

X-RAY PRODUCTION AND QUALITY

Beam Quality (x-ray)

- ❖ Quality means the penetrating ability of the beam.
- ❖ Synonymous with “hardness”
- ❖ The more penetrating, the higher the quality.
- ❖ It has to do with the energy spectrum of the x-ray beam

Means of producing beams

- ❖ Fluorescence x-rays (also called “characteristic”)
 - Collisions → only <1% of the c.p. goes into flrx
- ❖ Bremsstrahlung
 - $(dT/\rho dx)_r / (dT/\rho dx)_c \propto TZ$

Fluorescence x-ray

TABLE 9.1 Electron Binding Energies E_b in Tungsten^a

Shell (E_b) _K ↓ (keV)	Shell (E_b) _L ↓ (keV)	Shell (E_b) _M ↓ (keV)	Shell (E_b) _N ↓ (keV)
K 69.525	L _I 12.098	M _I 2.820	N _I 0.595
	L _{II} 11.541	M _{II} 2.575	N _{II} 0.492
	L _{III} 10.204	M _{III} 2.281	N _{III} 0.424
		M _{IV} 1.871	N _{IV} 0.256
		M _V 1.809	N _V 0.242
			N _{VI} 0.036
			N _{VII} 0.034

$$69.525 - 11.541 = 57.984 \text{ keV}$$

K-Fluorescence x-ray

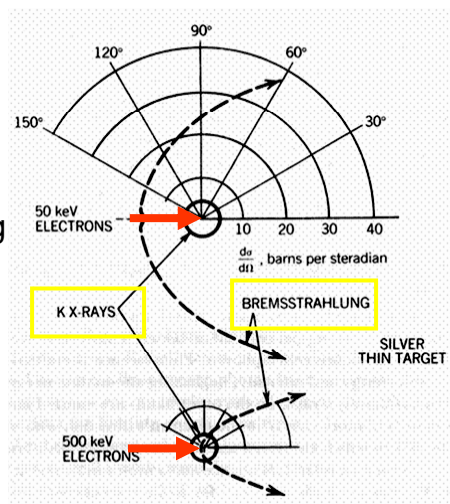
TABLE 9.2 K-Shell X-Ray Fluorescence Energies in Tungsten^a

Transition	Designation	Energy (keV)	Relative No. of Photons
<i>K-L</i> _{III}	α_1	59.321	100
<i>K-L</i> _{II}	α_2	57.984	57.6
<i>K-M</i> _{II}	β_3	66.950	10.8
<i>K-M</i> _{III}	β_1	67.244	20.8
<i>K-M</i> _{IV}	$\beta_{5/1}$	67.654	0.233
<i>K-M</i> _V	$\beta_{5/2}$	67.716	0.293
<i>K-N</i> _{II}	$\beta_{2/1}$	69.033	2.45
<i>K-N</i> _{III}	$\beta_{2/2}$	69.101	4.77
<i>K-N</i> _{IV}	$\beta_{4/1}$	69.269	0.127
<i>K-N</i> _V	$\beta_{4/2}$	69.283	0.127
<i>K-O</i> _{II}	$\beta_{2/3}$	69.478	1.07
<i>K-O</i> _{III}	$\beta_{2/4}$	69.489	1.07

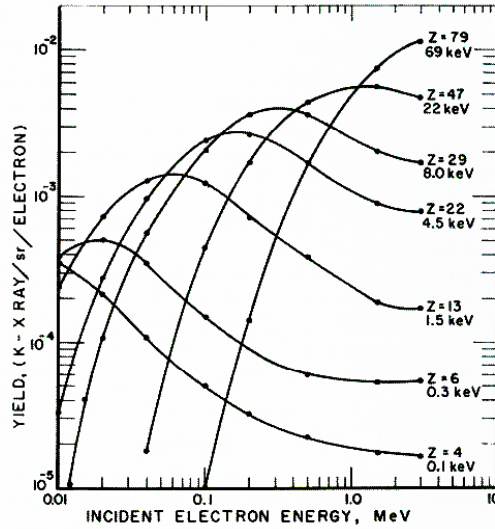
^aAfter Storm and Israel (1970). Reproduced with permission from Academic Press.

