Digital Imaging

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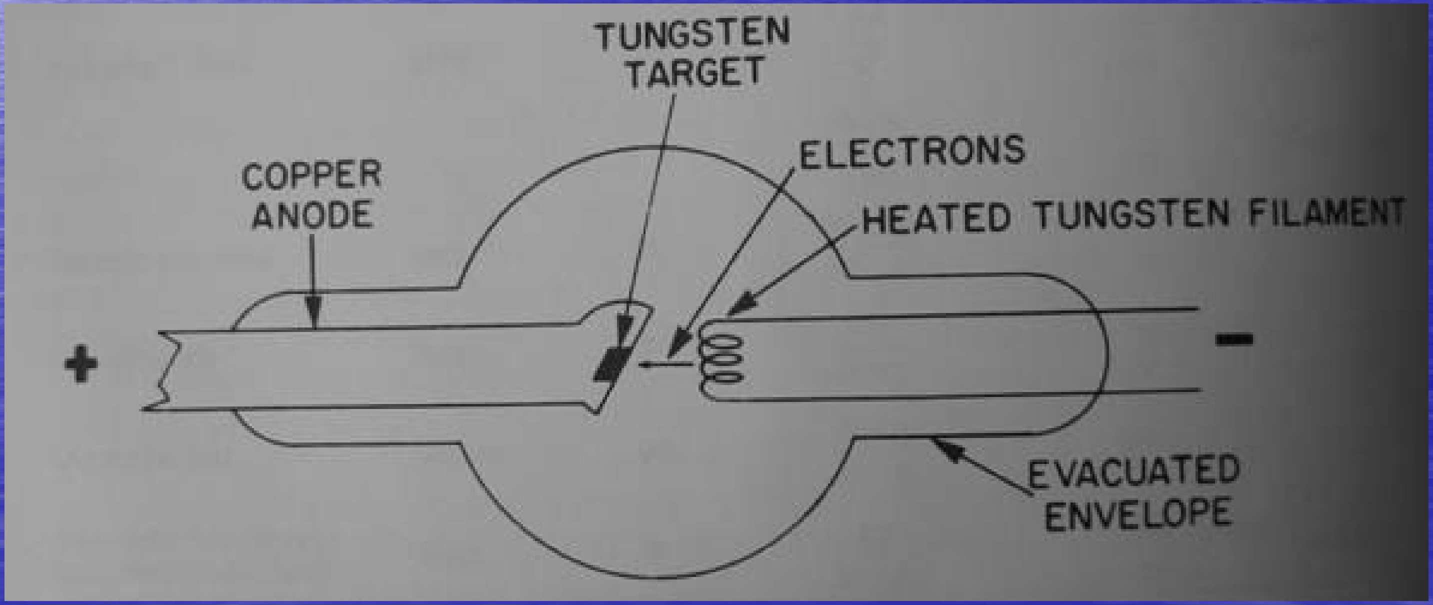
Traditional Radiography

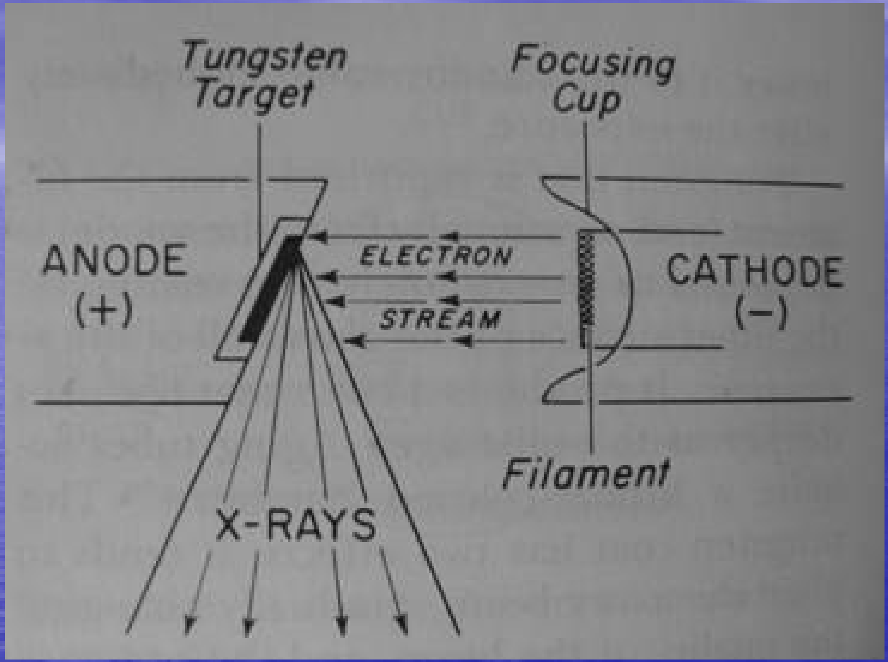
- Production of x-rays
- Beam restriction
- Grids
- Image recording
- Film processing

