How Low Can CT Dose Go? Future Dose Reduction Technologies: Optimization of X-Ray Spectra

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Disclosures

- *UCLA Department of Radiological Sciences has a Master Research Agreement with Siemens Healthineers*
- *Dr. McNitt-Gray receives research support from this MRA with Siemens Healthineers*
- *Dr. McNitt-Gray is a member of the Scientific Advisory Board, Hura Imaging, Inc.*

Motivation

- CT Scanners use X-ray beam with a Tungsten (W) anode
- This produces a polychromatic X-ray spectra with Characteristic X-rays and Bremsstrahlung
- These Spectra are Energy Dependent
- Beam is filtered and shaped with additional filtration and “bowtie” filter (compensation filter)
- Recently, some manufacturers have added filtration for specific clinical applications
- Originally for Dual Energy, extended to other applications

Purpose

- To describe the use of additional filtration in the context of radiation dose reduction in CT.
- Discuss the potential to tailor the use of beam filtration to specific applications and possibly patient-specific capabilities.

Fundamentals – the X-ray Spectrum

- CT scanners use Tungsten Anodes
- Typically operate between 70 and 150 kV
- Beam is polychromatic
- Consists of Bremsstrahlung and Characteristics X-rays

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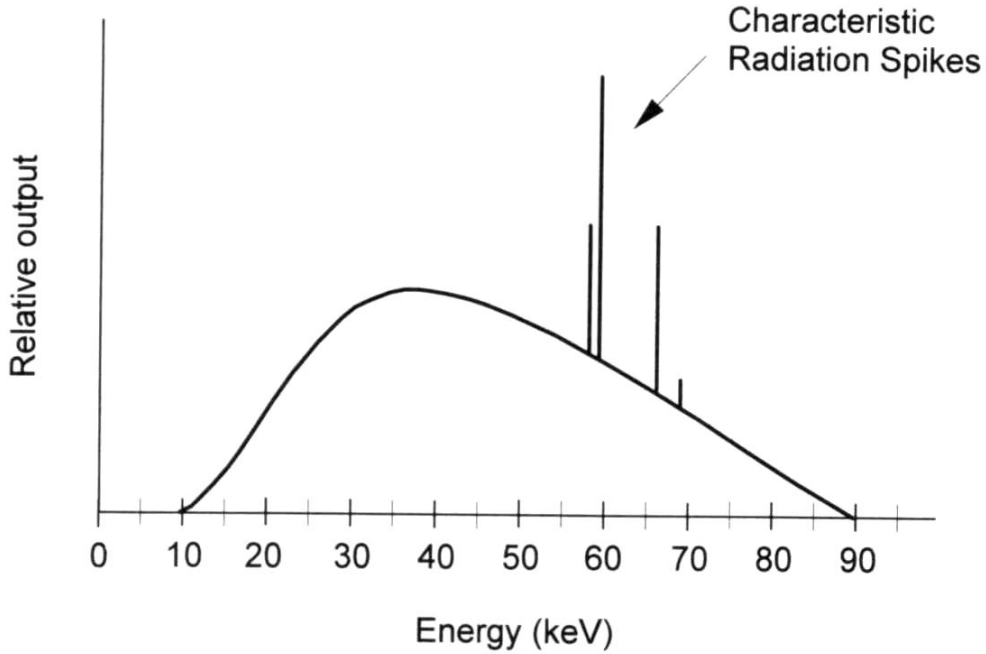

X-rays	Energy
$K_{\alpha,1}$	59.32 keV
$K_{\alpha,2}$	57.98 keV
$K_{\beta,1}$	67.24 keV

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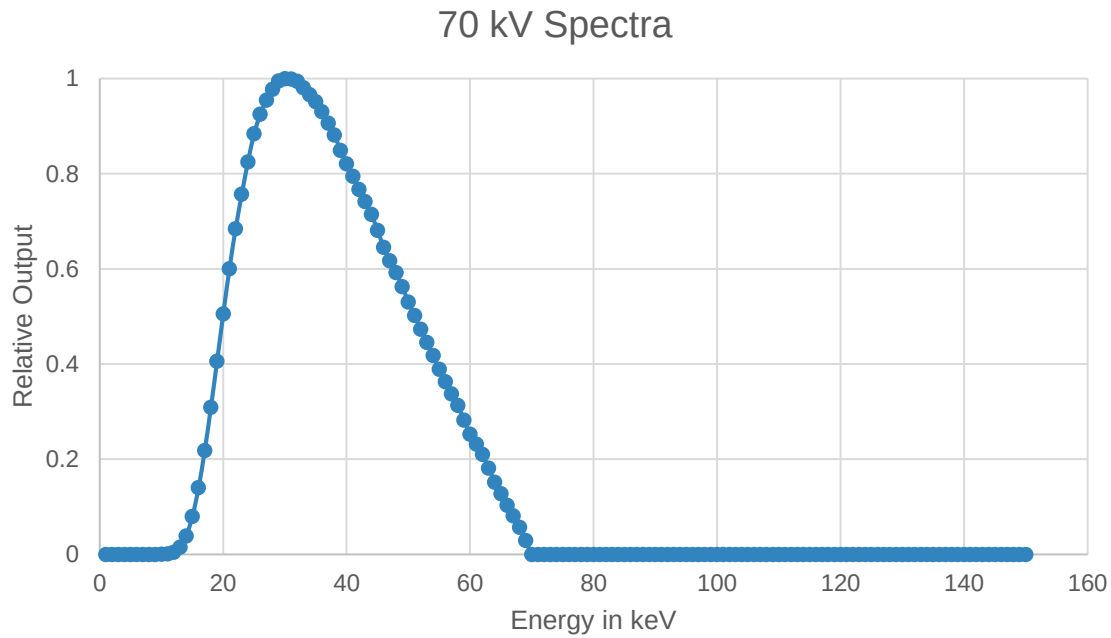

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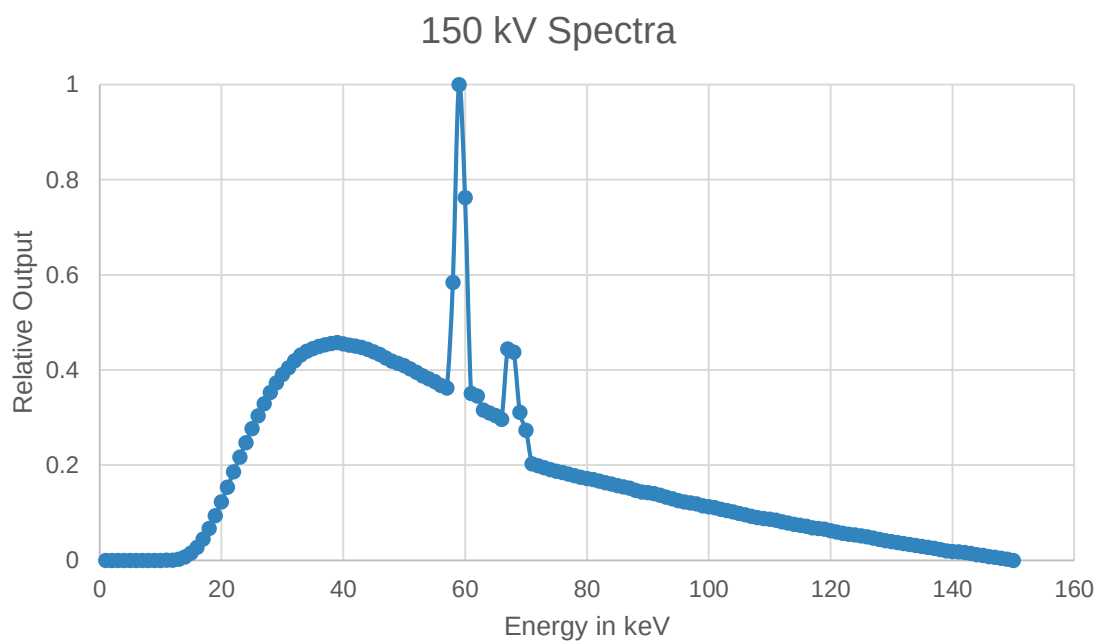