Directional Distributions

- ❖ Fluorescence
 - isotropically
- ❖ Bremsstrahlung
 - anisotropically, tending to go in the electron direction with increasing energy.



Fluorescence output vs. Electron energy



Thick Targets

FIGURE 9.3. Dependence of K x-ray yield from thick targets of Z = 4 to 79 on incident electron energy. The approximate mean energy of the K fluorescence is also given for each curve. (From Sparrow and Dick, 1976. Reproduced with permission from C. E. Dick.)

Bremsstrahlung x-rays - Yield -

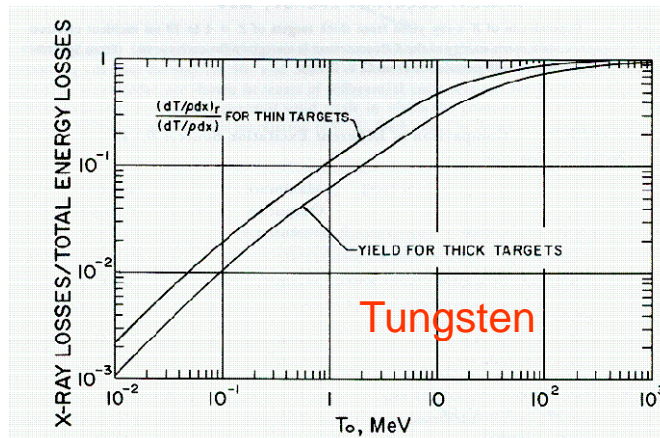
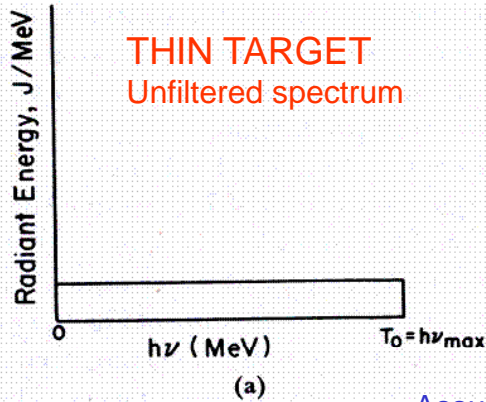


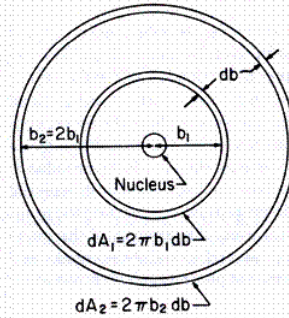
FIGURE 9.4. Fraction of electron energy losses that are spent in bremsstrahlung x-ray production in thin (upper curve) or thick (lower curve) tungsten targets (data after Berger and Seltzer, 1983). Upper curve: Eq. (9.2); lower curve: radiation yield (fraction of the incident electron kinetic energy T_0 that goes into x-ray production as the particle slows to a stop in a thick target).

Bremsstrahlung x-rays

- energy spectrum; $T_0 \ll 0.511 \text{ MeV}$ -



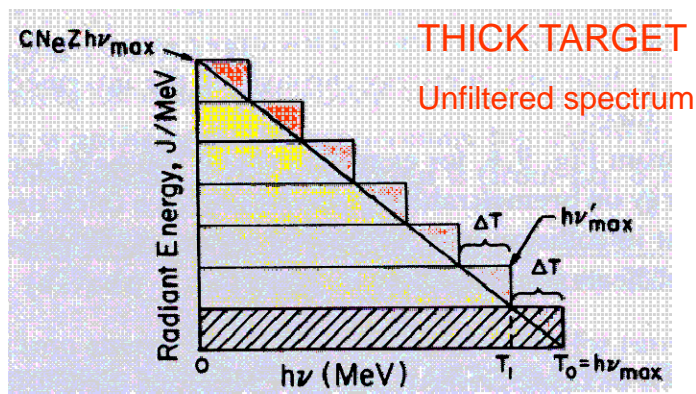
If $b_2 = 2b_1 \rightarrow dA_2 = 2dA_1$



