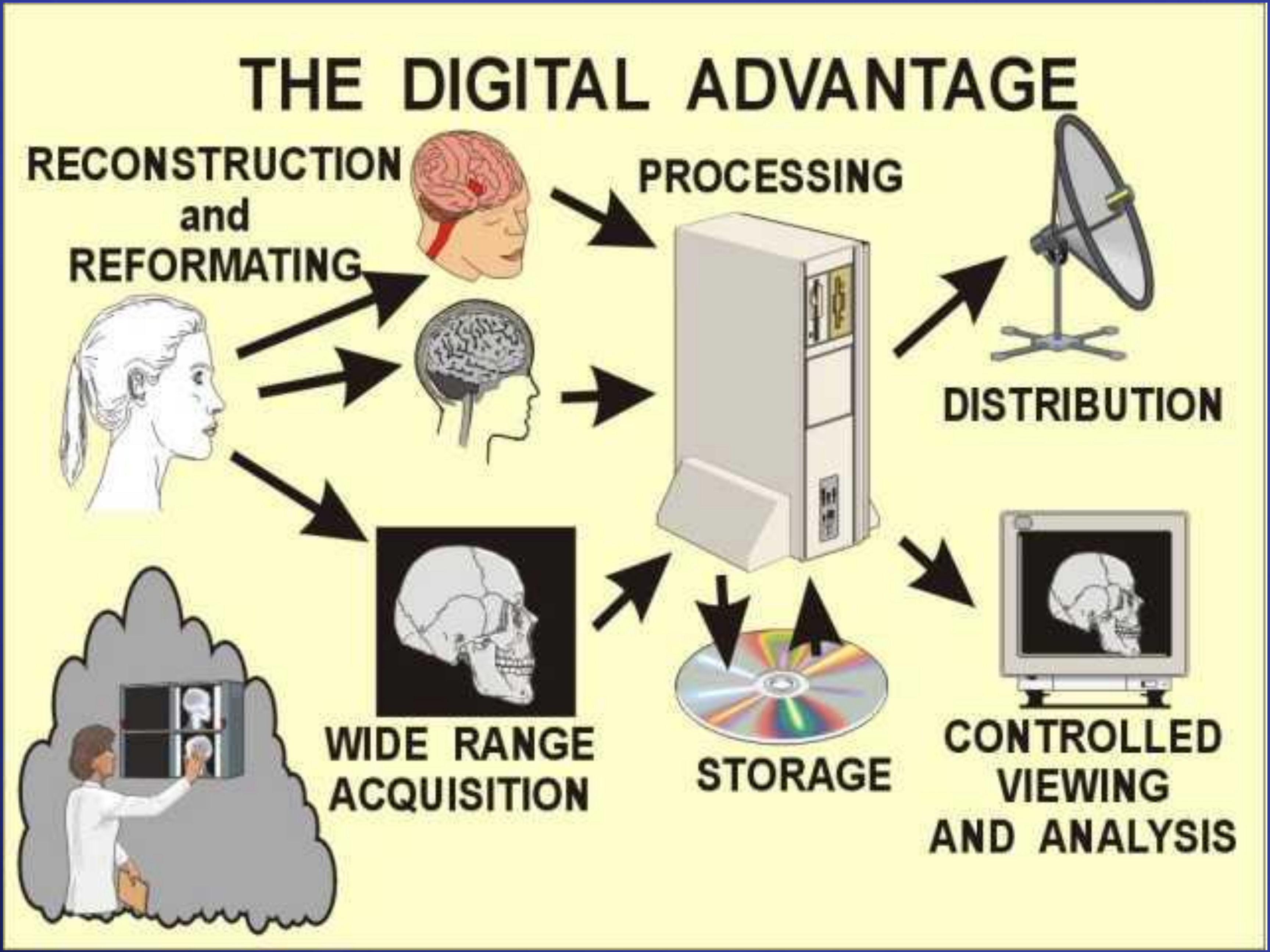
INSTRUMENTATION 3
BMI 2123

Digital and Computed Radiography

Digital imaging

- Is a broad term.
- In medicine, digital imaging was first used with introduction of CT.
- Basic definition digital imaging is
  - any imaging acquisition process that produces an electronic image that can be viewed and manipulated on a computer.

- Advantages of digital imaging
  - To improve radiological workflow
  - To improve in radiological diagnosis
  - To save cost and time
  - To reduce radiation dose


THE DIGITAL ADVANTAGE
RECONSTRUCTION and REFORMATING
PROCESSING
DISTRIBUTION
WIDE RANGE ACQUISITION
STORAGE
CONTROLLED VIEWING AND ANALYSIS

Digital Radiography

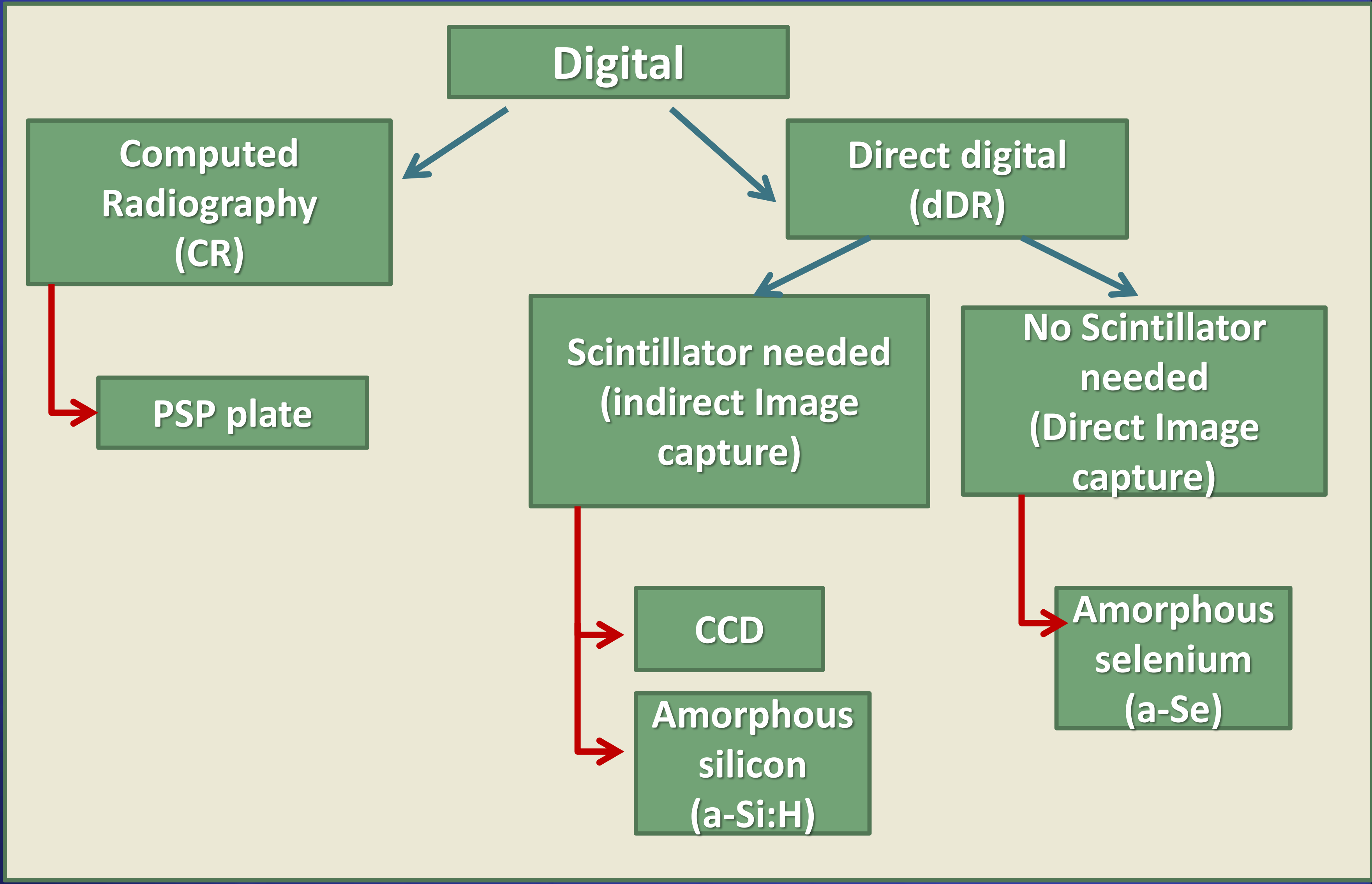
- Teleradiology
  - Moving images via telephone lines to and from remote locations.
  - Require PACS. (picture archiving and communication system)

- To provide PACS digital image, early analog radiographs were scanned into a computer(digitized), so image could be sent from computer to computer.