Production of x-rays

- Created by energy conversion within the TUBE
- The tube is made of pyrex glass and contains two electrodes in a vacuum. This is surrounded by oil and housed in a lead lined case



The x-ray tube



- Electrons are created at the cathode (neg electrode/filament) by passing a current through the filament
- They are accelerated toward the anode (pos electrode) where they will collide with the target

The cathode

- The x-ray tube current (mA) is the number of electrons flowing from the filament to the target per second
- The filament is made of tungsten
- The electrons leaving the filament are focused by a focusing cup usually made of nickel

The anode

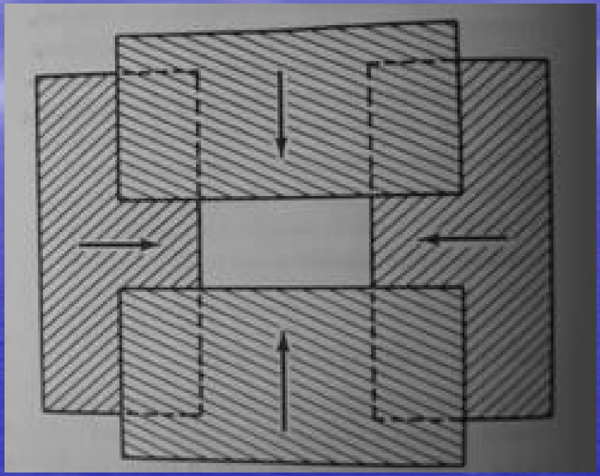
- The target is a small plate of 90% tungsten, 10% rhenium embedded in a large piece of copper
- The electrons strike the target and produce x-rays
- Only 1% of the energy of the electrons will become x-rays, 99% will result in heat
- Thus the anode rotates to facilitate heat dissipation into the copper

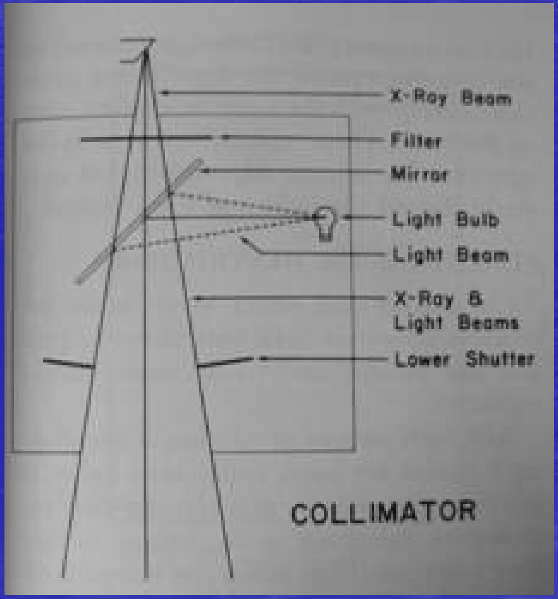
X-ray production

- The voltage difference created between the cathode and the anode (kVp) is responsible for the speed of the electrons
- X-rays are generated when electrons hit the target
- The faster the electron, the more energy it has and the higher the energy of the x-ray it will generate

Beam restriction

- Collimator = two sets of shutters define the beam dimensions
- Infinite number of square or rectangular fields
- X-ray field visible as a lightened area





