X-Ray Production, Tubes and Generators

The kinetic energy gained by an electron is proportional to the potential difference between the cathode (negative) and the anode (positive charge).

Bresstrahlung radiation – arises from electron interactions with the atomic nucleus of the target material. The x-ray energy depends on the interaction distance between the electon and the nucleus, it decreases as the distance increases.

The major factors that effect x-ray production efficiency are the atomic number (Z) of the target material and the kinetic energy (E_k) of the incident electrons.
Radiative energy loss/Collisional energy loss = E_k Z/820,000

Characteristic x-ray specturm –

- Electron binding energy decreases as you move away from the nucleus
- Electron shell binding energies are unique to a given element, so emitted x-rays have discrete energies that are characteristic of that element.
- For tungsten, an L-shell electron filling a K-shell vacancy results in a characteristic x-ray energy:

$E_{K\text{-shell}} - E_{L\text{-shell}}$ = 69.5 keV – 10.2 keV = 59.3 keV

- Characteristic x-rays are emitted only when the electrons impinging on the target exceed teh binding energy of a K-shell electron.

Standard voltage in wall plug = 120/240V. To make x-rays, you need 20,000 – 150,000V.

120V → (***step-up transformer***) → 20,000V

Transformers use ***electromagnetic induction***, based on coils of wire.

An ***autotransformer*** is a special transformer that lets you choose your output voltage, and this is what the machine uses to change your kVp.

X-ray generators use DC as opposed to AC current, so the AC input has to be rectified with a ***rectifier circuit***. This makes the sine wave into a series of humps.

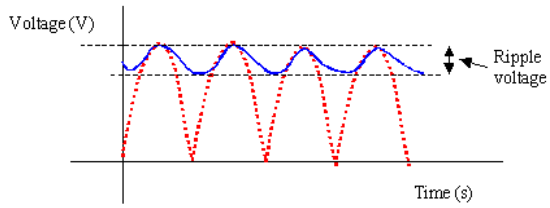
Modern machines use ***3-phase*** input, which is 3 series of voltage humps, each displaced from the others, which are added together to create a more uniform voltage/current.

Timing exposure of x-rays is done by simple stopwatch-like timers (old-school) to fancy ***phototimers*** which measure x-rays to a pre-determined density (with backup old school timer in case of failure).

Voltage Ripple and Root-Mean-Square Voltage:

- % Voltage Ripple (VR) = $(V_{max}-V_{min})/V_{max}$ x 100%
- Root-Mean-Square Voltage (V_{rms}): The constant voltage that would deliver the same power as the time-varying voltage waveform

- As %VR ↓, the V_{rms} ↑



Operator Console:

- Tech selects peak kilovolts (kVp), current (mA), exposure time (sec) and focal spot size
- kVP determines x-ray beam quality (penetrability) which plays role in subject contrast
- mA determines x-ray fluence rate (photons/cm^2-sec) emitted by x-ray tube at a given kVp (mAs = mA x sec which is proportionate to photons/cm^2 or fluence)
- Low mA selections allow small focal spot while higher mA settings require large focal spot size

Phototimers:

- Although a tech can manually time the x-ray exposure, phototimers help provide a consistent exposure to the image receptor
- Ionization chambers produce a current that induces a voltage difference in an electronic circuit
- Tech chooses kVp; the x-ray tube current terminates when induced voltage = reference voltage

Factors Affecting X-ray Emission:

Quantity = # of x-rays in beam
Proportionate to Z_{target} x $(kVp)^2$ x mAs

Quality = penetrability of x-ray beam and depends on:

- kVp
- Generator waveform (%VR)
- Tube filtration (mm Al)

Exposure depends on both quantity and quality
Changes in kVp can be compensated by changes in mAs to maintain the same exposure