Digital Radiography

- Divided into two;
  - Cassette based (use PSP imaging plate)
  - Cassette less

Digital Radiography System



COMPUTED RADIOGRAPHY (CR)

Computed Radiography (CR)

- Indirect digital radiography
- ‘Cassette based’ digital radiography.
- uses storage phosphor plates to produce projection images.
- Can be used in standard radiographic room-like film/screen, in bucky or for portable exams.
- Once the PSP is exposed, it is taken to reader to process the plate & create the image.
- Requirements:
  - CR cassettes & phosphor plates
  - CR readers & technologist quality control workstation.
  - Means to view the images (printer/viewing station)

Computed Radiography Cassette

- Constructed of:
  - Lightweight Aluminum
  - Plastic/steel frame
  - Front panel made of a low –attenuation carbon fiber.
- Designed to protect image plate from damage
- Back panel of cassette contains:
  - lead foil to minimize backscatter fog.
  - Memory chip- use to download pt demographic info & exam data from hospital information system at a PC-based ID terminal.

CR cassette

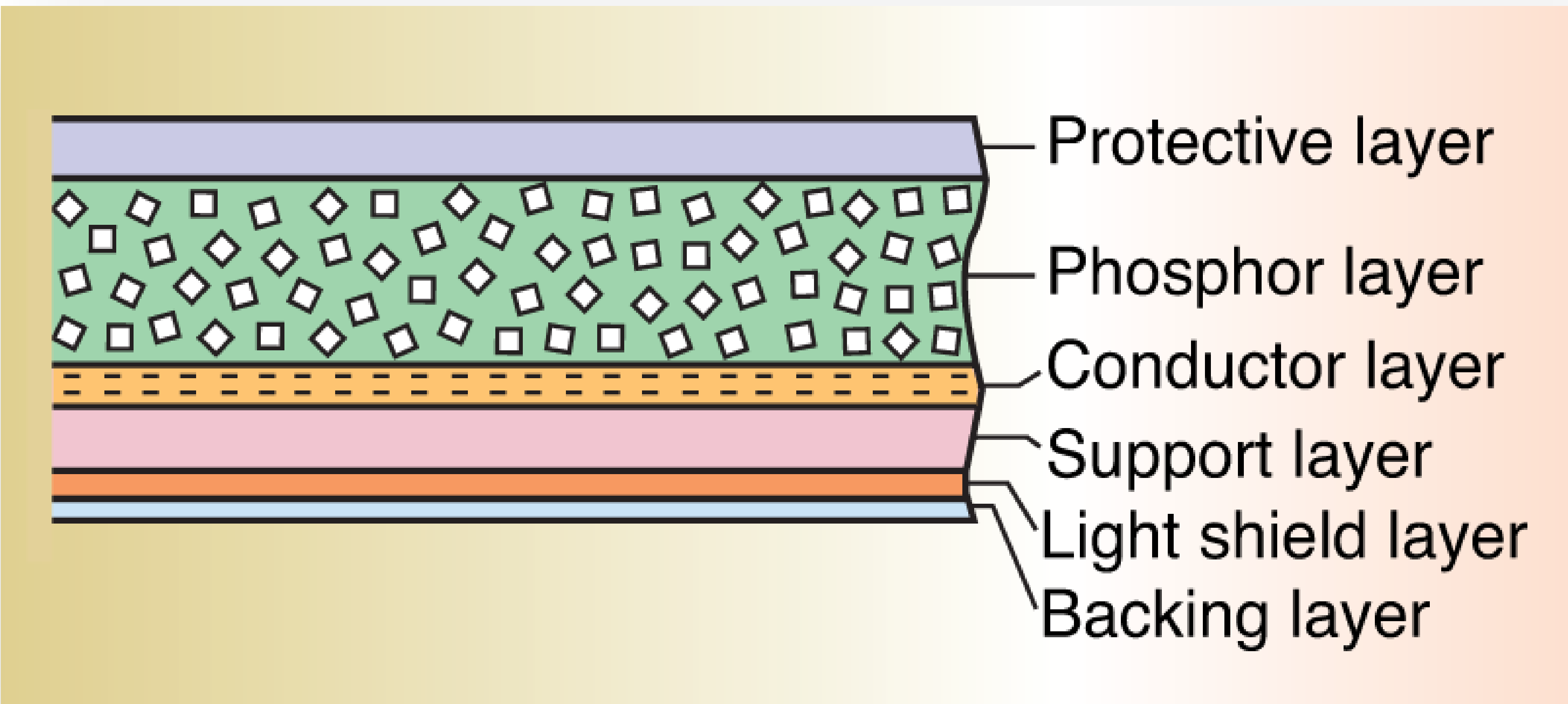
CR Reader

Photostimulable Phosphor Imaging Plate

- Designed to record & enhance transmission of the image from a beam of ionizing radiation.

- Contains several layers:
  - Protective layer
  - Phosphor layer
  - Support layer (made of polyester)
  - Conductor layer
  - Light shield layer

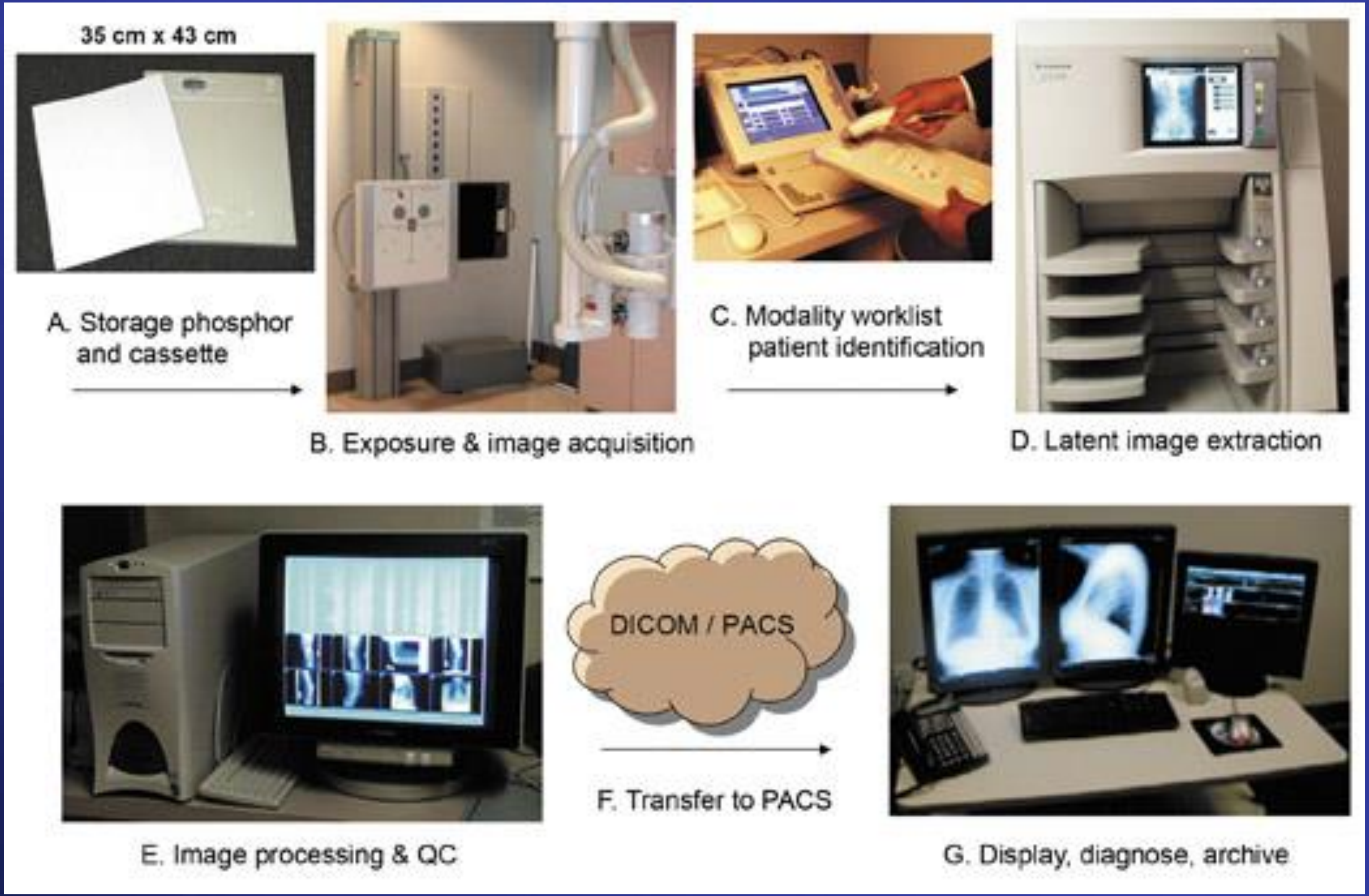
Photostimulable Phosphor Imaging Plate Layer



