

Chapter 9: Mammography

Slide set of 66 slides based on the chapter authored by M.J. Jaffe and A.D.A. Maidment of the IAEA publication (ISBN 978-92-0-131010-1):

*Diagnostic Radiology Physics:
A Handbook for Teachers and Students*

Objective:

To familiarize the student with the requirements and principles of imaging of the breast using X ray mammography.



IAEA
International Atomic Energy Agency

Slide set prepared
by C P Lawinski (BSc, MSc, MPhil),
London, UK

- 9.1. Introduction
 - 9.2. Radiological requirements for mammography
 - 9.3. X ray equipment
 - 9.4. Image receptors
 - 9.5. Display of mammograms
 - 9.6. Breast tomosynthesis
 - 9.7. Breast CT
 - 9.8. Computer-aided diagnosis
 - 9.9. Stereotactic biopsy systems
 - 9.10. Radiation dose
- Bibliography

9.1. INTRODUCTION

- ❑ **Breast cancer** is a major killer of women
- ❑ Over 1.38 million women diagnosed with breast cancer internationally in 2008
 - More than **458,000 deaths**
- ❑ Causes not currently known
- ❑ Mortality can be significantly reduced if disease is **detected at an early stage**

9.2. RADIOLOGICAL REQUIREMENTS FOR MAMMOGRAPHY

- ❑ **Mammography** is a radiographic (X ray) procedure optimized for examination of the breast
- ❑ Highly effective means of detecting early-stage breast cancer
- ❑ Mammography is used both for
 - Investigating **symptomatic patients** (diagnostic mammography)
 - Screening of **asymptomatic women** (selected age groups)
- ❑ A typical mammographic screening examination consists of one or more commonly two views of each breast
 - Cranio-caudal (CC) and medial-lateral oblique (MLO)
- ❑ Other uses
 - Pre-surgical localisation and guidance of biopsies.

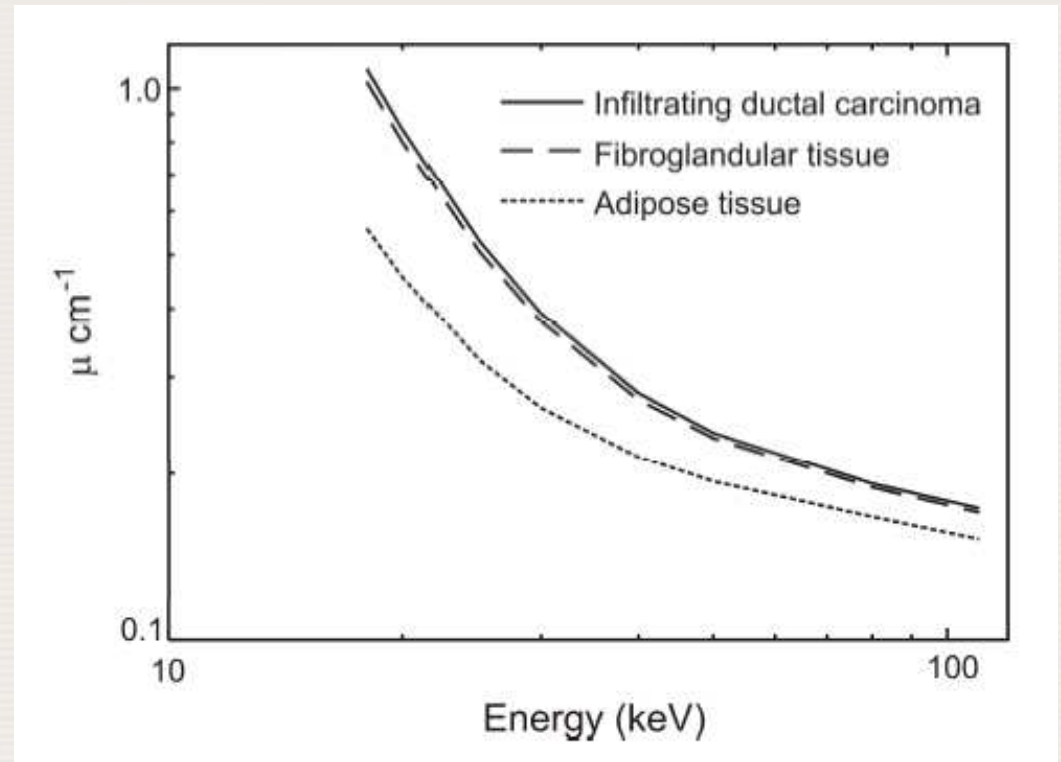
9.2. RADIOLOGICAL REQUIREMENTS FOR MAMMOGRAPHY

- ❑ A medial-lateral oblique (MLO) mammogram is shown
 - The pectoralis muscle is visualized
 - Characteristic benign calcifications are seen



9.2. RADIOLOGICAL REQUIREMENTS FOR MAMMOGRAPHY

- ❑ Breast tissues intrinsically lack **subject contrast**
- ❑ **Low-energy X ray spectrum** required
- ❑ Emphasises compositional differences of the breast



Dependence of the linear X ray attenuation coefficient (μ) on X ray energy.

9.2. RADIOLOGICAL REQUIREMENTS FOR MAMMOGRAPHY

- ❑ **Sufficient spatial resolution**
 - Details possibly as fine as 50 μm must be adequately visualised
- ❑ **Adequate contrast** in image
 - Low-energy X ray spectra
- ❑ **Broad dynamic range**
 - Required due to composition of the breast and age-dependent changes in the breast
- ❑ **Lowest absorbed dose** compatible with adequate diagnostic image quality

