X-Ray Backscatter

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Conclusions

- Conclusions are made on the basis of publicly available or inferred information - such information may not be correct
- XBS systems may have relatively poor SNR
  - Poor SNR lowers conspicuity
  - Standard noise reduction filters are hampered by anatomic structures
- Material properties
  - High-Z, dense objects may be conspicuous against tissue, but may be less conspicuous against dark backgrounds
  - Low density objects may low conspicuity against tissue
- Shape
  - Edges may produce an enhancement effect; conspicuity of the edge effect may be reduced by shaping the object
- Other modalities may be needed to complement low-conspicuity XBS material, placement, or shape

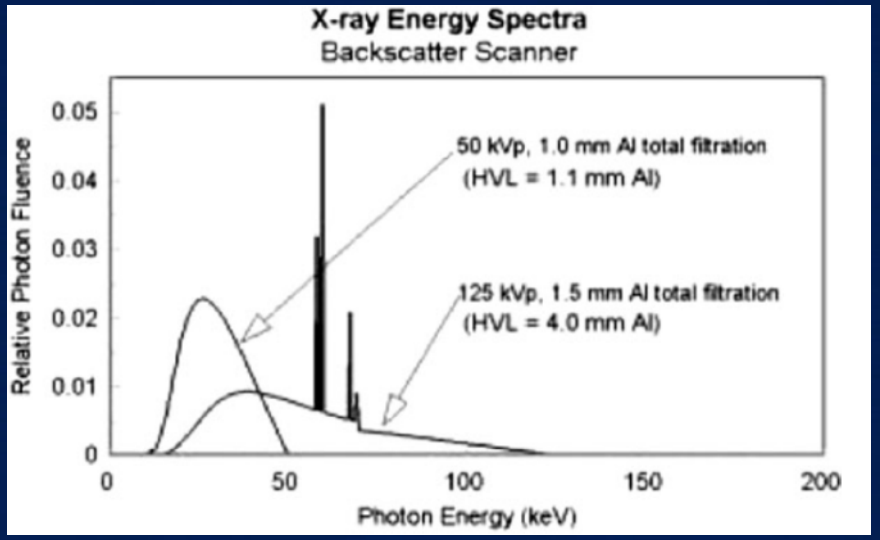
Caveats and Assumptions

- We have worked through XBS data* examining the subjective conspicuity of different objects and imaging scenarios
  - Assumption: the more conspicuous an object, the higher the probability of detection (Pd), and lower the probability of false alarm (Pfa)
  - Conspicuity is assumed to be a function of atomic number (Z), mass density, shape, and location of object
- However, that dataset (and our conclusions) is SSI
  - We cannot present in this forum
- Instead we will rely on system parameters and performance numbers in the public domain
  - We neither confirm nor deny the findings in these sources

*Funding received through ALERT, final report: “Advanced Imaging Technology: MGH Ground Truth Effort Final Report,” SSI, 31 Dec 2010.