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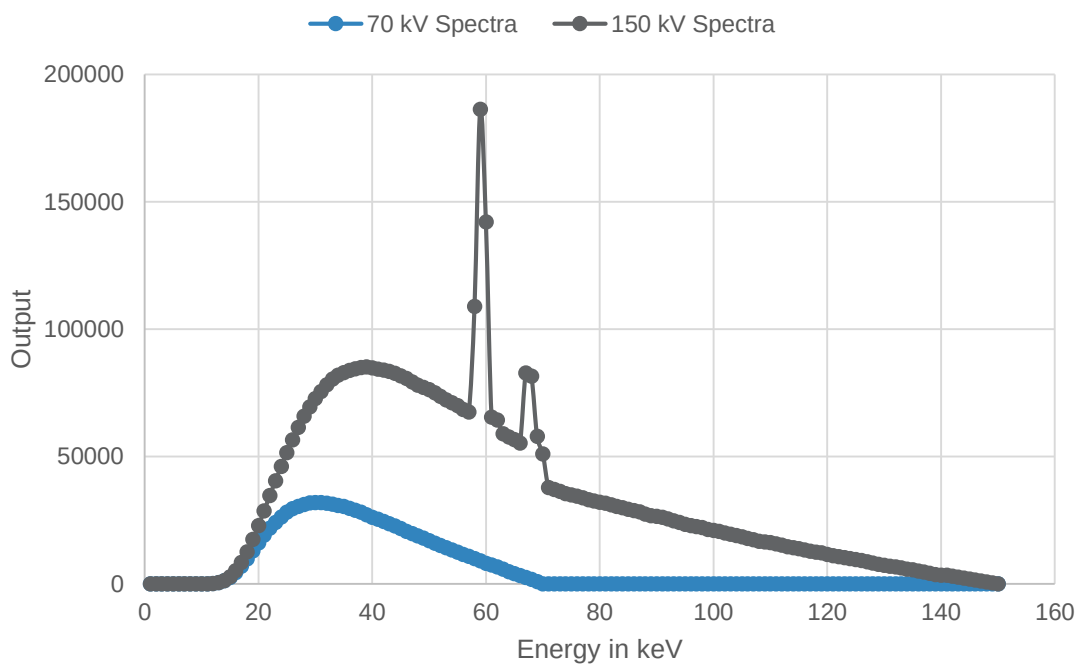

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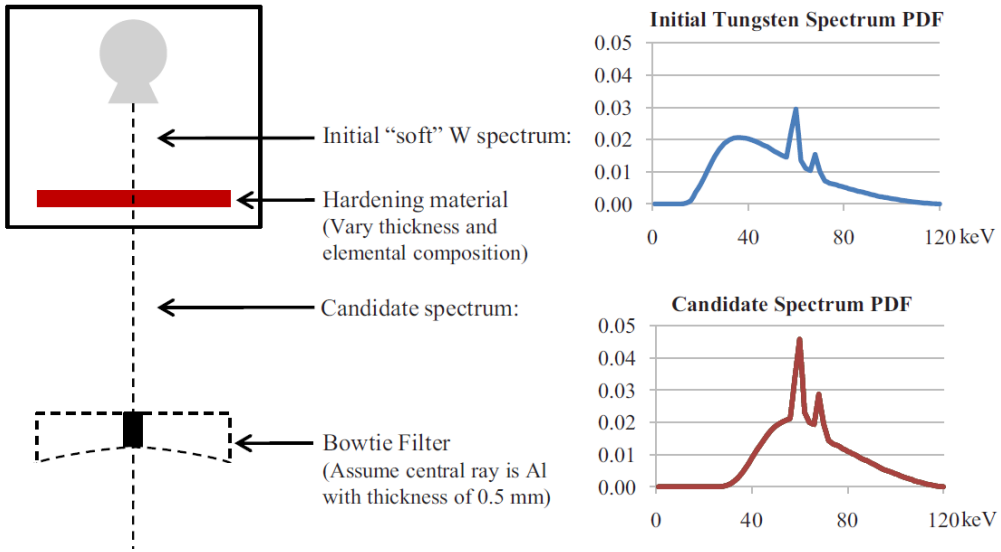
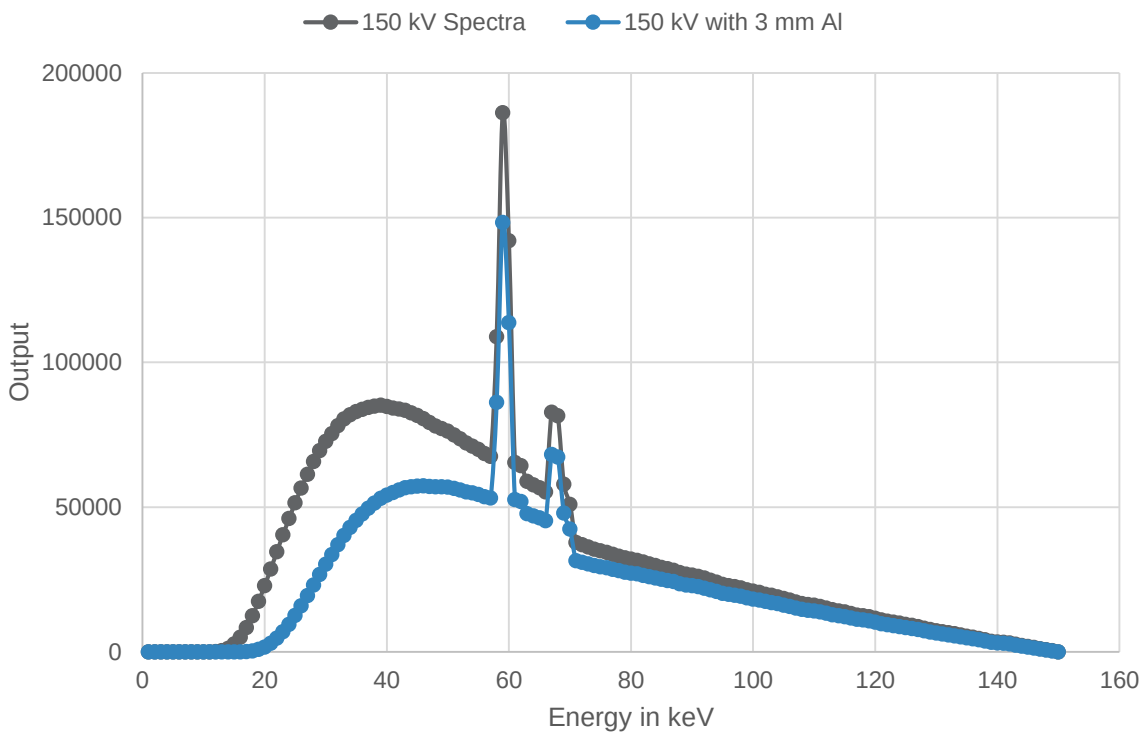
Fundamentals – the X-ray Spectrum

