

A spiral-bound notebook with a light-colored, textured cover. The spiral binding is on the left side. The text is centered on the cover.

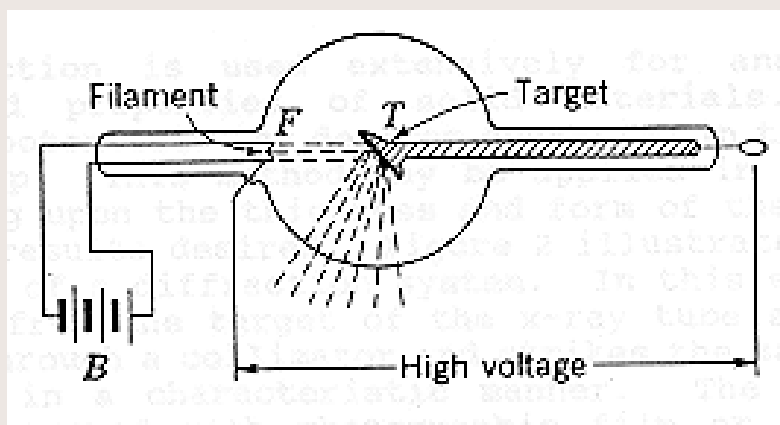
Analytical X-Ray

Training Notes for URI Radiation
Workers

X-Rays

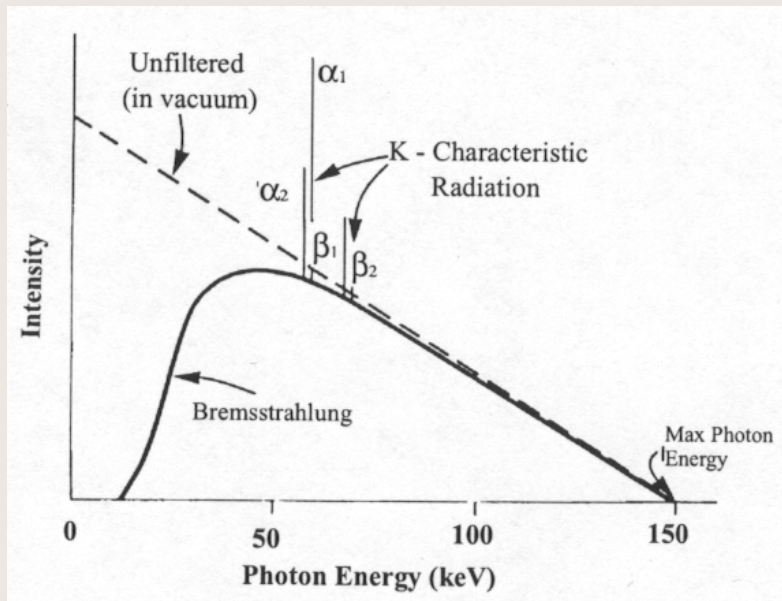
- Electromagnetic ionizing radiation
- Wavelengths: 1×10^{-9} to 6×10^{-12} meters
- Frequencies: 3×10^{17} to 5×10^{19} hertz

X-Ray Tube Operation



- A filament is heated to emit electrons.
- The electrons are accelerated in an electric field toward a target
- The interaction of electrons in the target results in the emission of an x-ray spectrum as shown on the next slide.

X-Ray Spectrum



The spectrum consists of a continuous bremsstrahlung spectrum along with characteristic x-rays from the particular target material.

Characteristic X-Ray Energies

- Copper Target.....8.05 keV
- Molybdenum Target.....17.46 keV
- Silver Target.....22.15 keV
- Chromium Target.....5.39 keV

Relationship Between Wavelength and Frequency

Analytical x-rays are sometimes described by their wavelength rather than their energy. The relationship between wavelength and x-ray photon energy is determined by the equation $E = hc/w$

where

E = energy in ergs ($1\text{eV} = 1.6 \times 10^{-12}$ erg)

h = Planck's constant = 6.614×10^{-27} erg-sec

c = velocity of light = 3×10^{10} cm/sec

w = wavelength in cm ($1\text{\AA} = 1 \times 10^{-8}$ cm)