Assuming that the magnitude of the x-ray beam energy produced to be proportional to $1/b$ then $h\nu_2 = 2h\nu_1 \rightarrow N_1 h\nu_1 = N_2 h\nu_2$

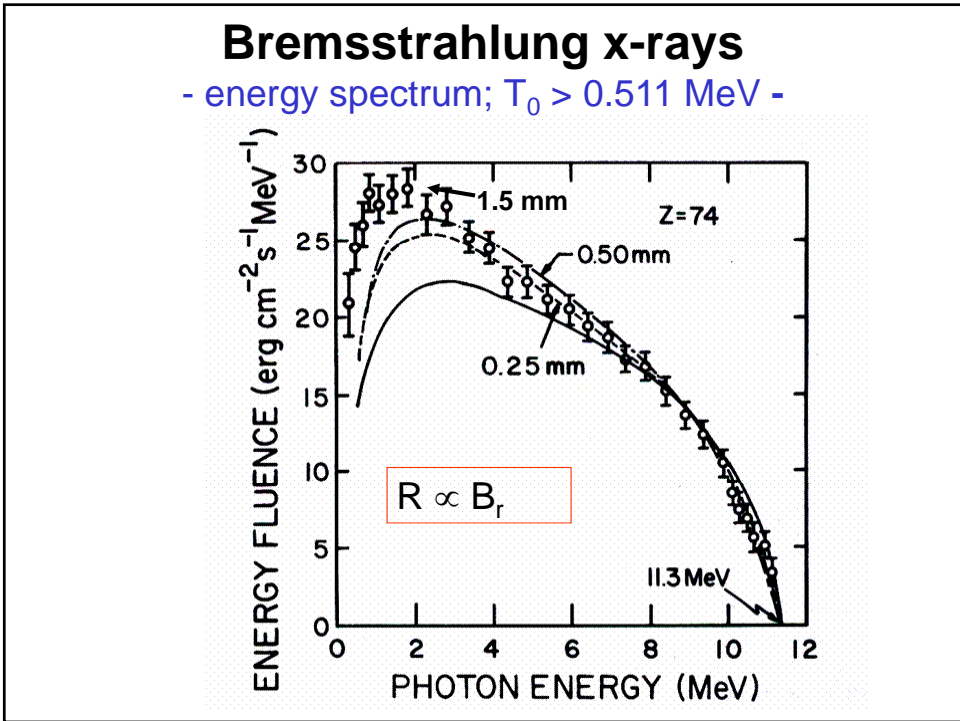
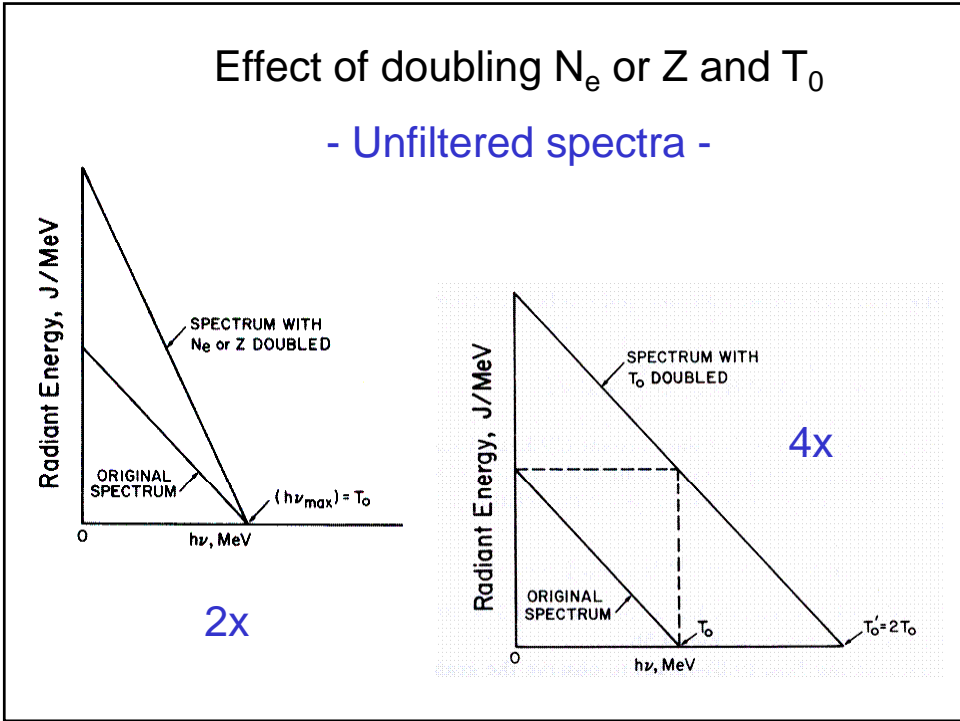
Bremsstrahlung x-rays

