Comparison of Dual-Energy Radiography Detectors

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Down under

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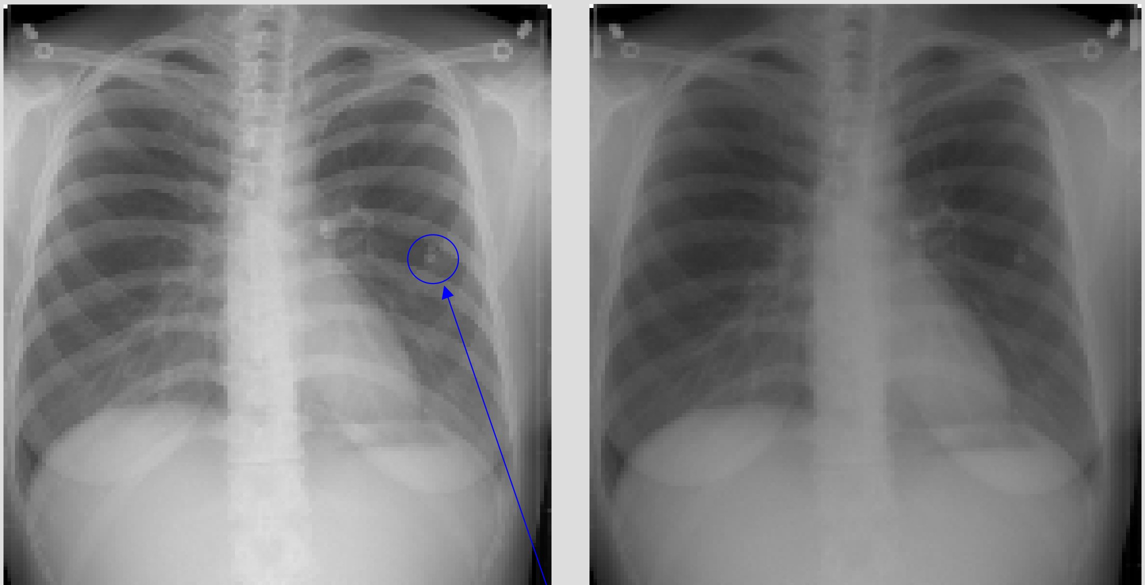
Dual-Energy Radiography

- First proposed by Alvarez and Macovski, 1970's
- Initial clinical implementation by Fuji (early 1990's)
  - "Passive" sandwich PSP detector with Cu filter
- General Electric Medical Systems flat-panel detector with dual energy capability in 1999
- Research detector with switched voltage acquisition
  - "Active" sandwich PSP detector

Selective tissue imaging

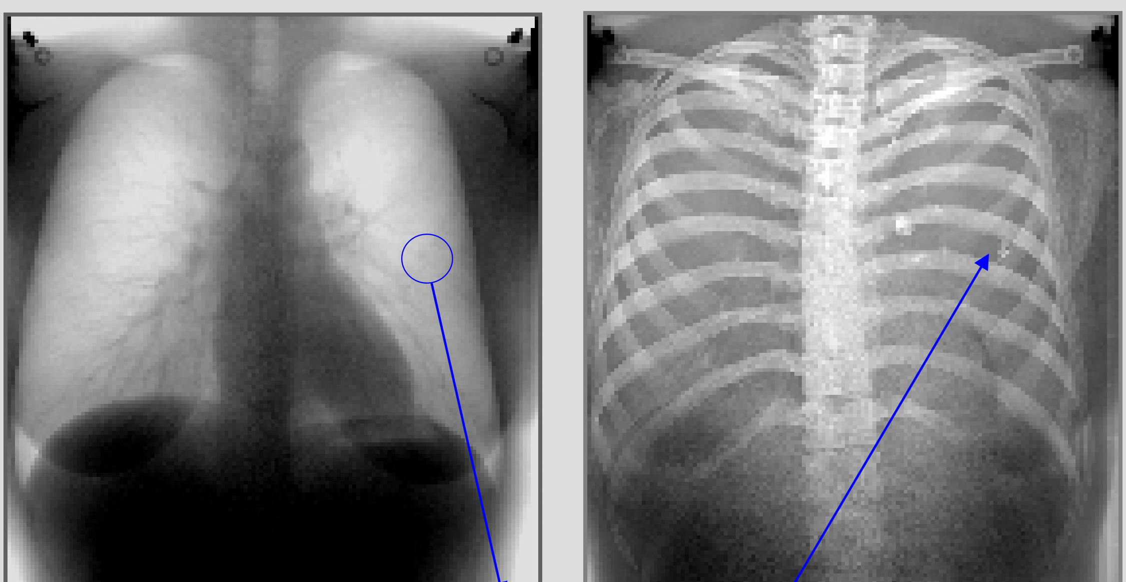
- Bone and soft tissue have energy dependent x-ray attenuation
- Acquisition of two x-ray images of widely different energy allows weighting and subtraction to *eliminate one tissue*
- Resultant images have higher diagnostic value:
  - Structured noise is removed (e.g., ribs)
  - Tissues are identified as calcified or non-calcified
  - Computer aided detection accuracy is improved

Conventional Imaging



? Nodule?