Wavelength of the Characteristic X-Ray Photon from Silver

Silver has a characteristic x-ray with an energy of 22.15 keV

$$E = hc/w$$

$$22.15 \text{ E}3 * 1.6 \text{ E}-12 = (6.614\text{E}-27 * 3\text{E}10) / w$$

$$W = 5.59\text{E}-9 \text{ cm or } 0.559 \text{ Angstroms}$$

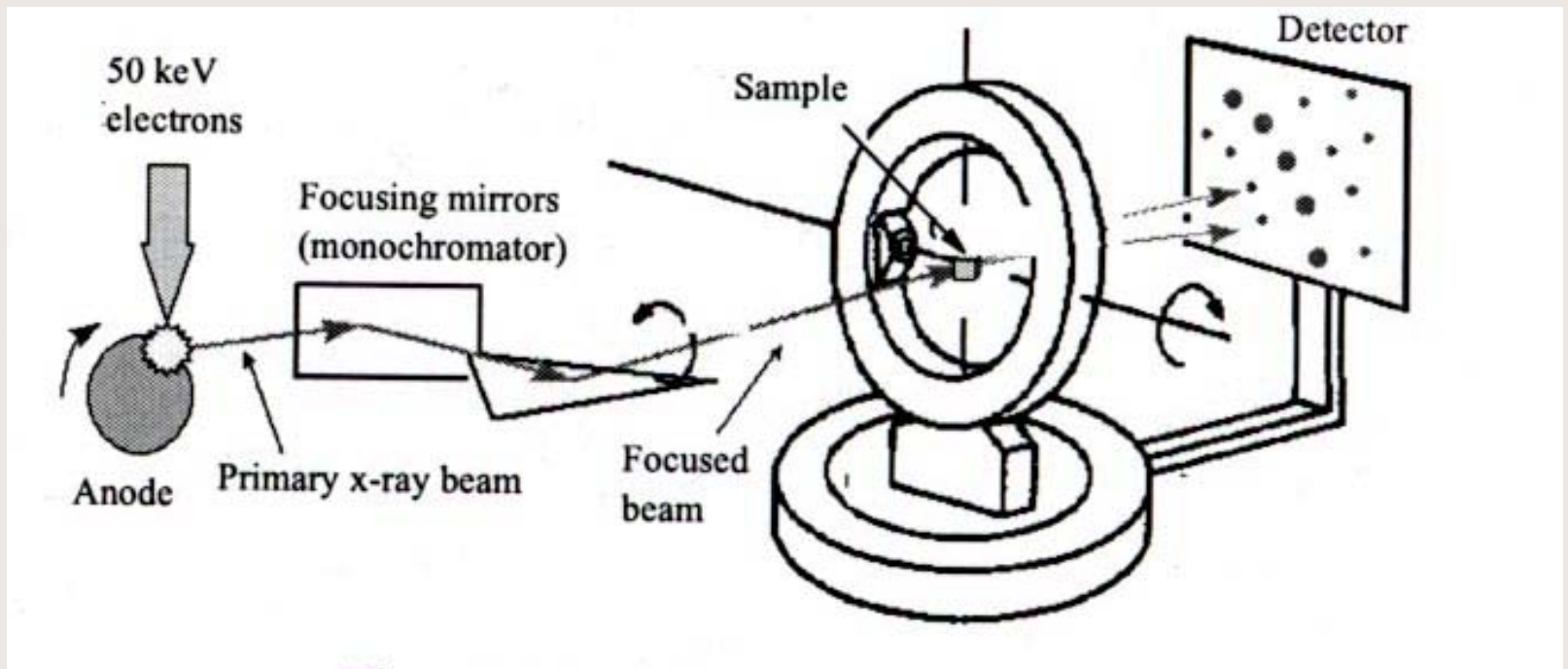
Analytical X-Rays

- Analytical x-ray machines produce intense beams of ionizing radiation that are used for diffraction and fluorescence studies.
- The most intense part of the beam is that corresponding to the K emission of the target material (characteristic radiation).
- In addition to the characteristic radiation, a continuous radiation spectrum of low intensity is produced ranging from a very low energy to the maximum kV-peak setting (bremsstrahlung).