9.3. X RAY EQUIPMENT

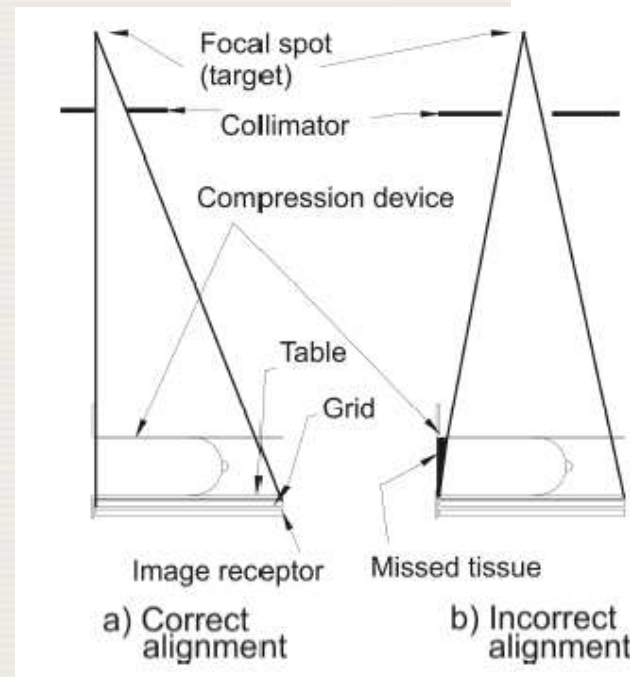
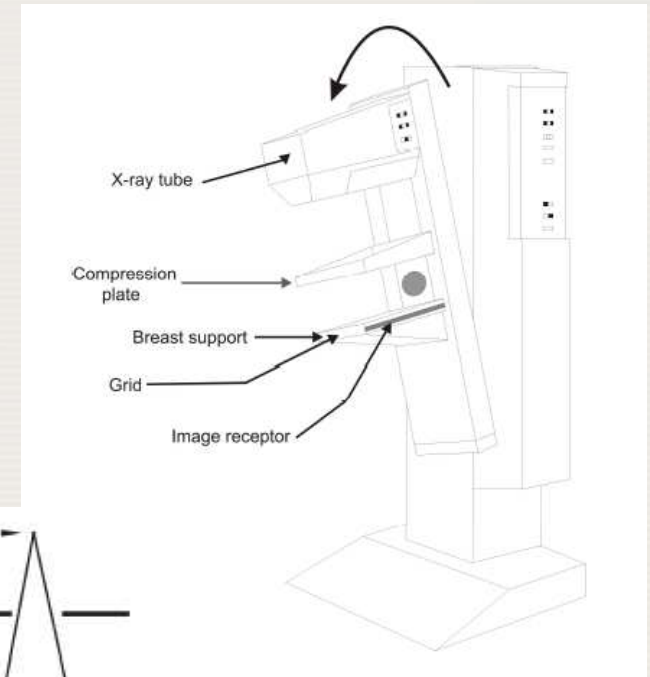
❑ Specialised gantry to accommodate the breast

- Rotation and vertical movement

❑ Specialised beam geometry

- Improves visualisation of chest wall edge

Schematic of a mammography imaging system.

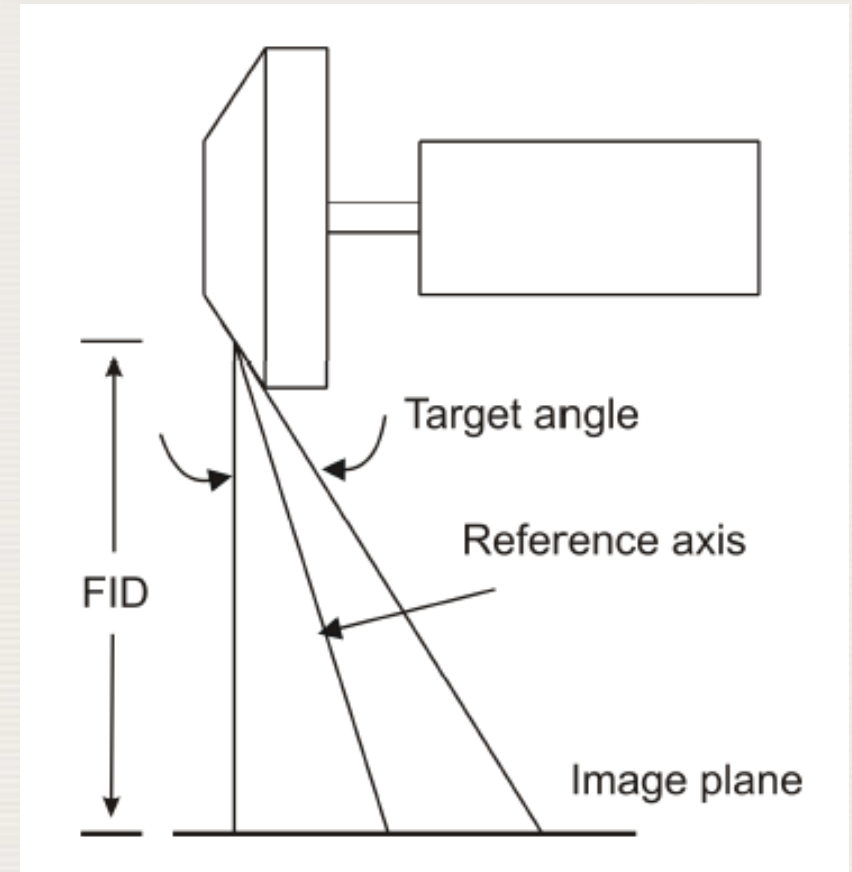


System geometry for image acquisition showing a) correct alignment and b) missed tissue associated with incorrect alignment.

9.3. X RAY EQUIPMENT

9.3.1. Tubes, filters and spectra

- ❑ X ray generator
 - High frequency
 - Near constant potential waveform
- ❑ X ray tube
 - Rotating anode
 - Dual focus 0.3/0.1 mm
 - **Beryllium** exit window (low attenuation)
- ❑ FID (focus image distance) generally in the range 60 to 65 cm



The geometry of an X ray tube. The perpendicular line abuts the chest wall. The reference axis on a particular system will be specified by the manufacturer.

9.3. X RAY EQUIPMENT

9.3.1. Tubes, filters and spectra

- ❑ X ray spectrum should provide a range of energies that give an appropriate compromise between **radiation dose** and **image quality** for the tissues under examination
- ❑ X ray spectrum determined by **target material, filter material, and tube voltage** (kV)
- ❑ For screen-film mammography optimum beam energy lies between 18 and 23 keV depending on breast thickness and composition
 - Characteristic X rays from **molybdenum and rhodium** are suitable
- ❑ Higher energies may be more optimal for digital mammography

