SAWA UNIVERSITY

اساسيات الفيزياء الشعاعية/ الكورس الاول

X-RAY EMISSION: FACTORS INFLUENCING X-RAY SPECTRA AND OUTPUT



Sawa University	جامعـــــــة ســـــــاوة الاهلية
College of health and medical techniques	كليـــــة التقنيـــات الصحيـة والطبيـة
Department of Radiology Tech.	قسم تقنيات الاشعة والسونار
Second Stage	المرحلـــــــــــــة الثانية

الجانب النظري

Theoretical

محاضرة رقم (6)

Lecture No. (6)

تدريسي المادة : م.م. احمد عكاب شراد

The factors influencing the X-ray spectra and output in X-ray tubes include both operational parameters and design elements. These factors affect the characteristics of X-rays produced, such as energy, intensity, and quality, and are critical for optimizing imaging and minimizing patient dose.

Factors Influencing X-Ray Spectra

The X-ray spectrum consists of two components: Bremsstrahlung radiation (continuous spectrum) and characteristic radiation (discrete peaks). Several factors influence these components:

1. Tube Voltage (kVp)

- **Effect on Energy:** Higher kVp increases the maximum energy of the X-rays (photon energy is proportional to the tube voltage).
- **Effect on Spectra:** A higher kVp increases the intensity of Bremsstrahlung radiation and makes the spectrum harder (more high-energy photons).
- **Threshold for Characteristic X-rays:** The tube voltage must exceed the binding energy of inner-shell electrons to produce characteristic radiation.

2. Target Material

- **Atomic Number (Z):** Higher atomic number materials (e.g., tungsten) produce more intense and higher-energy X-rays due to increased Bremsstrahlung efficiency and higher binding energies for characteristic radiation.
- **Binding Energy:** The specific energy levels of characteristic X-rays depend on the material, with tungsten producing prominent Kα and Kβ peaks (~59 keV and ~67 keV).

3. Filtration

- **Inherent and Added Filtration:** Filters (e.g., aluminum or molybdenum) absorb low-energy photons that do not contribute to image quality and increase patient dose.
- **Beam Hardening:** Filtration increases the mean photon energy (beam hardening) by removing softer X-rays from the spectrum.

4, Tube Current (mA)

Effect on Intensity: Higher mA increases the number of electrons emitted by the cathode, proportionally increasing the X-ray output (intensity) without altering the spectral shape.

5. Exposure Time

Effect on Output: Longer exposure times allow more X-rays to be produced, increasing the total intensity but not the spectrum shape.

5. Geometry and Focal Spot Size

Focal Spot Size: A smaller focal spot can improve spatial resolution but may concentrate heat, affecting the target's ability to handle high output.

5. 7. Target Angle

Effect on Distribution: The angle of the anode target affects the apparent focal spot size and the distribution of emitted X-rays. A steeper angle concentrates the beam, increasing intensity in the central axis.

Factors Influencing X-Ray Output

X-ray output refers to the intensity (quantity) of X-rays produced by the tube. Key influencing factors include:

1. Tube Voltage (kVp)

Higher kVp increases both the energy and the number of X-rays produced due to enhanced Bremsstrahlung production.

2. **Tube Current (mA)**

Directly proportional to X-ray output; doubling the mA doubles the output.

3. Filtration

While filtration reduces low-energy photons, it also decreases the overall output, requiring careful balancing to maintain diagnostic quality.

4. Target Material and Anode Design

High-Z materials enhance Bremsstrahlung output and support higher heat loads, improving efficiency and output stability during prolonged use.

5. Distance from Source (Inverse Square Law)

Intensity decreases with the square of the distance from the X-ray source (important for patient positioning and dose management).

X-Ray Quantity

X-ray quantity refers to the intensity or the total number of X-ray photons produced in the X-ray tube. It is a measure of the output radiation and is critical in determining the exposure and image brightness in diagnostic imaging. Several factors influence the quantity of X-rays generated.

Factors Influencing X-Ray Quantity

a. Tube Current (mA)

- Proportional Relationship: The quantity of X-rays is directly proportional to the tube current.
- If the mA is doubled, the number of X-rays produced also doubles.
- Mechanism: Increasing mA increases the number of electrons emitted from the cathode, leading to more electron-target interactions.