- CT scanners use Tungsten Anodes
- Operate between 70 and 150 kV
- In CT, there is added filtration to harden and shape the beam



Fundamentals – the X-ray Spectrum

- 150 kV spectrum with added Al filtration



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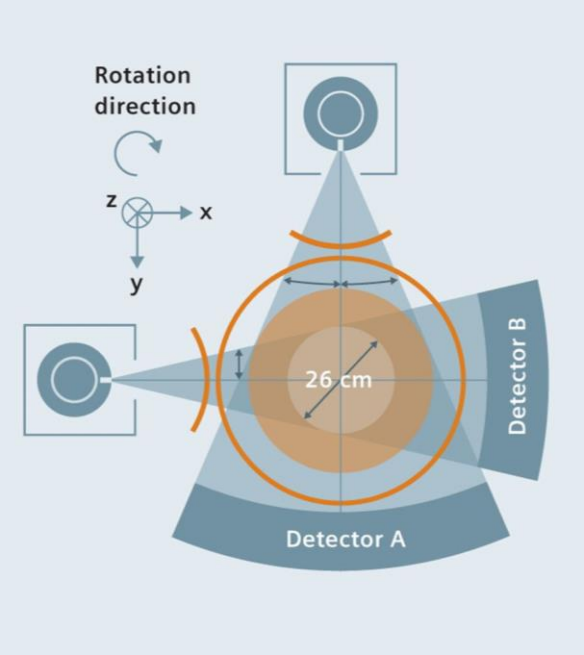
- Typically operate between 70 and 150 kV
- Beam is polychromatic
- Consists of Bremsstrahlung and Characteristics X-rays
- Beam is Energy Dependent
- Added Filtration Reduces Output
  - Hardens beam
  - Shapes beam to patient (Bowtie filter)

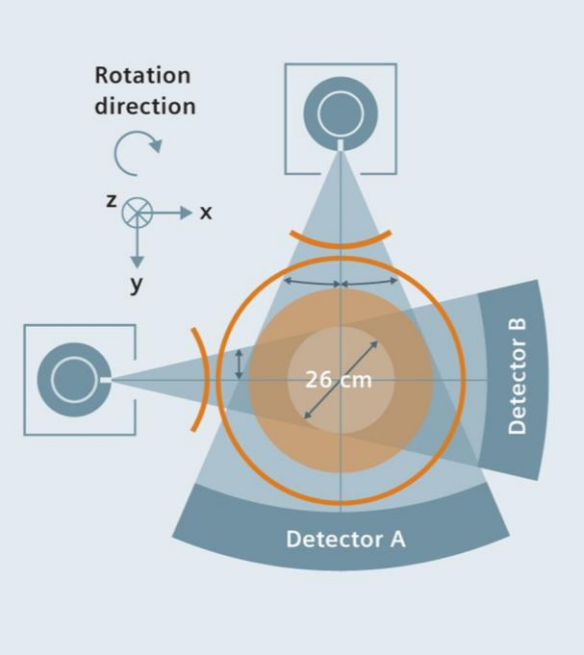
Next Steps – Dual Energy

- Probe anatomy with two different spectra
- The more separation between spectra, the better
- One manufacturer (Siemens) introduced a Dual Source approach to Dual Energy



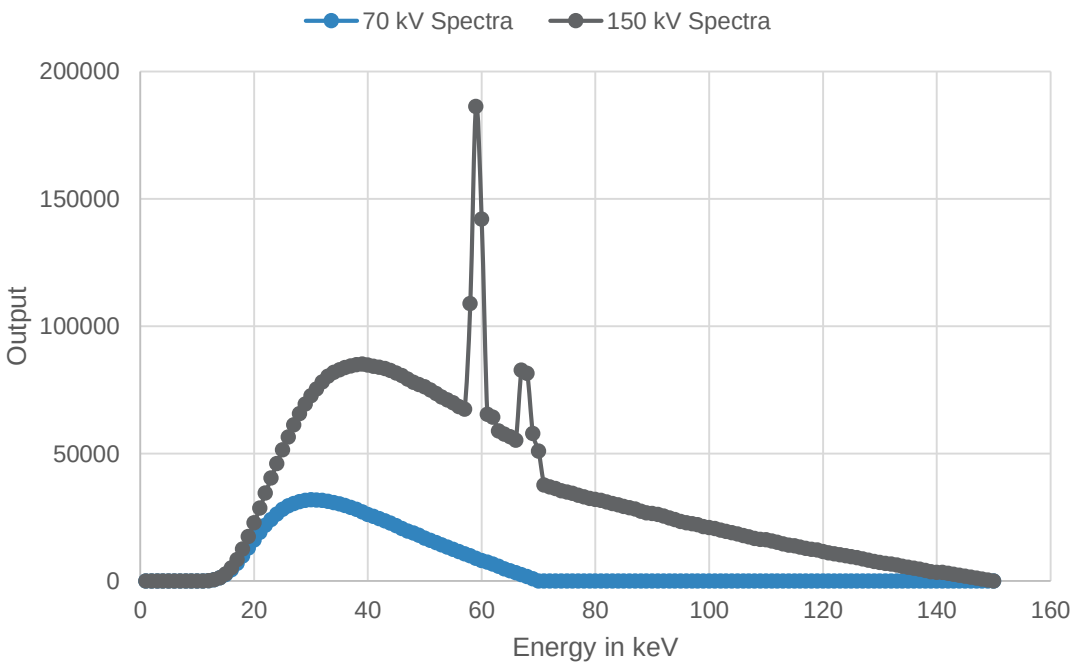
Next Steps – Dual Energy

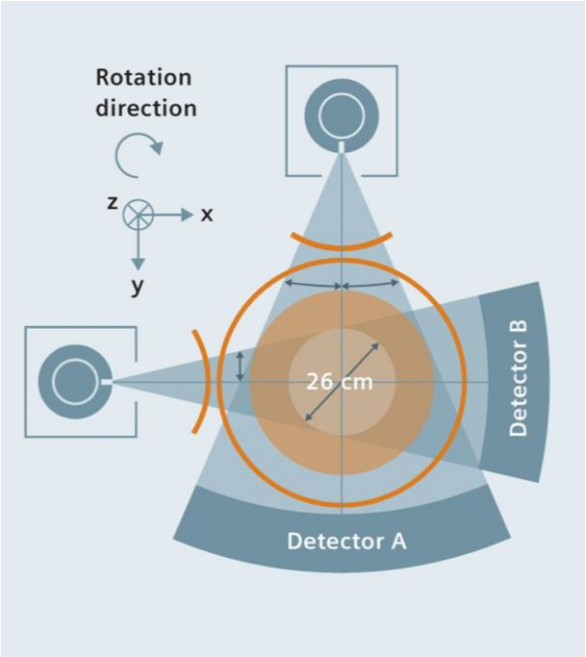
- Probe anatomy with two different spectra
- The more separation between spectra, the better
- One manufacturer (Siemens) introduced a Dual Source approach to Dual Energy
- Operate:
  - Tube A – high energy (orig. 140 kV)
  - Tube B- low energy (orig. 80 kV)