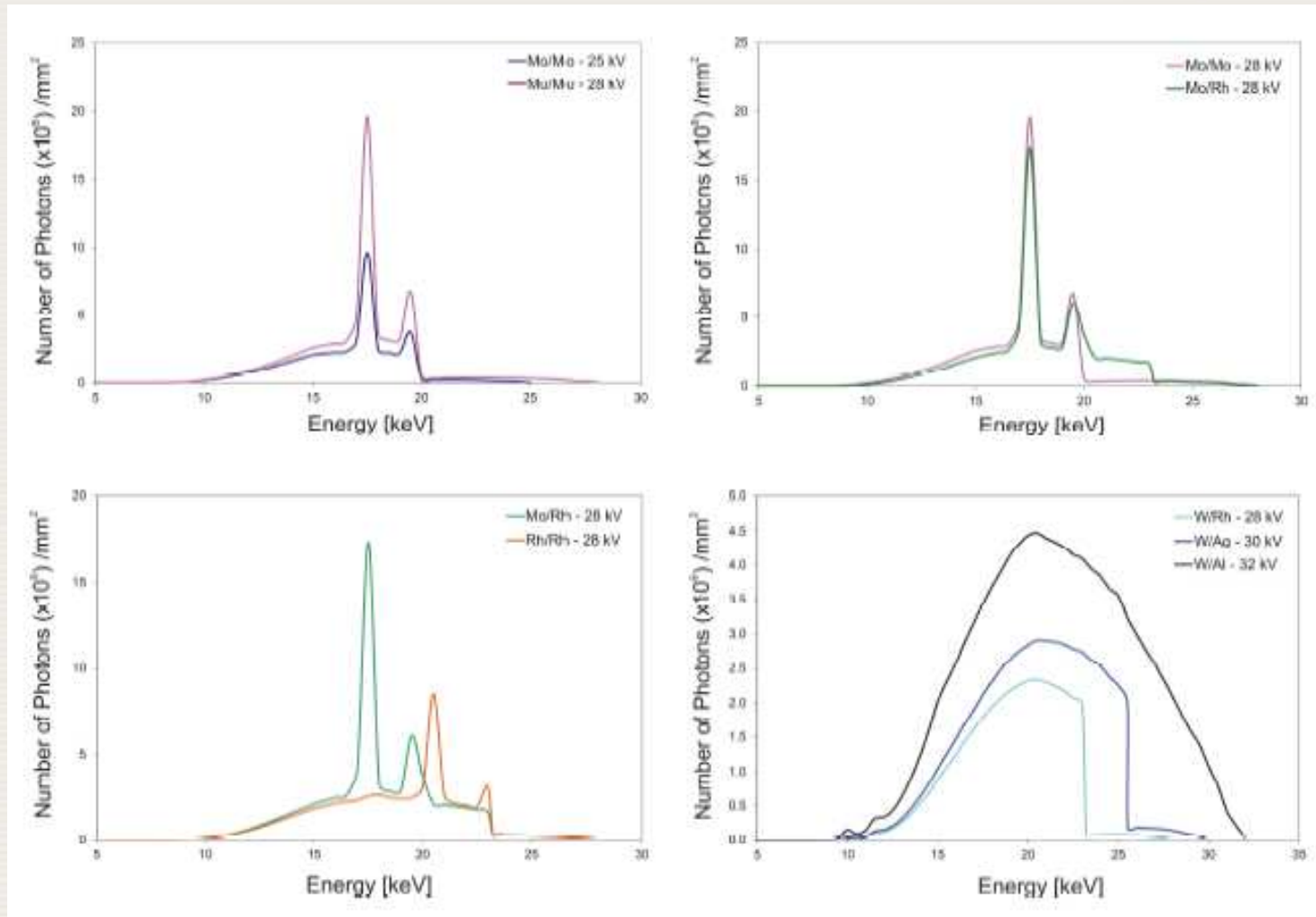
9.3. X RAY EQUIPMENT

9.3.1. Tubes, filters and spectra

- ❑ Metallic filters used in mammography
- ❑ Molybdenum (Mo) filter (30 to 35 μm thick) commonly employed with Mo anode
- ❑ Filter acts as energy window
 - Greater attenuation of X rays at low energies and at energies above the K-absorption edge of Mo at 20 keV
 - Mo characteristic X rays from the target and X rays of similar energy produced by bremsstrahlung pass through the filter
 - Resultant spectrum enriched with X rays in the range 17 to 20 keV
- ❑ **Higher energies** are desirable for imaging **thick, dense breasts**
 - Use of Mo/Rh (molybdenum/rhodium) and Rh/Rh target/filter combinations

9.3. X RAY EQUIPMENT

9.3.1. Tubes, filters and spectra



Examples of mammographic X ray spectra.

9.3. X RAY EQUIPMENT

9.3.2. Compression

- ❑ Compression should be firm but not painful
- ❑ Reasons for applying compression
 - Reduces superposition of tissues
 - Decreases ratio of scattered to transmitted radiation reaching the image receptor
 - Decreases the distance from any plane within the breast to the image receptor reducing geometric unsharpness
 - Compressed breast provides lower overall attenuation allowing radiation dose to be reduced
 - Compressed breast provides more uniform attenuation over the image reducing the exposure range which must be recorded
 - Provides a clamping action reducing anatomical motion during the exposure reducing image unsharpness

9.3. X RAY EQUIPMENT

9.3.3. Grids

- ❑ **Scattered radiation** reduces image quality
- ❑ Use of grid significantly decreases ratio of scattered to transmitted radiation reaching the image receptor
- ❑ Focused linear grids (integral part of the system)
- ❑ **Grid moves during exposure** to blur the image of the grid septa
 - Motion must be uniform and of sufficient amplitude to avoid non-uniformities in the image
- ❑ Bucky factor (increase in dose due to use of grid) can be as large as 2 to 3
 - Justified by improvement in image quality

9.3. X RAY EQUIPMENT

9.3.4. Automatic exposure control

- ❑ All modern mammography units are equipped with **automatic exposure control (AEC)**
- ❑ Essential in order to provide the **optimum dose** to the image receptor
 - **Target optical density** for screen-film mammography
 - Target SNR (signal-to-noise ratio) or preferably **SDNR (signal-difference-to- noise ratio)** for digital mammography

9.3. X RAY EQUIPMENT

9.3.4. Automatic exposure control

- ❑ For screen-film mammography and cassette-based digital systems AEC sensor located behind image receptor to avoid a shadow on the image
- ❑ Sensor terminates exposure when pre-set amount of radiation received by the image receptor
- ❑ Location of sensor adjustable
 - Can be positioned below appropriate region of the breast
- ❑ AEC generally microprocessor controlled
 - Correction for reciprocity law failure of the film
 - Automatic selection of exposure parameters (kV, filter, target) depending on breast thickness and composition
 - Sensing of breast thickness (compression device) and attenuation (short (typically <100 ms) X ray pre-exposure)

9.3. X RAY EQUIPMENT

9.3.4. Automatic exposure control

- ❑ For digital mammography the digital detector can act as the AEC sensor
- ❑ Pre-exposure concept typically used
 - Entire low-dose image captured by the digital detector
 - Image analysed to determine the overall SDNR or minimum SDNR over small ($\sim 1\text{cm}^2$) region-of-interest (roi) in the image
 - Target, filter and kV selected automatically to give desired SDNR when main exposure performed
 - As digital detectors can be operated at a wide range of input dose levels, possible to optimize imaging according to a priority of SDNR, low dose or a combination.
- ❑ Development in this area is on-going
 - Location of the edges or critical areas of breast identified automatically

9.3. X RAY EQUIPMENT

9.3.5. Magnification mammography

- ❑ Magnification mammography can be used to **improve the diagnostic quality** of the image
- ❑ **Breast supported above the image receptor**
 - Focus object distance reduced
 - Object to image receptor distance increased
 - Magnification results
- ❑ **Benefits of magnification mammography**
 - Increased SNR
 - Improved spatial resolution
 - Dose-efficient scatter rejection.

