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INDEPENDENT X-RAY
QUALITY ASSURANCE

XMM Technology - Before and Today

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Introduction

Non-invasive x-ray multimeters (XMMs) have been used for x-ray quality control for over 40 years. In the 80's and 90's the meters were designed with separate detectors for measurement of air kerma, and tube potential respectively. Since then, the XMMs have developed to measure several parameters simultaneously. Today there are a range of different brands that measure tube potential, air kerma, HVL, and total filtration equivalent (TF) in one single exposure.

The technology behind the XMMs will be presented from an historical perspective.

About me

Sören is technical manager at the ISO 17025 accredited dosimetry calibration laboratory at RTI in Sweden. In parallel Sören has been working close to 30 years as application and product specialist working with development of X-ray multimeters (XMMs).

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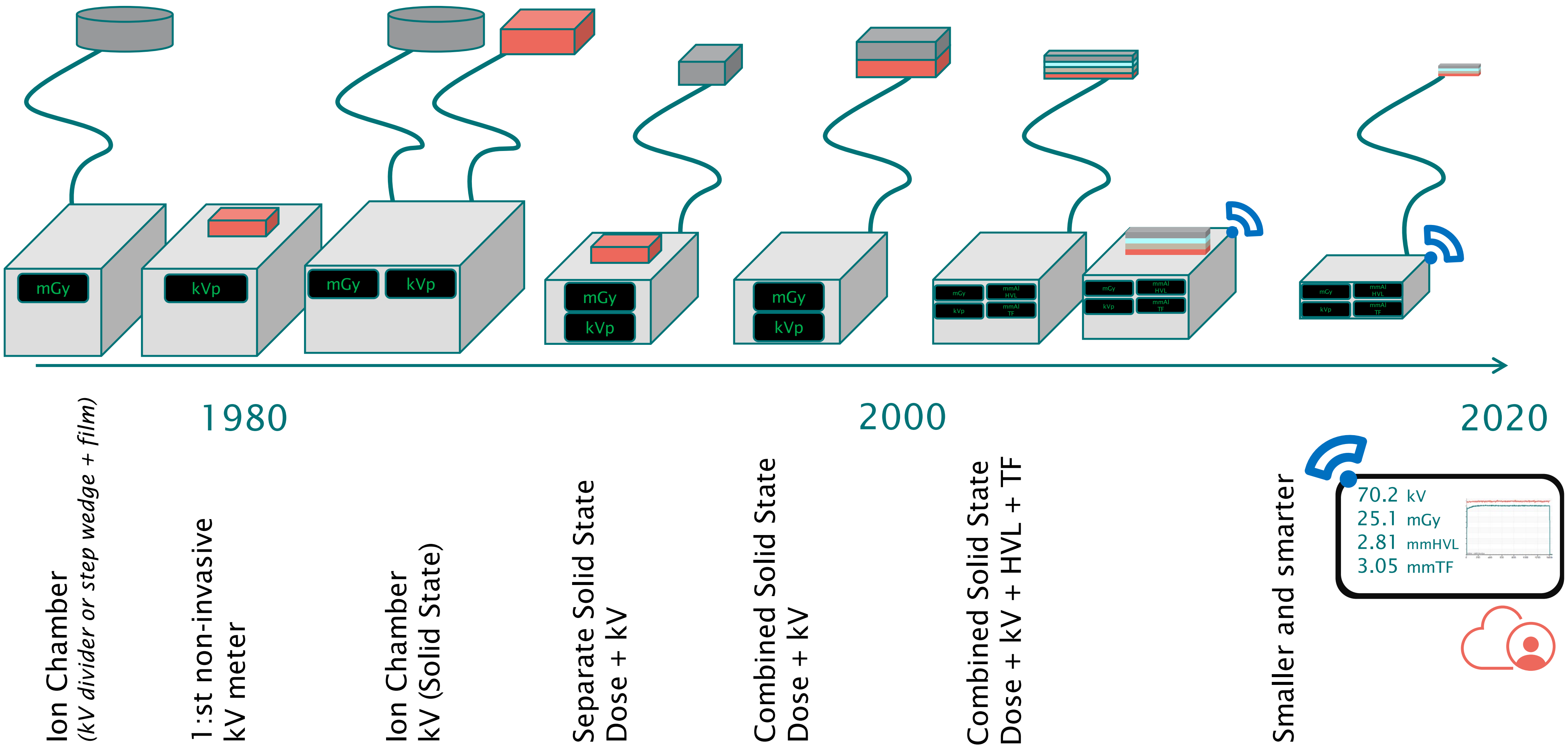
40 Years of X-ray safety & quality

