Radiation Protection for Assistant Practitioners in Mammography

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1. Fundamental Physics of Radiation

Production of X-rays

The Nature of X-rays

X-rays are a type of ELECTROMAGNETIC RADIATION

They have

- wavelength (measured in metres, m)
- frequency (measured in Hertz, Hz)
- energy (measured in kilo-electron-volts, keV)

Other types of electromagnetic radiation are

- Radio wave (longest wavelength, lowest frequency and lowest energy)
- Microwaves
- Infra-red radiation
- Visible light
- Ultra-violet radiation
- X-rays
- Gamma rays (shortest wavelength, highest frequency and highest energy)

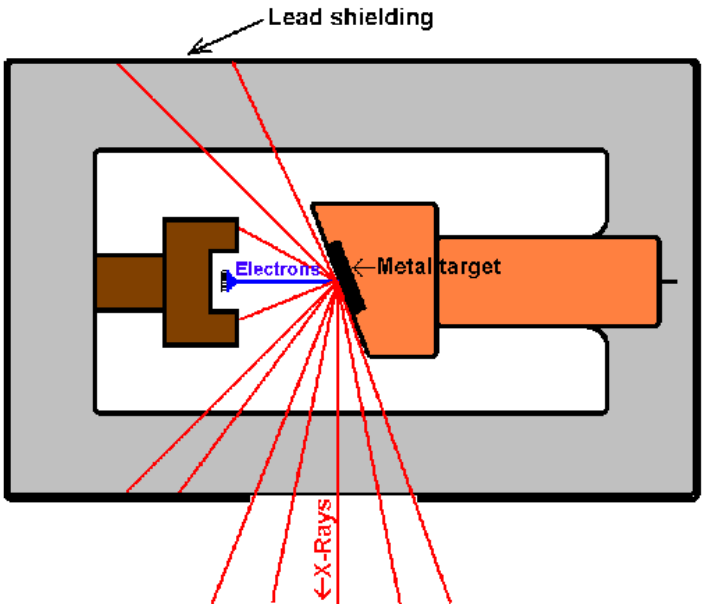
X-rays (and all types of electromagnetic radiation) come in little packets of energy called PHOTONS.

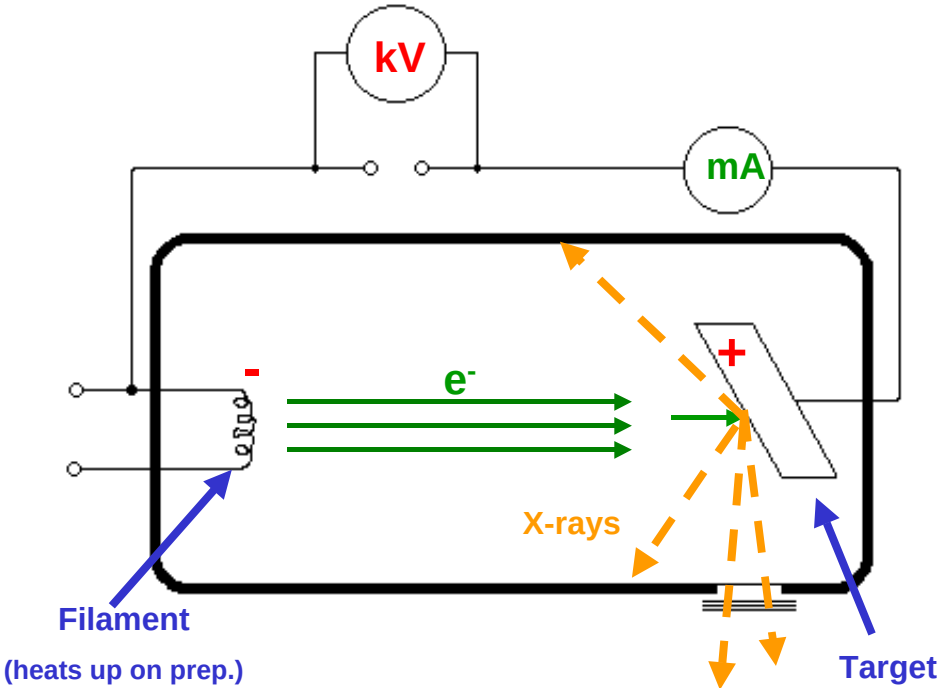
Making X-rays

Photons are made by decelerating ELECTRONS[1] (tiny negatively charged particles). In slowing down the electrons give up some of their energy as photons.