9.3. X RAY EQUIPMENT

9.3.5. Magnification mammography

- ❑ Main benefit of magnification is to increase the size of the projected anatomic structures compared to the granularity of the image
 - SNR in the image is improved
 - Improvement can be valuable, particularly for the visualization of fine calcifications and spiculations
- ❑ Magnification in digital mammography
 - Film grain noise eliminated
 - Limiting spatial resolution of detector lower than that provided by the screen-film image receptor
 - Benefits of magnification may be different in nature
 - Increase in projected size of anatomical features does improve the effective resolution of the detector, which in some cases is a limiting factor

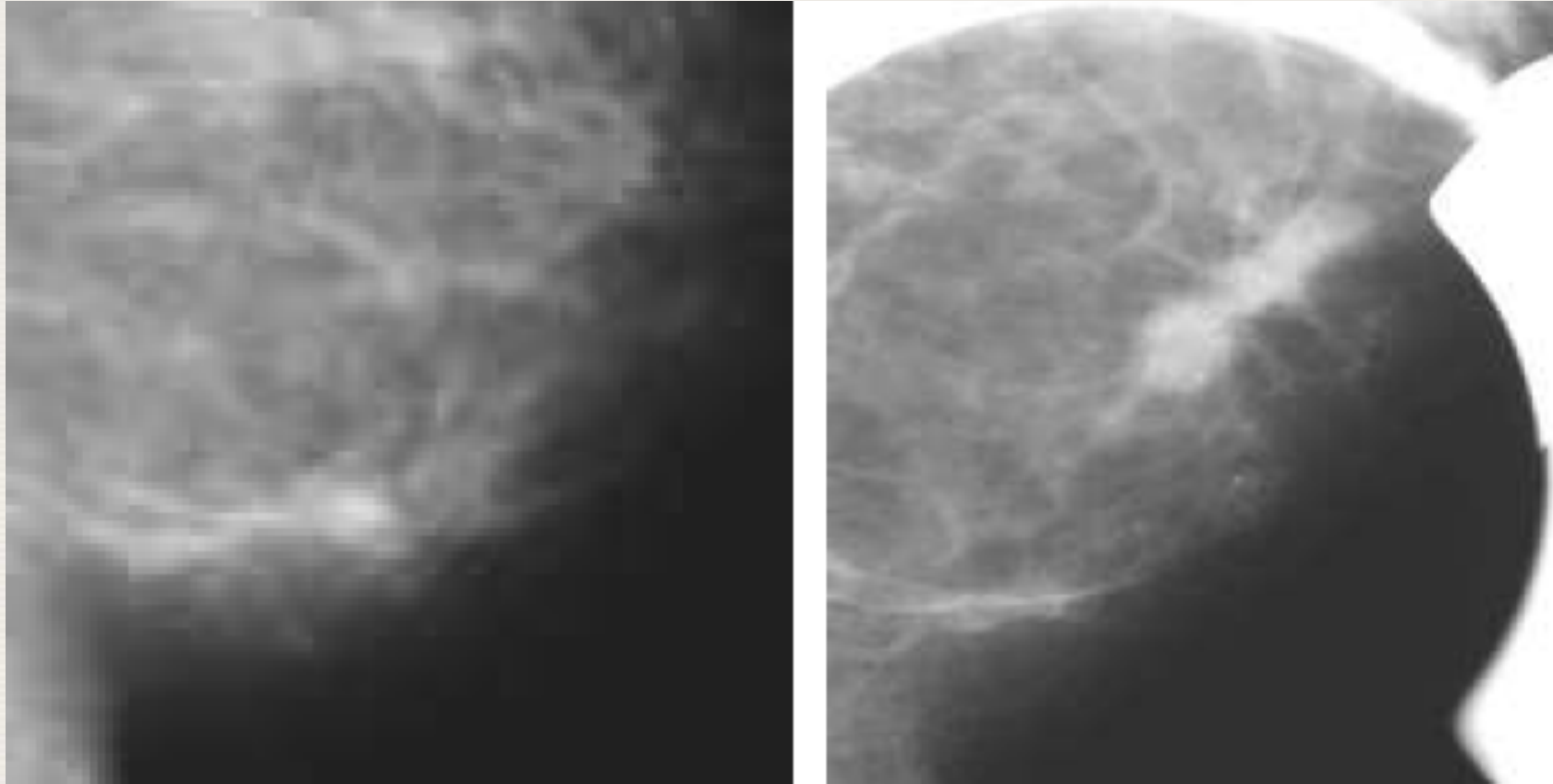
9.3. X RAY EQUIPMENT

9.3.5. Magnification mammography

- ❑ Spatial resolution in magnification mammography is limited by focal spot size
 - Use of a small spot (typically 0.1 mm) is critical
- ❑ As the breast is closer to the X ray source in magnification mammography
 - Dose to breast increases (compared to contact mammography)
 - Air gap between the breast and image receptor provides some scatter rejection
 - Anti-scatter grids not employed for magnification (partially offsets increase in dose)

9.3. X RAY EQUIPMENT

9.3.5. Magnification mammography



A suspicious region is visible in the lower aspect of the mammogram (left). A magnified image of this region obtained with focal compression shows an obvious mass (right).

9.4. IMAGE RECEPTORS

- ❑ Screen-film mammography
- ❑ Digital mammography
 - Area detectors
 - Indirect detectors
 - Direct detectors
 - Photo-stimulable phosphors (computed radiography or CR)
 - Scanning detectors
 - Photon counting detectors

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ **Single back intensifying screens** used with **single emulsion radiographic film** enclosed in a light-proof cassette
- ❑ High resolution fluorescent intensifying screen
 - Absorbs X rays
 - Converts the pattern of X rays into an optical image
- ❑ Two sizes of film typically available
 - **18 cm x 24 cm** and **24 cm x 30 cm**
- ❑ Customary to use the smallest possible size which ensures complete coverage of the breast
 - Superior breast positioning and compression
- ❑ Women with large breasts, may require multiple films to image the breast fully