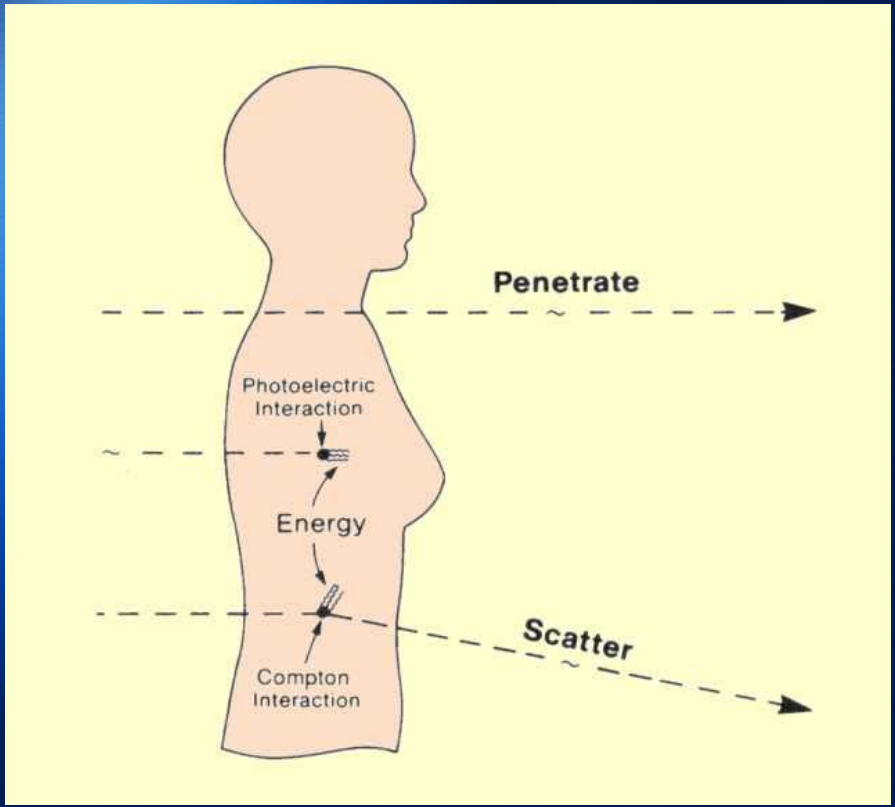
Assumed XBS Operating Parameters

- Energy regime
  - Average: 30 and 60 keV
  - Peak: 50 and 125 kVp
- Scattering angles of interest
  - > 145^{o}
- Resolution
  - ~ 2-mm/pix



X-ray Photon Propagation

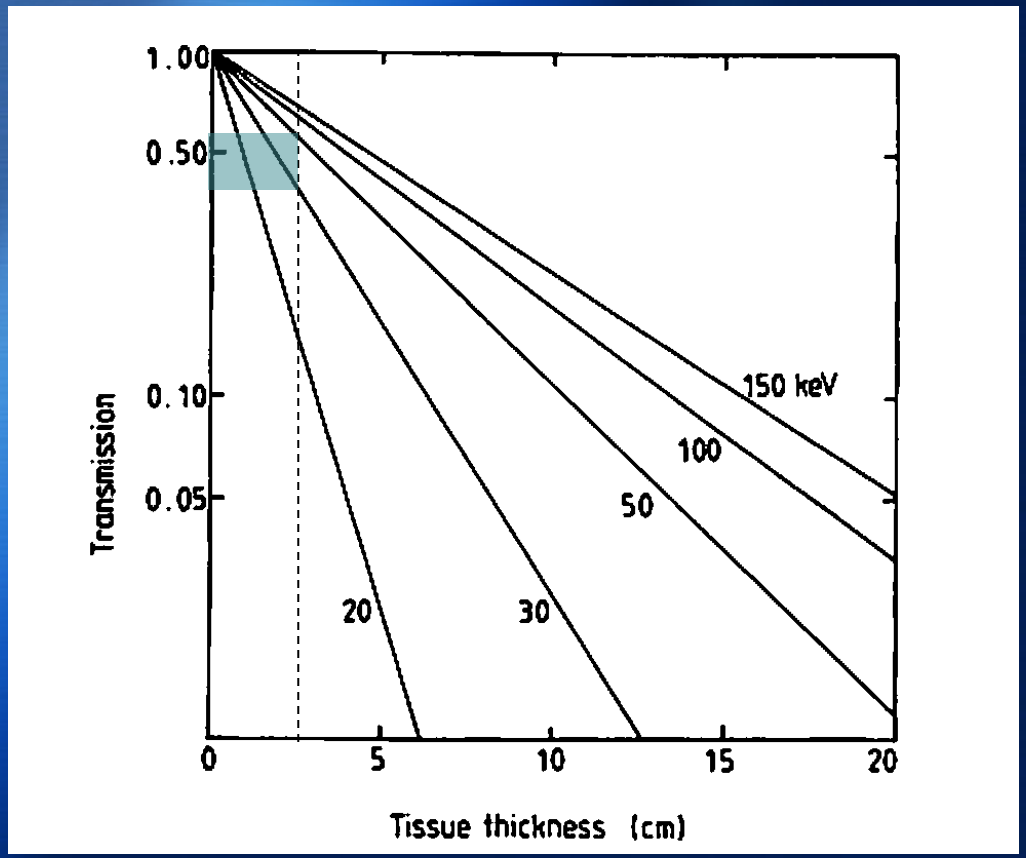
Incoming photons = transmission + attenuation
= transmission + absorption + scatter