Selective Tissue Images



Soft Tissue

Nodule *not* in soft tissue image → Nodule calcified

Bone

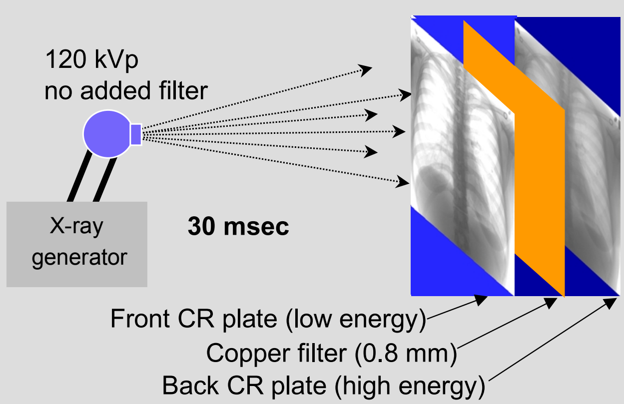
Methods

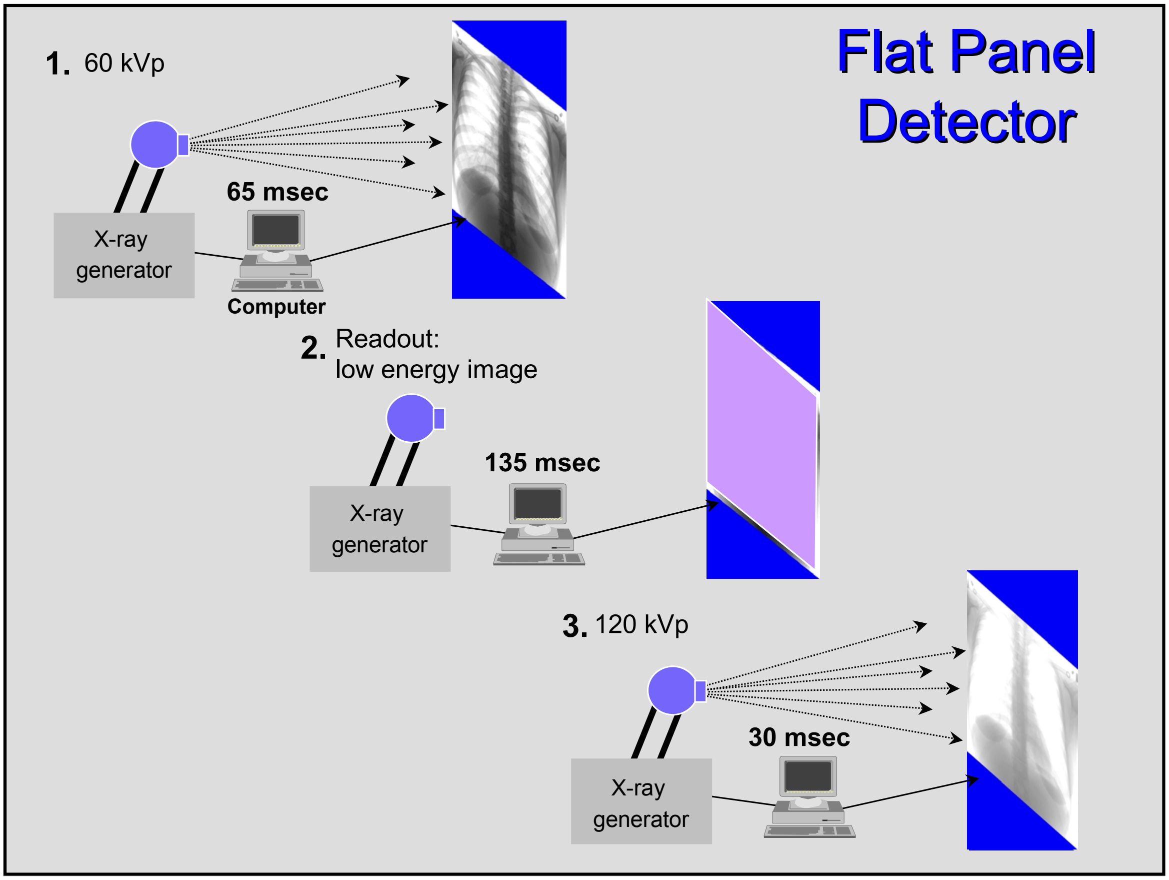
Systems comparisons:

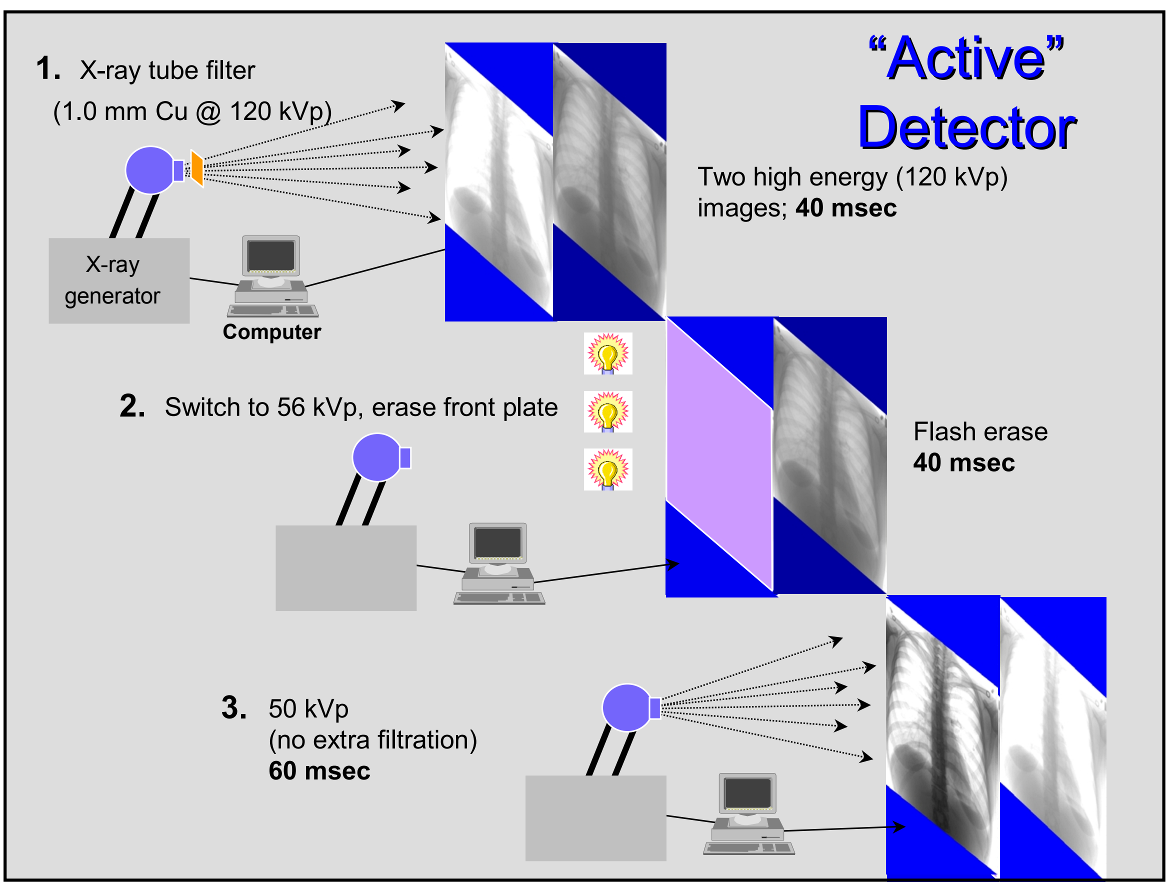
1. X-ray spectral quality
2. Noise in the cancelled image vs exposure
3. Amount of motion artifact.