Pros of collimation

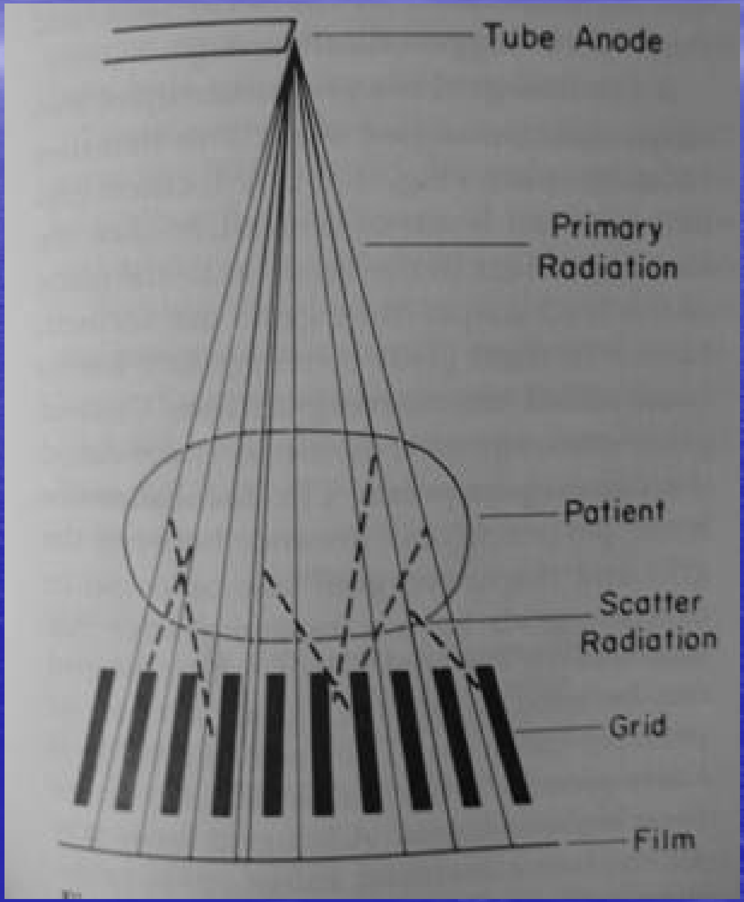
- Limit the area exposed to the primary beam → limit patient exposure

  →limit the scatter that degrades the image

  →and limit the scatter that interacts with personnel
- Win – Win maneuver
- Tricks for collimating rapidly

Grids

- Series of lead strips separated by radiolucent filler material
- Primary radiation is oriented in parallel with the strips and passes through untouched
- Scatter radiation is at off angles to the strips and is absorbed by them



- Grid ratio = ratio of height of lead strips to distance between them
- Grids range between 4:1 and 16:1 (8:1 most commonly used)
- The higher the ratio the better the grid is at removing scatter but the more primary beam is necessary

Image recording

- X-rays strike the cassette which contains fluorescent screens and the film
- Phosphors in the screen emit light within 10^{-8} seconds of stimulation by the x-ray (fluoresce)
- Light exposes the film
- Important that light sensitivity of the film matches that emitted by the phosphors

Intensifying screens

- Decrease the x-ray dose to the patient (intensification factor)
- Allow shorter exposure times – important to minimize motion blur
- Original phosphor = crystalline calcium tungstate (produces blue light)

Screen speed

- Faster screens (ie require less patient x-ray exposure to produce the same amount of x-ray film exposure)
- Made faster by increasing thickness of phosphor layer
- Increased thickness decreases image clarity due to light diffusion

Newer phosphors: Rare earth

- Increase screen speed by having

  →higher conversion efficiencies of x-rays to light

  →higher efficiency of x-ray absorption

X-ray film

- Photographic emulsion attached to a supportive base
- Important emulsion components are gelatin and silver halide
- Gelatin holds silver halide grains evenly dispersed and is easily penetrated by processing solutions

Silver halide

- Light sensitive material
- 90-99% silver bromide
- 1-10% silver iodide
- Silver (Ag^+), bromine (Br^-) and iodine (I^-) ions are arranged in a cubic lattice to form a crystal suspended in the gelatin