Next Steps – Dual Energy- More Separation

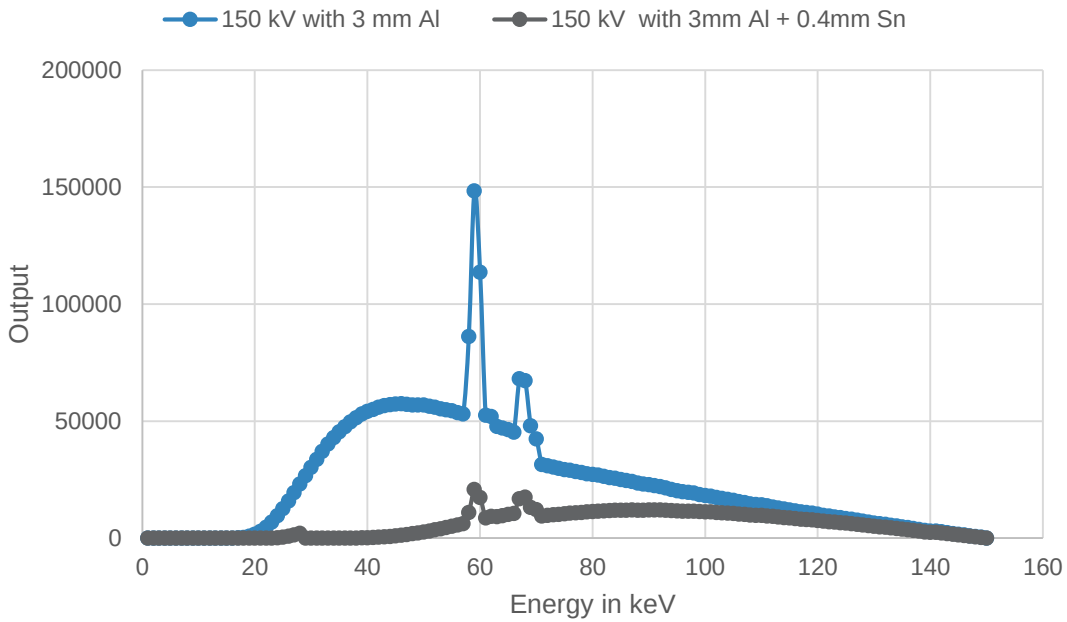
- To get better separation, use different spectra
  - High Energy now 150 kV (up from 140)
  - Low Energy now 70 kV (down from 80)





Next Steps – Dual Energy- EVEN More Separation

- To get EVEN better separation, 150 kV + Tin (Sn) filtration
  - High Energy now 150 kV + 0.4 mm Sn
  - Low Energy now 70 kV (down from 80)



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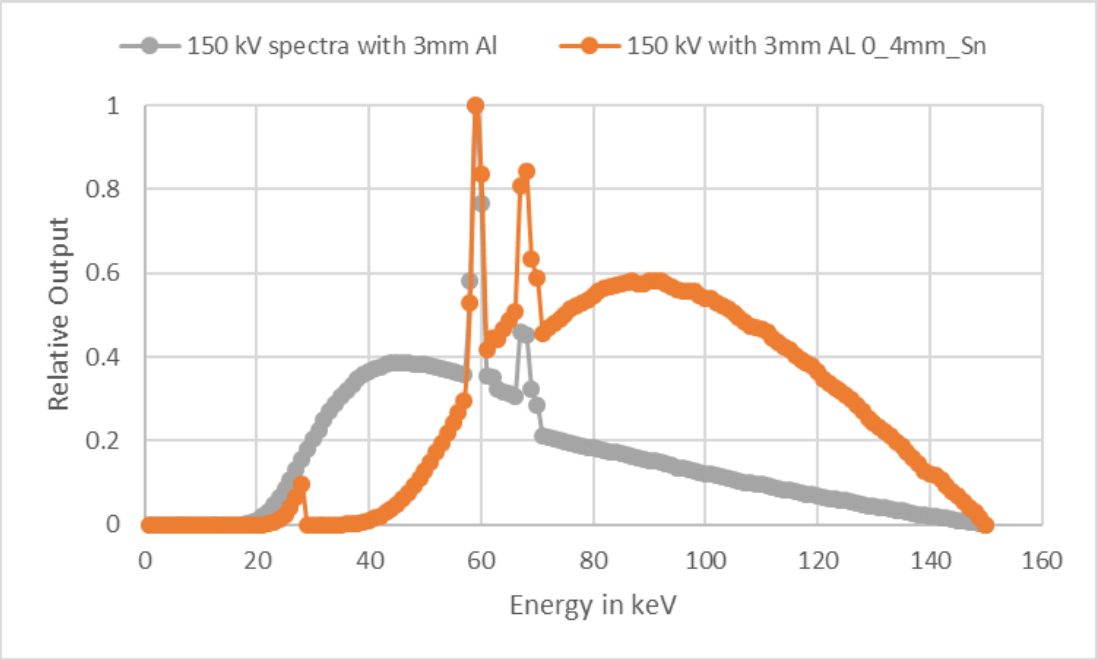

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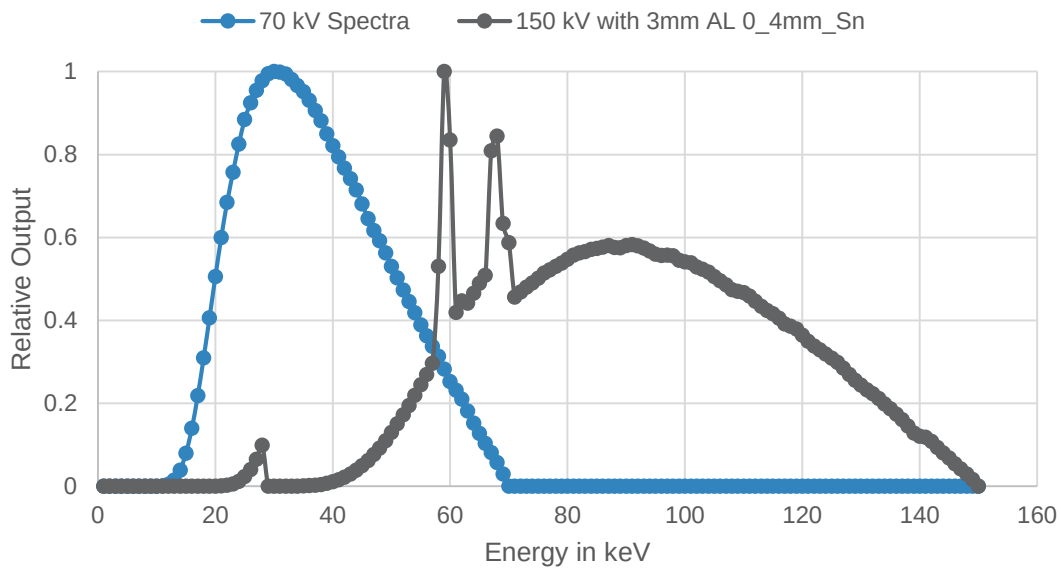