- energy spectrum; $T_0 \ll 0.511 \text{ MeV}$ -



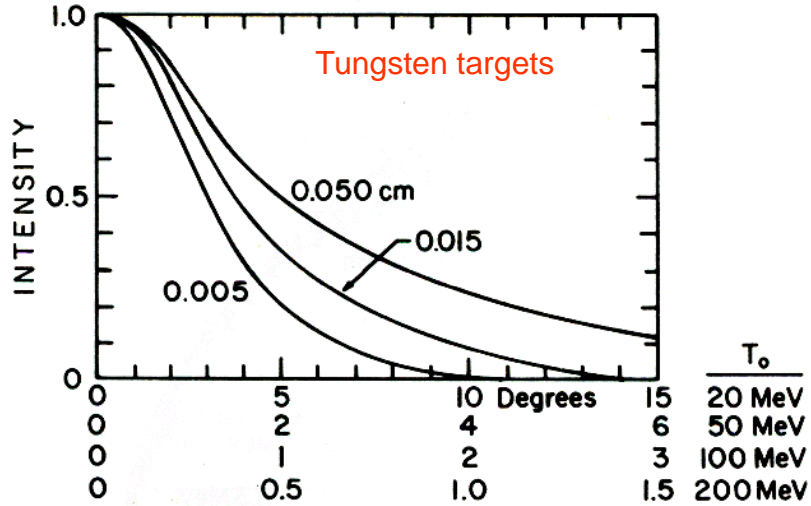
Kramers spectrum $\rightarrow R'(h\nu) = C N_e Z (h\nu_{\max} - h\nu),$

Area $\rightarrow R = \frac{C}{2} N_e Z (h\nu)_{\max}^2 = \frac{C}{2} N_e Z T_0^2$

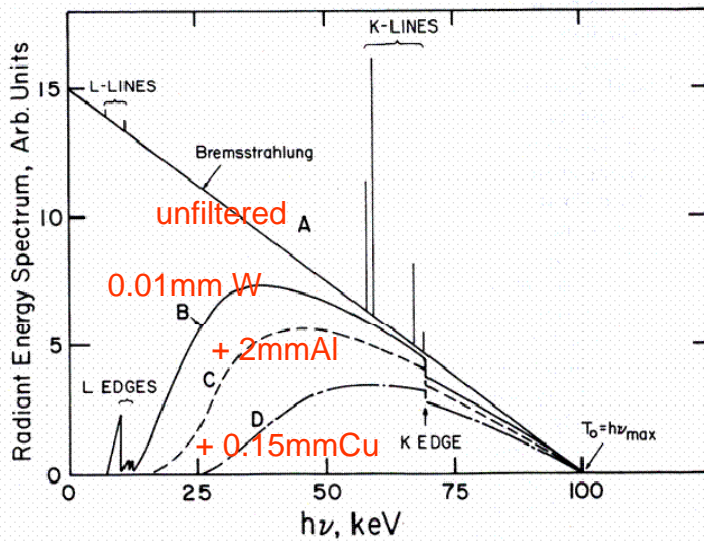


Bremsstrahlung directional Dependence

For thin foils, the spectral shape is isotropic but not the intensity. It depends strongly on direction.