- radio waves are made by electrons flowing up and down an aerial.
- infra-red is made by electrons vibrating in warm objects
- visible light is made by electrons vibrating in very hot objects (e.g. filament in a light bulb), or hitting the fluorescent material on the inside of a TV screen.
- X-rays are produced by very fast moving electrons hitting a metal target in an X-ray tube.

[1] 1,000,000,000,000,000,000,000,000,000 electrons weighs one gram!





When the exposure button is pressed, the X-ray unit first goes into "prep." mode.

The FILAMENT heats up and boils off electrons. The anode also spins around to reduce the build up of heat, and making a whirring sound.

A high voltage is then applied across the tube. You hear a "ker-chunk" sound of the circuit breakers switching this high voltage on and off very quickly. This high voltage (often called the "kV" because it is measured in kilo-volts") makes the TARGET[2] positively charges and the filament[3] negatively charged. The negatively charged electrons are repelled from the filament and attracted to the target.

The electrons gain energy as they speed across the tube. The X-ray tube is a vacuum so that the electrons are not slowed down by air in the tube. If the tube voltage is set to 28 kV (which is typical for mammography) then the electrons will have 28 keV of energy when they hit the target. **The kV**

[2] also known as the ANODE (which means a positively charged electrode)

[3] also known as the CATHODE (which means a negatively charged electrode)

can be set by the radiographer and controls the energy of the individual X-ray photons. Some mammography sets automatically set kV, or recommend a kV for the radiographer to select.

When the electrons hit the target 99% of their energy is wasted as heat. The target gets white not. 1% of their energy is turned into X-rays.

An electrical CURRENT is the flow of electrons (usually along a wire), so electrons flowing across an x-ray tube also produce a current. This is measured in milli-amps (mA). At the end of a mammography exposure a value of "mAs" is displayed. This is the current (mA) times the length of the exposure in seconds. **The mAs tells us how many electrons have hit the target, hence how many X-ray photons are produced** for a given kV. (e.g. Twice as many electrons hit the target for an X-ray exposure of 10mAs, as for an exposure of 5 mAs). Mammography sets normally set the mA automatically. The exposure time is usually determined by the "AEC"[4]. The radiographer can over-ride the AEC and set the mAs manually.

Filtration

Not all the X-rays will be at the maximum energy (keV). They will be a spread of energies. Lower energies do not penetrate tissue as well as higher energies. Very low energy x-ray photons will all be absorbed in the breast, adding to the patient's radiation dose, and will never reach the film to add to image quality. Therefore, X-ray sets have added FILTRATION to remove the low energy x-ray photons.

Filters are simply thin sheets of metal. Mammo. sets must have at least 0.03 mm of molybdenum (Mo) to remove the "soft" x-rays.

For thick breast, you need higher energy x-ray photons to get to the film. Therefore, extra filtration is sometimes added to get rid of more of the low energy x-ray photons. e.g. for the Alpha RT units, a 0.03 mm rhodium (Rh) filter is automatically added for breasts above a certain thickness.

Target

In most mammography sets the target is made out of molybdenum (Mo). Some sets (e.g. Siemens Mammomat 3000) also have a tungsten target (W) which gives higher on average energy x-ray photons than Mo, and can be used for very large breasts.

Properties of Radiation

When an x-ray photon is fired at a patient it may

a) pass straight through the breast and hit the film, making a black spot on the film
b) be ABSORBED in the breast
c) be SCATTERED by the breast so that it misses the film
d) be scattered by the breast, but still hit the film in a random position

a, b and c above all add to image quality, but d will add to fogging on the film and reduce image quality.

So ABSORPTION is good for image quality. SCATTERING is good in some ways and bad in others for image quality. ATTENUATION is ABSORPTION plus SCATTERING

For an average mammogram, 99.8% of the X-ray energy is attenuated, with 0.2% reaching the film.

[4] Automatic Exposure Control

Materials

Different materials attenuate by different amounts. A material will attenuate X-rays more if

- it is denser (more grams per cubic centimetre)
- it has a higher atomic number
- it is bigger

kV

The higher the keV of a photon, the less it is attenuated. So the higher the kV set by the radiographer, the more X-ray photons will get through the patient to the film.

At very low kV, virtually all the attenuation is absorption, with very little scattering. As you increase the kV setting, you get a greater proportion of scattering, and therefore more "fogging" and lower image quality.

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