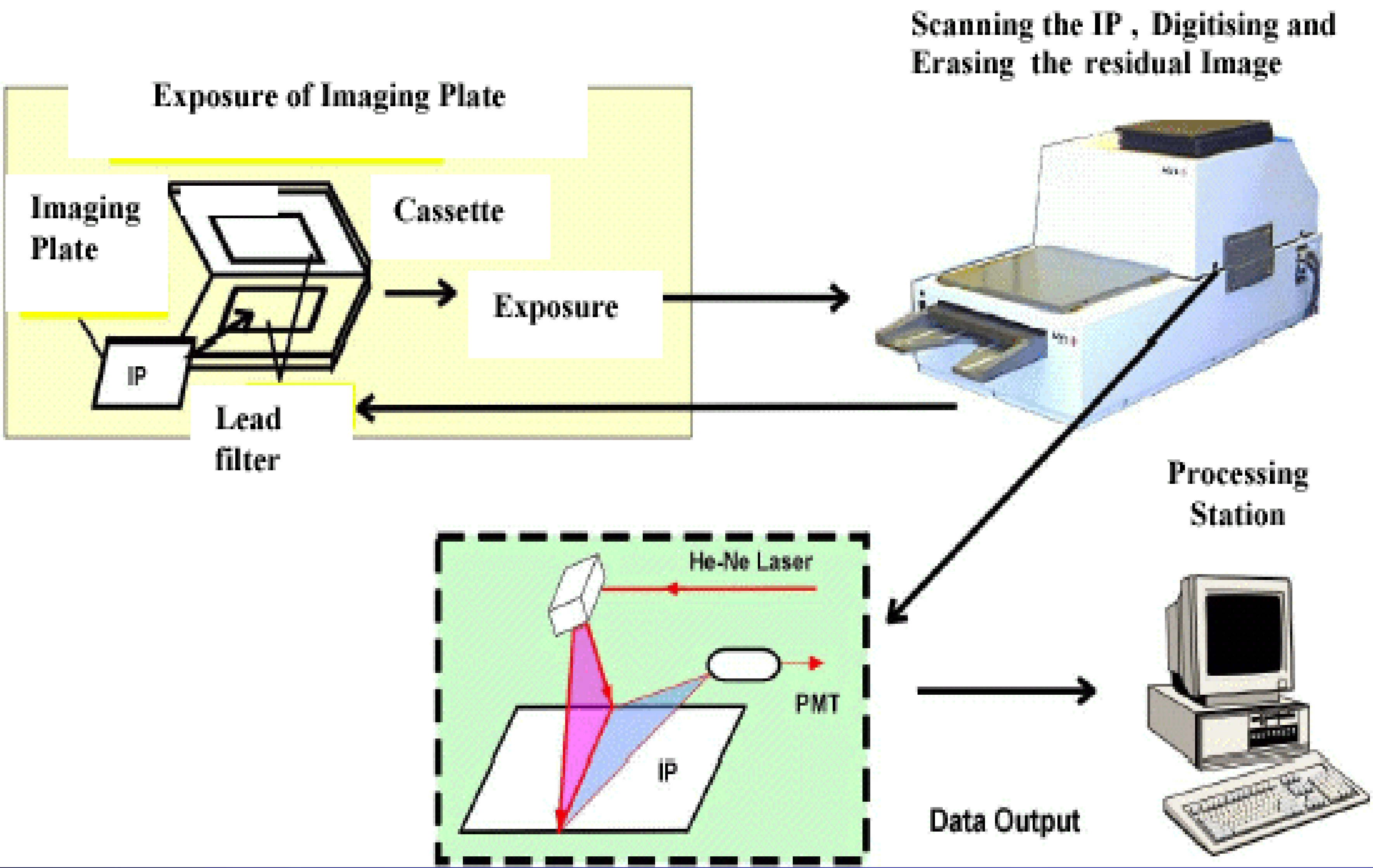
- **Protective layer**
  - Shield phosphor layer from mechanical wear & cleaning solution.
  - Provides smooth surface that improves SNR.
- **Phosphor /active layer**
  - Layer that hold photostimulable phosphor, the active component in the plate.
  - To trap electrons during exposure.
- **Conductor layer**
  - Eliminate electrostatic problems & absorb light to increase sharpness.
- Support layer
  - Base to coat the other layer

- **Light shield layers**
  - Prevents light from erasing data on the imaging plate or leak through the backing, decrease spatial resolution.
- **Backing layer**
  - Protect the base from damage during handling.