Dual panel screening systems which are capable of detecting both transmission and back-scatter are also available, but not in the scope of this talk

P. Sprawls, The Physical Principles of Medical Imaging, www.spralws.org/ppmi2

Transmission versus Depth of Penetration

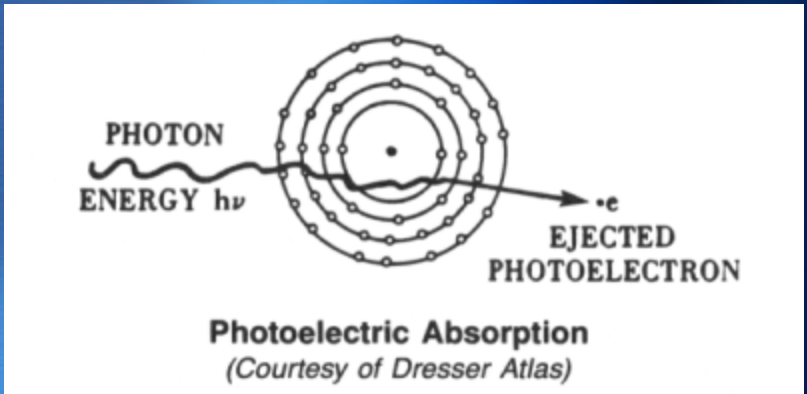


At "operating" kVp range, ~ 50% of energy is transmitted through 2.5 cm of tissue

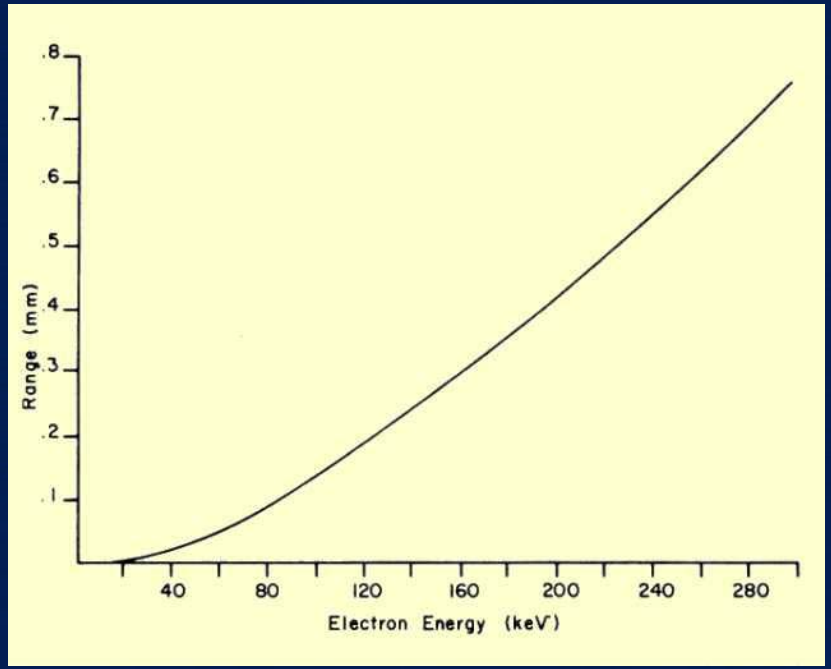
i.e., ~ 50% of energy is either absorbed or scattered