Quantitative measurement of dual energy system performance.

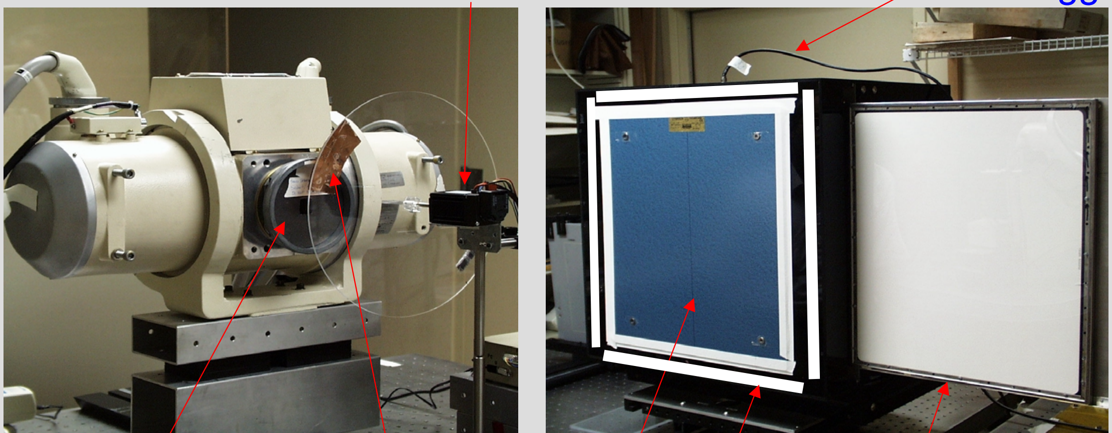
Sandwich "Passive" Detector



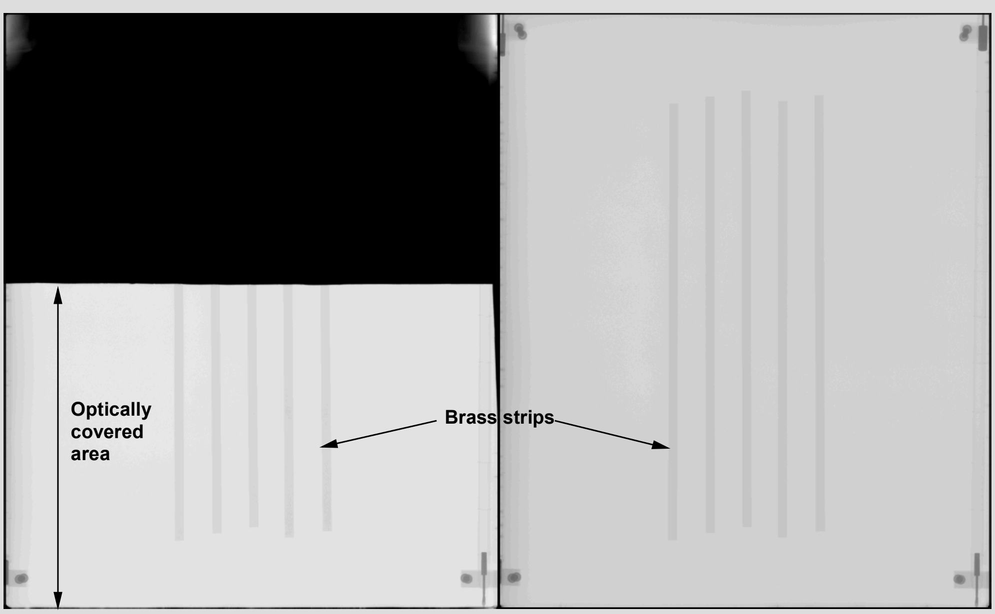

Flat Panel Detector
1. 60 kVp
65 msec
X-ray generator
Computer
2. Readout: low energy image
135 msec
X-ray generator
3. 120 kVp
30 msec
X-ray generator


"Active" Detector
1. X-ray tube filter (1.0 mm Cu @ 120 kVp)
X-ray generator
Computer
Two high energy (120 kVp) images; 40 msec
2. Switch to 56 kVp, erase front plate
Flash erase 40 msec
3. 50 kVp (no extra filtration) 60 msec