2. **Exposure Time (s)**

- Linear Effect: X-ray quantity is also directly proportional to the exposure time.
- Longer exposure times result in more electrons interacting with the target and, therefore, more X-rays being produced.

3. Tube Voltage (kVp)

- Quadratic Relationship: X-ray quantity increases approximately with the square of the kVp.
- For example, increasing the kVp from 60 to 80 results in a significant rise in X-ray quantity.
- Mechanism: Higher kVp accelerates electrons to higher velocities, increasing their interaction with the target material and producing more photons.

4. Distance from the Source

- Inverse Square Law: The intensity of X-rays decreases with the square of the distance from the source.
- If the distance is doubled, the quantity of X-rays per unit area is reduced by a factor of four.

5. Filtration

- Reduction of Low-Energy Photons: Filtration reduces the quantity of X-rays by removing low-energy photons that are unlikely to penetrate the patient or contribute to the image.
- While filtration improves beam quality, it decreases the overall quantity of X-rays.

6. Target Material

- Atomic Number (Z): Higher-Z materials, like tungsten, produce more X-rays due to increased Bremsstrahlung efficiency.
- Efficiency: A target with a higher atomic number increases the interaction probability, thus generating a higher photon quantity.

7. Collimation

Beam Restriction: Collimation limits the size of the X-ray beam to the area of interest, reducing unnecessary exposure but also decreasing the total quantity of X-rays emitted in directions outside the collimated field.

Measurement of X-Ray Quantity

X-ray quantity is typically measured in terms of:

- Exposure (Roentgen, R): The amount of ionization produced in air.
- Air Kerma (Gray, Gy): The energy transferred from radiation to air per unit mass.
- Intensity: The number of photons per unit area at a specific distance from the X-ray source.

X-Ray Intensity

X-ray intensity refers to the energy delivered by the X-ray beam per unit area and per unit time. It represents the concentration of the X-ray beam and is often synonymous with the term X-ray beam quality and quantity combined. Intensity is critical in medical imaging and radiation therapy as it influences image contrast and patient dose.

Definition and Formula

X-ray intensity is defined as the amount of radiation energy passing through a unit area per unit time, and it is influenced by the number and energy of the X-ray photons.

Mathematically:

$$I \propto \frac{\text{Number of Photons} \times \text{Energy per Photon}}{\text{Area} \times \text{Time}}$$

Influence of Electron Energy

The energy of the incident electrons in an X-ray machine plays a critical role in determining the production and characteristics of X-rays, including characteristic radiation.

1. Electron Energy and Characteristic Radiation

a. Threshold Energy for Production

The energy of the incoming electrons must be at least equal to the binding energy of the inner-shell electrons of the target material for characteristic X-rays to be generated.

Example: For tungsten, the K-shell binding energy is 69.5 keV. If the electron energy is below this value, no K-shell characteristic X-rays are produced.

b. Efficiency of Characteristic X-ray Production

As electron energy increases above the threshold, the probability of inner-shell electron ejection increases, leading to a higher production of characteristic X-rays.

However, if electron energy is excessively high, bremsstrahlung (continuous) radiation becomes dominant, reducing the relative contribution of characteristic radiation to the total X-ray output.

2. Influence on Dose

a. Dose Efficiency

At optimal electron energy, characteristic X-rays dominate, delivering efficient radiation with minimal waste, reducing the patient dose.

At very high electron energies, bremsstrahlung becomes dominant, and the X-ray beam includes many photons that may not contribute significantly to imaging but increase patient dose.

b. Unnecessary Low-Energy Radiation

If electron energy is only slightly above the binding energy, many low-energy X-rays are produced. These are absorbed by superficial tissues, increasing the patient dose without improving image quality.

Filters are used to remove these low-energy photons, emphasizing higher-energy characteristic radiation.