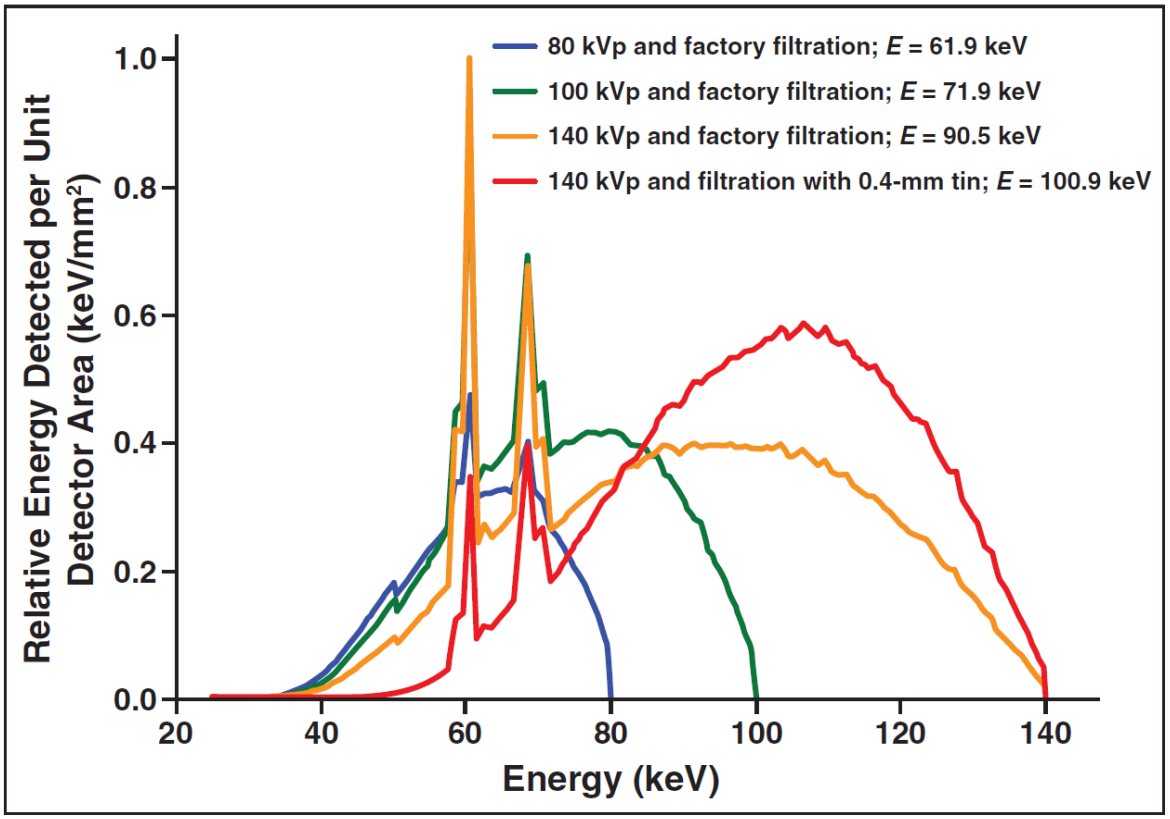

Fig. 1—Simulated x-ray spectra for dual-source CT system at 80, 100, and 140 kV with factory-supplied filtration and at 140 kV with addition of 0.4 mm of tin filtration. Details of this simulation are described elsewhere [31]. Ratios of mAs used for simulation correspond to clinical dual-energy abdominal protocols in our practice. Mean energy, *E*, was calculated according to equation 8 in [31].

Figure 1 from Primak et al, AJR:195, November 2010

Additional Filtration (e.g Sn)

- Reduces Fluence (reduced dose)
- Changes Spectrum (harder beam, effective energy ↑)

- How can we exploit this in conventional diagnostic imaging!

Low Dose Lung Cancer Screening

- Exam is performed
  - Low Dose
  - No Iodinated Contrast
  - High Inherent contrast between nodules and lung (air)

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- Typical Scan is performed:
  - 120 kV
  - 25 effective mAs (25 mAs, pitch 1)
  - Tube Current Modulation AEC (CAREDose4D)
    - X,y and z modulation
  - CTDIvol ~ 1.8 to 2 mGy for a standard sized patient

Tube Current Modulation (TCM) in x,y and z

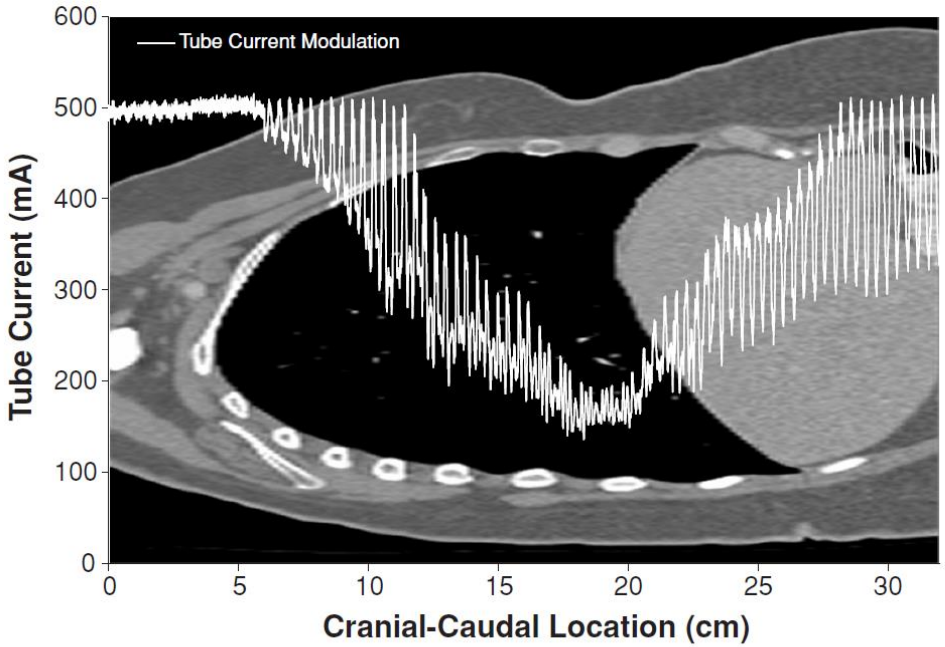
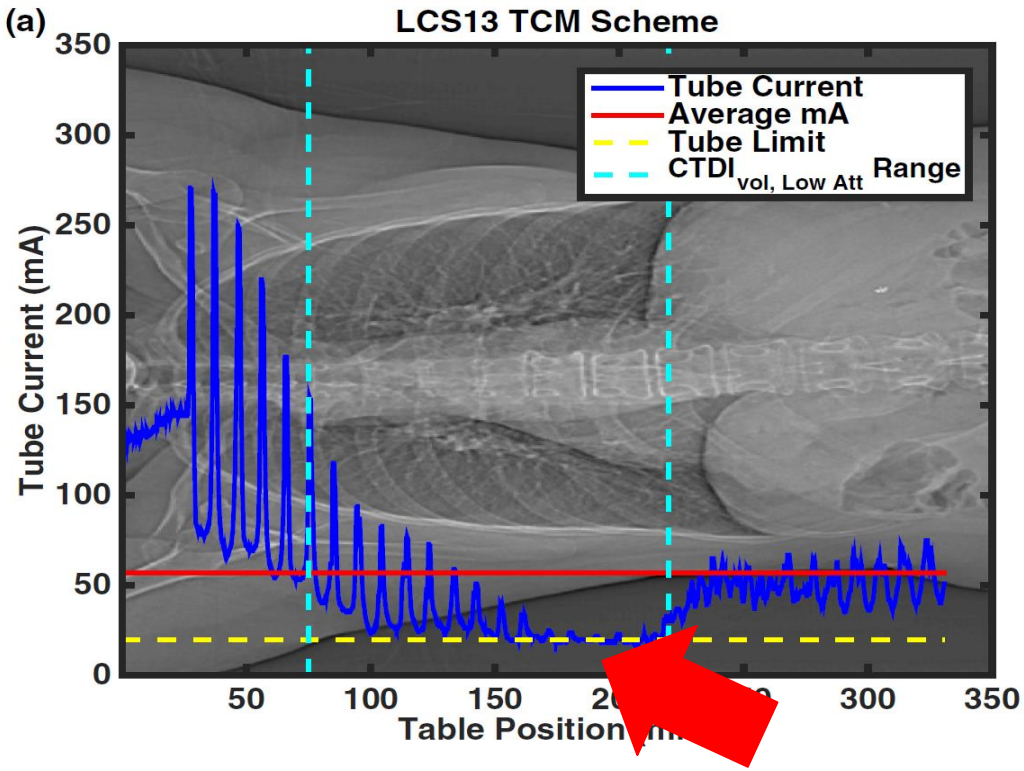