Analytical X-Ray Beam

- X-rays emitted from an open, uncollimated port form a cone of about 30 degrees and include both characteristic and bremsstrahlung x-rays.
- Collimators are used to reduce the beam size to about 1 mm diameter.
- Monochromators are used to filter out undesirable wavelengths.

Schematic for X-Ray Diffraction



Radiation Levels Associated With Analytical X-Ray Machines

| Source | Exposure Rate |
|------------------------------------------------------------|----------------------|
| Primary beam at an open, unshielded port | 50,000-500,000 R/min |
| Primary beam between collimator/slit assemblies and sample | 5,000-50,000 R/min |
| Leakage of primary beam at 5 cm | 0.5-5 R/hr |
| Primary beam at one meter | ~10,000 R/hr |
| Scatter at 5 cm | < 10 - 300 mR/hr |

Analytical X-Ray Hazards

- X-rays produced by diffraction machines are absorbed in the first few millimeters of tissue and do not contribute any dose to the internal organs of the body.
- Tissues at risk include the skin and the lens of the eye.
- Overexposure of the eye can lead to the development of lens opacities and cataracts.

Eye Protection

- The Radiation Safety Office encourages the use of safety glasses or prescription lenses when working with analytical x-rays.
- Glasses cannot provide complete protection of the eyes but they will reduce the x-ray exposure.
- Glass lenses are about 10 times more effective than plastic lenses.
- Neither lens will afford complete protection for the eyes from direct exposure to the primary beam.

Skin and Hand Exposures

- Analytical x-rays are relatively low energy and are readily absorbed by the skin.
- X-ray exposure of the hands may also result in exposure to the bones of the fingers.
- The most common effect of direct exposure is reddening of the skin (erythema).
- The erythema is transitory in nature at absorbed doses of a few hundred rads.
- Higher doses may produce significant cellular damage resulting in pigment changes and chronic radiation dermatitis.

Effects of Acute X-Ray Exposures to Skin

| Exposure | Time Period | Effect(s) |
|-----------|-------------|-------------------------------------------------|
| < 300 R | | Effects generally not observed |
| 300-800 R | 24-48 hours | Erythema |
| 300-800 R | 8-14 days | Erythema peaks |
| 300-800 R | ~4 weeks | Recurrence of erythema |
| > 1,500 R | long term | Scar tissue, Chronic Radiation Dermatitis |

Analytical X-Ray Safety

- Incorporate engineered safety features of a fail-safe design to prevent possible exposures
- For open beam configurations, provide a safety device to prevent entry of hands and other body parts into the primary beam, or that will shut off the X-rays if the beam path is entered.
- Secure unused ports so that the shutters cannot be opened unless a collimator or coupling is connected.
- Employ safety interlocks on tube head ports or shielding.

Analytical X-Ray Safety

- Prevent stray X-rays from escaping the coupling between the X-ray tube and the collimator of the diffractometer, camera, or other accessory.
- Use visual warnings to indicate the potential for radiation exposure on all devices of open beam configuration.
- Provide easily visible flashing lights or equally conspicuous signals located near the tube housing that indicate when the X-ray tube is on or off if the primary beam is controlled in this manner.

Analytical X-Ray Safety

- If the beam is controlled by shutters, locate a readily discernible indication of shutter status (open or closed) near each port on the radiation source housing.
- Use a fail-safe design for warning devices and label them so that their purpose is easily identified.
- Locate a red warning light with the notation "X-RAY ON" or the equivalent, on the control panel and light it only when the X-ray tube is activated.

Analytical X-Ray Safety

- Place a sign or label bearing the words "CAUTION - RADIATION, THIS EQUIPMENT PRODUCES X-RADIATION WHEN ENERGIZED" or words having similar intent, near any switch which energizes an X-ray tube.
- Place a label bearing the radiation symbol and the words "CAUTION - HIGH INTENSITY X-RAY BEAM" on or adjacent to each X-ray tube housing.
- Locate the label so it is clearly visible to any person who may be working near the primary radiation beam.

Analytical X-Ray Safety

- Post each area or room containing analytical X-ray equipment with a sign bearing the radiation symbol and the words "CAUTION - X-RAY EQUIPMENT".
- Test all safety devices (e.g., interlocks, shields, shutters, warning lights, etc.) to insure their proper operation.