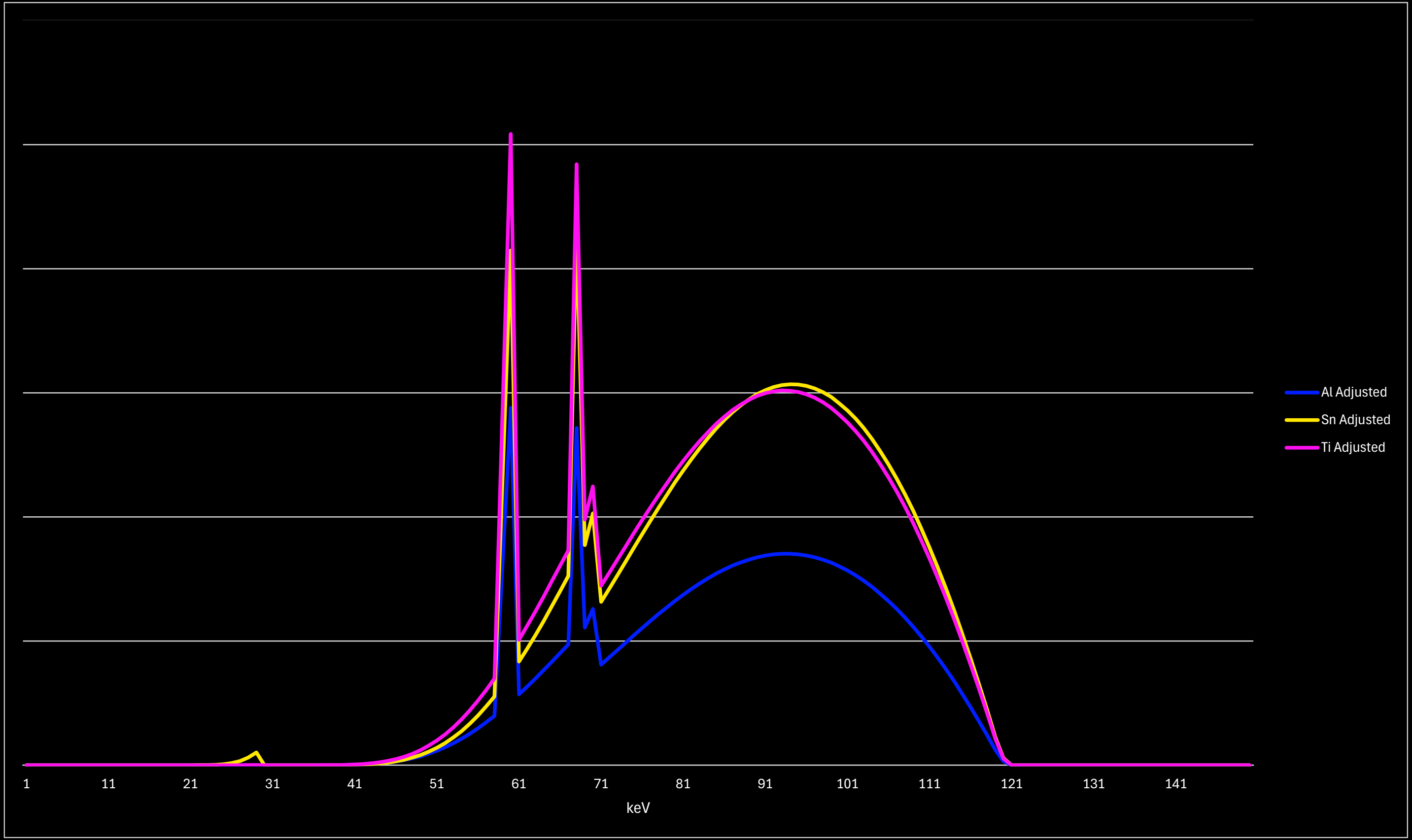
- The HVLs determined by linear regression are on average 1% higher than the HVLs determined by the exponential model.
- HVLs determined by the exponential model are on average 8% higher than listed in the documentation.
- The actual mean energy from the scanner was estimated by adding Al in the simulation until it matched the empirical HVL.

