Chapter 6

Mammography
Rationale

- Mammography is a radiographic procedure specially designed for detecting breast pathology
- Approximately 1 woman in 8 will develop breast cancer over a lifetime
- Breast cancer screening programs rely on x-ray mammography because it is a low-cost, low-radiation-dose procedure with the sensitivity to detect early-stage breast cancer
Same breast imaged 10 years apart

- High kVp
- Hard beam
- Early screen-film technology
- Minimal compression

- Lower kVp
- “Tuned” energy beam
- Current screen-film technology
- Better compression
Differential Attenuation

- Small x-ray attenuation differences between normal and cancerous tissues in the breast require the use of x-ray equipment specially designed to optimize breast cancer detection.
- Attenuation differences between these tissues is highest at very low x-ray energies (10 to 15 keV) and is poor at higher energies (>35 keV).
- Low x-ray energies provide best differential attenuation between the tissues; high absorption results in high tissue doses and long exposure time.
Because of the risks of ionizing radiation, techniques that minimize dose and optimize image quality are essential, and have led to:

- Refinement of dedicated x-ray equipment
- Specialized x-ray tubes
- Compression devices
- Antiscatter grids
- Phototimers
- Detector systems
Mammographic x-ray tubes typically have dual filaments in a focusing cup that produces 0.3 and 0.1 mm nominal focal spot sizes
  ◦ Minimize geometric blurring and maintain spatial resolution necessary for microcalcification detection

*Space charge effect* causes nonlinear relationship between filament current and tube current
  ◦ Feedback circuits adjust filament current as a function of kV to deliver desired tube current
Mammographic x-ray tubes use a rotating anode

Molybdenum is the most common anode material; rhodium & tungsten also used

Source to image distance (SID) of 65 cm requires the effective anode angle to be at least 20° to avoid field cutoff for the 24 x 30 cm field area

Combination of anode angle and tube tilt used
0° Anode angle

24° tube tilt

Cathode

16° Anode angle

6° tube tilt

Approximately same field coverage
Heel Effect

- Lower x-ray intensity on the anode side of the field at short SID is very noticeable.
- Positioning the cathode over the chest wall of the patient and the anode over the nipple achieves better uniformity of the radiation transmitted through the breast.
- Orientation of the tube in this fashion also decreases the equipment bulk near the patient’s head for easier positioning.
Focal Spot considerations

- Focal spot sizes range from 0.3 to 0.4 mm for nonmagnification (contact) imaging, and from 0.1 to 0.15 mm for magnification imaging.
- Focal spot and central axis are positioned over the chest wall at the image receptor edge.
- A *reference axis*, which typically bisects the field, is used to specify the projected focal spot size.
24° tube tilt

65 cm SID

$\phi = 12°$

$\theta = 24°$

Reference Axis

Central Axis

Projected focal area

Actual focal area

- length
- width

29 cm
Computer modeling studies show that the optimal x-ray energy to achieve high subject contrast and the lowest radiation dose would be a monoenergetic beam of 15 to 25 keV, depending on breast composition and thickness.

Optimal x-ray energy is achieved by the use of specific x-ray tube target materials and added filtration materials.

Molybdenum and rhodium are used for targets.
Molybdenum target
26 kVp

Bremsstrahlung

Binding Energy
K = 20 keV
L = 2.5 keV
M = 0.4 keV

Characteristic

Composite

19.6 keV
17.5 keV
Filtration

- Inherent filtration must be kept low; beryllium (Z = 4) is used for the tube port.
- Added tube filters of the same element as the target reduce the low- and high-energy x-rays in the spectrum and allow transmission of the characteristic x-ray energies.
Linear Attenuation Coefficient

\[ \mu \text{ (cm}^{-1}) \times 10^3 \]

Energy (keV)

\[ \begin{align*}
\mu_{\text{Mo}} & \quad \text{Mo} \\
\mu_{\text{Rh}} & \quad \text{Rh}
\end{align*} \]
Mo target -- Unfiltered spectra

Energy, keV

x 10^6 photons/mm²

30 kVp
26 kVp

to 72 x 10^6
Mo target -- 0.030 mm Mo filter

![Graph showing photon intensity vs. energy for Mo target with 0.030 mm Mo filter. The graph includes two curves for 30 kVp and 26 kVp, with peak intensities observed around 15 keV for 30 kVp and 20 keV for 26 kVp. The y-axis represents the number of photons per square millimeter, with values ranging from 0 to 35 x 10^6. The x-axis represents energy in keV, ranging from 5 to 30 keV.](image-url)
30 kVp -- 0.025 mm Rh filter

x $10^6$ photons/mm²

Energy, keV

- --- Mo target
- ---- Rh target
Collimation

- For most mammography examinations, the field size matches the film cassette sizes (e.g., 18 x 24 cm or 24 x 30 cm)
- Variable shutters on some systems allow the x-ray field to be more closely matched to the breast volume
  - In practice, the large unexposed area of the film from the tight collimation allows a large fraction of light transmission adjacent to the breast anatomy on a light box, and can result in poor viewing conditions
High-frequency generators are the standard for mammography systems.

Unlike most conventional x-ray units, the AEC detector is located *underneath* the cassette.

Phototimer algorithms take into account the radiographic technique (kVp, target/filter) and, in the case of extended exposure times, reciprocity law failure, to achieve the desired film optical density.

- Fully automatic AEC sets the optimal kV and filtration from a short test exposure of ~100 msec.
End of Chapter