Latent image formation

Br^- + light photon → Br + electron

Electron moves within the crystal until it is trapped by a sensitivity speck (site of crystal imperfection)

Attracts silver ions

Ag^+ + electron → Ag

Repeated trapping of electrons at the sensitivity speck causes the accumulation of silver

Clumps of silver = latent image centers

Film processing - developer

- Development will amplify the latent image by a factor of millions
- Developer is a reducing agent which changes the silver ion back to black metallic silver
- Reaction happens much more rapidly at latent image sites so time is important in development process

Replenishment

- Bromide and acid are formed and developer is consumed each time a film is developed
- Developer therefore needs to be replenished regularly and a has a limited lifetime
- In a busy practice a tank of developer will last from 2 to 3 months

Fixer

- After development the image must be washed and then fixed
- Fixer removes silver halide not reduced to silver (not exposed → washed away)
- Fixing agent forms water soluble complexes with silver ions which are then washed away in the subsequent water bath
- Fixer also hardens the gelatin

The permanent image

- Assuming proper development, fixation and washing ..

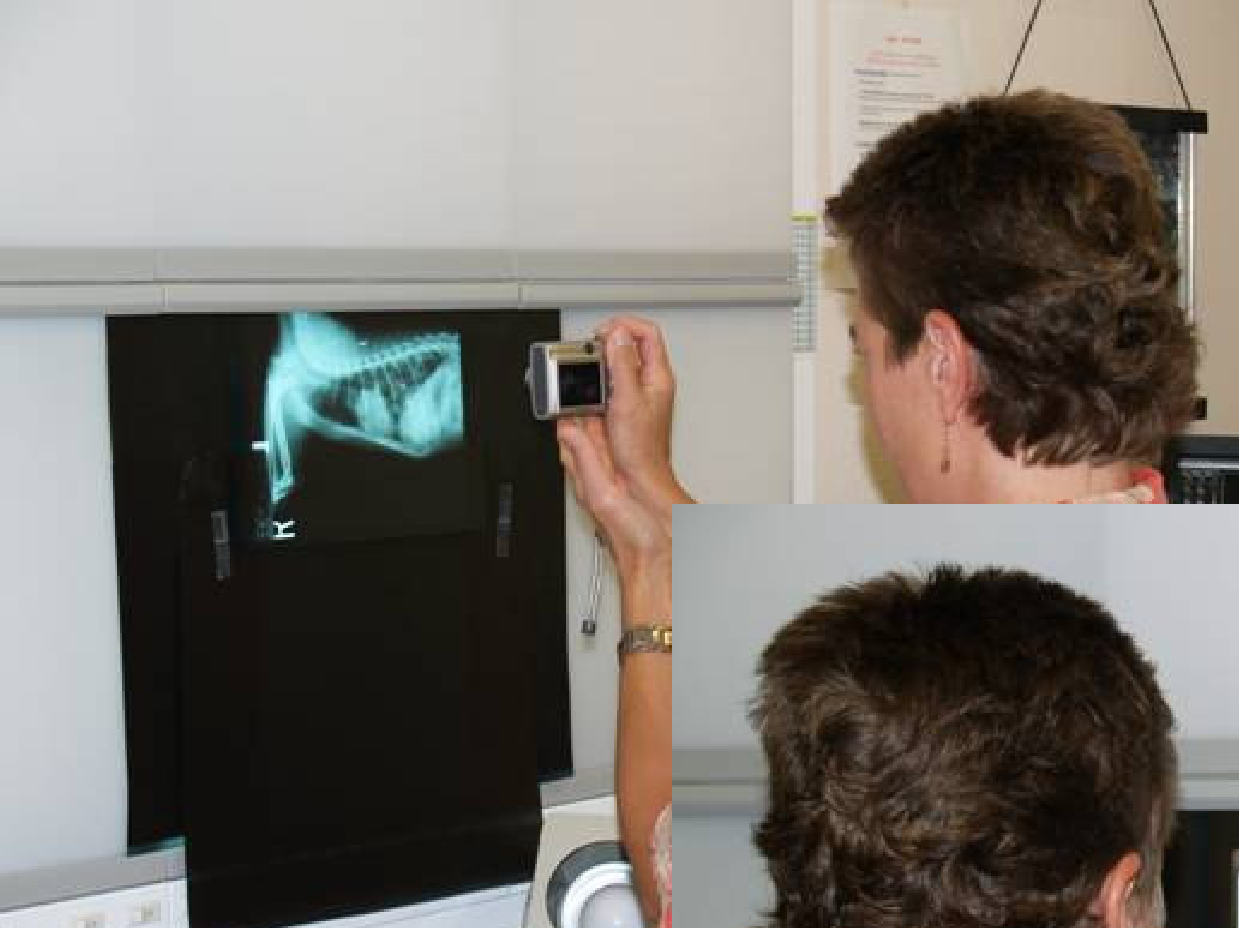
Areas hit by light from x-ray exposure will be black (metallic silver) and non exposed areas will be white (silver halide washed out of emulsion)