Preliminary Results

Scanner specs/ settings							Measured value	Simulated	
Vendor	Model	kV	mm Al	mm Sn	mm Ti	HVL [mm Al] given in specs	HVL [mm Al] measured	achive measured HVL	Mean energy [keV]
Siemens	SOMATOM Force	70	6,2		0,3	4,9	5,225	2,31	47,8
Siemens	SOMATOM Force	80	6,2		0,3	5,5	5,875	1,52	51,9
Siemens	SOMATOM Force	90	6,2		0,3	6,2	6,78	2,335	56,1
Siemens	SOMATOM Force	100	6,2		0,3	6,6	7,409	2,275	59,4
Siemens	SOMATOM Force	110	6,2		0,3	7,2	8,494	4,935	63,8
Siemens	SOMATOM Force	120	6,2		0,3	7,8	8,506	2,295	65,1
Siemens	SOMATOM Force	130	6,2		0,3	8,3	8,894	1,86	67,4
Siemens	SOMATOM Force	140	6,2		0,3	8,8	9,254	1,44	69,6
Siemens	SOMATOM Force	150	6,2		0,3	9,2	9,638	1,25	71,8
Siemens	SOMATOM Force	100Sn	6,2	0,6	0,3	11,8	12,448	40,75	79,5
Siemens	SOMATOM Force	150Sn	6,2	0,6	0,3	14,7	15,62	46,22	107,2

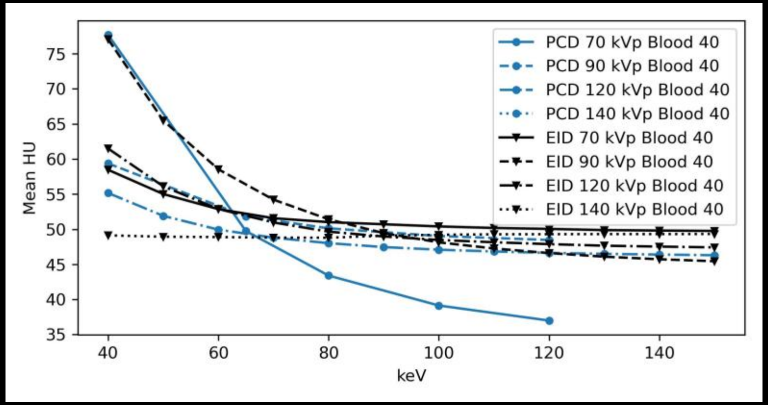
Discussion

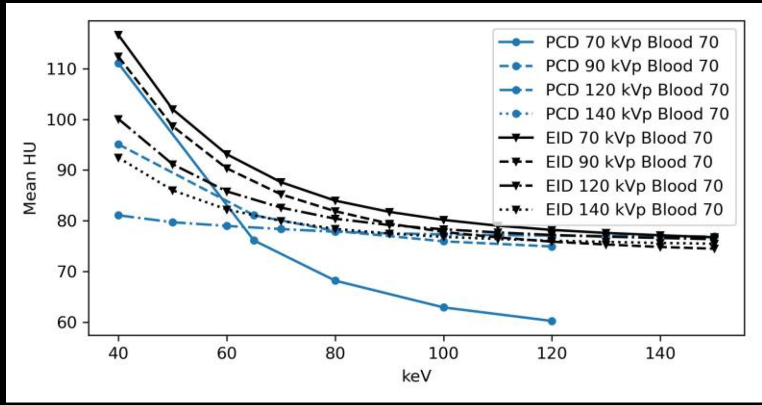
- Even the corrected spectra will not be 100% accurate.
- The 5% uncertainty in dose measurements with the Piranha multimeter.
  - Is it the same for every measurement?
- Wear and tear on x-ray tubes
- Potential differences between same model scanners