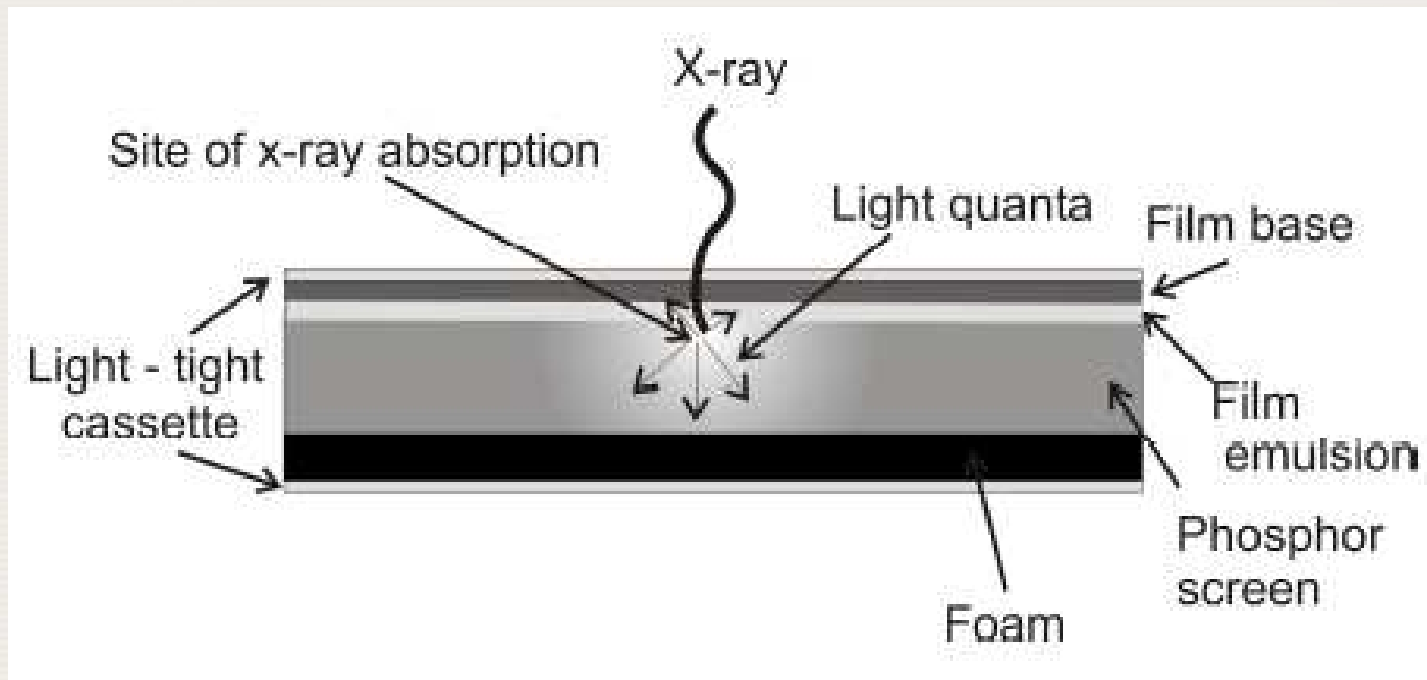
9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ Screen and film are arranged in the cassette as shown (next slide)
- ❑ X rays must pass through cover of the cassette and the film to impinge upon the screen
 - As absorption is exponential, a larger fraction of the X rays are absorbed and converted to light near the entrance surface of the screen
 - By minimizing the distance that the light must travel before being collected by the film, blurring due to lateral spreading is reduced
 - Spatial resolution is improved
 - To further discriminate against light quanta travelling along long oblique paths, the phosphor material may be treated with a dye which absorbs much of this light, giving rise to a sharper image

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography



Configuration for a mammographic screen-film image receptor. A single-emulsion radiographic film is held in close contact with a fluorescent screen in a light-proof cassette.

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ Typical phosphor used for screen-film mammography is **gadolinium oxysulphide** ($\text{Gd}_2\text{O}_2\text{S:Tb}$)
- ❑ Phosphor material is dense
 - Quantum detection efficiency (fraction of incident X rays which interact with the screen) is reasonably high
 - Approximately 60% for a typical screen thickness and X ray spectrum
- ❑ Conversion efficiency (fraction of absorbed X ray energy converted to light) exceeds 10% (high for a phosphor)
- ❑ Photographic film emulsion for mammography is matched to be sensitive to:
 - Spectrum of light emitted from the particular phosphor screen
 - Range of X ray fluence exiting the breast

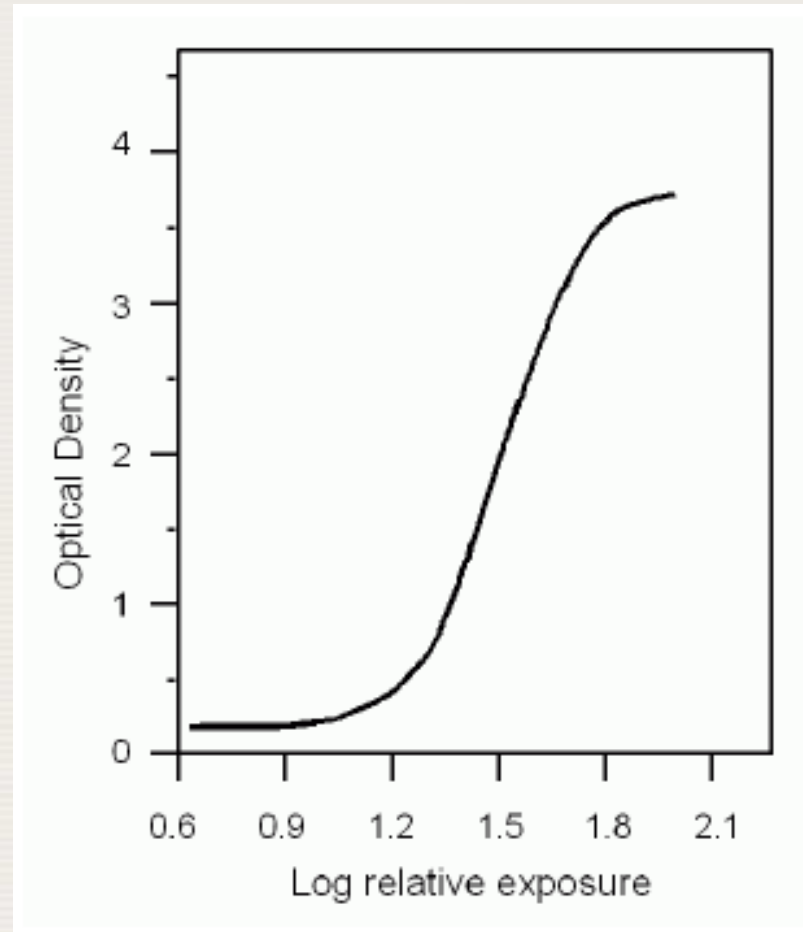
9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ Important to examine the overall characteristics of the screen and film combination rather than those of the individual components
- ❑ Compression of the breast reduces overall range of X ray fluence exiting the breast
 - Allows films with high gradient to be used
 - Enhances contrast between subtly varying soft-tissue structures
- ❑ In addition, mammography film has a high D_{\max} (4.0 to 4.8 OD)
 - Maximizes exposure latitude over which the high gradient exists
 - Important near the periphery of the breast (skin edge) where its thickness decreases rapidly
 - Nevertheless, some regions of the mammogram will generally be under or overexposed, i.e. rendered with sub-optimal contrast.

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography



Characteristic curve of a film emulsion used for mammography.