Figure 3. Plot of tube current versus *x*-axis location of the TCM schema for a patient model with a perimeter of 125 cm. The background of the plots is a sagittal view of the patient.

From Angel et al, PMB, 2009

TCM in Lung Cancer Screening



Note mA hits scanner minimum in lung region

From Hardy et al, Med Phys 2018

TCM in Lung Cancer Screening

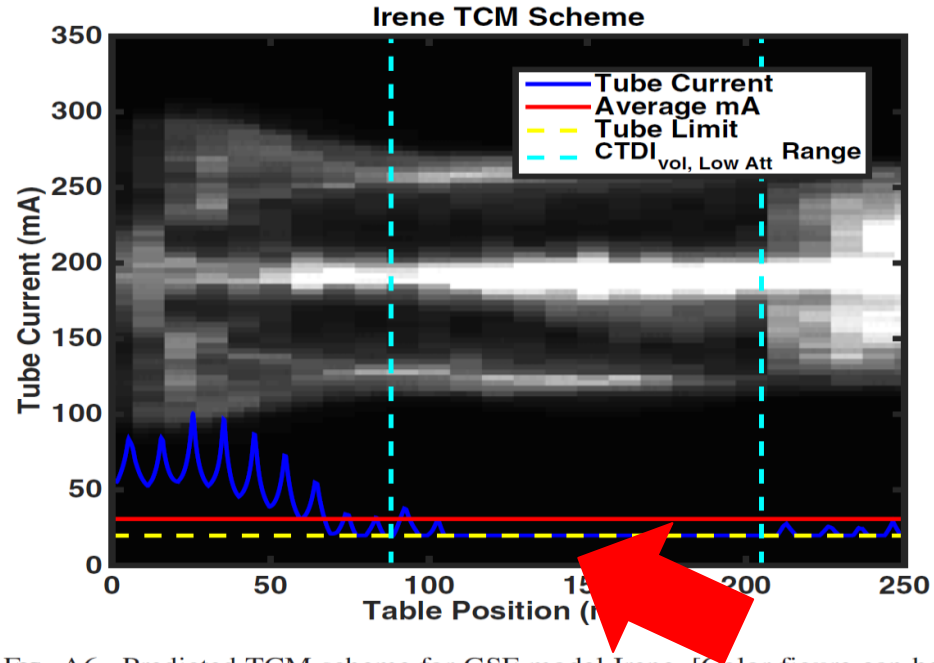


FIG. A6. Predicted TCM scheme for GSF model Irene. [Color figure can be viewed at wileyonlinelibrary.com]

For very small patients, mA can hit minimum for a substantial portion of scan – effectively no modulation

From Hardy et al, Med Phys 2018

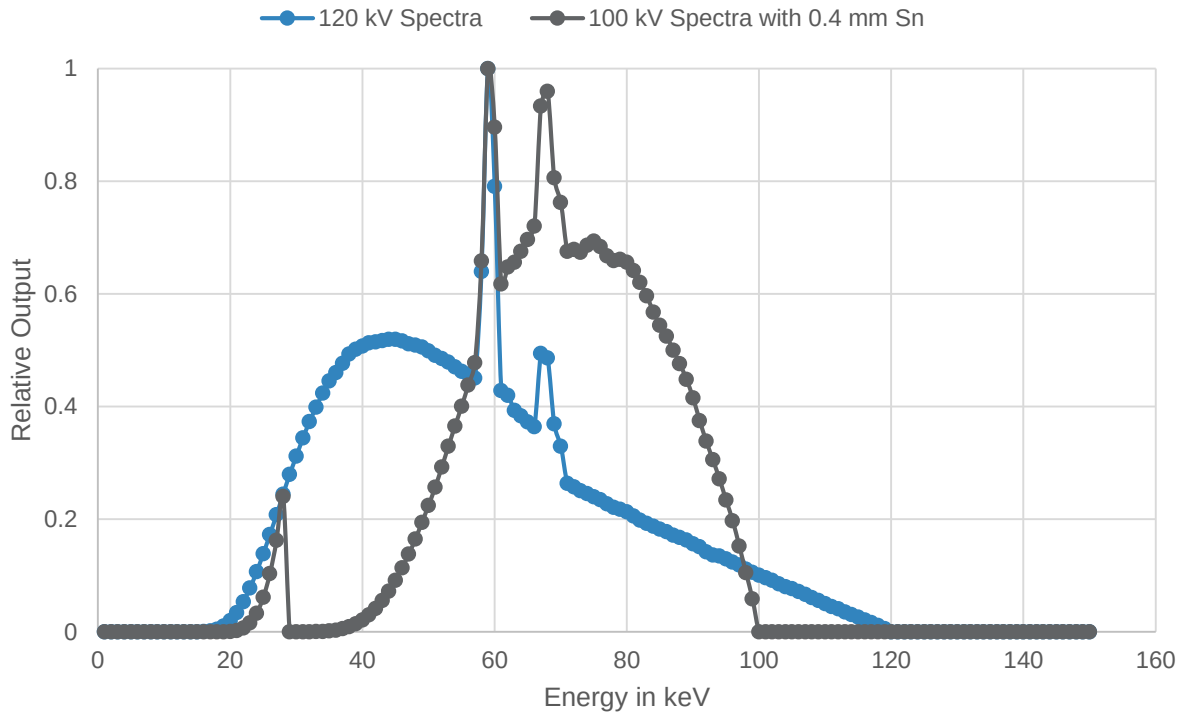
Low Dose Lung Cancer Screening

- AAPM protocols for Siemens Force
- 100 kV with Sn
- Quality ref mAs – 101!!
- <u>But CTDIvol = 0.4 mGy</u>
- (Compared to 2.0 mGy
- For conventional scanners)

	Definition Force (Dual source 192-slice)
Software version	VB10
Scan Mode	Spiral
Rotation Time (s)	0.5
Detector Configuration	*192 × 0.6 mm (96 x 0.6 mm = 57.6 mm)
Pitch	1.2
kV	100Sn[a]
Quality ref. mAs	101
CARE Dose4D	ON
CARE kV	ON
CTDIvol***	0.4 mGy