X-ray filtration and beam quality

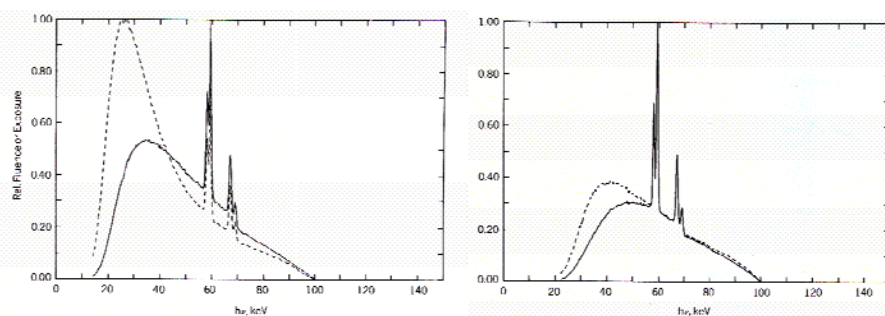


X-ray beam quality specification

- ❖ Spectrum
- ❖ Attenuation characteristics in a reference medium

X-ray beam quality specification - Spectrum -

- ❖ Solid curve = photon number
- ❖ Dashed curve = exposure spectrum



2mmAl

3.9mm Al + 0.15 mmCu

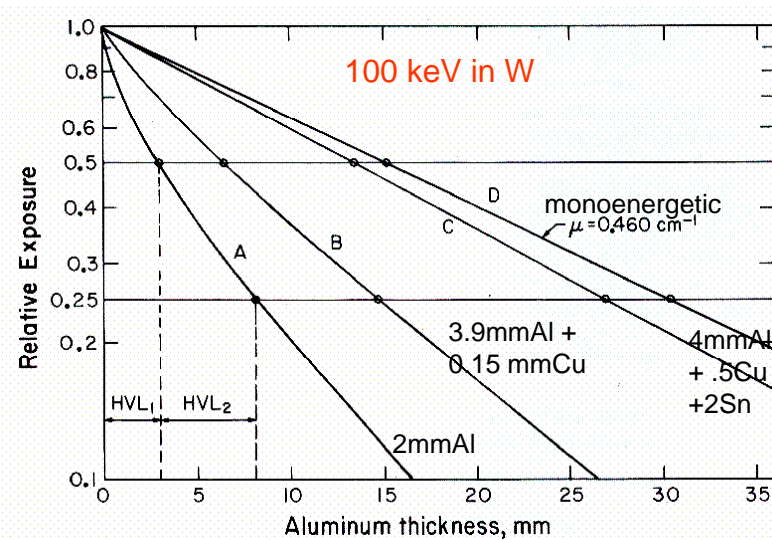
Attenuation curves and HVL

- ❖ Attenuation curves can (with some limitation) be used to derive an x-ray spectrum.
- ❖ The attenuation curve shape is a “signature” of the spectrum, and it can be used to characterize an x-ray beam.

CONVENTIONS GENERALLY FOLLOWED:

- ❖ Pure aluminum or copper is used as the attenuating medium
 - Al preferred for $T_0 < 120$ keV
 - Cu for higher energies < 0.5 MeV
- ❖ Narrow-beam geometry is required (i.e., scattered rays from the attenuator must not reach the detector)
- ❖ The detector (e.g., ion chamber) must be air-equivalent, that is, must give a constant response per unit of exposure, independent of photon energy.

Attenuation curves and HVL



Attenuation curves and HVL

TABLE 9.4. Half-Value Layers and Homogeneity Coefficients for the Aluminum Attenuation Curves in Fig. 9.12

Curve	Energy (keV)	Filter (mm)	HVL ₁ (mm Al)	HVL ₂ (mm Al)	HC (Al)
A	100	2 Al	3.02	5.12	0.59
B	100	0.15 Cu + 3.9 Al	6.56	8.05	0.81
C	100	2 Sn + 0.5 Cu + 4 Al	13.4	13.5	0.99
D	100 ^a	none	15.1	15.1	1.00

^aMonoenergetic.