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ Mammography film is processed in an **automatic processor** similar to that used for general radiography
- ❑ Important that the development temperature, time and rate of replenishment of the developer chemistry are compatible with the type of film emulsion used and are designed to maintain good contrast of the film
- ❑ **Daily quality assurance is required in mammography** to ensure on-going optimal performance
- ❑ In **screen-film mammography**, the film must act as the **image acquisition detector as well as a storage and display device**

9.4. IMAGE RECEPTORS

9.4.1. Screen-film mammography

- ❑ Several factors associated with screen-film mammography can limit the ability to display the finest or most subtle details
- ❑ Sigmoidal shape of the characteristic curve results in limited latitude (range of X ray exposures over which the film display gradient is significant)
 - If a tumour is located in a more lucent or more opaque region of the breast, contrast displayed may be inadequate due to limited gradient of the film
 - Particularly of concern in patients whose breasts contain large amounts of fibroglandular tissue (dense breasts)
- ❑ Effect of fixed pattern noise due to the granularity of the phosphor screen and film emulsion
 - Can impair the detectability of microcalcifications and other fine structures

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Digital mammography introduced commercially in 2000
 - Able to overcome many of the technical limitations of screen-film mammography
- ❑ In digital mammography, **image acquisition, processing, display, and storage are performed independently, allowing optimisation** of each
- ❑ Acquisition performed with low-noise X ray detectors with wide dynamic range
- ❑ As the image is stored digitally:
 - It can be displayed with contrast independent of the detector properties
 - Image processing techniques that are found to be useful can be applied prior to image display

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Challenges in creating a digital mammography system with improved performance are mainly related to the X ray detector and the display device.
- ❑ The detector should have the following characteristics:
 - Efficient absorption of the incident radiation beam
 - Linear or logarithmic response over a wide range of incident radiation intensity
 - Low intrinsic noise and little-to-no fixed-pattern noise to ensure that images are X ray quantum noise limited
 - Limiting spatial resolution of the order of 5 to 10 cycles/mm (50 to 100 μm sampling)
 - Can provide at least an 18x24 cm and preferably a 24x30 cm field size
 - Can image immediately adjacent to the chest wall

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Two main approaches in detector development
- ❑ Area detectors
 - Entire image is acquired simultaneously
 - Fast image acquisition
 - Can be used with conventional design of mammography X ray unit equipped with a grid to reduce scatter
- ❑ Scanning detectors
 - Image is obtained by scanning the X ray beam and detector across the breast
 - Mechanically complex and longer acquisition times
 - Use relatively simple detector(s)
 - Good intrinsic scatter rejection

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Typical area detectors are based of an amorphous silicon thin-film transistor (TFT) panel
 - Contains a rectangular matrix of 2000 to 3000 columns by 3000 to 4000 rows of detector elements (dels)
 - Each del is connected to electrical lines running along each row and column by a TFT switch
 - This array is covered by a phosphor or a photoconductor X ray detector

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ In “indirect” detectors each del includes both a light-sensitive photodiode and a TFT switch
- ❑ The array is covered with a **phosphor layer**
 - Typically thallium-activated **CsI**
- ❑ X rays transmitted by the breast are absorbed by the phosphor and light produced is converted in the photodiode to charge which is stored in its capacitance
- ❑ After the X ray exposure
 - Readout signals sent sequentially along the lines for each row activate corresponding switches
 - The charge is transferred down the columns to readout amplifiers and multiplexers and digitized to form the image

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ This readout system allows the signals from all of the dels to be read in a fraction of a second
 - Fast image display
- ❑ The needle-like phosphor crystals of **CsI** behave somewhat like fibre-optics
 - Conduct the light to the photodiodes with less lateral spread than would occur with granular phosphors
 - Allows the thickness of the phosphor to be increased relative to a granular phosphor to improve the quantum detection efficiency of the detector without excessive loss of spatial resolution

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ In “direct” detectors a similar readout strategy is used but the phosphor is replaced with an X ray absorber composed of **amorphous selenium** which is a photoconductor
- ❑ The energy of the absorbed X rays causes the liberation of electron-hole pairs in the selenium
- ❑ The charged particles are drawn to the opposite faces of the detector by an externally applied electric field
- ❑ To collect the signal an array of electrode pads (rather than photodiodes) forms the delts
- ❑ Unlike the phosphor-based detectors, the electric field can be tailored to collect the charge with minimal lateral spread

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ This allows the use of a relatively thick detector to achieve excellent quantum detection efficiency without significant reduction in resolution at near normal incidence
- ❑ Other materials in which X ray energy is directly converted to charge are under development
- ❑ These materials include:
 - Lead iodide, zinc cadmium telluride and thallium bromide
 - The higher atomic number of these materials allow the thickness of the X ray converter to be reduced
 - This can mitigate against the degradation of the MTF due to the oblique incidence of the X rays

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ **Computed radiography** (CR) systems can be used for mammography
- ❑ Employs a **photo-stimulable phosphor** (PSP) plate housed in a light-proof cassette
 - When exposed to X rays, electrons in the crystalline material are excited and subsequently captured by traps in the phosphor
 - After exposure the plate is placed in a reader device and scanned with a laser beam
 - The energy of the laser light stimulates the traps to release the electrons
 - The transition of these electrons through energy levels in the phosphor crystal results in the emission of light
 - The light is collected by a photomultiplier tube, the signal digitised and attributed to a particular pixel in the image

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- For Mammography CR systems the resolution of the image is determined by:
 - Size of the scanning laser beam
 - Underlying scatter of the readout laser light in the phosphor
 - Distance between sample measurements

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Mammography CR systems differ from the general radiography CR systems in several key areas
 - Mammography CR system is designed for higher spatial resolution
 - Uses a thinner phosphor material and is scanned with finer sampling pitch (typically 50 μm)
- ❑ However, the result is less signal per pixel
- ❑ To overcome this limitation various innovations have been developed to improve light coupling and reduce readout noise, including:
 - Dual-sided readout of the phosphor plates
 - Needle-like phosphors which permit the use of thicker detectors having superior quantum detection efficiency

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Detector systems discussed so far acquire the image by integrating the signal from a number of X ray quanta absorbed in the detector and digitizing this signal
- ❑ The image noise from these systems depends on:
 - Poisson X ray quantum fluctuations associated with X ray absorption
 - Additional noise sources associated with the production of the converted electronic signal
 - These noise sources can arise from:
 - Fluctuation in the amount of light produced in a phosphor in response to absorption of an X ray of a particular energy or from the X ray spectrum itself
- ❑ As an alternative it is possible to **count the number of interacting quanta directly**, thereby avoiding these additional noise sources

9.4. IMAGE RECEPTORS

9.4.2. Digital mammography

- ❑ Typically **quantum-counting detectors** employ a geometry in which the X ray beam is collimated into a slot or multi-slit format and scanned across the breast to acquire the image
- ❑ The detector can be based on:
 - Solid-state approach (electron-hole pairs are produced in a material such as crystalline silicon)
 - Pressurized gas (the signal is in the form of ions formed in the gas)
 - Collection of charge signal plus amplification produces a pulse for each interacting X ray quantum and pulses are counted to create the signal
- ❑ As the beam is collimated to irradiate only part of the breast at a time the system has:
 - Good intrinsic scatter rejection without the need for a grid
 - Increased dose efficiency