Lung Cancer Screening

- 120 kV vs. 100 kV with 0.4mm Sn



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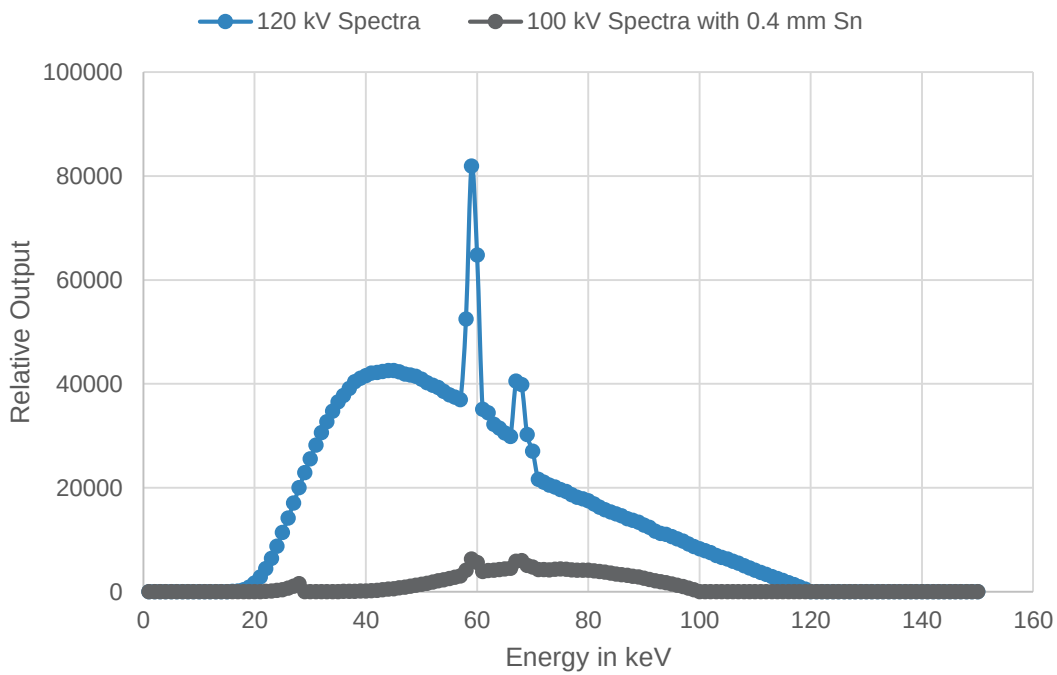
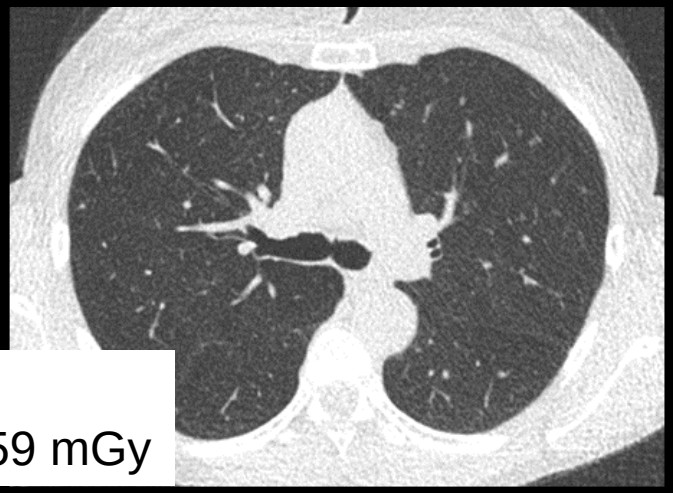
Lung Cancer Screening

- 120 kV vs. 100 kV with 0.4mm Sn
- Changes spectra AND reduces fluence!!!
- Can use higher mA and get lower dose (CTDIvol) for 100/Sn

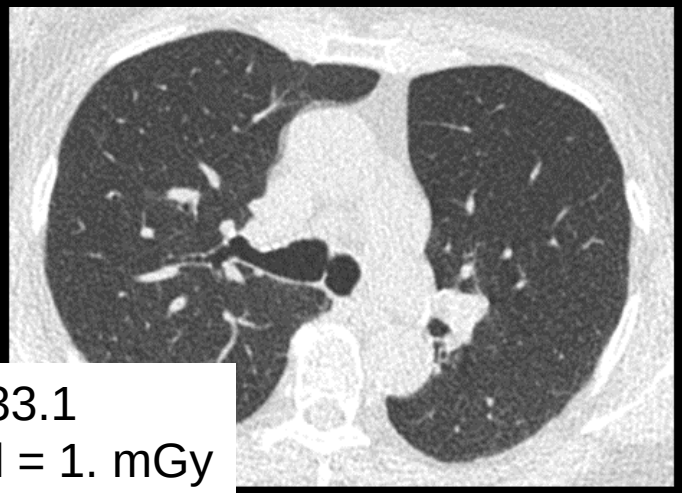


Lung Cancer Screening

- What about the effect on Image Quality?