History of XMM's – X-ray MultiMeters



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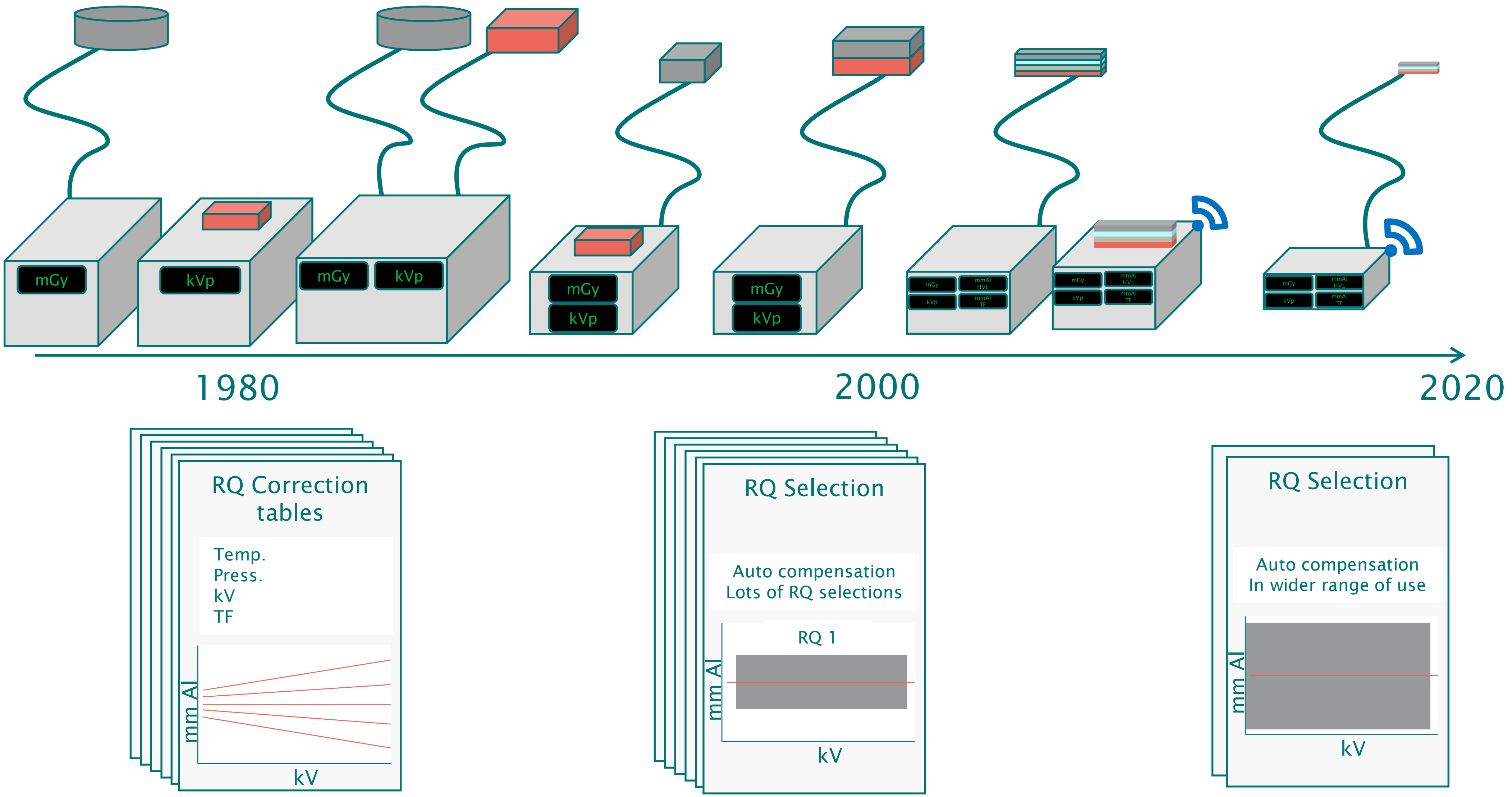
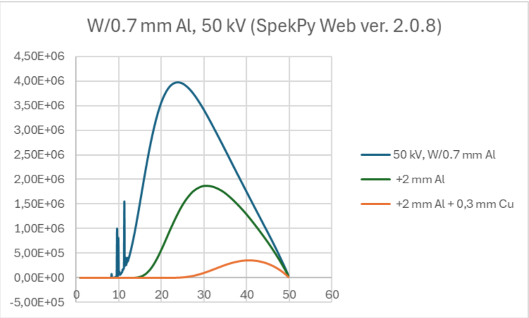
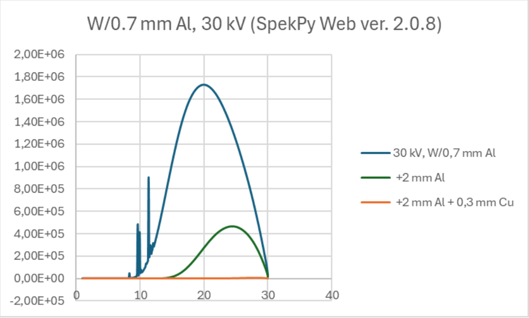
History of XMM’s – X-ray MultiMeters



The Physics behind XMM's



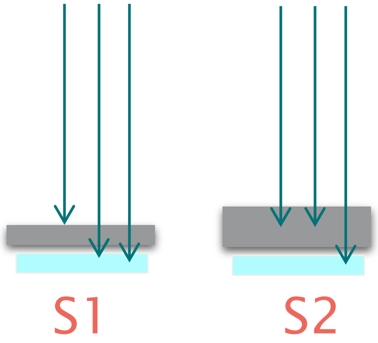


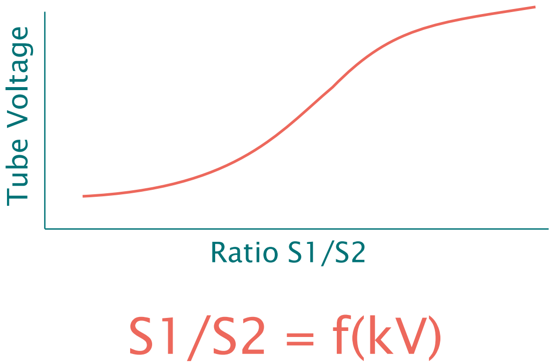
kV and the X-ray spectra

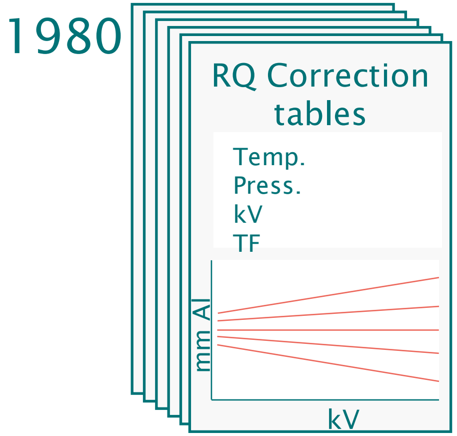
The tube voltage that creates the x-ray represents the highest photon energy represented in the x-ray spectra.

Adding metal filters in the beam will reduce the low energy photons relatively more than the high energy photons. The mean energy increases.

The ratio of signals from detectors with various filtration that attenuates radiation differently will vary with tube potential.



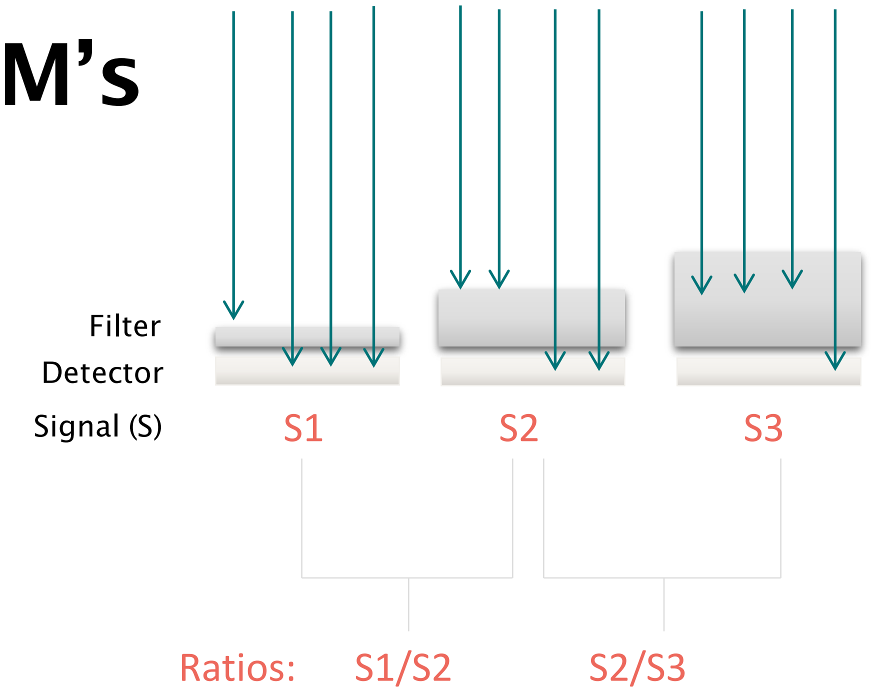




The Physics behind XMM's

"Unknown" parameters that influences the x-ray spectra

- Tube Voltage
- Filtration
- Anode angle
- Ripple
- Tube aging



From a ratio of **two** signals, **one** unknown parameter can be calculated based on the assumption that the other parameters are constants.
Eg. If inherent filtration is known, then kV can be measured with **one** ratio.