Webb, The Physics of Medical Imaging, Institute of Physics Pub, 1988

Photoelectric Absorption

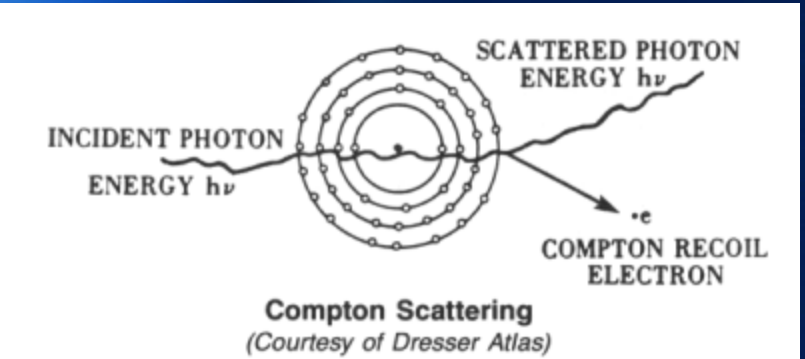


Photoelectric Absorption
(Courtesy of Dresser Atlas)



- X-ray photon transfers energy to electron
- Electron is ejected
- Electron travels a short distance (~ 0.05 mm) until energy is absorbed
- Probability of absorption is greater if the atomic number Z is higher

Compton Scattering

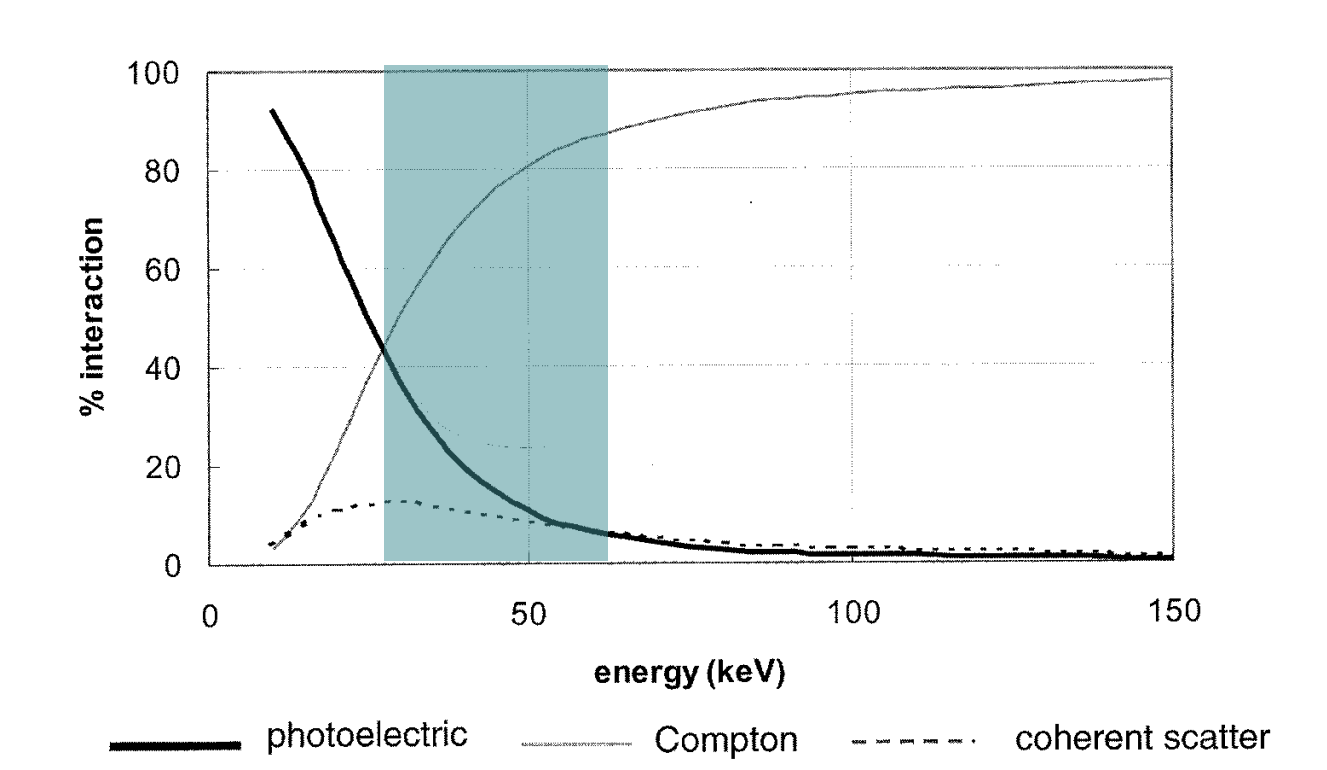


Compton Scattering
(Courtesy of Dresser Atlas)