9.5. DISPLAY OF MAMMOGRAMS

- Film mammograms
 - Specially designed transillumination devices
- Digital mammograms
 - Computer displays and workstations

9.5. DISPLAY OF MAMMOGRAMS

9.5.1. Display of film mammograms

- ❑ **Specially designed transillumination devices** are available for reading film mammograms
 - The luminance levels must be appropriate for reading mammograms and sufficient to illuminate areas of interest (luminance of at least 3000 cd m^{-2})
 - The illuminator surface should provide diffused light of uniform brightness
- ❑ **Optimal viewing conditions essential** for reviewing screen-film mammograms
 - Allows visualization of as much of the information recorded in the mammogram as possible
- ❑ Mammograms should be interpreted under conditions that provide good visibility, comfort, and minimal fatigue

9.5. DISPLAY OF MAMMOGRAMS

9.5.1. Display of film mammograms

- ❑ Contrast sensitivity of the eye (ability to distinguish small differences in luminance) is greatest when surroundings are of about the same brightness as the area of interest
- ❑ Therefore to **optimally** see detail in a mammogram
 - **Glare** should be reduced to a minimum
 - **Surface reflections** should be avoided
 - **Ambient light level** should be subdued and approximately that reaching the eye through the mammogram
- ❑ Important to have a variable brightness, high output light source to view high optical density (dark) areas on the film mammogram

9.5. DISPLAY OF MAMMOGRAMS

9.5.2. Display of digital mammograms

- ❑ Display system plays a major role in influencing overall performance of digital mammography
 - Image quality presented to the film reader
 - Ease of image interpretation
- ❑ Images viewed on a computer (“softcopy”) display
 - Cathode ray tube (CRT) or more commonly LCD monitor
- ❑ Typical reporting workstation has matched pair of high quality, **high resolution monitors** (normally 5 megapixel (MP))
 - A 5 MP monitor is capable of displaying only a single mammogram at full resolution
 - Wide range of image manipulation tools available
 - Brightness, contrast, zoom, , roam, scroll, etc.

9.5. DISPLAY OF MAMMOGRAMS

9.5.2. Display of digital mammograms

- ❑ “**Hardcopy**” images use a laser printer to produce a printout of the digital image on transparent film
- ❑ Image brightness and contrast usually adjusted before printing out the image making use of the controls provided at the acquisition workstation
- ❑ “**Hardcopy**” images do not allowing control of image processing operations during viewing
- ❑ Therefore, it is **strongly recommended** that digital mammography images are displayed and reviewed using a high quality “**softcopy**” device

9.6. BREAST TOMOSYNTHESIS

- ❑ In projection radiography tissue superposition can result in a masking effect
- ❑ Breast tomosynthesis can provide reconstructed planar images of sections of the breast
 - Can aid in reducing the masking effect
- ❑ Breast tomosynthesis generally based on modified digital mammography systems
 - Planar digital imaging and tomosynthesis
 - Tomosynthesis only

9.6. BREAST TOMOSYNTHESIS

- ❑ X ray tube pivots about a point
- ❑ Breast platform remains stationary
- ❑ Detector usually stationary but may also move
- ❑ Series of low-dose projection images (typically 9 to 25) acquired over a limited range of angles ($\pm 7^\circ$ to $\pm 30^\circ$)
- ❑ X ray spectrum
 - Higher energy typically employed (e.g.W/Al)
- ❑ X ray tube movement
 - Continuous exposure or series of discrete exposures (“step and shoot”)
- ❑ Total acquisition time must be minimized
 - Possible image degradation due to patient motion

9.6. BREAST TOMOSYNTHESIS

- ❑ **Planar cross-sectional** images are reconstructed from the projections using **filtered back projection** or an **iterative reconstruction algorithm**
- ❑ Spatial resolution of tomosynthesis is anisotropic
 - Highest resolution in-plane
 - Relatively poor resolution between planes
- ❑ Reconstructed voxels are generally non-isotropic
 - Pixel size approximately equal to the size of the del
 - Reconstructed slice spacing is typically 1 mm
- ❑ Because of the limited range of acquisition angles
 - Projection data do not form a complete set
 - Reconstructed image is not a true 3D representation of the breast
 - Possibility of artefacts in the images

9.7. BREAST CT

- ❑ **Dedicated breast CT systems** have been developed using **cone-beam geometry** and a flat-panel X-ray detector
 - Data for all of the CT slices acquired simultaneously
 - Rapid image acquisition
 - Pixel dimensions substantially larger than for digital mammography or tomosynthesis
 - Large number of projections
 - To keep doses at an acceptable level images are generally acquired at a higher tube voltage (50 to 80 kV)
 - Very low dose per projection can result in noisy images
- ❑ Current designs provide a dedicated prone imaging table
- ❑ Breast CT can be performed without the need to compress the breast.

9.8. COMPUTER-AIDED DIAGNOSIS

- ❑ Computer-aided diagnosis or computer-aided detection (CAD) systems are designed to assist the film reader in detecting breast cancers
- ❑ Computer system with sophisticated pattern recognition software
 - Natural adjunct to digital mammography
 - Screen-film mammograms must be digitised (scanned)
- ❑ Interpretive aid used during image review
- ❑ Identifies “suspicious” features and alerts image reader
 - Does not replace the image reader
- ❑ CAD algorithms must be trained using sets of mammograms for which the presence or absence of cancers is known

9.8. COMPUTER-AIDED DIAGNOSIS

- ❑ Results of CAD are conveyed to the film reader by means of an image annotated to show the computer detections
 - Different symbols for different lesions
- ❑ Main use in screening mammography
 - Double reading has been shown to increase the cancer detection rate
 - CAD has the potential to be a cost-effective alternative to double reading
 - CAD algorithm could be used to simulate the second film reader
 - CAD has the potential to:
 - Reduce the number of missed cancers
 - Reduce the variability between film readers
 - Improve the consistency and productivity of a single film reader