Parameter	Low Electron Energy	High Electron Energy
X-ray Type	Dominated by characteristic radiation	Dominated by bremsstrahlung radiation
Beam Hardness	Soft beam (low penetration)	Hard beam (high penetration)
Image Contrast	High (photoelectric effect dominates)	Low (Compton scatter dominates)
Patient Dose	Higher if energy is too low	Higher if energy is excessive

Influence of Target Material

Target Material	Atomic Number (Z)	Kα Energy	Applications	Advantages
Tungsten	74	~59 keV	General radiography, fluoroscopy, CT	High-energy X-rays, good penetration, durable.
Molybdenum	42	~17 keV	Mammography	Low-energy X-rays for soft tissue contrast, reduced patient dose.
Rhodium	45	~20 keV	Mammography (alternative to molybdenum)	Slightly higher energy than molybdenum, suitable for denser breast tissues.
Copper	29	~8 keV	X-ray diffraction (XRD)	Low-energy characteristic X-rays for material analysis.

Influence of Filtration

Filtration in X-ray machines significantly impacts the quality of the X-ray beam, image contrast, and patient dose. Filters are used to selectively absorb lower-energy X-rays that contribute to patient dose without improving image quality, allowing the higher-energy (more penetrating) photons to dominate the beam.

1. Purpose of Filtration

a. Remove Low-Energy X-rays

Low-energy X-rays from the bremsstrahlung spectrum:

- Are absorbed in the patient's superficial tissues without contributing to image formation.
- Increase the patient's radiation dose unnecessarily.

b. Beam Hardening

Filters remove low-energy photons, leaving a beam with a higher average photon energy (a "harder" beam). This improves the beam's penetration, especially for dense tissues like bone, and reduces scatter.

c. Optimize Imaging for Specific Applications

Filtration tailors the X-ray spectrum to match the diagnostic needs of different modalities:

- High-energy X-rays for general radiography.
- Lower-energy X-rays for soft tissue imaging like mammography.

2. Types of Filtration

Filtration is classified into inherent and added filtration.

a. Inherent Filtration

Provided by the X-ray tube design and housing, including:

- The glass or metal envelope of the X-ray tube.
- Cooling oil surrounding the tube.
- Any protective window.
- Typical inherent filtration: 0.5–1.0 mm of aluminum equivalent.

b. Added Filtration

Additional materials are placed in the path of the X-ray beam to further modify its spectrum.

Materials commonly used:

- **Aluminum (most common):** Effective at absorbing low-energy photons while allowing higher-energy photons to pass.
- **Molybdenum or Rhodium**: Used in mammography to shape the beam for soft tissue imaging.
- **Copper**: Used in specialized applications requiring higher-energy filtration.
- Added filtration typically ranges from 1–3 mm of aluminum equivalent for general radiography.

Aspect	Advantages	Limitations
Beam Quality	Removes low-energy photons, increases penetration, and improves contrast.	Excessive filtration reduces beam intensity, possibly requiring higher settings.
Patient Dose	Reduces skin dose by removing non-diagnostic radiation.	Inappropriate filtration can increase dose if higher exposure settings are needed.

Lecture 6 | End-of-lecture MCQ review

Choose one answer for each question. Correct answers are highlighted in green.

1. The X-ray spectrum contains continuous radiation and:

A. Characteristic peaks ✓ B. Visible light
C. Only electrons D. Ultrasound
E. Neutrons

2. Increasing kVp generally increases maximum photon:

A. Number only **B. Energy ✓**
C. Wavelength D. Exposure time
E. Filtration

3. Doubling mA at fixed settings approximately doubles:

A. X-ray output ✓ B. Maximum photon energy
C. Target Z D. Peak energy
E. Anode angle

4. Longer exposure time increases total:

A. Photon quantity ✓ B. Peak energy
C. Atomic number D. Tube voltage
E. Filter thickness

5. Filtration reduces total photon count while increasing:

A. Mean beam energy ✓ B. mA
C. Exposure time D. Target Z
E. Field size

6. When source distance doubles, intensity becomes:

A. Twice B. Half
C. One quarter ✓ D. Four times
E. Unchanged

7. Tungsten K-shell characteristic emission needs about:

A. 20 keV B. 40 keV
C. 69.5 keV ✓ D. 5 keV
E. 150 keV

8. A smaller focal spot generally improves:

A. Spatial resolution ✓ B. Heat tolerance
C. Tube ripple D. Filtration
E. Exposure time

9. Increasing target atomic number generally raises:

A. Bremsstrahlung efficiency ✓ B. Source distance
C. Anode speed D. Detector area
E. Tube current

10. Inherent filtration may include tube envelope and:

A. Cooling oil ✓ B. Patient table
C. Image monitor D. Stator windings
E. Grid lines