- X-ray photon hits material
- Material contains weak binding energy atoms
- A portion of the energy is absorbed
- A portion of the energy is released in the form of lower-energy photon
- Photon travels in a direction different from original x-ray photon (scatter)
- Probability of scatter depends
  - Strongly on the number of electrons per unit mass (i.e., density)
  - Weakly on the number of electrons in the material (i.e., atomic number Z)
    - all material, with the exception of H, have ~ same # of electrons / gram

P. Sprawls, The Physical Principles of Medical Imaging, www.spralws.org/ppmi2
http://www.e-radiography.net/radtech/i/interaction%20xray.htm

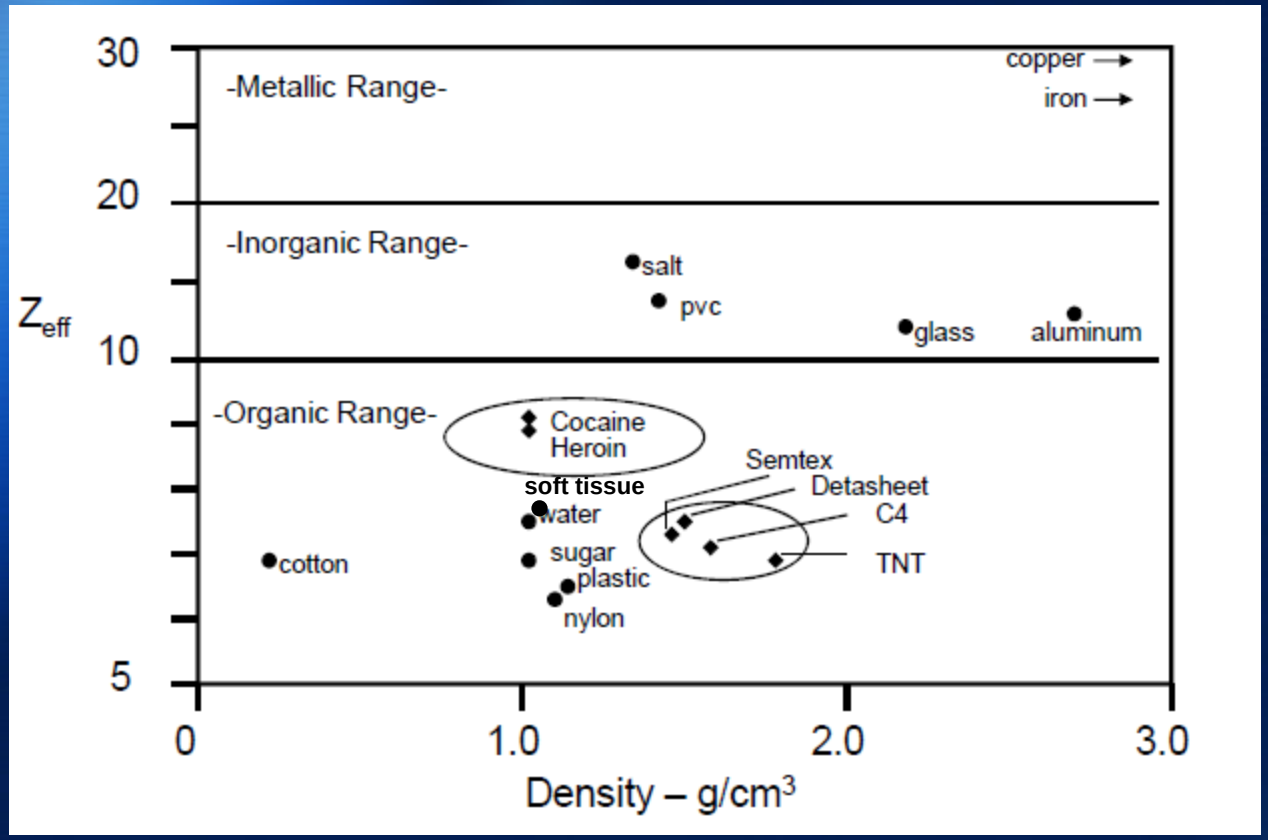
Relative Frequency of PE and CS in Water