How to make an image digital

- Digital camera
- Scanner
- Charge coupled devices (CCD)
- Computed radiography (CR)
- True digital or flat panel radiography (DR)

Digital Camera

- The image will be only as good as the original radiograph
- Eliminate all light except what is coming through the film
- Set camera on black and white, macro setting, highest resolution, NO flash
- Do not move
- Take one image of the entire film and another close up of suspect area. Move in close to the film to do this, don’t use zoom.

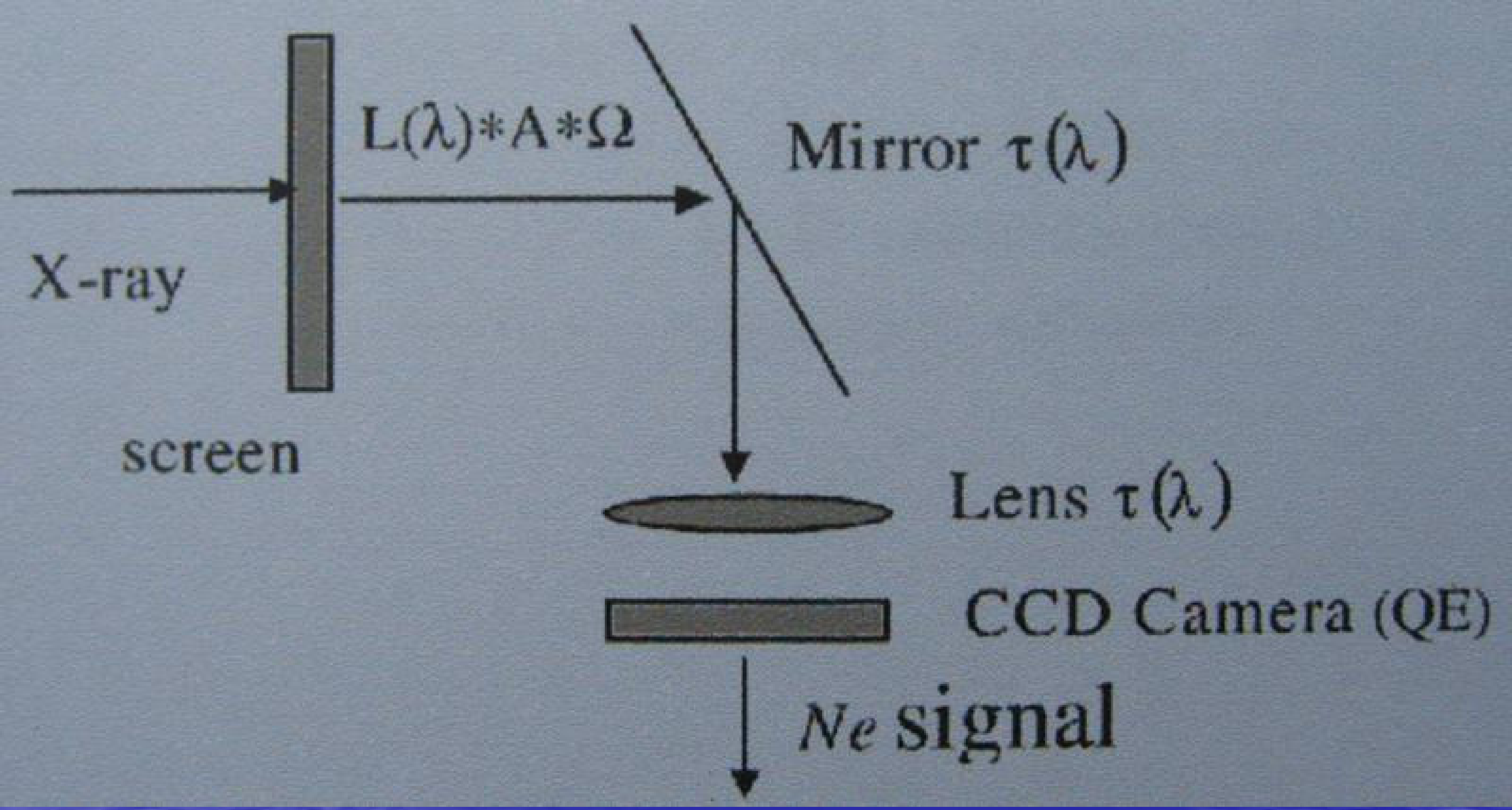


Scanners

- Good ones are very expensive!

Charge Coupled Devices (CCD)

- X-rays pass through patient and hit scintillator screen
- Image created is projected by a mirror/lens assembly onto a CCD chip just as a camera focuses an image onto film
- CCD converts visible light into electrons that are stored in the CCD pixels



L(λ)*A*Ω
Mirror τ(λ)
X-ray
screen
Lens τ(λ)
CCD Camera (QE)
Ne signal

CCD

- Consists of an integrated circuit containing an array of capacitors sensitive to light
- Each capacitor accumulates a charge proportional to the light intensity it sees
- The charge is then passed through an analog-to-digital converter
- Main uses are digital photography and astronomy

CCD concerns

- CCDs are small relative to the scintillation screen – creates a lot of noise
- Practical limit to the size of the CCD because of the time to read them out
- Light loss through the lens assembly

The image

- Quality inferior to CR and DR
- Noisy image with what looks like movement artifact
- Contrasty
- Not enough information stored for magnified images to be clear (grainy and blurry)

Computed Radiography

- Traditional tube setup
- Special cassette records image
- Cassette manually placed in reader