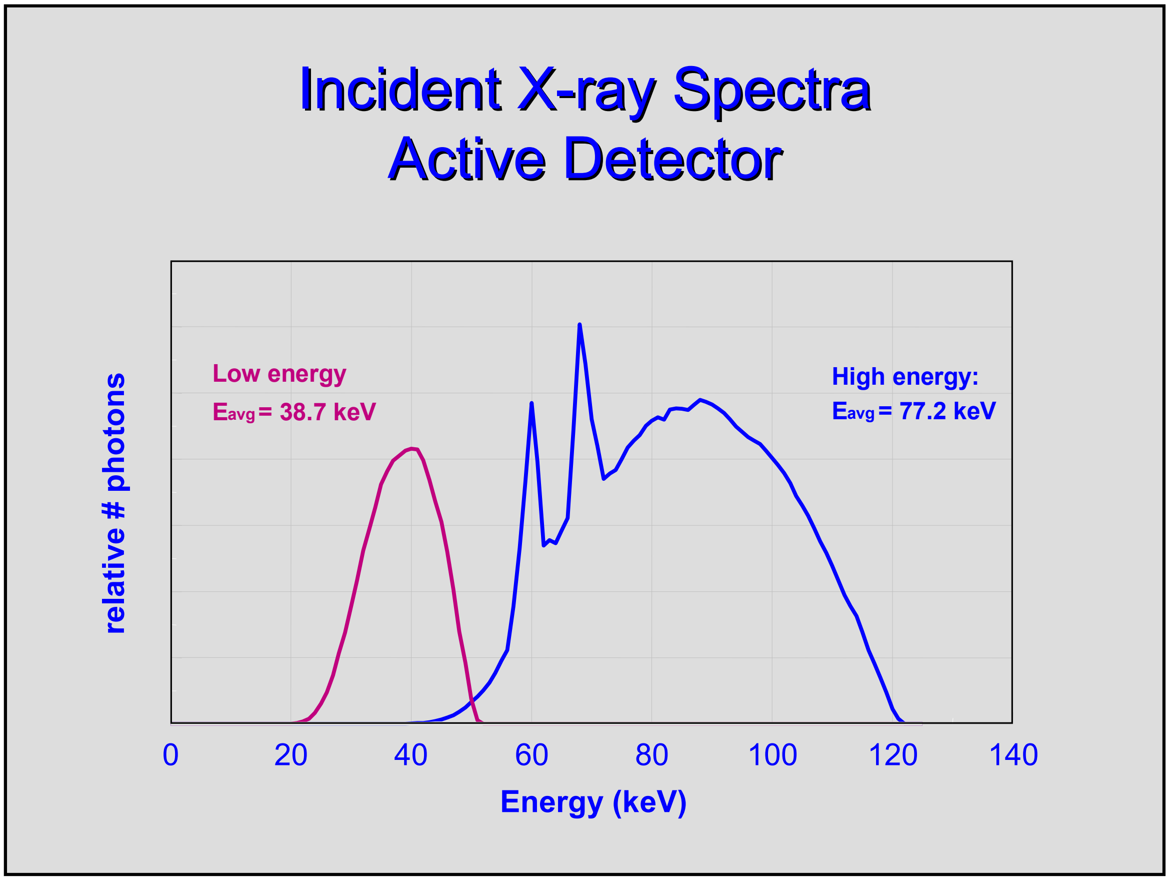
X-ray System components

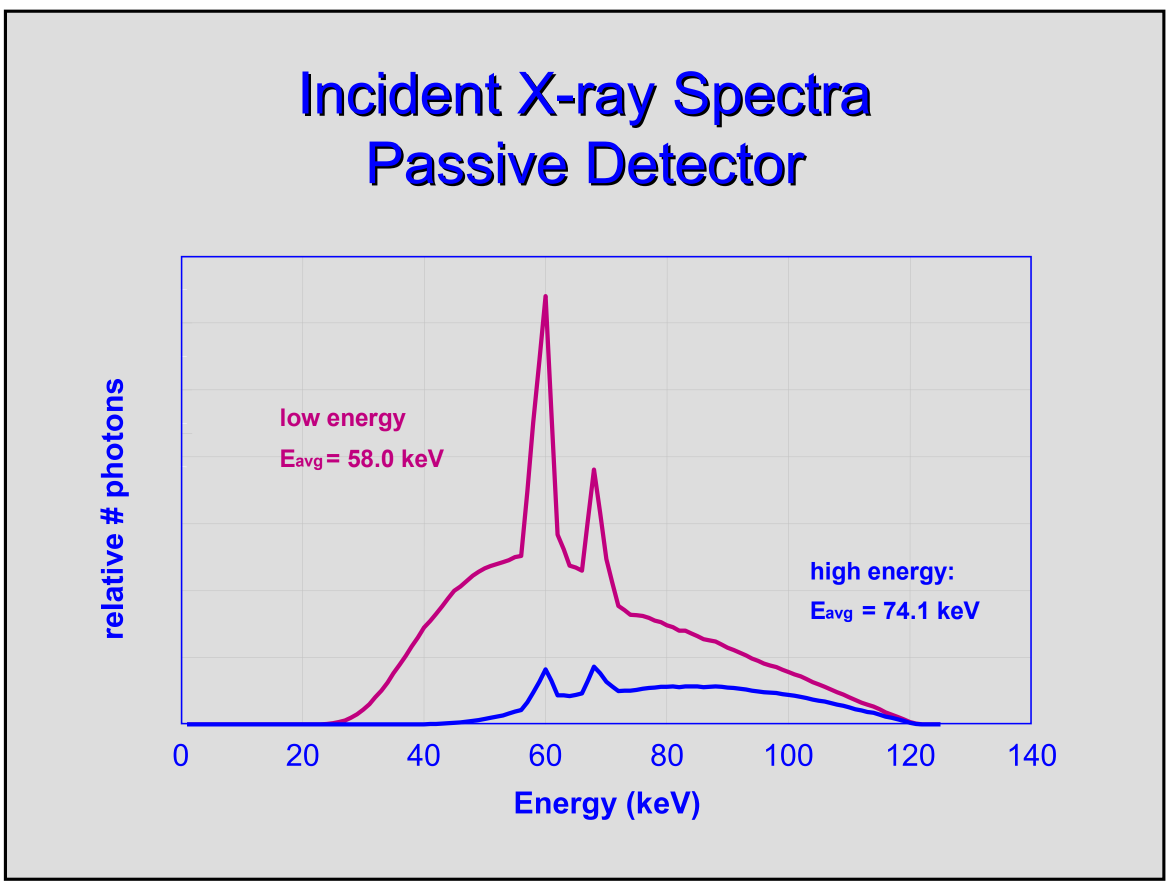


Erasure Efficiency

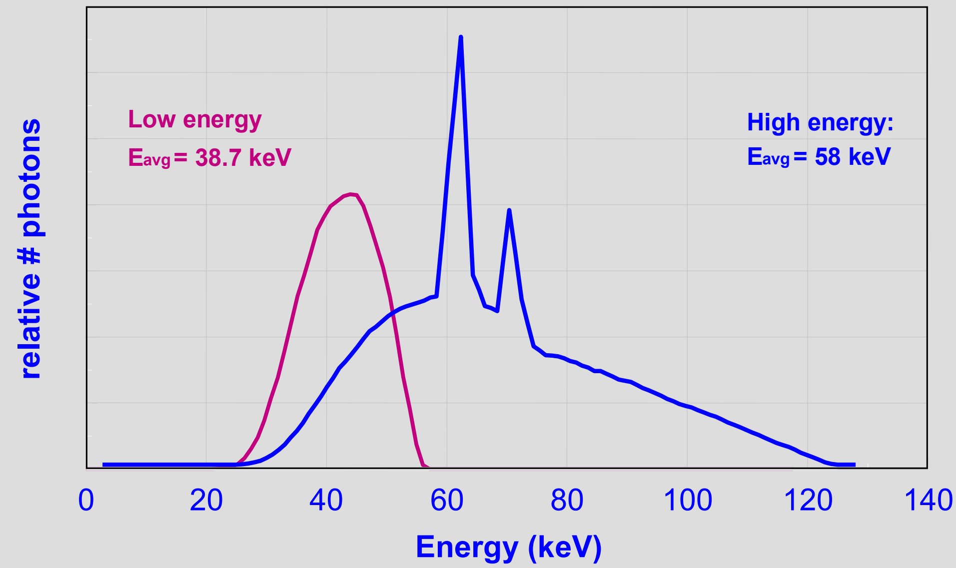


Front plate (low energy) Back plate (high energy)

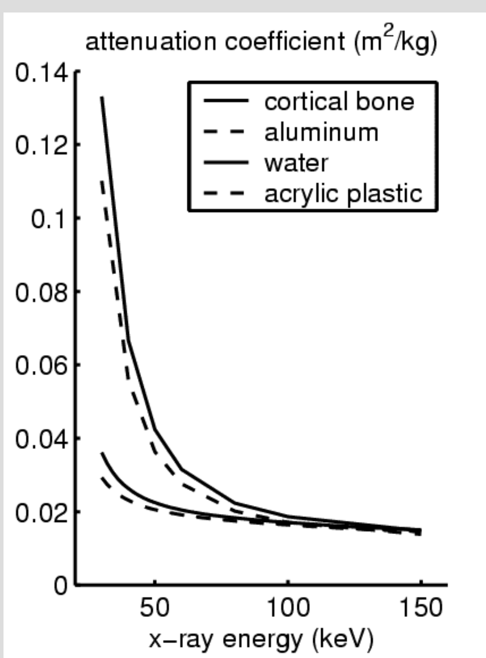

Incident X-ray Spectra
Active Detector
Low energy
Eavg = 38.7 keV
High energy:
Eavg = 77.2 keV
relative # photons
0
20
40
60
80
100
120
140
Energy (keV)


Incident X-ray Spectra
Passive Detector
low energy
Eavg = 58.0 keV
high energy:
Eavg = 74.1 keV
relative # photons
0
20
40
60
80
100
120
140
Energy (keV)

Incident X-ray Spectra
Flat Panel Detector



X-ray Spectral Quality



Aluminum and plastic reasonable substitute for bone and soft tissue

$$\mu(E) = a_1\mu_1(E) + a_2\mu_2(E)$$

