Production of X-rays

Radiation Safety Training for Analytical X-Ray Devices

Module 9

- This module presents information on what X-rays are and how they are produced.

Introduction

Questions? E-mail the RSO: sarah.grant@wku.edu

- X-rays are a type of electromagnetic radiation.
- Other types of electromagnetic radiation are radio waves, microwaves, infrared, visible light, ultraviolet, and gamma rays.
- The types of radiation are distinguished by the amount of energy carried by the individual photons.
- All electromagnetic radiation consists of photons, which are individual packets of energy. For example, a household light bulb emits about 1021 photons of light (non-ionizing radiation) per second.
- The energy carried by individual photons, which is measured in electron volts (eV), is related to the frequency of the radiation.
- Different types of electromagnetic radiation and their typical photon energies are listed in the table on the next slide.

Electromagnetic Radiation

Electromagnetic Radiation		
Type	Typical Photon Energy	Typical Wavelengths
radio wave	1 ueV	1 m
microwave	1 meV	1 mm (10^{-3}m)
infrared	1 eV	1 um (10^{-6}m)
red light	2 eV	6000 Angstrom (10^{-10}m)
violet light	3 eV	4000 Angstrom
ultraviolet	4 eV	3000 Angstrom
X-ray	100 keV	0.1 Angstrom
gamma ray	1 MeV	0.01 Angstrom

Electromagnetic Radiation

- X-rays ionize atoms.
- The energy required for ionization varies with the material (e.g., 34 eV in air, 25 eV in tissue) but is generally in the range of several eV.
- A 100 keV X-ray can potentially create thousands of ions.
- X-rays originate from atomic electrons and from free electrons decelerating in the vicinity of atoms (i.e., Bremsstrahlung).

X-Rays and Ionization

- Radiation-producing devices produce X-rays by accelerating electrons through an electrical voltage potential and stopping them in a target.
- Many devices that use a high voltage and a source of electrons produce X-rays as an unwanted byproduct of device operation. These are called *incidental* X-rays.

X-Ray Production

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- Most X-ray devices emit electrons from a cathode, accelerate them with a voltage, and allow them to hit an anode, which emits X-ray photons.
- These X-ray photons can be categorized as Bremsstrahlung or Characteristic.

X-Ray Production

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- When electrons hit the anode, they decelerate or brake and emit *Bremsstrahlung* (meaning *braking radiation* in German).
- Bremsstrahlung is produced most effectively when small charged particles interact with large atoms, such as when electrons hit a tungsten anode.
- However, Bremsstrahlung can be produced with any charged particles and any target. For example, at research laboratories, Bremsstrahlung has been produced by accelerating protons and allowing them to hit hydrogen.

Bremsstrahlung X-Rays

- When electrons change from one atomic orbit to another, *characteristic X-rays* are produced.
- The individual photon energies are characteristic of the type of atom and can be used to identify very small quantities of a particular element.
- For this reason, they are important in analytical X-ray applications at research laboratories.

Characteristic X-Rays

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- It is important to distinguish between the energy of individual photons in an X-ray beam and the total energy of all the photons in the beam.
- It is also important to distinguish between average power and peak power in a pulsed X-ray device.
- Typically, the individual photon energy is given in electron volts (eV), whereas the power of a beam is given in watts (W).
- An individual 100 keV photon has more energy than an individual 10 keV photon.

Effect of Voltage and Current on Photon Energy and Power

- However, an X-ray beam consists of a spectrum (a distribution) of photon energies, and the rate at which energy is delivered by a beam is determined by the number of photons of each energy.
- If there are relatively more low energy photons, it is possible for the low energy component to deliver more energy.
- The photon energy distribution may be varied by changing the voltage.
- The number of photons emitted may be varied by changing the current.

Effect of Voltage and Current on Photon Energy and Power (cont'd)

- The power supplies for many X-ray devices do not produce a constant potential (D.C.) high voltage but instead energize the X-ray tube with a time varying or pulsating high voltage.
- In addition, since the Bremsstrahlung X-rays produced are a spectrum of energies up to a maximum equal to the electron accelerating maximum voltage, the accelerating voltage of the X-ray device is often described in terms of the peak kilovoltage or kVp.
- A voltage of 50 kVp will produce a spectrum of Xray energies with the theoretical maximum being 50 keV.
- The spectrum of energies is continuous from the maximum to zero. However, X-ray beams are typically filtered to minimize the low-energy component.
- Low-energy X-rays are not useful in radiography, but can deliver a significant dose.
- Whenever the voltage is on, a device can produce some X-rays, even if the current is too low to read.

Voltage

- The total number of photons produced by an X-ray device depends on the current, which is measured in amperes, or amps (A).
- The current is controlled by increasing or decreasing the number of electrons emitted from the cathode.
- The higher the electron current, the more X-ray photons are emitted from the anode.
- Many X-ray devices have meters to measure current. However, as X-rays can be produced by voltage even if the current is too low to read on the meter.
- This is sometimes called dark current. This situation can cause unnecessary exposure and should be addressed in operating procedures.

Current

- Power, which is measured in watts (W), equals voltage times current (P = V x I).
- For example, a 10 kVp device with a current of 1 mA uses 10 W of power.

Determining Electrical Power

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- When X-rays pass through any material, some will be transmitted, some will be absorbed, and some will scatter.
- The proportions depend on the photon energy, the type of material and its thickness.
- X-rays can scatter off a target to the surrounding area, off a wall and into an adjacent room, and over and around shielding.
- A common mistake is to install thick shielding walls around an X-ray source but ignore the roof; X-rays can scatter off air molecules over shielding walls to create a radiation field known as skyshine.
- The emanation of X-rays through and around penetrations in shielding walls is called radiation streaming.
- Enclosed analytical X-ray systems are typically designed by the manufacturer to shield areas outside the enclosure from scattered X-Rays.

Scattering

- When high-speed electrons strike the anode target, most of their energy is converted to heat in the target, but a portion is radiated away as X-rays.
- Cooling the anode is a problem that must be addressed in the design of X-ray machines. Tungsten is used because of its high melting temperature, and copper is used because of its excellent thermal conductivity. These elements may be used together, with a tungsten anode being embedded in a large piece of copper.
- The dose rate in a typical X-ray beam is estimated in Module 5.

Implications of Power and X-Ray Production

- Low- and high-energy photons are sometimes referred to as *soft* and *hard* X-rays, respectively.
- Because hard X-rays are more penetrating, they are more desirable for radiography (producing a photograph of the interior of the body or a piece of apparatus).
- Soft X-rays are less useful for radiography because they are largely absorbed near the surface of the body being X-rayed. However, there are medical applications where soft X-rays are useful.

Filtration

- A filter, such as a few millimeters of aluminum, or copper may be used to *harden* the beam by absorbing most of the low-energy photons. The remaining photons are more penetrating and are more useful for radiography.
- In X-ray analytical work (X-ray diffraction and fluorescence), filters with energy selective absorption edges are not used to *harden* the beam, but to obtain a more monochromatic beam (a beam with predominantly one energy).
- By choosing the right element, it is possible to absorb a band of high energy photons preferentially over an adjacent band of low energy photons.

Filtration

References

- *Radiological Safety Training for Radiation-Producing (X-Ray) Devices*, DOE Handbook, DOE-HDBK-1109-97, August 1997, Reaffirmation with Errata July 2002.