Of the attenuated energy, 40 – 85% will be Compton scattering

J. Hsieh, *Computed Tomography*, SPIE, 2003

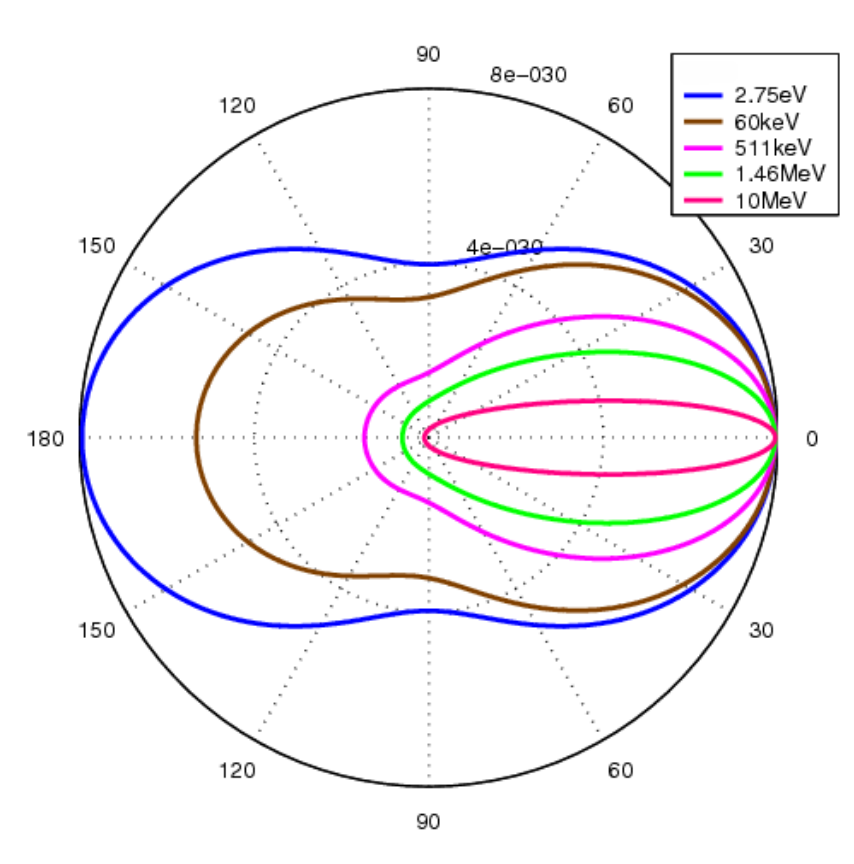
Atomic Number and Mass Density



From L. Eger, BU
Graph from R. F. Eilbert and K. D. Krug, SPIE 1824, 127–143 (1993)

Backscatter: Klein-Nishina

$$\frac{d\sigma}{d\Omega} = \alpha^2 r_c^2 P(E_\gamma,\theta)^2[P(E_\gamma,\theta) + P(E_\gamma,\theta)^{-1} - 1 + \cos^2(\theta)]/2$$