Basis functions (Al and plastic):

$$\mu_i(E),\ i = 1,2$$

Subtracted image represents line integrals of coefficients:

$$A_i = \int a_i(\mathbf{r})\,dl$$

Different energy spectra, Q_j:

$$Q_j,\ j = 1,2$$

effective energy detector

Subtracted image variance

$$\sigma_{A_1}^2 = \frac{\dfrac{\mu_{22}^2}{SNR_1^2} + \dfrac{\mu_{12}^2}{SNR_2^2}}{(\mu_{11}\mu_{22} - \mu_{12}\mu_{21})^2} \qquad \sigma_{A_2}^2 = \frac{\dfrac{\mu_{21}^2}{SNR_1^2} + \dfrac{\mu_{11}^2}{SNR_2^2}}{(\mu_{11}\mu_{22} - \mu_{12}\mu_{21})^2}$$

SNR_i are computed from images with spectra 1 and 2

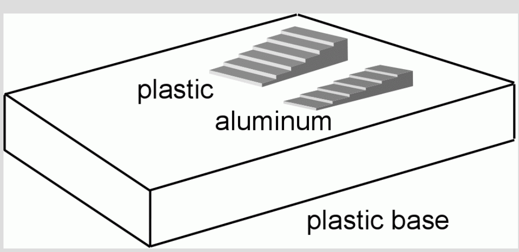
$$\mu_{ij} = -\frac{1}{Q_i}\frac{\partial Q_i}{\partial A_j} = -\frac{\partial \log(Q_i)}{\partial A_j} \quad (i, j = 1,2)$$