- Reader sends digital image to computer

The cassette

- Photostimulable phosphor that phosphoresces (emission of light after stimulation delayed beyond 10^{-8} seconds)

Preparing the plate for imaging

- Plate flooded with light from high intensity sodium discharge lamps → erases any previous image

Photostimlable phosphor exposed to x-ray beam

- Some of energy of x-ray beam absorbed by phosphor
- Stored as valence electrons in high energy traps which forms the latent image
- Number of trapped electrons is proportional to the amount of x-rays absorbed
- Latent image will be retained for up to 8 hours but image will degrade over time

The reader

- Laser beam scans latent image in cassette
- Trapped electrons return to the valence band and emit light
- Photomultiplier tube records the light emission
- Photomultiplier tube output sent to computer where digital image is created

The reader

- Cassettes must be manually carried to and placed in reader

The image

- Of lesser to equal image quality as a traditional radiograph with screen

True digital imaging or flat panel imaging

- Traditional tube setup
- X-rays recorded by detector
- Information sent immediately to computer

The detector

- Stored permanently in your bucky tray
- Direct wiring to computer image acquisition station
- Near immediate appearance of image on the screen


B NNETT

truDR

The detector – Amorphous-Si/scintillator

- On top: x-ray scintillator made of thick layer of thallium-doped CsI or Gadolinium Oxide.
- Next: Array of amorphous silicon pin photodiodes and thin film transistors (TFT). Peak quantum efficiency of photodiodes = that of light emitted by scintillator
- Next: readout and drive electronics. Chips perform charge to voltage conversion.