Add another ratio, and two unknown parameters can be calculated. Eg kV and Filtration.

Add one more… and three unknown…
Etc…

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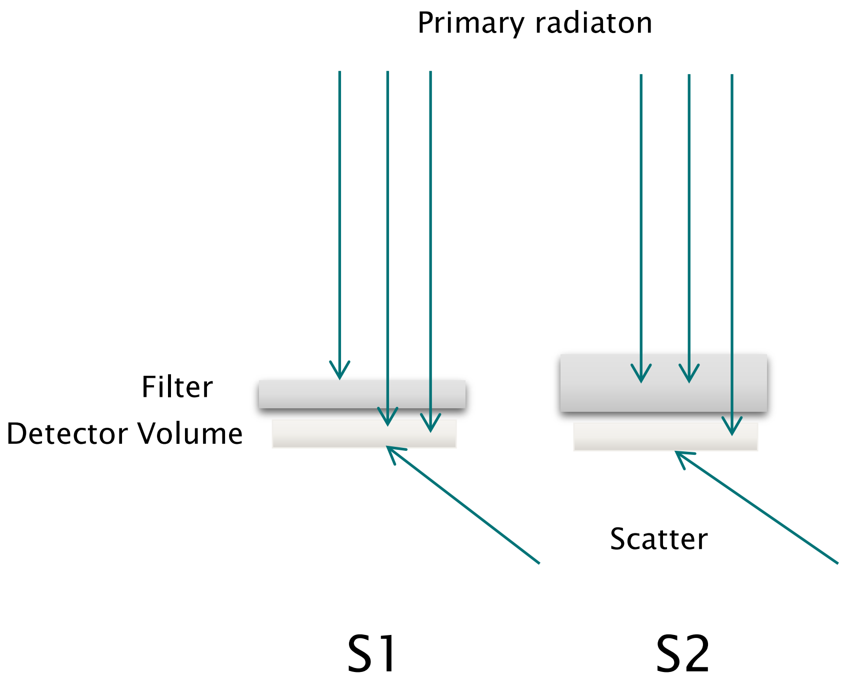
The Physics behind XMM's

When measure ratios – Scattered radiaton must be eliminated



Without Back scatter:

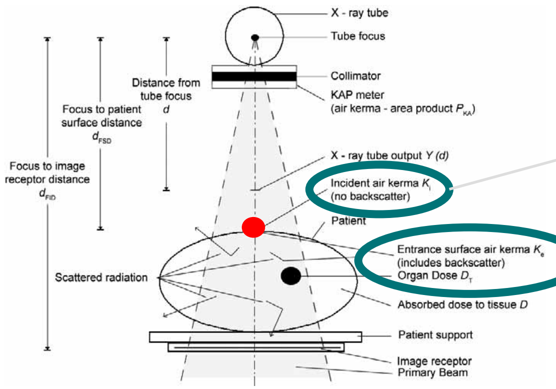
S1/S2 = 2 / 1 = 2

With Back scatter:

S1/S2 = (2+1) / (1+1) = 1,5

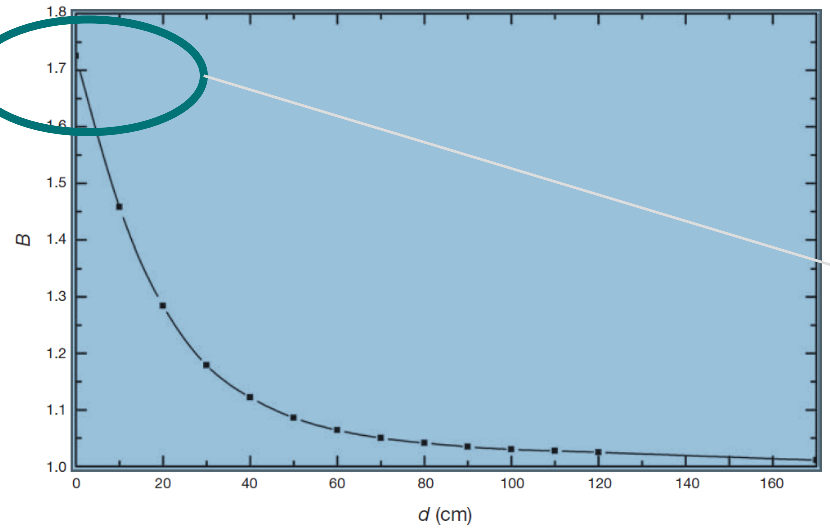
The Physics behind XMM’s

Images from ”IAEA Code of Practice”



Incident air kerma K_i
(no backscatter)

Entrance surface air kerma K_e
(includes backscatter)