Attenuation curves and HVL

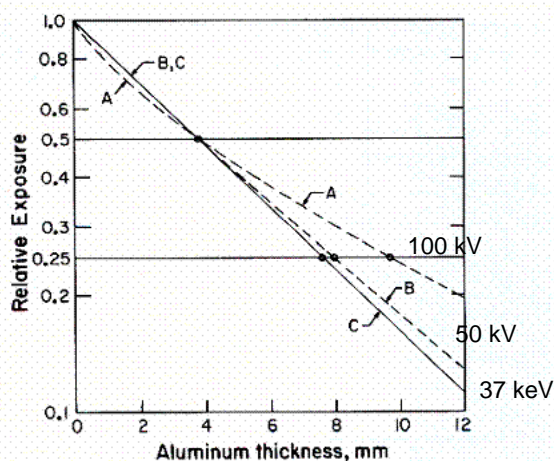
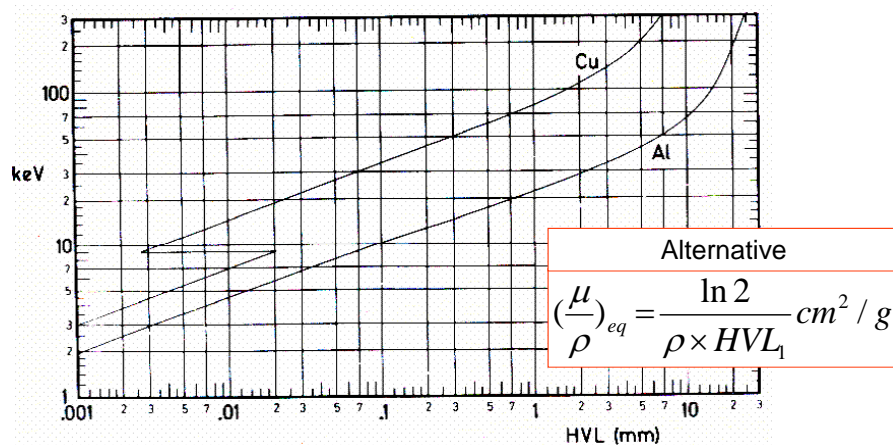


FIGURE 9.13. An example of the attenuation of three dissimilar x-ray beams having practically the same value of HVL₁ (3.8 mm) in aluminum. Curve A: 100 kV, 3 mm Al filter, HVL₂ = 5.82 mm. Curve B: 50 kV, 0.1 mm Pb + 4 mm Al filter, HVL₂ = 4.13 mm. Curve C: monoenergetic 37-keV beam, HVL₂ = 3.8 mm. Note that 37 keV is the equivalent photon energy for both beams A and B. (HVL data after Seelentag et al., 1979.)

Attenuation curves and HVL

❖ Equivalent photon energy:

The quantum energy of a monoenergetic beam having the same HVL_1 as the beam being specified.



For high Energy

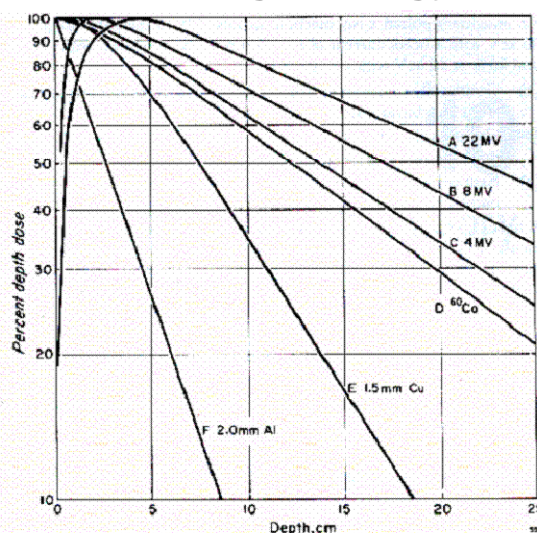


FIGURE 9.15. Variation of absorbed dose vs. depth in a water phantom for the following $10 \times 10\text{-cm}^2$ photon beams: A, 22 MV, 70-cm SSD; B, 8 MV, 100-cm SSD; C, 4 MV, 100-cm SSD; D, ^{60}Co γ -rays, 100-cm SSD; E, 200 keV, $HVL_1 = 1.5$ mm Cu, 50-cm SSD; F, 120 kV, $HVL_1 = 2.0$ mm Al, 15-cm SSD. (From Johns and Cunningham, 1983. Reproduced with permission from J. R. Cunningham, and Charles C. Thomas, Publisher.)