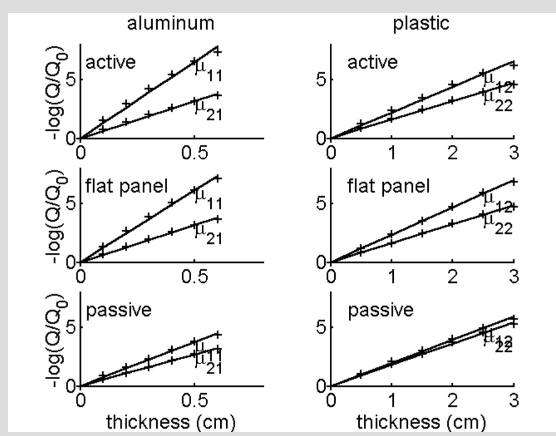
$u_{i,j}$ are the slopes of the logarithms of image data versus thickness for each energy

$$Q_i = Q_{i0}\,\mathrm{e}^{-A_1\mu_1(E_i) - A_2\mu_2(E_i)} \longrightarrow \mu_{ij} = \mu_j(E_i)$$

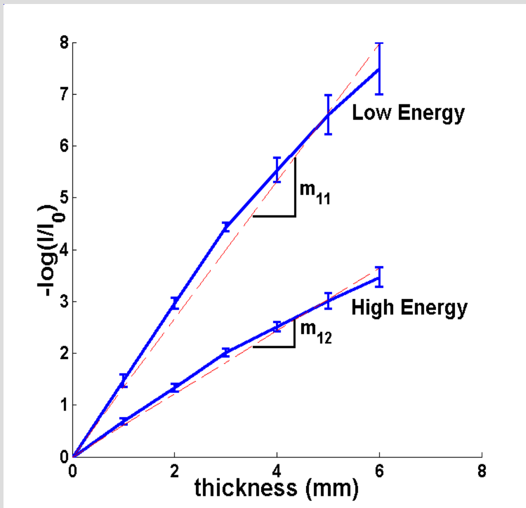
Spectral quality factor

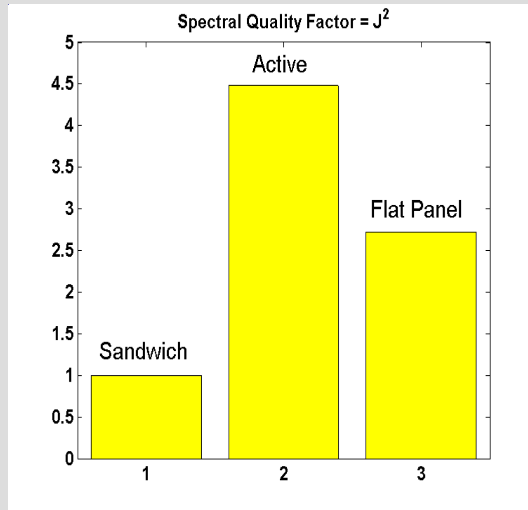
computed from: $J^2 = (\mu_{11}\mu_{22} - \mu_{12}\mu_{21})^2$





- Plastic wedge: 5-30 mm by 5 mm steps
- Aluminum wedge: 1-8 mm by 8 mm steps



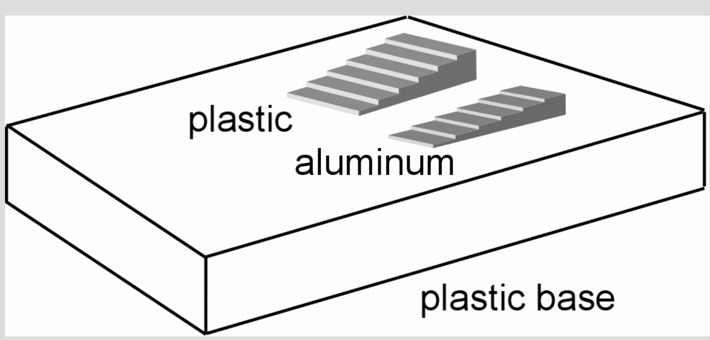


Effective linear attenuation coefficients for the low and high energy beams for bone (active detector)

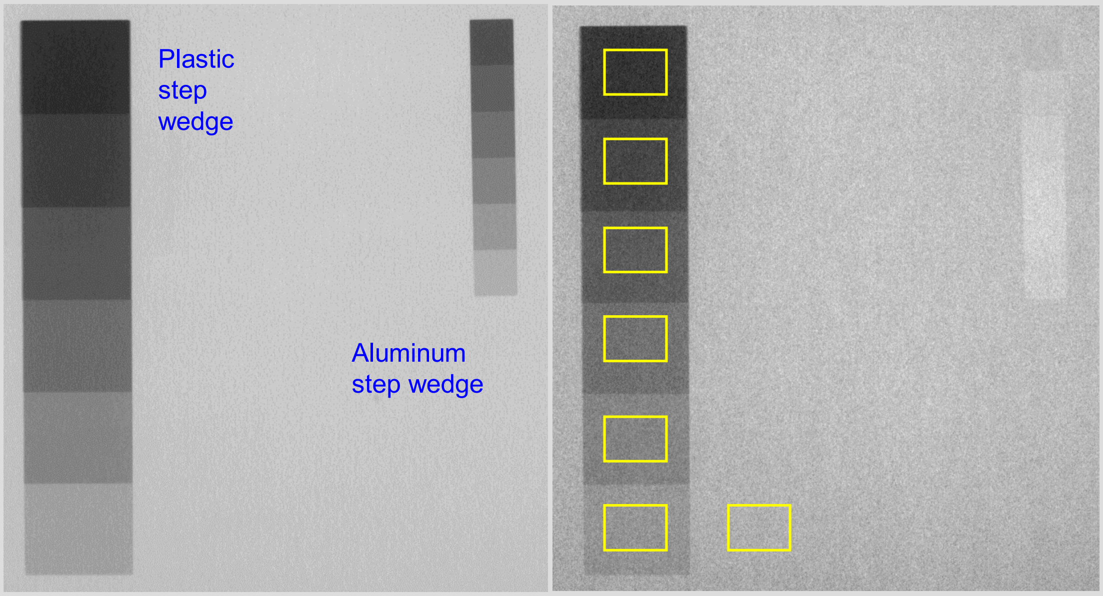
Relative "spectral quality" merit: Normalized to passive detector Larger value indicates lower noise