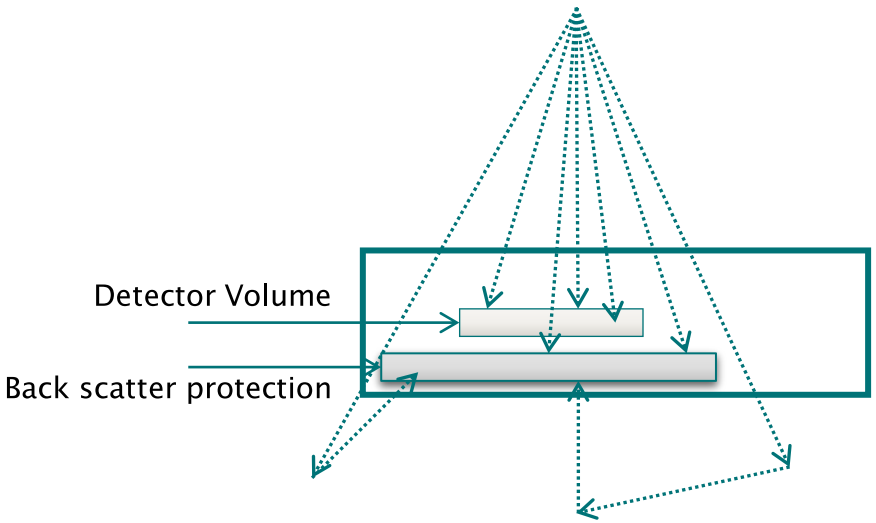


1.7

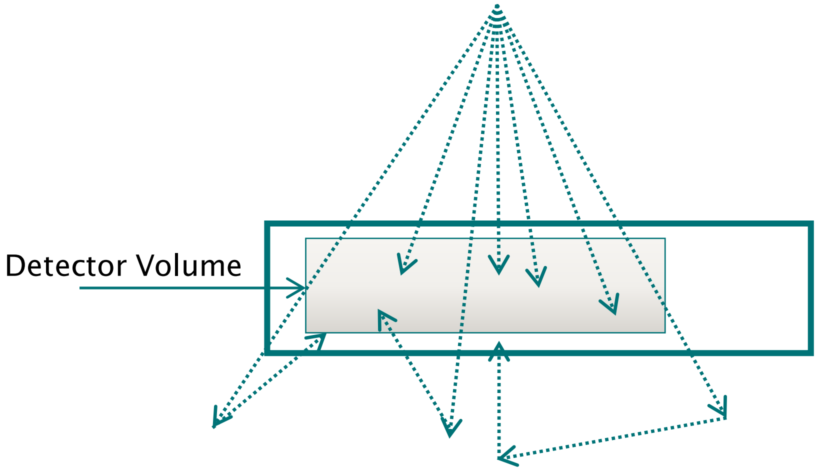
FIG. 6.1. An upper limit for the backscatter factor, B, as a function of the distance, d, from the surface of the backscattering wall. Radiation quality RQR 10, field size 600 mm × 600 mm, backscattering material Perspex (PMMA) of at least 100 mm thickness.

The Physics behind XMM’s

- Back-scatter protected
  - Measures thereby **Incident Air Kerma** (K_i) independently of positioning.



- No Back-scatter protection
  - Will measure differently depending on design. Often **Entrance Surface Air Kerma** (K_e)

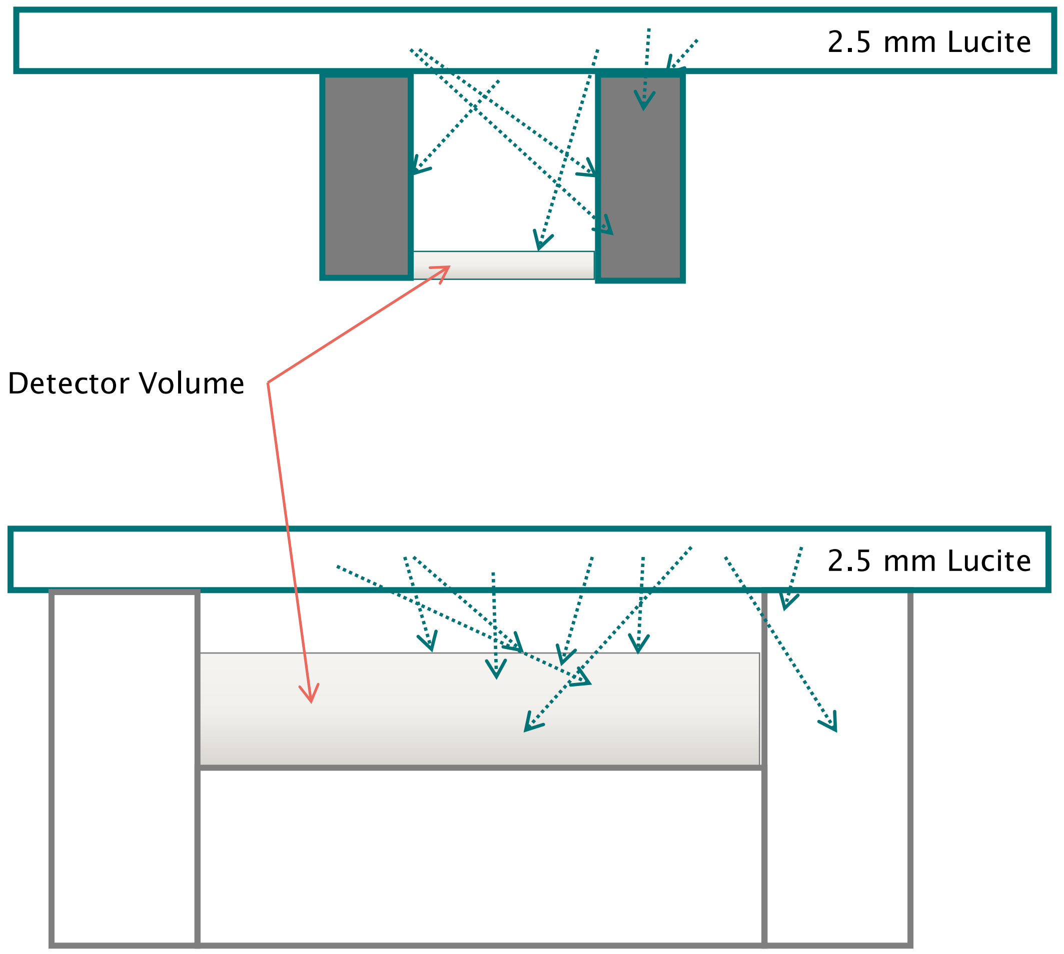


The Physics behind XMM's

"Front Scatter"

Collimation in the detector design and relative distance to the compression paddle in mammography matters.