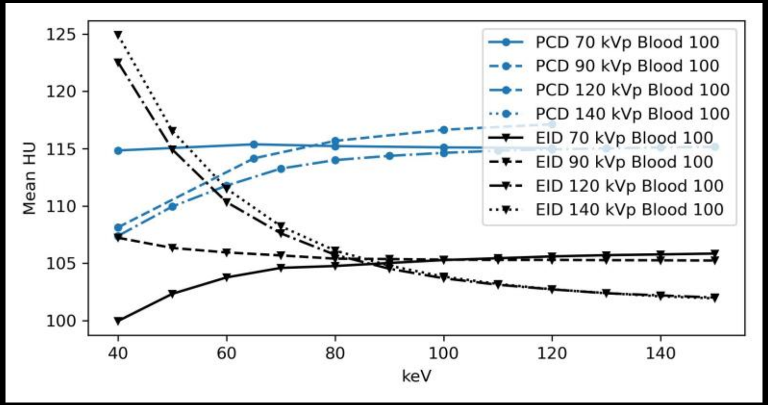


- Siemens On.Site, 120 kVp, 0.4 mm Sn + 0.4 mm Ti.
- Adjusted with:
  - 18.85 mm Al, Mean energy 83,2 keV
  - 0.2186 mm Sn, Mean energy 84,3keV
  - or 2.43 mm Ti, Mean energy 83,1 keV
- HVL 12.744 mm Al

Problematic cases of using HU-values for diagnostic purposes







CT or MRI findings cannot be used to accurately date SDHs. *Sieswerda-Hoogendoorn* 2014, Review *European journal of radiology*

"hematom with expansion 55.7 ± 2.9 HU, hematoma with no expansion 58.6 ± 3.1 HU .. Intracerebral hemorrhage with lower mean HU of hematoma at presentation is more likely to undergo hematoma expansion. *Jeong et al.* 2021, *International Journal of Stroke*

"Cerebral vein thrombosis (CVT) ...The mean HU value was 75 ± 7 HU in the CVT group and 52 ± 6 HU in the control group , threshold 66 HU *Canakci et al 2021 The Journal of Emergency Medicine*

Moving forward

November 2025 preliminary results

Presented in Oslo and Stockholm

Complete data collection

Finish measuring on all available scanners

Final calculations/ Simulations

Estimate alle the mean energies based off the meassurments

Evaluation of results

Choose Branche

Branche 1: Create a lookup table relating scan parameters to mean energy for the involved models – publish results

Branche 2: The variation between scanners of the same models are too big to create a general lookup table – publish results

References

[1] Konst B, Nøtthellen J, Bilet E, Båth M. Radiographic and fluoroscopic X-ray systems: Quality control of the X-ray tube and automatic exposure control using theoretical spectra to determine air kerma and dose to a homogenous phantom. J Appl Clin Med Phys. 2021 Aug;22(8):204-218. doi: 10.1002/acm2.13329. Epub 2021 Jul 1. PMID: 34196461; PMCID: PMC8364276.

[2] Bushber, J. T., Seibert, J. A., Leidholft Jr, E. M., & Boone, J. M. (2021). Table 3-3: HVL as a function og the effective energy of an x-ray beam. In The Essential Physics of Medical Imaging (p. 60). Philadelphia: Wolters Kluwer.

[3] Fernández-Pérez, G., Fraga Piñeiro, C., Oñate Miranda, M., Díez Blanco, M., Mato Chaín, J., & Collazos Martínez, M. (2022). Dual-energy CT: Technical considerations and clinical applications. Radiología (English Edition), 64, ss. 445-455. Hentet 10 20, 2025 fra https://www.sciencedirect.com/science/article/pii/S2173510722001094

[4] Trianni, A., Rogers, A., Bertolini, M., Bosmans, H., Marshall, N., Paruccini, N., . . . Trevisan, D. (2024). QUALITY CONTROL OF DYNAMIC X-RAY IMAGING SYSTEMS/ EFOMP PROTOCOL. EFOMP. Hentet November 06, 2025 fra https://www.efomp.org/uploads/be68860f-5f48-4450-9d96-27dc634a32a6/Angio%20QC%20Protocol_v4.pdf