Image acquisition

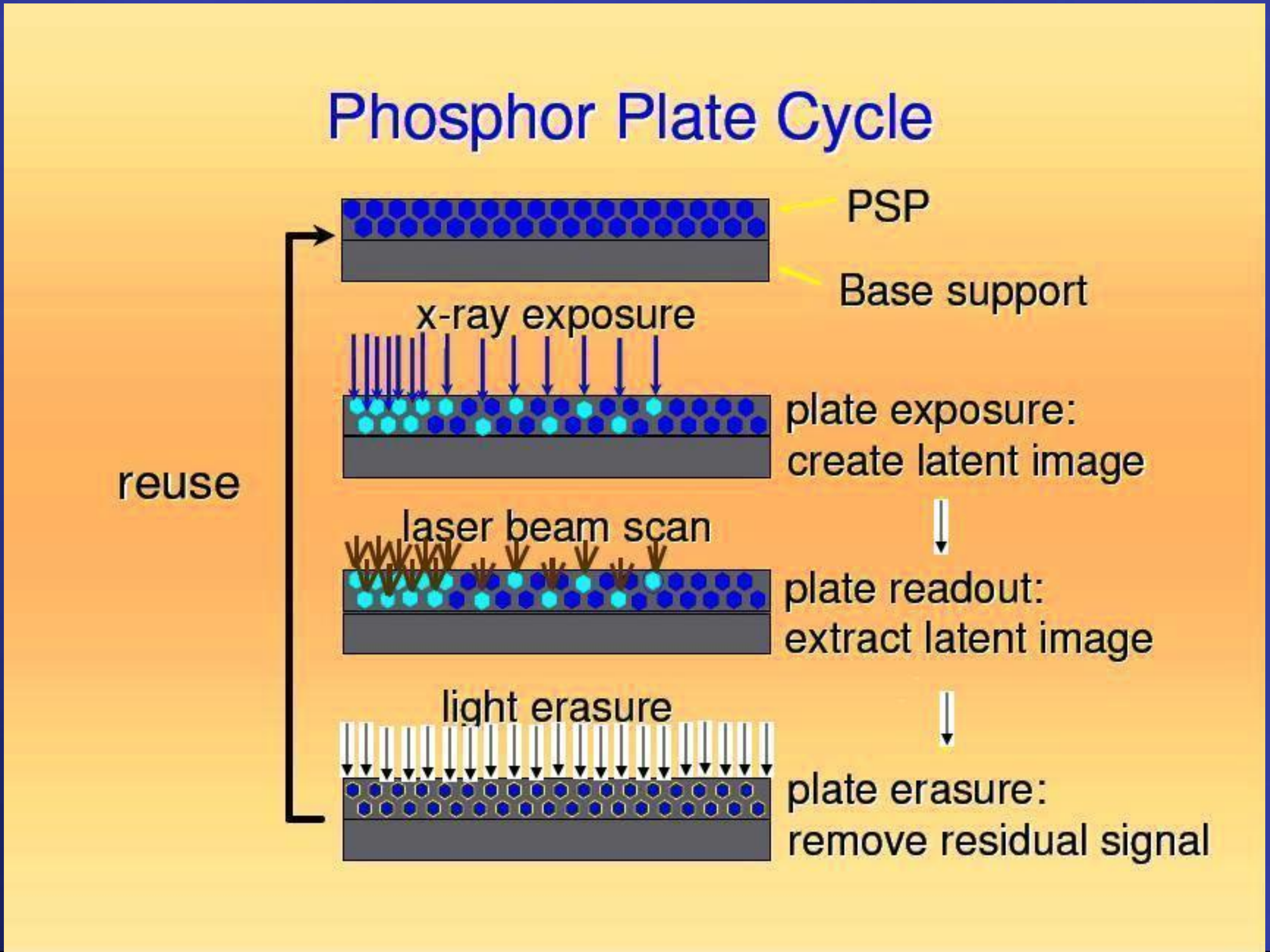


The Imaging Plate Cycle



- For CR to function, the imaging plate must have the ability to store & release the image information in a useable form.
- Most common phosphor with characteristics favourable for CR is barium fluorohalide bromides & iodides with europium activators (BaFBr:Eu & BaFI:Eu)
- The imaging plate is more sensitive to scatter both before & after it is sensitized through exposure to the X-ray beam.

Process of image acquisition



Latent image production

- When remnant X-ray strike imaging plate, some of X-ray energy is absorbed & immediately this energy is released in form of visible light.
- Visible light is produced when some of crystals are ionized, producing electron-hole pair within them.
- The ionizing event caused crystal electron to be trapped/stored at <u>higher energy level</u>.
- The stored electron constitute the latent image.
- The latent image will remain stored for 24 hours but will gradually weaken through <u>fading process</u>.

Fading process

Image on fresh plate.

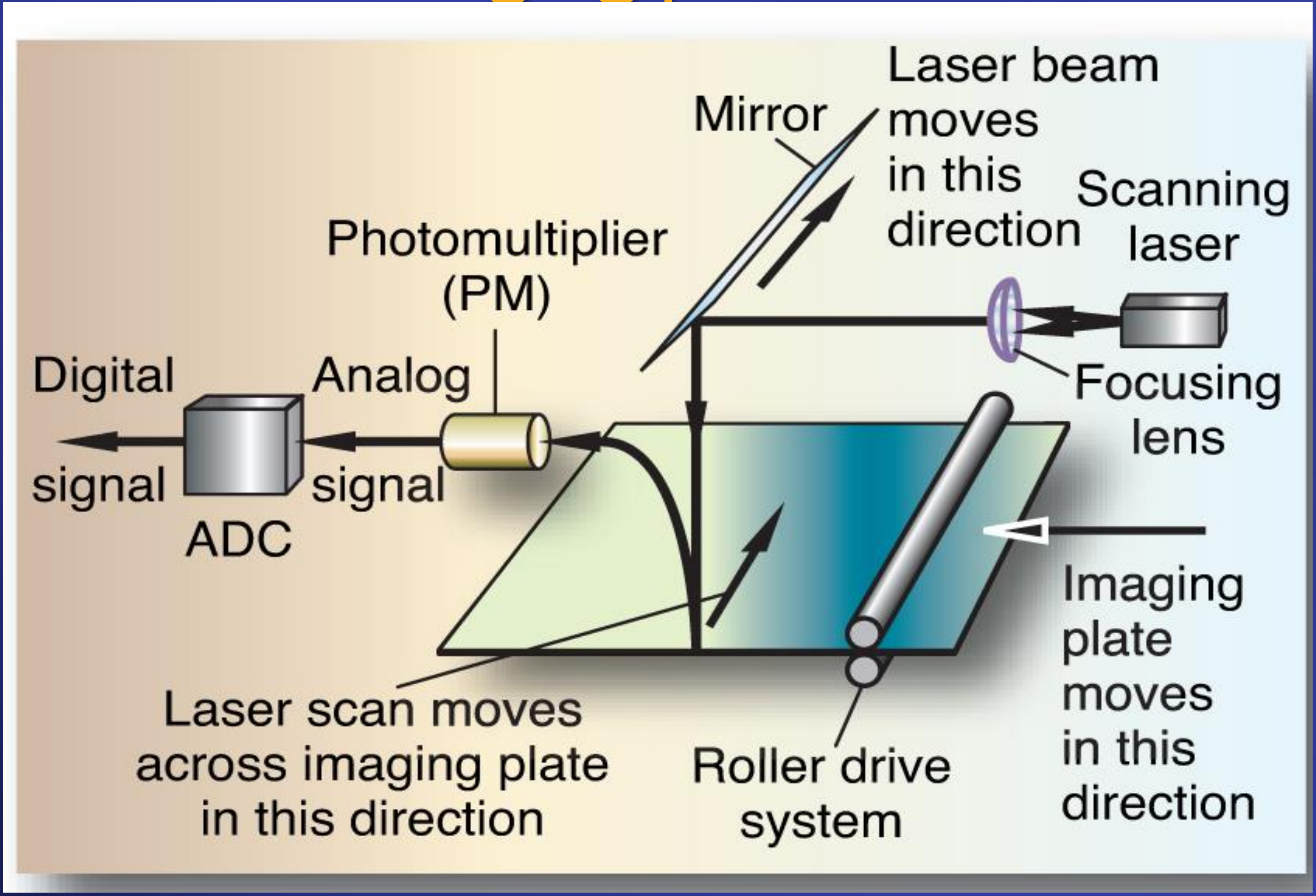
Image on plate not erased after four day weekend.

CR reader process

- After exposed, CR cassette is inserted into CR scanner where it is automatically open & image plate is removed.
- CR scanner scan the image plat with laser light & reads latent image from phosphor (readout process).
- Laser light (Helium-neon) scan the IP in raster pattern as the plate is fed through processor.
- Finely focused laser beam freed the trapped electrons, allowing them return to lower energy state.(photostimulated luminescence(PSL) process)