Radcal 6M vs Piranha ≈1.06 when compression paddle placed in contact with the detector



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Clinically used Radiation Qualities

1980

Modality	Target	Filter alternatives		
R/F	W	2-4 mm Al		
CT	W	3 mm Al	+0.25 mm Cu	
Dent	W	1-2.5 mm Al		
Mam	Mo	30 µm Mo	25 µm Rh	1 mm Al
	Rh		25 µm Rh	1 mm Al

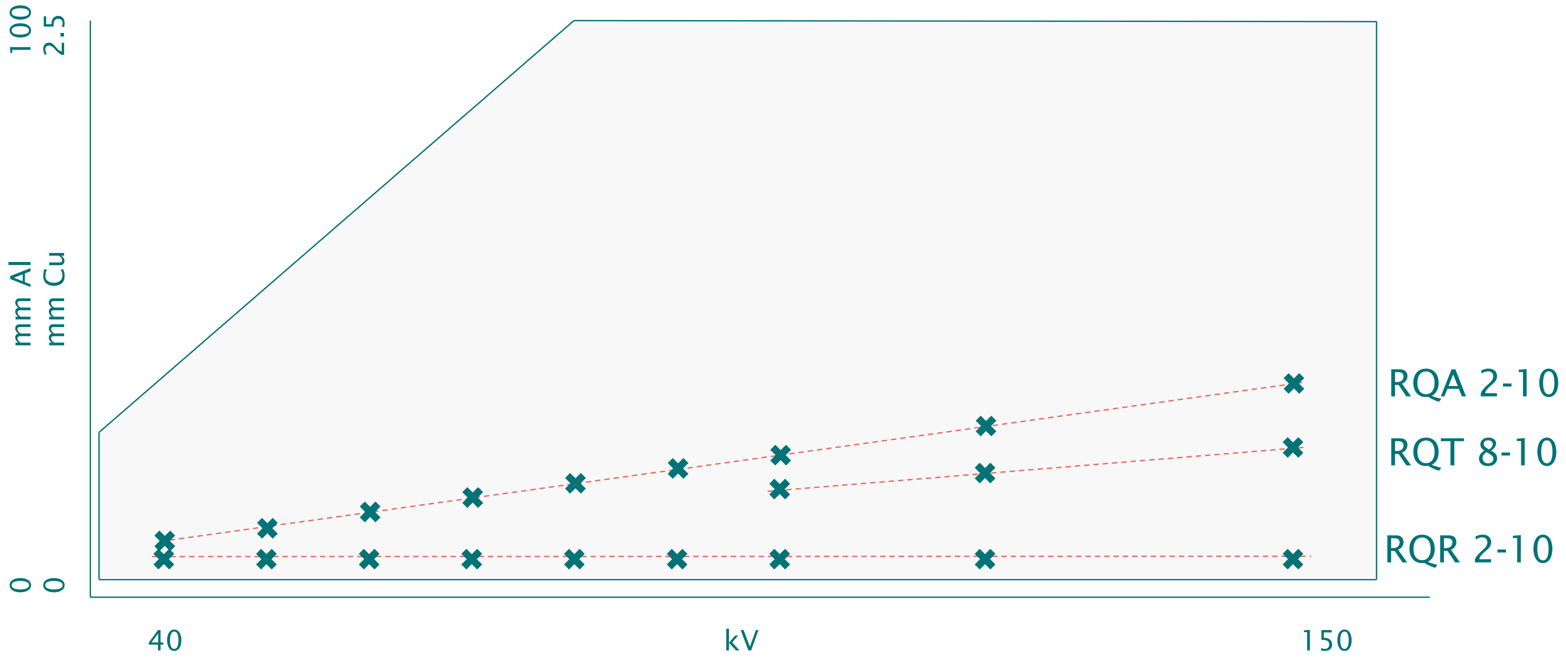
2024

Modality	Target	Filter alternatives					
R/F	W	2-4 mm Al	0-1.5 mm Cu				
CT	W	2-5 mm Al	+Cu	+Sn	+unknown		
Dent	W	1-2.5 mm Al					
Mam	Mo	30 µm Mo	25 µm Rh	1 mm Al		0.25 mm Cu	
	Rh		25 µm Rh	1 mm Al	30 µm Ag	0.25 mm Cu	
	W		40-60 µm Rh	0.5-1 mm Al	40-75 µm Ag	0.25-0.3 mm Cu	1.0-1.3 mm Ti

Air Kerma

Clinical conditions vs Available Traceable Radiation Qualities

R/F - 40–150 kV

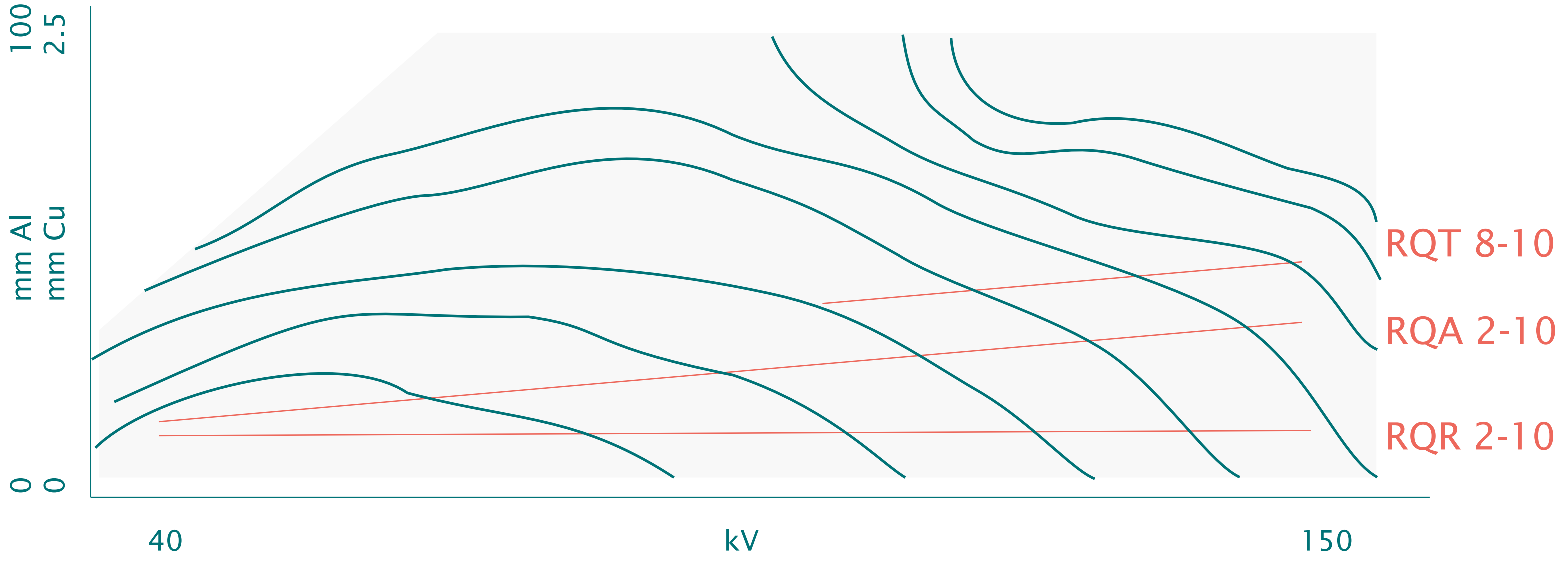


Air Kerma Radiation Qualities in the R/F range of energies

RQR, RQA, RQT - IEC 61267;Ed.2, 2005

How do XMM's handle this?