Noise vs. Exposure

- Plastic wedge: 5-30 mm by 5 mm steps
  - Soft tissue image most important
- SNR: difference of adjacent steps / std dev
- 13, 25 and 50 mR entrance exposure

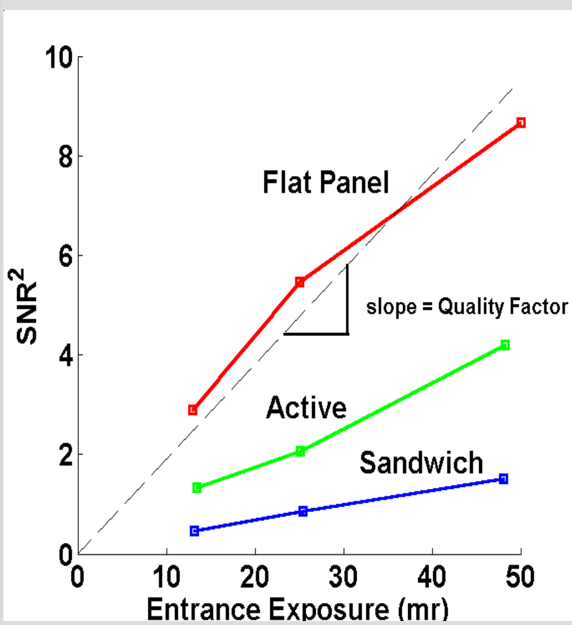


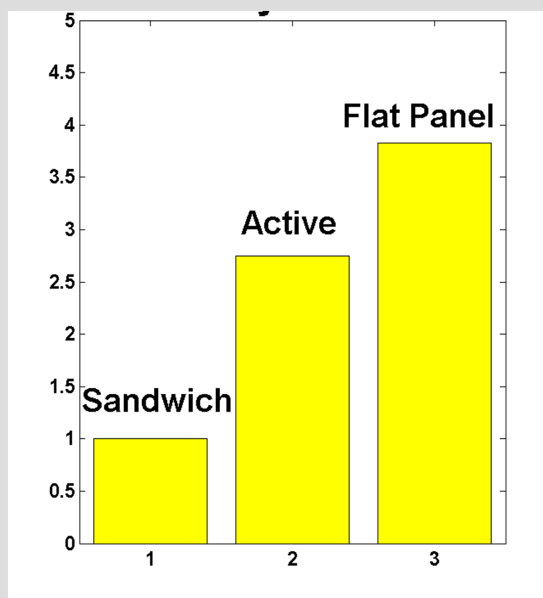
Conventional Image — Al Cancelled Image



Low energy composite image — ROI positions

SNR² vs. incident exposure — Noise Quality Factor





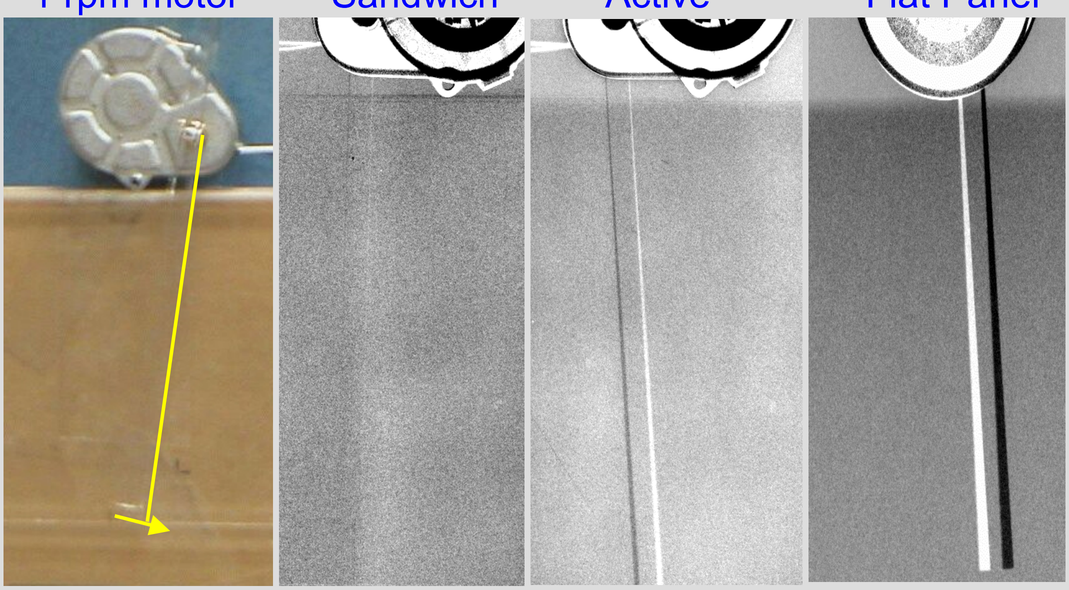
$$NQF = \frac{SNR^2_{\text{Cancelled Image}}}{EntranceExposure}$$

Motion Artifact

- Involuntary and voluntary motion
- Expressed during energy subtraction
- Evaluation:
  - 1 rpm synchronous motor and plastic bar
  - Acquire typical image sequence
- Use soft-tissue decomposition

Motion artifact experiments

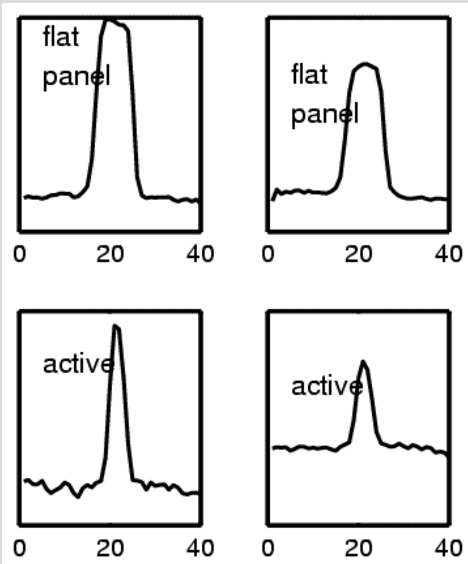
1 rpm motor | Sandwich | Active | Flat Panel