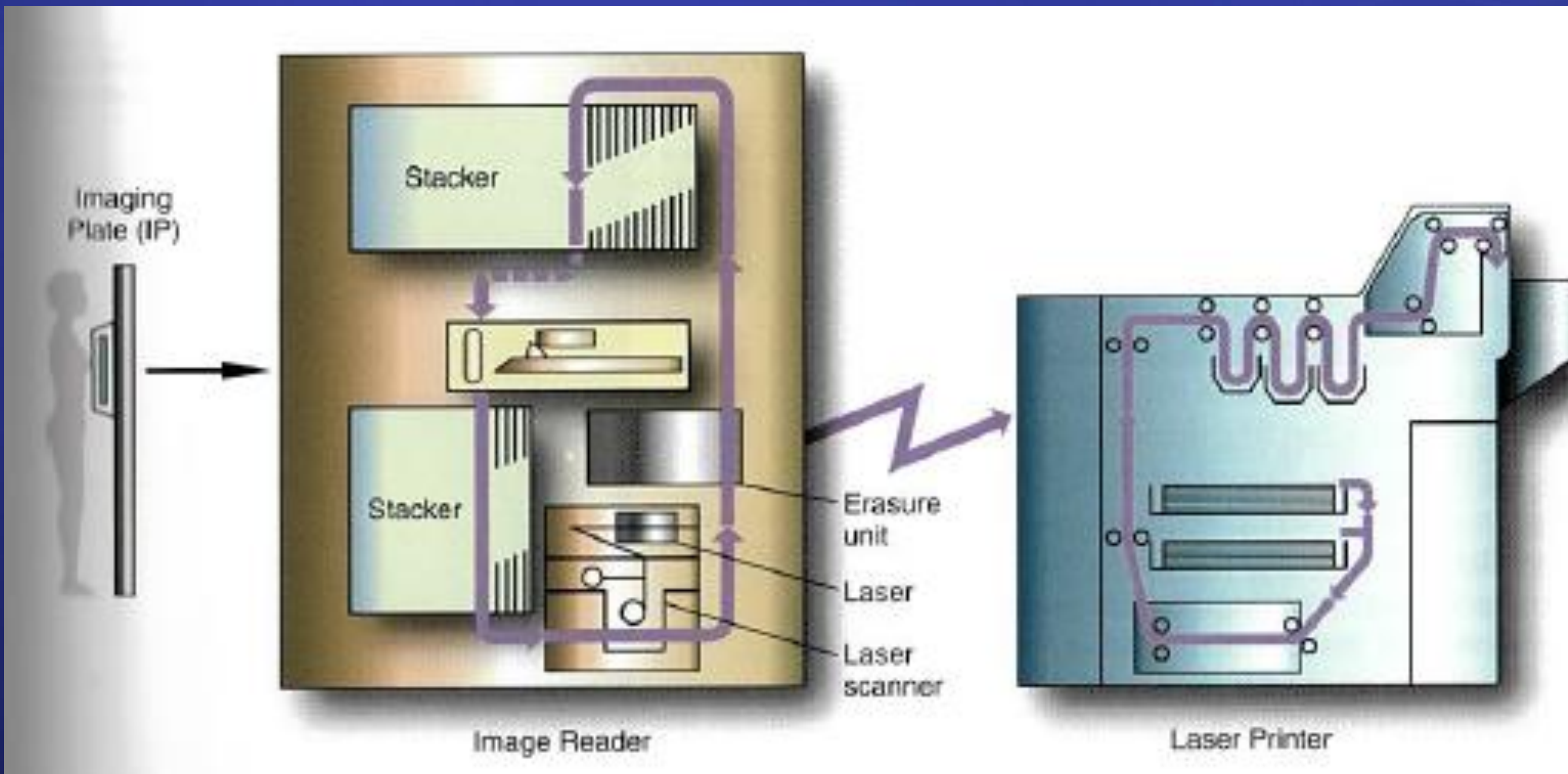
- Electron moving to a lower energy state release blue-purple light which proportion to the absorbed radiation.
- Light emitted from IP in all directions & is collected by optical systems & direct it to one or more photomultiplier tube (PMT)- sensitive only to blue light.
- PMT converts the visible light into electronic signal (in analog form)
- Analog Digital Converter(ADC) convert the analog signal to digital to be processed by computer. (image information)
- The PMT adjust the output signal range so it can be optimally handled during the digitization process.

PSP Imaging plate reader

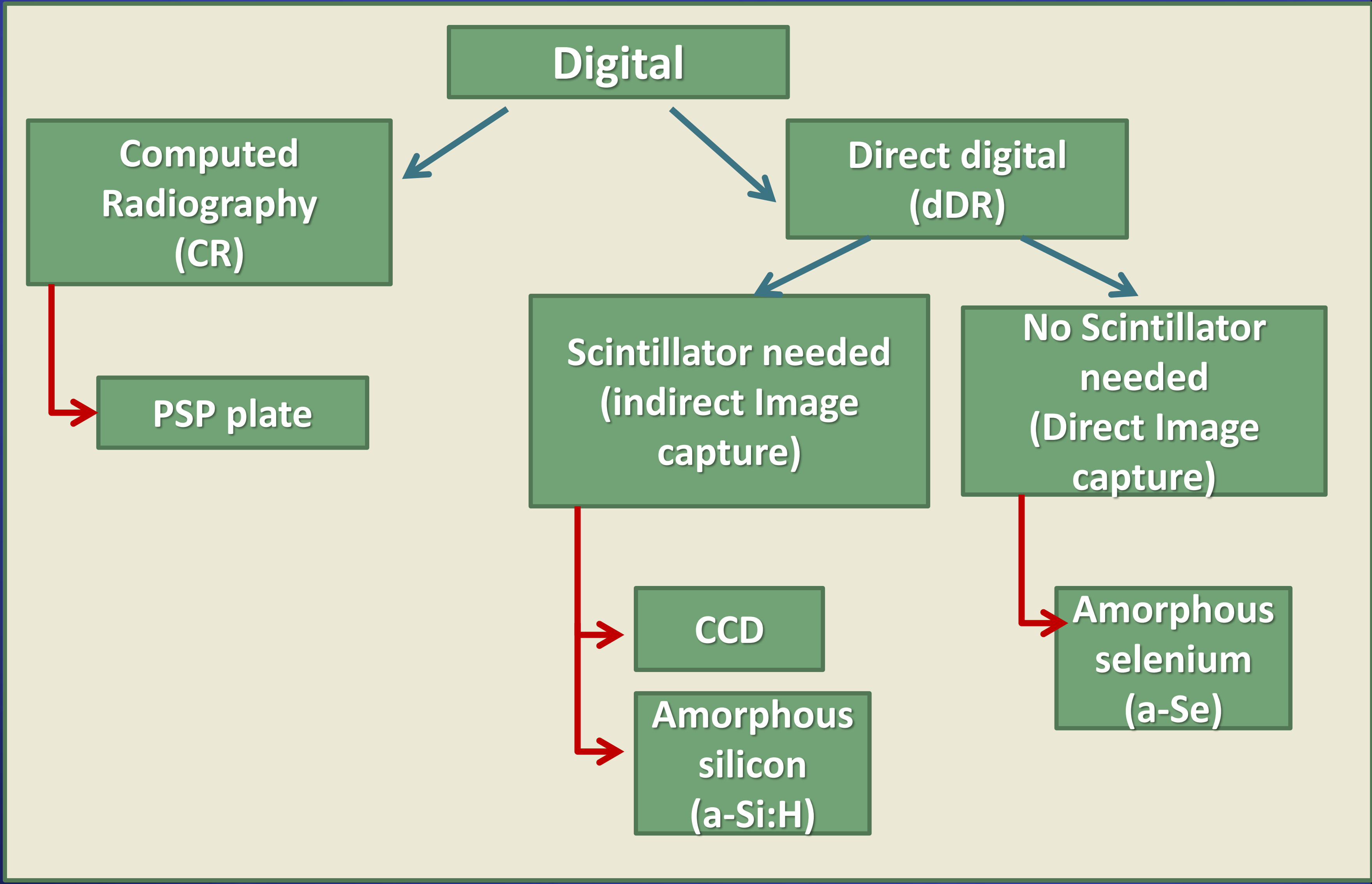


- Any residual image left on IP is erased by exposure to intense light to released any remaining trapped electron.
- Once IP is processed, digital image is immediately displayed on monitor- radiographer can check positioning errors or gross technical errors.
- If image is acceptable, radiographer can download the image into a computer where it can be manipulated & transferred to a picture archiving and communication system (PACS).

- The reading & erasing of an imaging plate can occur in a single processor unit, or it can be accomplished with separate desktop processor or erasure unit.
- Larger unit allow stacking & loading of multiple cassettes, whereas a desktop processor requires the imaging plate to be removed from the cassette & fed into processor.