XMM internal polynomial fits to handle non-linarity in the internal detectors. Depending on the design this can be more or less complex.



Hard work if it looks like this?

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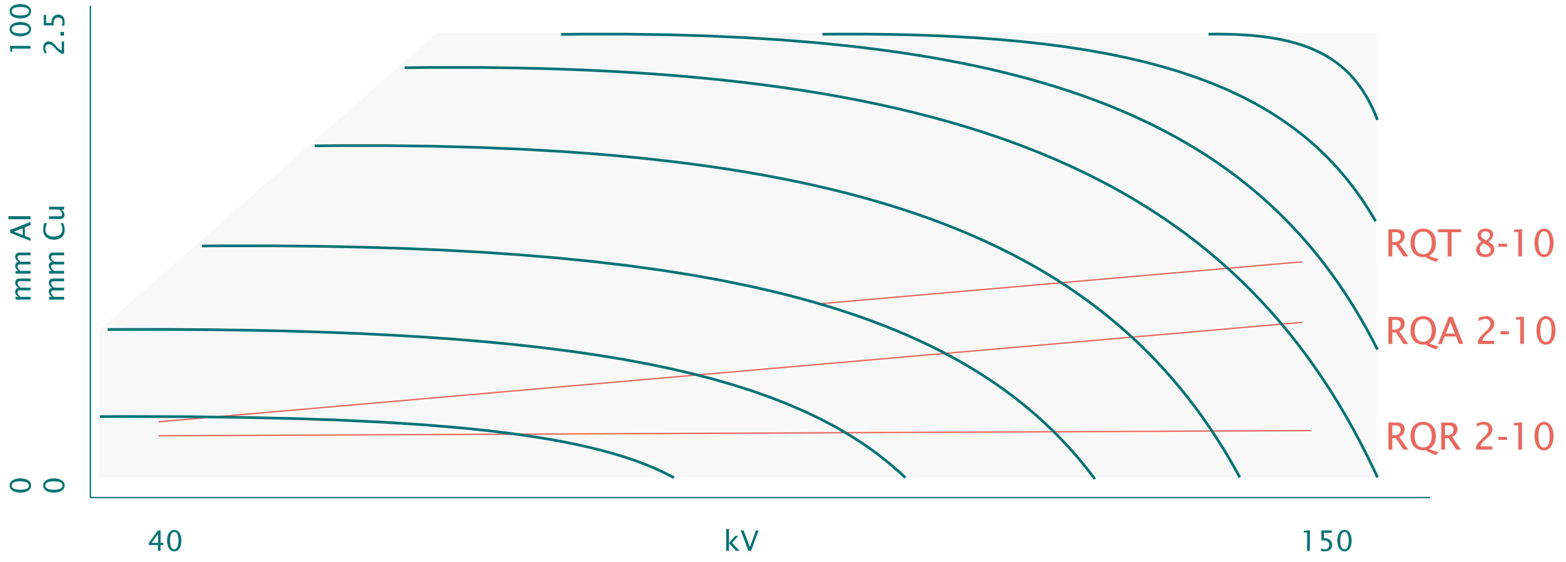


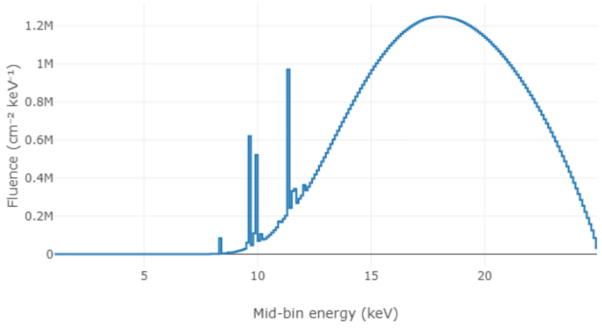
Easier and qite predictable if it looks like this?

Mammography

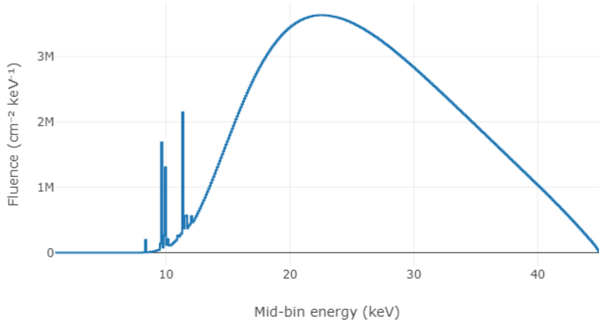
Basically the same applies to mammography range of radiation qualities

Though – for mammography there is another challenge with large variations in X-ray spectra due to k-edges in the kV range from 20 to 50 kV

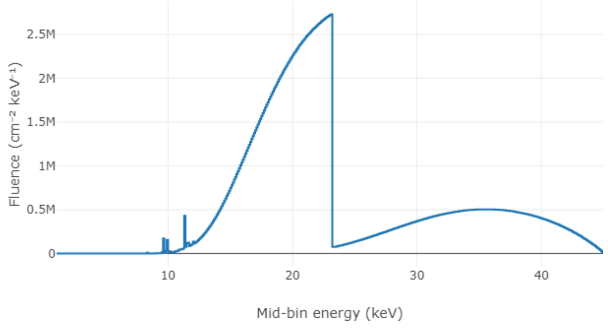
W/0.7mmAl, 25 kV



W/0.7mmAl, 45 kV



W/50μmRh, 45 kV



Simulations with SpekPy Web
ver. 2.0.8
https://spekpy.smile.ki.se/

Half Value Layer (HVL)

HVL is used to define radiation qualities. It’s also used clinically to assure that unnecessary low energy radiation is not present.

definition of HVL?

The quick answer is that HVL is a simplified description of a radiation spectra, and that it is defined by the amount of a material (Al) that reduces the Air Kerma (or photon fluence?) to 50%.

- What about field size? Does’n the HVL vary with collimation depending on amount of contribution from scatter in the collimators?