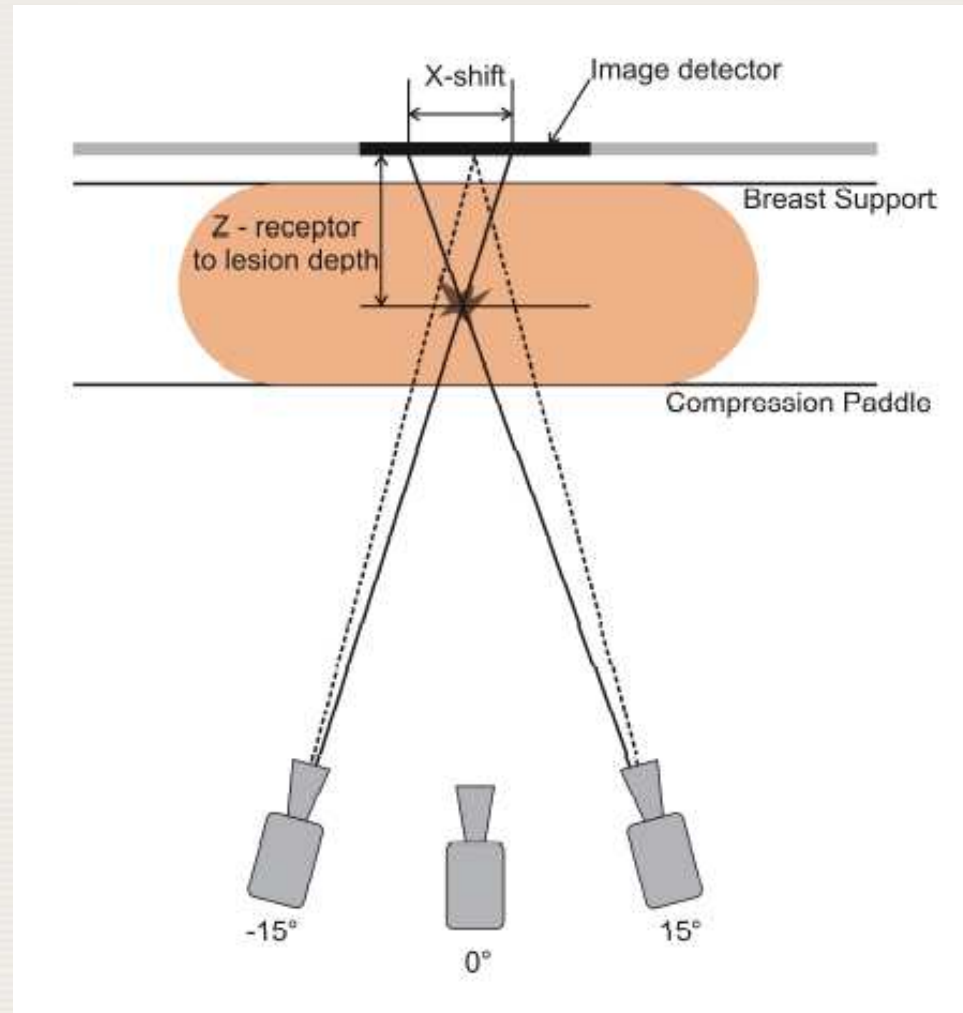
9.8. COMPUTER-AIDED DIAGNOSIS

- ❑ Recent research in CAD considers the combination of information from multiple images
 - Different views from the same examination
 - Same view from a previous examination
 - This approach more closely mimics how a film reader reads a case
 - May improve the performance of a CAD scheme
- ❑ CAD may be particularly valuable in 3D breast imaging
 - Large amount of image data to be considered
 - CAD may be useful for automatic detection of microcalcifications
 - Film reader can focus attention on more sophisticated interpretation tasks

9.9. STEREOTACTIC BIOPSY SYSTEMS

- ❑ Stereotactic procedures are used to investigate suspicious mammographic or clinical findings without the need for surgical (excisional) biopsies
 - Reduced patient risk, discomfort and cost
- ❑ In stereotactic biopsies, the gantry of a mammography unit has the facility to allow a pair of angulated views of the breast (typically at $\pm 15^\circ$ from normal incidence) to be obtained
- ❑ From measurements obtained from these images, the three-dimensional location of a suspicious lesion is determined and a needle equipped with a spring-loaded cutting device can be accurately placed in the breast to obtain tissue samples

9.9. STEREOTACTIC BIOPSY SYSTEMS



The geometry for stereotactic breast biopsy is shown. The X ray tube is rotated about the breast to produce two views. The Z-depth of an object can be determined by the lateral (X) displacement observed between the two views.

9.9. STEREOTACTIC BIOPSY SYSTEMS

- ❑ These systems may use **small-format** (e.g. 5 cm x 5 cm) **digital detectors** or **full-field digital detectors**
- ❑ Stereotactic procedures can be performed on a conventional mammography unit with a stereotactic attachment with the patient standing
- ❑ Dedicated stereotactic units where the patient lies prone on a table with the breast pendant through an aperture in the table top into the imaging region are also available

9.10. RADIATION DOSE

- ❑ Three dosimetric quantities used in mammography
 - Incident air kerma (IAK), K_i
 - Entrance surface air kerma K_e
 - Mean glandular dose (MGD, mean dose to the glandular tissue of the breast), D_G
- ❑ **MGD is the primary quantity of interest** related to the risk of radiation induced cancer in breast imaging
- ❑ MGD is calculated using factors obtained experimentally or by Monte Carlo radiation transport calculations
- ❑ **IAK (measured) converted to MGD** for a breast of specific composition and size
 - **Conversion coefficients are tabulated in various publications** (including IAEA Technical Report TRS-457)

9.10. RADIATION DOSE

- ❑ Dose in mammography depends on the **size and composition** of the breast as well as the imaging device and **exposure settings** selected
- ❑ In **screen-film mammography** goal is to maintain a **target value of optical density**
- ❑ K_e increases as the thickness and/or density of the breast increase resulting in a corresponding increase in MGD
- ❑ Increase in beam energy (tube voltage, target/material combination) will mitigate against some of dose increase
 - Image contrast will be reduced and at some point this will become unacceptable

9.10. RADIATION DOSE

- ❑ In **digital mammography** goal is to maintain a **target SDNR** at the detector
- ❑ K_e increases as the thickness and/or density of the breast increase resulting in a corresponding increase in MGD
- ❑ Increase in beam energy (tube voltage, target/material combination) will mitigate against some of dose increase
- ❑ On a digital system where contrast can be adjusted during image display, an acceptable compromise can be achieved at a higher energy than with screen-film imaging
- ❑ This allows the advantage of a greater relative decrease of dose compared to film for large and/or dense breasts

9.10. RADIATION DOSE

- ❑ There is a **risk of cancer induction** associated with the radiation doses received in mammography.
- ❑ BEIR VII report critically examined data on doses and increased cancer incidence to develop a radiation risk model for breast cancer
- ❑ Model can be useful in predicting the lifetime risk following a single mammographic examination or from multiple exposures at different ages as would occur in periodic screening
- ❑ Risk for a woman at age 60 from a dose to the breasts of 0.004 Gy previously received from mammograms at age 45 is predicted to be 7.9×10^{-7}

9.10. RADIATION DOSE

- ❑ For a screening regimen that consists of annual mammography examinations from ages 40 to 55 and biennial examination thereafter until age 74 (i.e. 25 screenings) with a dose of 3.7 mGy to both breasts, it is estimated that in 100,000 women 86 radiation-induced cancers will be caused resulting in 11 deaths and a loss of 136 women-years of life.
- ❑ In the same group, earlier detection through screening would save 500 lives or 10,670 women-years, resulting in a benefit-to-risk ratio of 47 (in lives) or 78 (in women-years). If the same diagnostic accuracy could be achieved at reduced radiation dose, the benefit-to risk would become even higher

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