Imaging Plate (IP)
Stacker
Stacker
Erasure unit
Laser
Laser scanner
Image Reader
Laser Printer

Digital Radiography System



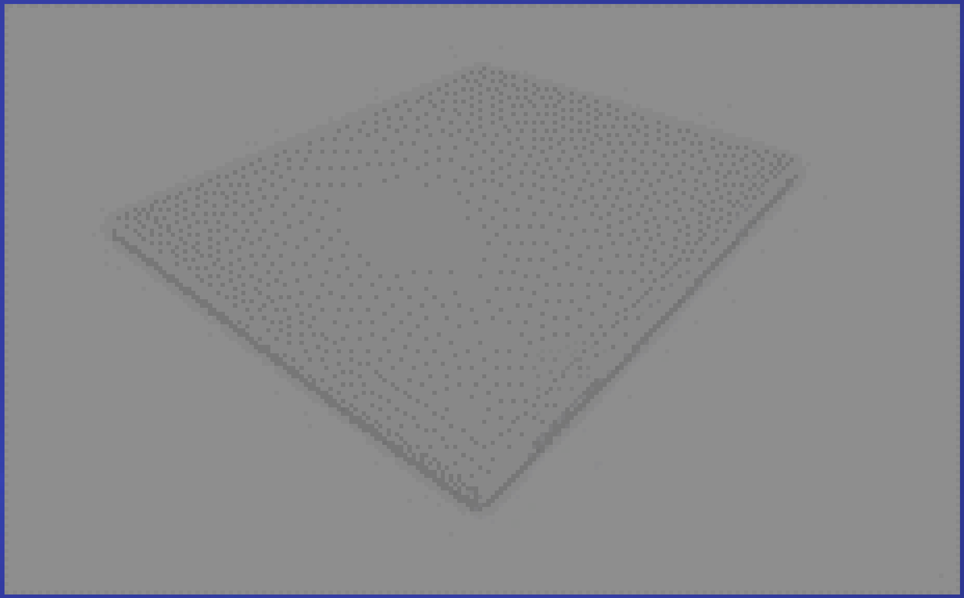
DIRECT DIGITAL RADIOGRAPHY (dDR)

Direct Digital Radiography (dDR)

- Cassette less
- Capture & converts X-ray energy directly into digital signal- immediately seen on monitor.
- dDR employ either direct acquisition (without scintillator) or indirect acquisition (with scintillator)
- Use silicon combine with photodiodes, charge couple device (CCD) detector or flat plate digital detector based on amarphous selenium or amarphous silicon.

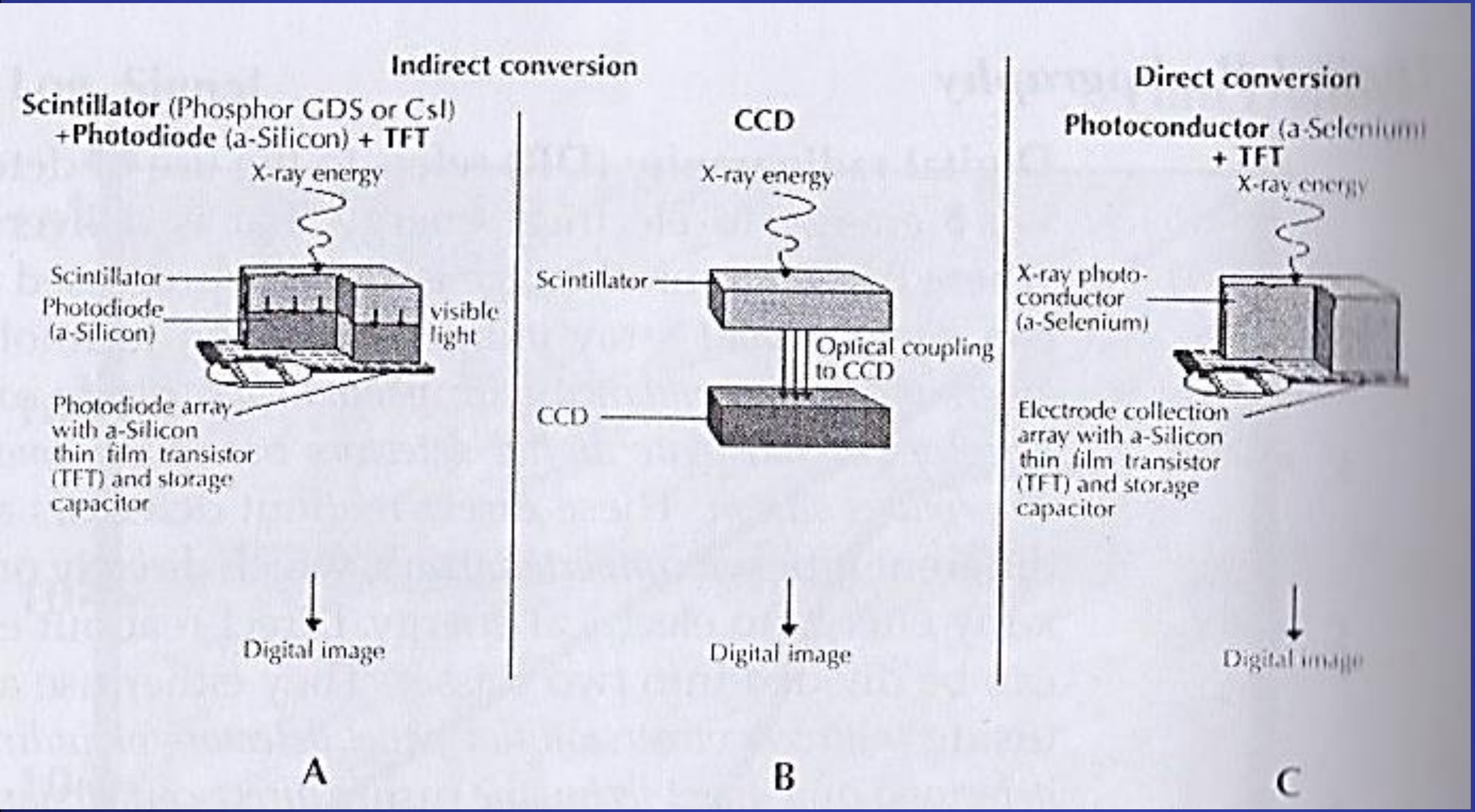
Direct digital Radiography

dDR flat panel detector



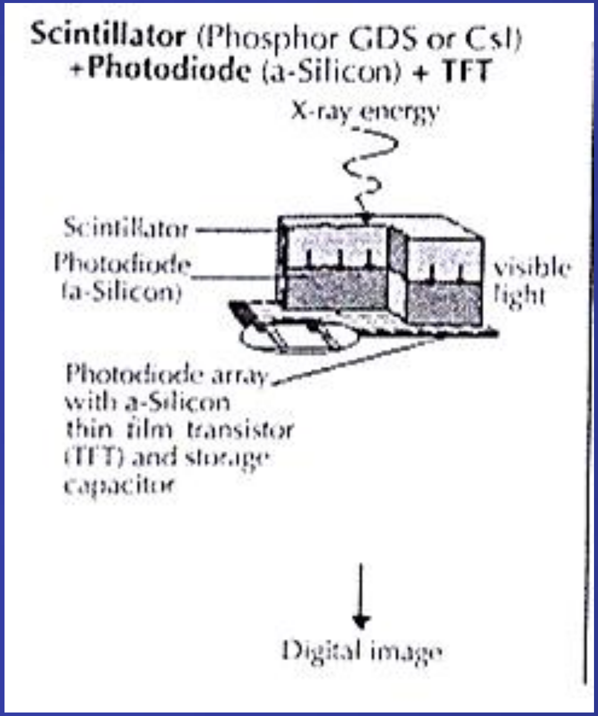
Direct Digital Radiography (dDR)

- Indirect conversion /acquisition
  - Process involving scintillator(which converts incoming X-ray photon to light) & a photodetector (which convert light into an electronic signal)
  - System include photostimulable storage phosphor imaging plate, charge coupled device & silicon.
- Direct conversion
  - System directly convert incoming X-ray photon to an electronic signal.
  - System use selenium


Indirect conversion
Scintillator (Phosphor GDS or CsI)
+Photodiode (a-Silicon) + TFT
X-ray energy
Scintillator
Photodiode
(a-Silicon)
visible
light
Photodiode array
with a-Silicon
thin film transistor
(TFT) and storage
capacitor
Digital image
A
CCD
X-ray energy
Scintillator
Optical coupling
to CCD
CCD
Digital image
B
Direct conversion
Photoconductor (a-Selenium)
+ TFT
X-ray energy
X-ray photo-
conductor
(a-Selenium)
Electrode collection
array with a-Silicon
thin film transistor
(TFT) and storage
capacitor
Digital image
C