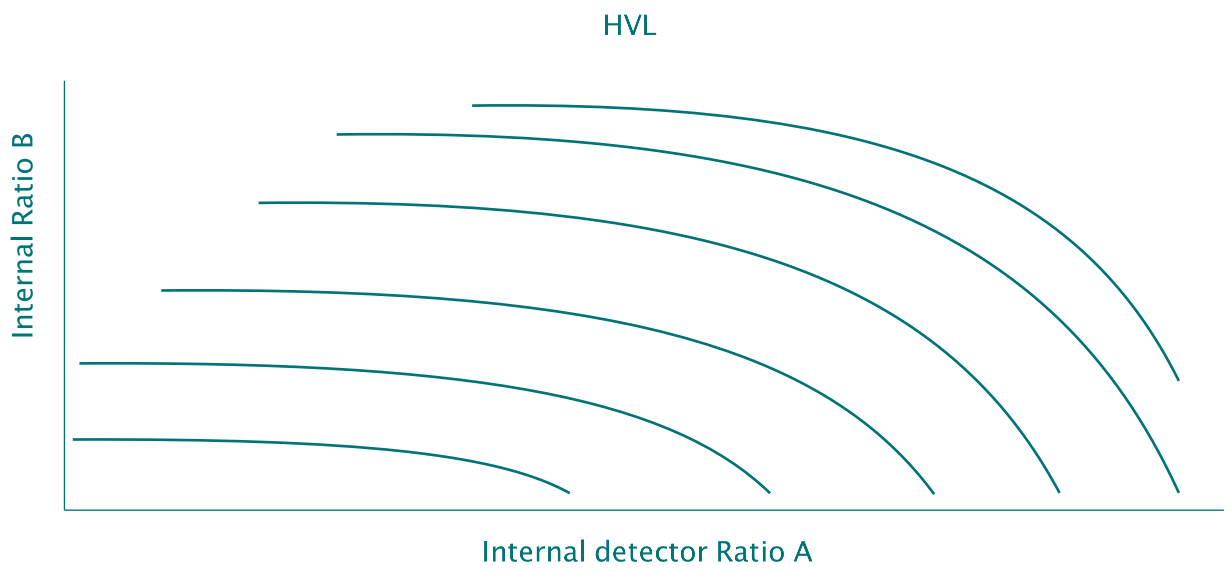
When measure HVL in the tradional way using Al filters and an energy linear dose detector, uncertainty tend to be quite high.

Filter Purity – use at least 99.9% pure filters.
Filter Thickness – Can easily be 10 % off especially in mammo ranges
non-ideal narrow beam geometry especially at high energy in R/F
Energy linearity for Air Kerma detector
Measure Repeatability

What is a realistic “Best measuring ability”?

Half Value Layer (HVL)

XMM HVL



The XMMs HVL model ”analyzes” the radiation. How accurate it will be depend on the XMM design.

Advantage is that there are no uncertainties by use of external filters, need of several measurements that requries high repeatability, and no fuzz with ”non-narrow” beam geometry.

Tube Potential

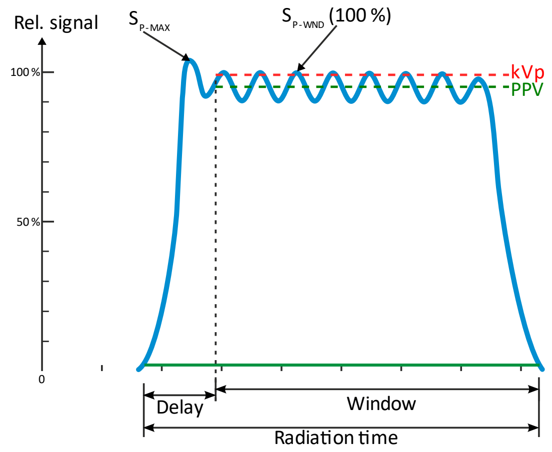
- **kVp vs PPV**

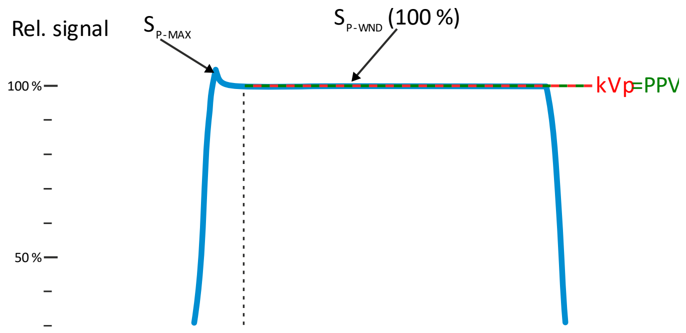
Generators are in general adjusted to kVp – but is there a common definition? And how does it comparison to expectation?

One single peak value? – or an average over several peaks?

The defined term by IEC, Practical Peak Voltage (PPV) is used by some XMM brands as complementary.

PPV has a more direct relevance to image quality in clinical use. But as as said above, not what the generator manufacturer use. For modern Constant Potential generators this is not an issue since any definition becomes the same when tube voltage is constant.



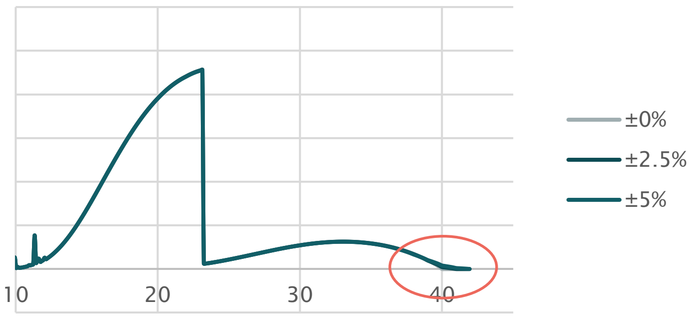


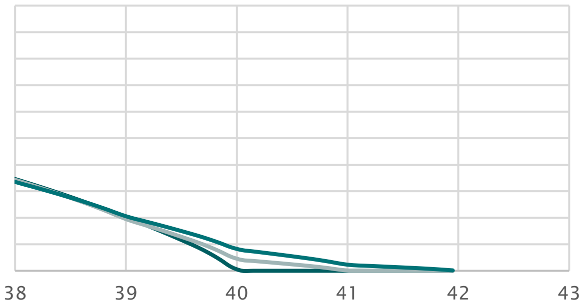
Tube Potential

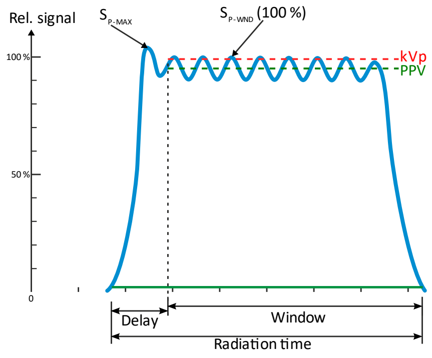
- **Comparing to a spectrometer measurement – one has to be aware of that the spectrometer will take all data into account.**

  Simulating ripple at 40 ±2 kV, W/50 µm Rh, show that it may be difficult to evaluate without having any information about the kV waveform

W/50 µm Rh, 40 kV (SpekPy Web ver. 2.0.8)







Time

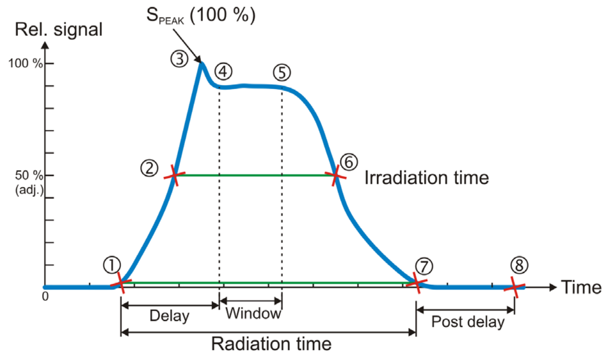
◇ **Irradiation Time, Radiation Time and/or Exposure Time**

Generator standards refer to loading state in the generator. How does that compare to the time that irradiation is present?