The detector - Se

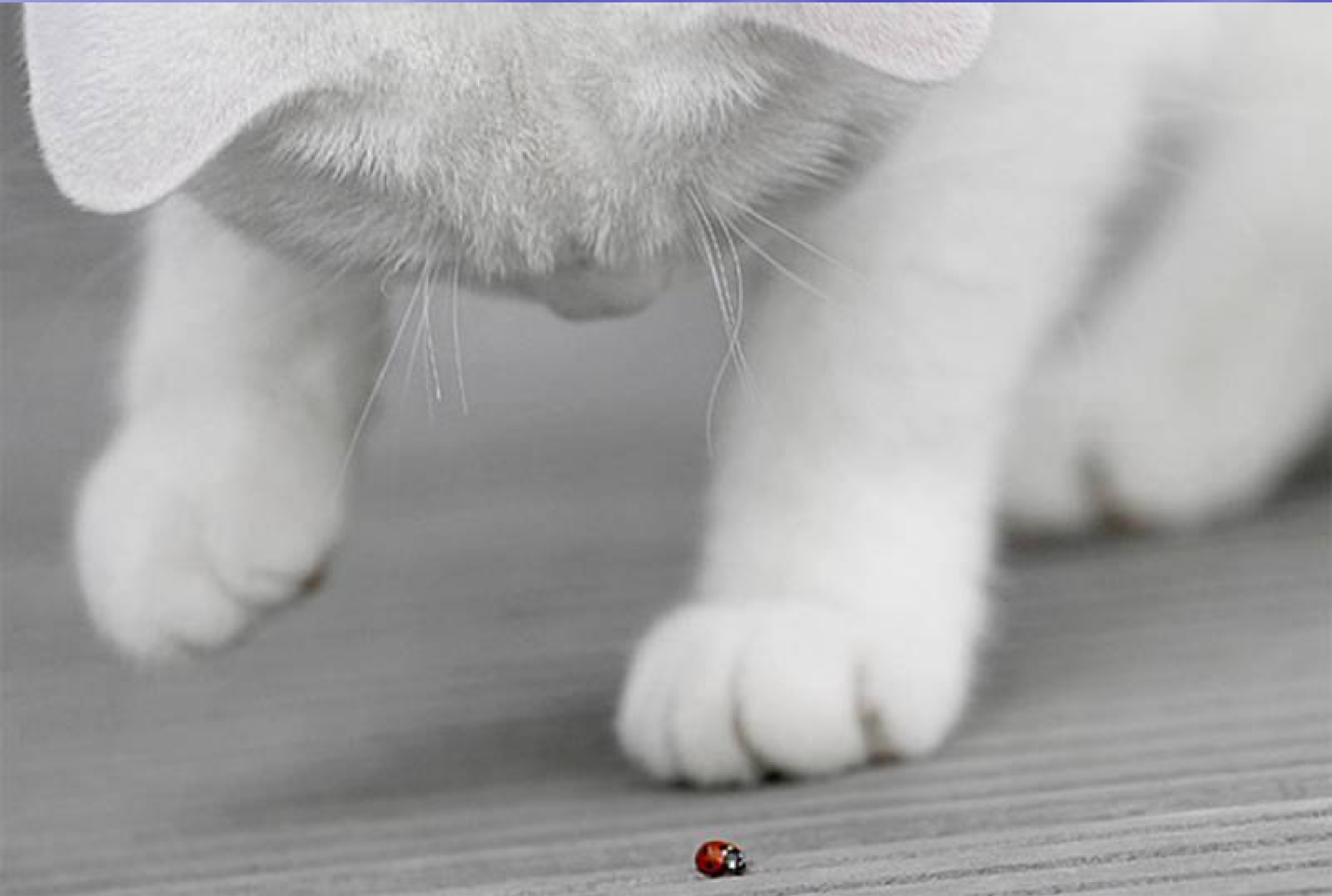
- No scintillator intermediate, direct x-ray to electron conversion
- Pass through Selenium photoconductor
- Read by thin film transistors (TFT) detector elements

The detector

- Charge is collected by an integrating amplifier and converted to a voltage
- Programmable gain is applied to the signal voltage
- Output voltage is converted to digital data by analog-to-digital converter (ADC)
- This is performed row by row

The image

- Excellent quality
- Images contain adequate information to magnify many times and still have great image