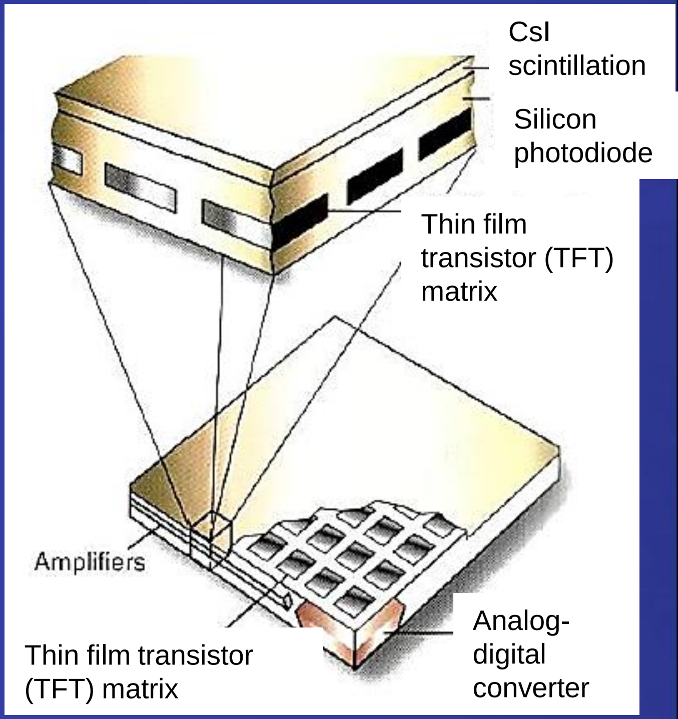
Indirect conversion

1. <u>Indirect conversion flat panel detector</u>
   - Use silicon combine with photodiodes
   - Photodiode coated with scintillation phosphor.
   - When Scintillator struck by remnant X-ray, visible light emitted (proportion to X-ray beam).
   - Visible light is converted into electrical charge by photodiode arrays.
   - Electrical signal is then sent to ADC to be changed into digital signal.



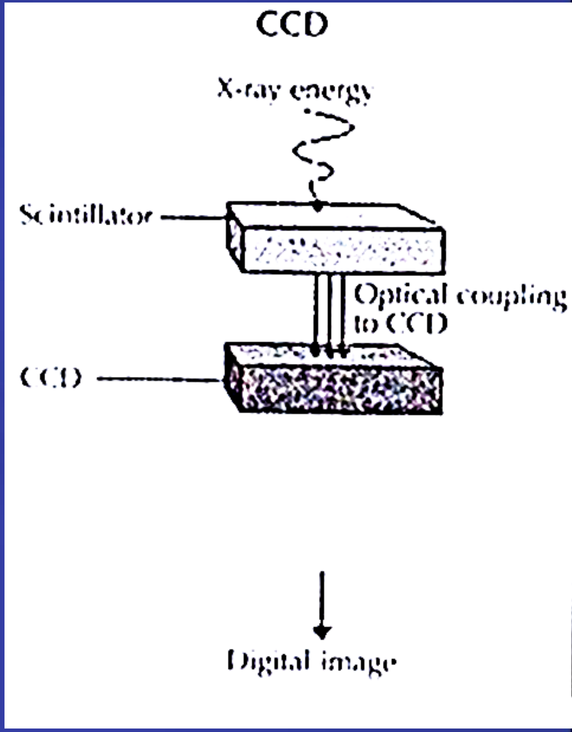
Thin film transistors (TFT)

- Both amorphous silicon & amorphous selenium flat plat detectors use thin film transistors (TFT) for electronic readout.
- TFT collects the electric charges produced by either selenium or silicon (matrix of pixel-size detector elements).
- Each TFT element collect the charge & then, when a gate is activated by the computer, sends a signal.
- TFT are positioned in a matrix that allows the charge pattern to be read out on a pixel-by pixel column-by column basis.



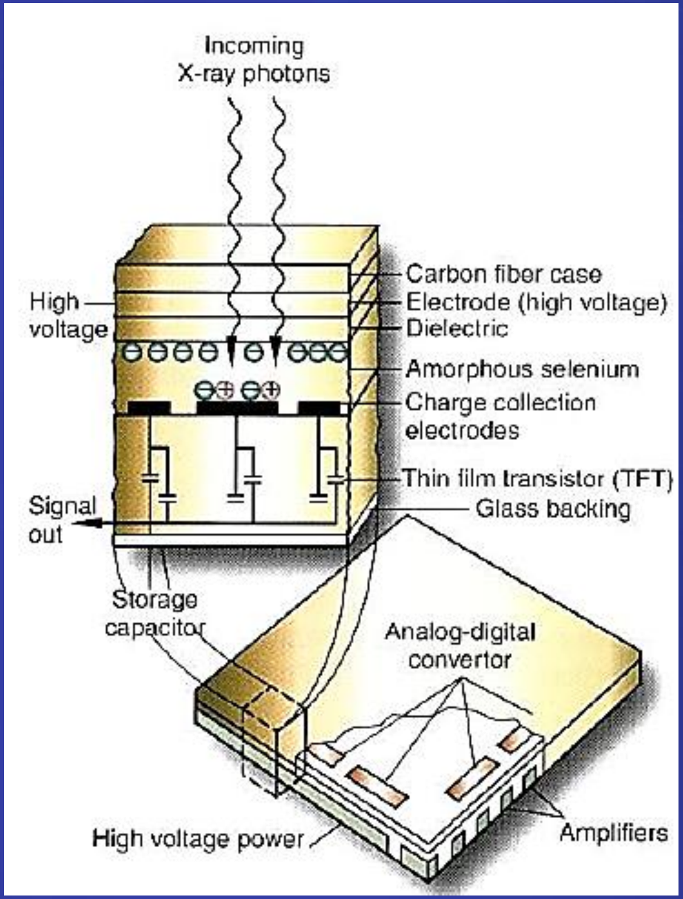
Indirect conversion

2. <u>Indirect conversion charge-coupled device detector</u>
   - CCD is a photodetector, a device that is capable of converting visible light into an electric charge & storing it in a sequential pattern.
   - This stored charge can then be released line by line to the ADC.
   - Typically, a screen is used as a scintillator and the light produced from x-ray interactions must be optically coupled to the CCD by lenses or fiber-optics.
   - The electric signal produced by the CCD is then sent to the computer for image processing.

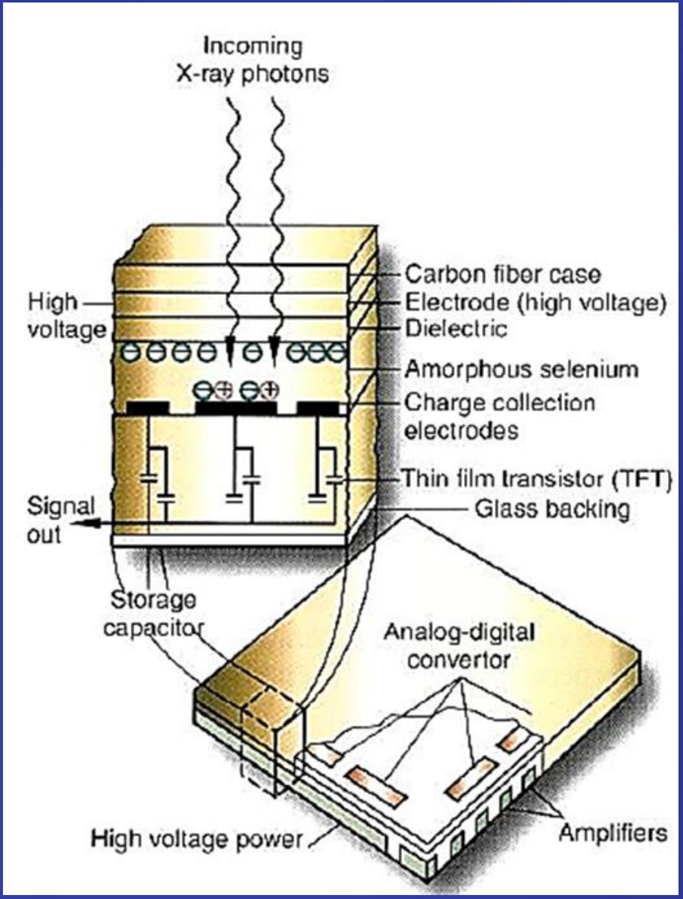


Direct Conversion

- Use amarphous selenium (a-Se)-coated thin film transistor (TFT) that directly converts X-ray energy into electrical signal.
- Prior to the exposure, a high voltage charge is applied from the top surface of selenium layer.
- Ionization caused by the X-ray photons results in the selenium atoms freeing electrons for collection by the electrodes at the bottom of the selenium layer.