IEC 60601-2-63, IEC 60601-2-65

IRRADIATION TIME
IRRADIATION TIME is measured as the time interval between the instant when the AIR KERMA RATE has risen for the first time to a value of 50 % of the peak value, and the instant when it finally drops below the same value.
NOTE 1 see also definition 3.32 of IEC 60601-1-3:2008

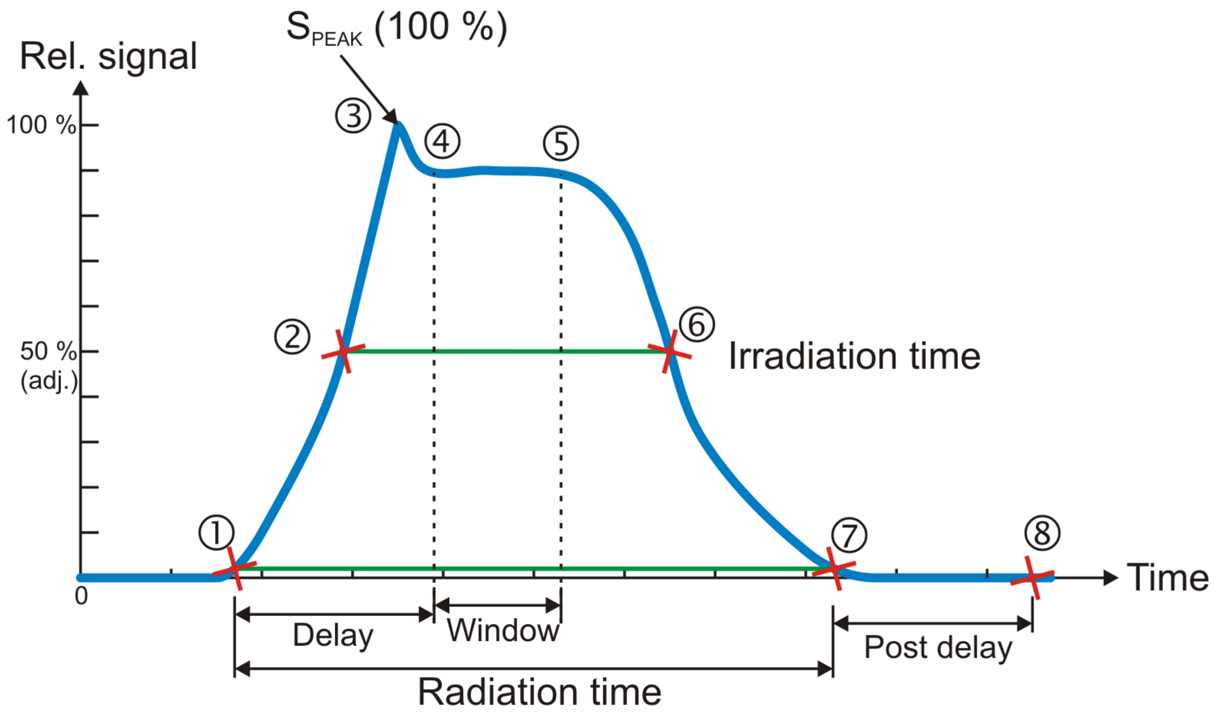
Citating IEC 60601-2-65
"LOADING TIME (the time during which the X-RAY MONOBLOCK ASSEMBLY is powered) and the IRRADIATION TIME (the time during which the AIR KERMA RATE exceeds a given percentage of the maximum and steady-state value - or in other words the time during which there is significant emission of X-ray)"



Irradiation Time, Radiation Time and/or Exposure Time

The “raw” trigger point, (1) and (7), for an XMM will depend on the sensitivity of the XMM.

To find the “irradiation time trigger points, (2) and (6), some kind of additional intelligence is required. Various XMM’s handles this differently. Modern meters don’t vary much. But rise times and peak variations may matter.



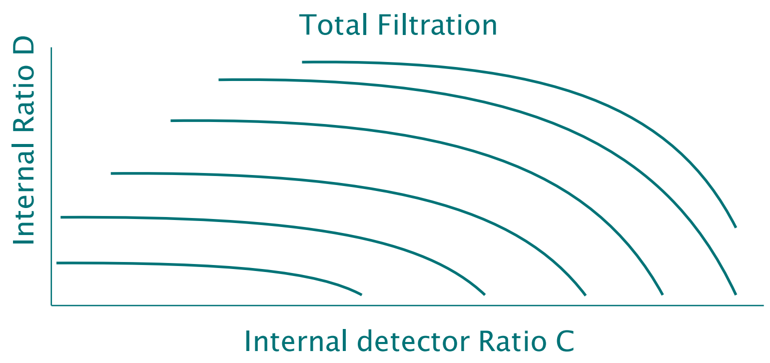
Total Filtration

What is common standard? Is there a need?

Some safety standards refer to minimum total filtration equivalent.

It is also clinically handsome since the Total Filtration is constant and do not vary with change of other parameters.

Different XMM’s handles this differently. Can be a calculation based on kV and HVL, but can also be a directly measured parameter, in similarity to kV and HVL.



Influencing factors on measurement uncertainty for XMM's in daily use

Everything that has influence on the X-ray spectra will have effect on the measurement uncertainty with the XMM

How much it will influence depends on the XMM design

Major influencing parameters are:

- Tube Potential and it's ripple
- Additional filtration
- Anode angle (and anode surface)
- Back Scatter
- Scatter from phantom, compression paddle or other material nearby the device

Conclusion

International standards and definitions

together with

Primary and Secondary laboratories who offers relevant calibration

sets a baseline

Usability

The XMM design must cover the range of intended use.

The user of the XMM must be aware of what has influence on measurement uncertainty

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