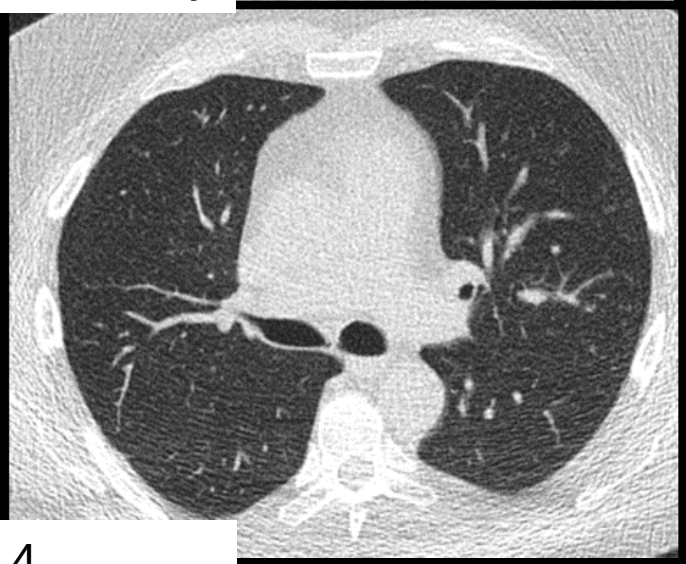


WED=28.4
CTDIvol = 0.59 mGy



WED= 33.1
CTDIvol = 1. mGy

WED=36.4
CTDIvol = 1.22 mGy



WED=38.4
CTDIvol = 2.1 mGy

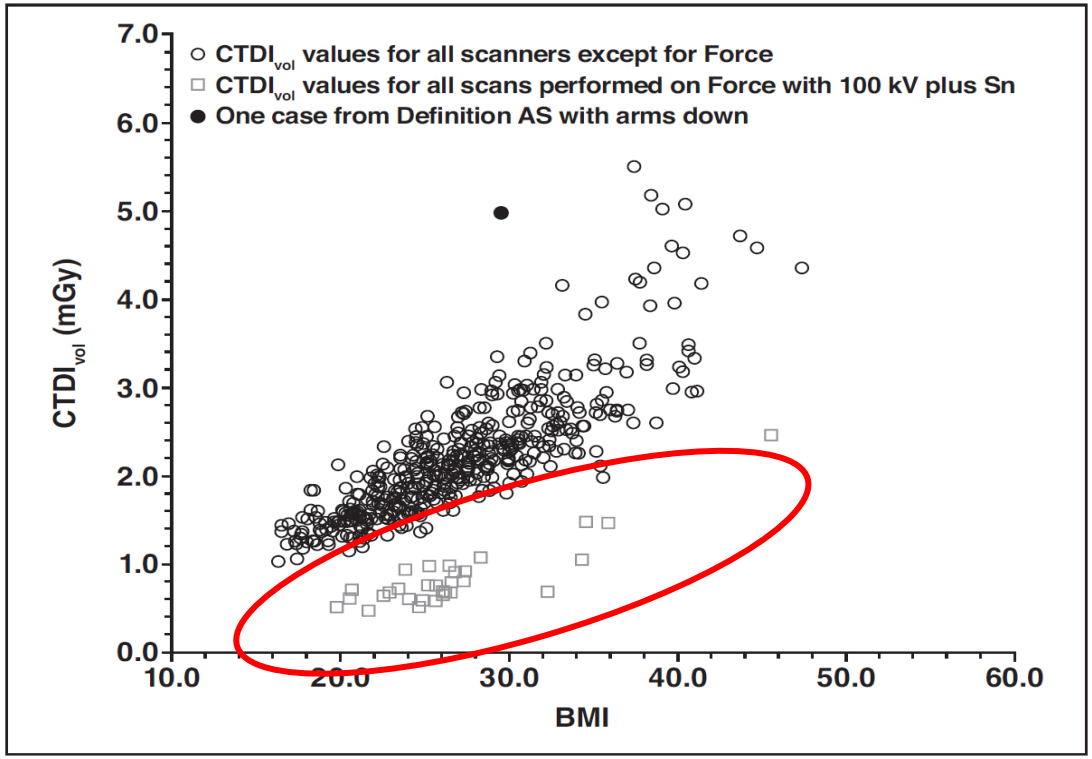
From Fujii et al, AJR 2017

Lung Cancer Screening

- What about the effect on Image Quality? Seems pretty good
- What about actual dose reduction?

Lung Cancer Screening

- From Lung Screening Program at UCLA



Cases from Force Scanner performed with 100 kV/Sn

~ 40-50% lower dose

Lung Cancer Screening

- What about the effect on Image Quality? Seems pretty good
- What about actual dose reduction? Approx 40-50%
- Because it uses higher mA, TCM does not high scanner minimum – modulation even for smaller patients!

Other Clinical Applications

- Non-Contrast Exams
  - Coronary Artery Calcium (high contrast objects)
  - Renal Stones (high contrast objects)

Contraindications for Sn Filtration - Iodine

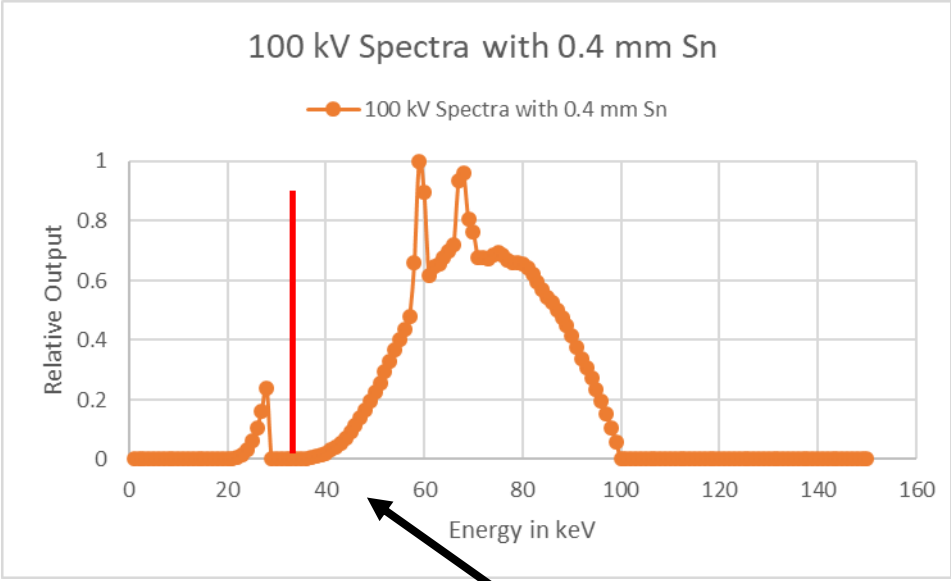
- Many clinical scans performed with Iodinated Contrast
- K-edge of I = 33.1 keV

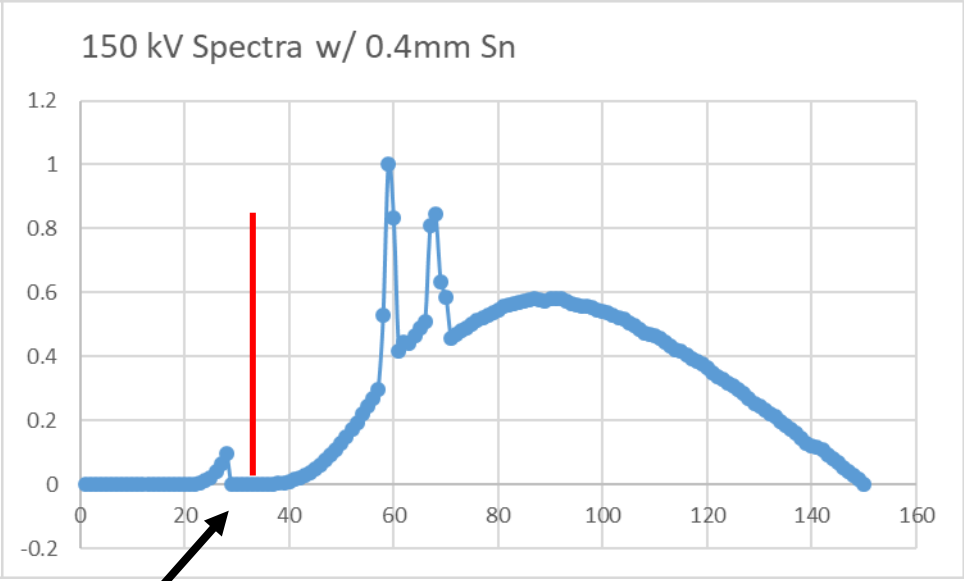
- For 100kV/Sn or 150 kV/Sn this can be an issue

- Remember that Sn removes low energy photons!
- Not many photons available at I's k-edge

Therefore Sn filtration – NOT for contrast scans

Contraindications for Sn Filtration - Iodine





K-edge Iodine = 33.1 keV

Conclusions

- Filtration of X-ray spectra
  - Shape Spectra (Dual Energy)
  - Reduce fluence which can reduce dose to patient
    - Also seen to assist in avoiding hitting scanner minimum mA for small patients -> allows modulation even for small patients
  - Filter out low energy photons and reduce dose, especially for clinical applications that do not use Iodinated contrast
    - Ex. Lung Cancer Screening which has high inherent contrast
- In Lung Cancer Screening we have seen the use of Sn filtration to reduce dose by 40-50% compared to conventional scans

- FUTURE – Other materials (and effects on spectra)

Future

- Other filtration materials (and effects on spectra)
- Tailoring amount of filtration to patient (thickness)
- This could possibly be combined with kV selection
  - CarekV and other manufacturers' options for this
  - (NOTE this is NOT kV modulation – kV does NOT vary during scan)
  - Optimize kV and filtration material/thickness for patient size and clinical indication

- Challenge is ALWAYS to reduce dose while maintaining the image quality necessary to accomplish the diagnostic task

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