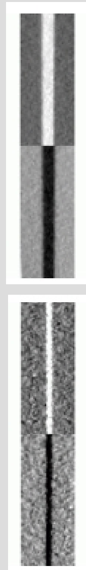


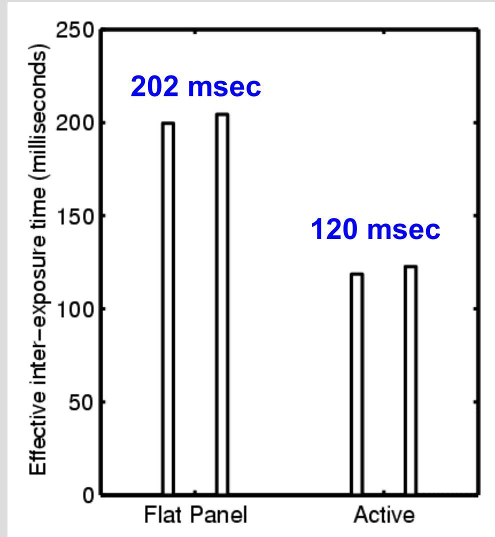
Plastic cancelled images

Effective exposure time

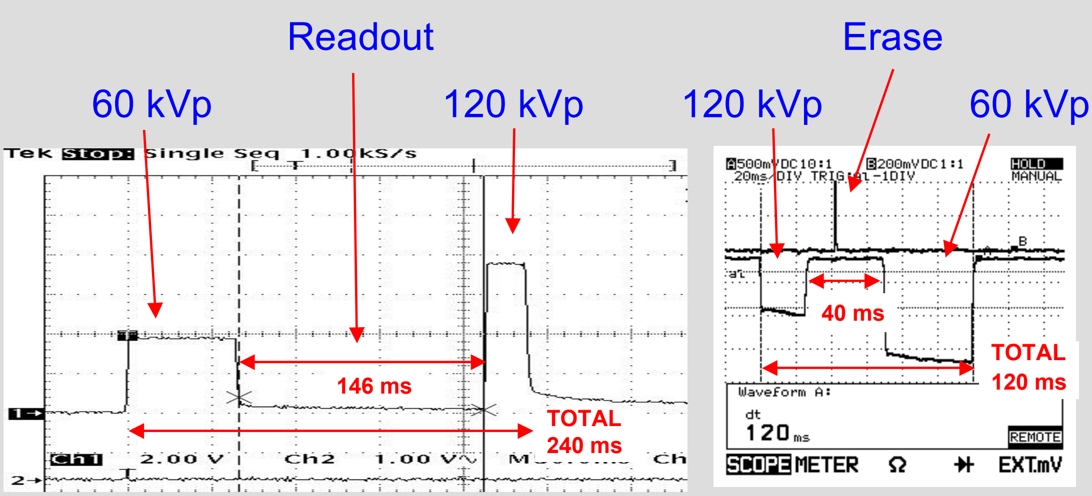
$$T_{eff} = \frac{L_{fwhm}}{2\pi fr}$$







Timing acquisition sequence



Flat panel detector

Active detector

Discussion

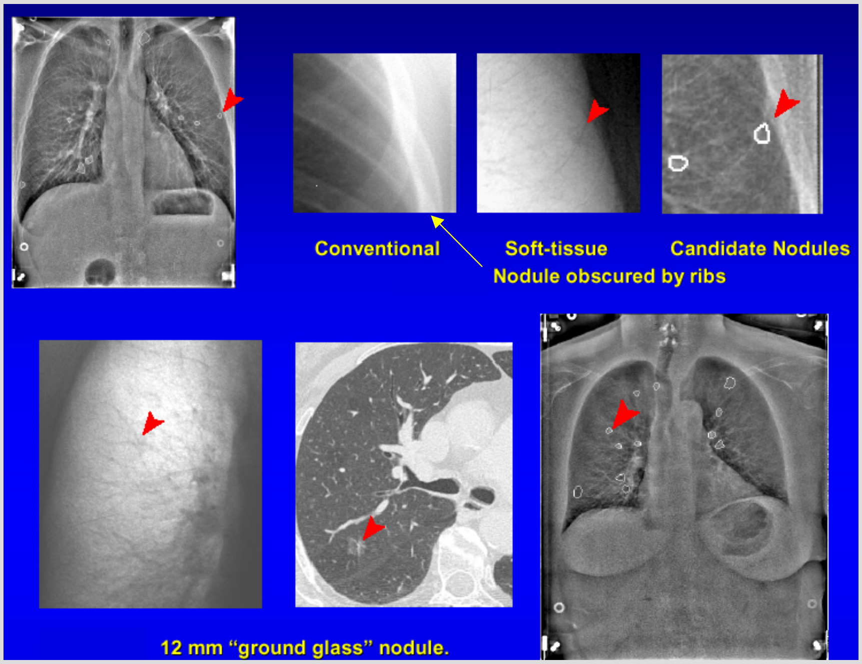
- Several factors must be considered in the design of a dual energy detector
  - Spectral quality issues and dose
  - Effective exposure time
  - Detective Quantum Efficiency of the system

Conclusions

- Flat panel detector provides best noise quality factor (highest DQE)
  - 5.9 (Flat-panel) to 2.7 (Active) to 1 (Passive)
- Passive detector gives best motion immunity (simultaneous image acquisition)
  - 121 msec (Active) to 202 msec (Flat-panel)
- Active detector provides best spectral quality (switched voltage + filtration)
  - 4.5 (Active) to 2.7 (Flat-panel) to 1 (Passive)

Future work

- Computer Aided Detection with dual energy



Conclusions

- Each dual-energy system tested has weaknesses and strengths in terms of spectral quality, motion artifact reduction and image quality factor

- Design of future dual-energy systems should benefit from these investigations