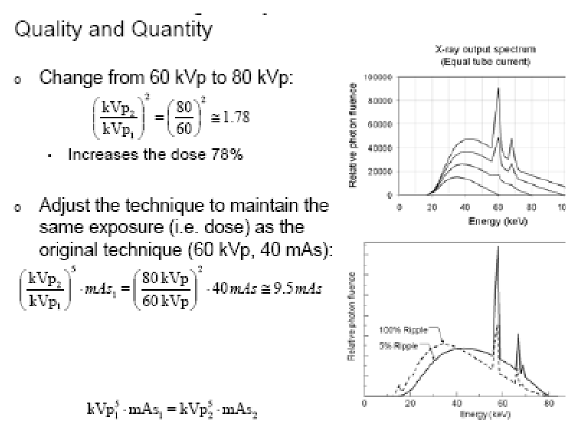


TABLE 5-6. X-RAY TUBE FOCAL SPOT SIZE AND TYPICAL POWER RATING

Nominal X-ray Tube Focal Spot Size (mm)	Typical Power Rating (kW)
1.2–1.5	80–125
0.8–1.0	50–80
0.5–0.8	40–60
0.3–0.5	10–30
0.1–0.3	1–10
<0.1 (micro-focus tube)	<1

Power Ratings and X-ray Tube Focal Spots:

- Describes the energy per unit time that the generator can supply
- Power (kW) = 100 kVp x A_{max} (for a 0.1 second exposure)
  - 100 kW = 100 kVp x 1000 mA @ 100 ms exposure
  - A_{max} (tube current) limited by the focal spot: ↑ focal spot → ↑ power rating
- Generally range = 10 kW to 150 kW
- Typical focal spots:

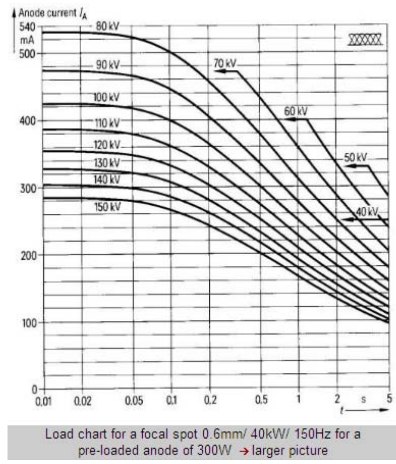
- Radiography: 0.6 and 1.2 mm
- Mammography: 0.1 and 0.1 mm

X-ray Tube Heat Loading:

- Energy deposition on anode (during x-ray production, 99% heat production)
- Heat Unit (HU) = kVp x mAs x factor
  (factor = 1.0 for 1-phase generator, 1.35 for 3-phase & HF generators, 1.4 for CP generator)
- Energy (J) = V_{rms} x mA x sec
  (V_{rms} = 0.71 for 1-phase, 0.95-0.99 for 3-phase & HF and 1.0 for CP)
- Heat Input (HU) ~ 1.4 x Heat input (J)

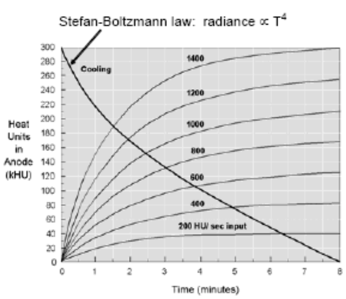
Exposure Rating Charts:

- Determine operational limits and permissible heat load of anode and tube housing
- Charts show the limitation and safe techniques for operation of the system
- Parameters affecting rating charts include focal spot size, anode rotation speed, anode angle, anode diameter and generator type (1-phase, 3-phase, HF)

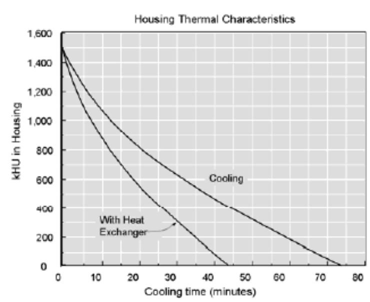


Sample Exposure Rating Chart

Anode Heat Input and Cooling Chart



Housing Cooling Chart



* Sources include lecture slides at http://courses.washington.edu/radxphys/PhysicsCourse.html, Bushberg et al, The Essential Physics of Medical Imaging, http://www.antonine-education.co.uk/Physics_A2/options/Module_9/Topic_3/ripple_10.gif and http://health.siemens.com/med/rv/x_ray_tubes/faqs/default.asp