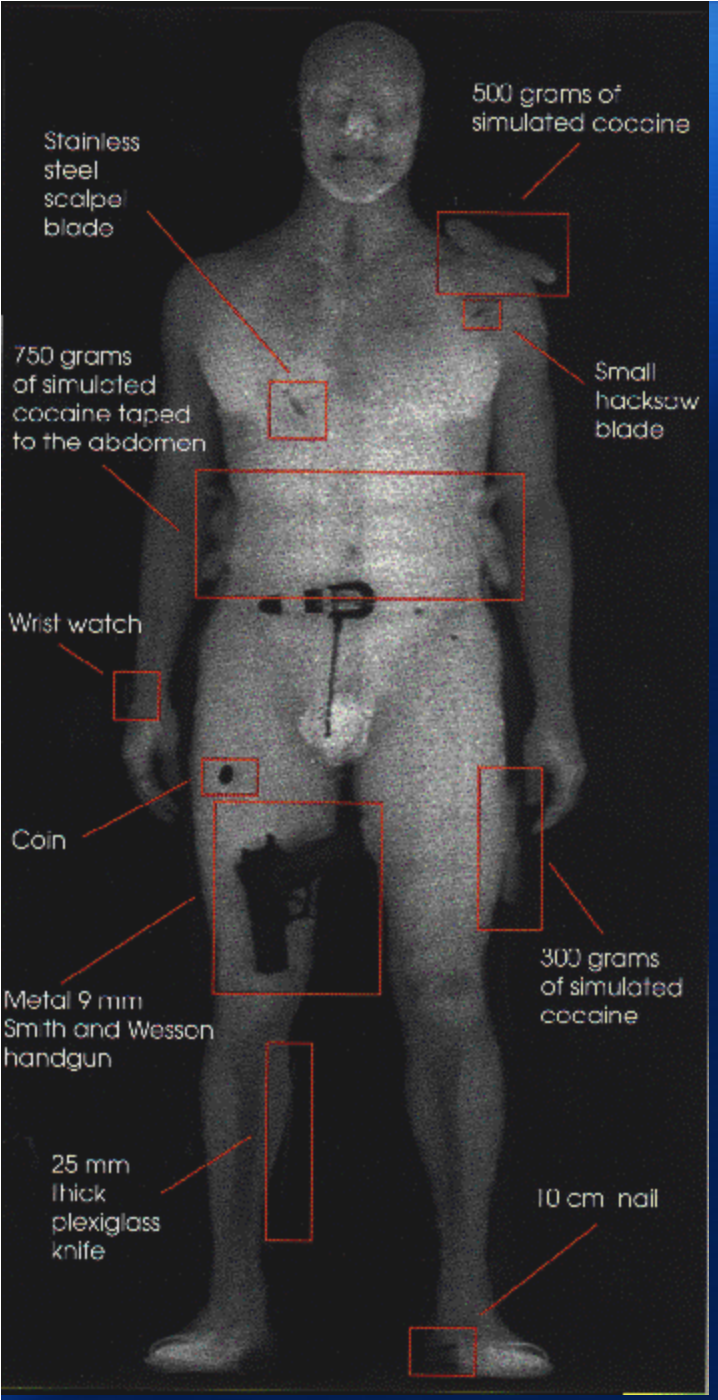
Klein-Nishina Distribution: cross section of photons scattered from a single free electron

At 60 keV, ~ 20 – 30% of energy Is backscattered

www.en.wikipedia.org

Observations

- With stated operating parameters, backscatter represents ~ 10% of the transmitted energy
  - Of 100% incident x-ray energy
  - ~ 50% is transmitted through 2.5 cm of tissue
  - Of the remaining 50%, 80% is scattering
  - Of the scattering component, about 25% is backscattered
  - Ignores detector efficiency
- Assumes soft tissue / water for material
- Minimization of radiation dose => SNR will not be great


500 grams of simulated cocaine
Stainless steel scalpel blade
750 grams of simulated cocaine taped to the abdomen
Small hacksaw blade
Wrist watch
Coin
300 grams of simulated cocaine
Metal 9 mm Smith and Wesson handgun
25 mm thick plexiglass knife
10 cm nail

Opportunities for Fusion

- Conspicuity in XBS may be improved through fusion
  - Multi-perspective XBS
    - Improves aspect angle geometry
  - Backscatter tomography
    - Derives 3-D information
  - Dual-panel x-ray system
    - Combines transmission and backscatter
  - Multi-energy transmission x-ray
    - (effective) atomic number and mass density
  - MMW
    - Dielectric differences between material
  - Thermal IR
    - Thermal occlusion, thermal inertia

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