Pros and cons of digital radiography

- Some true of all “digital” systems
- Some vary by system chosen

Decreased costs

- No processor, processing space, processing solutions or maintenance
- No film expenses, film jackets or storage space needed
- No storage space for completed radiographs needed except computer
- No time spent filing new films or looking for old

Time investments

Taking radiographs

- Time to take films is same for traditional and CR – around 20-25 minutes a case. CR might be slightly faster as exposure latitude increased so retakes may be fewer
- Time with true DR or CCD drastically reduced to around a third of the time

Time Investments

Developing radiographs

- Regular processors around 1.5 minutes but films can go in one right after the other
- CR: takes around 1.5 minutes for image to be read and appear on computer, must wait for one to be completely done to go to next
- DR and CCD: Image appears on computer within seconds of exposure

Improvements – all systems

- Ability to see the image from any site within the hospital
- Ability to manipulate the image: magnification, altering contrast/brightness
- Ability to send (remote reads) or copy (for the client or referral) the exact image quickly

Improvements DR

- Exposures can be so close together that it will approximate fluoroscopy

Downside DR + CCD

- Mobile radiography is difficult due to the need for the cable attaching sensor and computer
- Cross table views cannot be obtained as the sensor is attached to the table

Downside to all - change

- You will have to train personnel
- You likely will have to alter your technique chart

Downside - expense

- Computed systems: 35 to 55 K
- CCD: 45-70 K
- Digital systems: 80 K and up
- Number of workstations will cause the price to vary

Volume needed to consider a system

- CR around 30 studies a month
- CCD around 50
- DR around 60 studies a month

Viewing stations

- Need very high resolution monitor to take advantage of image quality
- Grey scale vs color LCD

Imaging software and PACS systems

- Don’t just need ability to produce the digital image
- Need software to view and manipulate the image
- Need to archive the image, retrieve the image, send the image, distribute the image throughout the hospital

PACS System - efficient storage and retrieval

- P - Picture viewing at various workstations
- A - Archiving images
- C - Communication using LAN or internet
- S - System

PACS

- Immediate retrieval of all radiographs taken on a given patient
- Storage and retrieval of any digital image generated on the patient (US, CT, MRI)
- Off site backup by the PACS vendor or other independent image storage companies
- Access to images at the off site storage server by the client or referral hospitals

Image format

- Beware of vendor lock-in: Make sure images are not stored in a proprietary manner
- Common nonproprietary image formats: JPEG, JPEG200, TIFF, DICOM

DICOM – Digital Imaging and Communications in Medicine

- DICOM is an organization that concerns itself with the standardization of the communication of medical images and associated important information
- DICOM is a published standard with 18 different parts the goals of which are to "achieve compatibility and to improve workflow efficiency between imaging systems and other information systems in heathcare environments worldwide."
- DICOM is an imaging format.

DICOM image format

- File format that permanently stores information about the date, patient and type of scan in the image header
- Require a DICOM viewer to view image
- DICOM image software should protect the image integrity and not allow you to alter the original image – it is part of the medical record

DICOM Standards

- Published and maintained by NEMA (National Equipment Manufacturers Association)
- A product should have a DICOM conformance statement that details what the product does and does not do relative to the DICOM standard
- Not all parts are relevant to all products

Seven relevant parts for medical imaging

- Verification – confirms is properly connected before communicating (pinging)
- Modality Worklist management – scheduling communications
- Performed Procedure Step – Communications about completed exams
- Store – sending images to PACS
- Storage commit – transfers ownership of images
- Print – printing images
- Query/Retrieve – exchange between display station and archive

Providers and users

- DICOM Store – Modality (eg CT) is user, PACS system is provider
- DICOM Query/Retrieve – PACS system is both provider (provides images to users) and user (uses images from storage)

DICOM specifications for a device

- Tell you what class of service it supports
- What role it plays (user, provider, both)
- What objects (modalities) it supports

In summary – most important points to consider when shopping for a digital system

- Image quality most important
- Availability and dependability of service once installed – examine vendor's reputation closely
- PACS system inclusion/availability
- DICOM compatibility
- Type of system: DR, CR, CCD – what are your goals and how much can you spend