- The charge that is collected is then transmitted through thin film transistors (TFT) to the computer for processing.
- Signal is sent to ADC to be converted to digital signal.



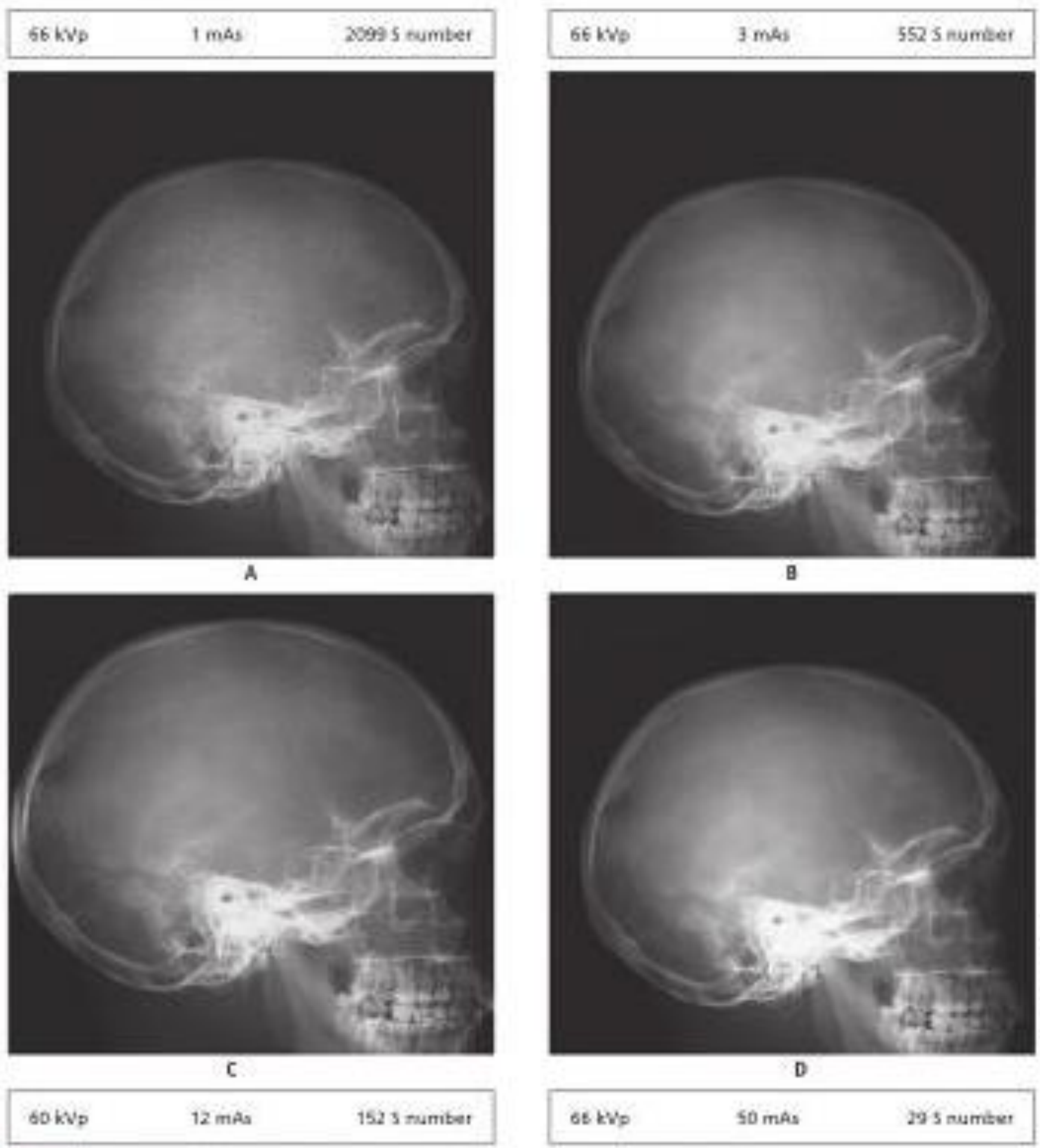
Digital Radiography Image Quality

Image quality

- CR processing system indicates several values that are useful to ensure maximum data acquisition.
- Fuji CR- uses S number to assist in evaluating exposure.
- It is inversely proportional to the exposure reaching the imaging plate.
- Eg;
  - S value of 200 indicates that imaging plate received 1 mR.
  - A higher S value indicates imaging plate (IP) was underexposed, while a lower S value indicates overexposure of the IP.
  - Properly exposed imaging plates should produce S values of <u>150-250</u>.

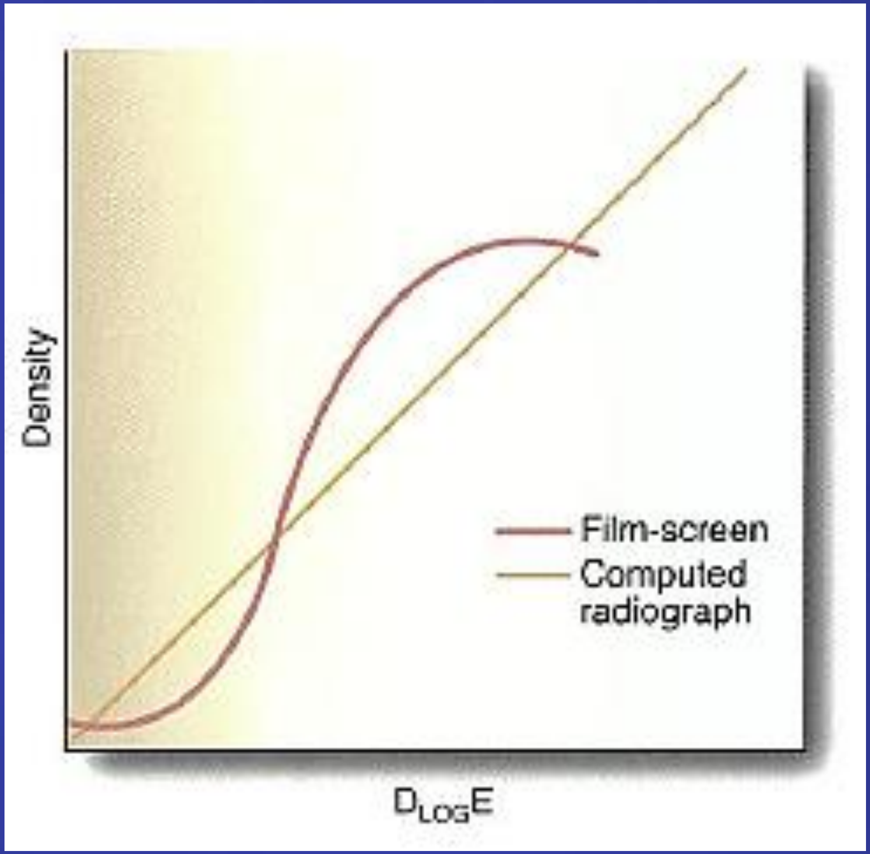
Underexposed- loss of detail & graininess

Only image C is within optimal range of fuji S number though all images appear to have appropriate density range



- KV for CR control contrast similar to film radiography.
- Some CR manufacturers recommend avoiding the use of more than 80 kVp for non-grid because higher kVp level produce excessive fog that will decrease contrast.

- CR has dynamic range response of the imaging plate detector.
- The response of an imaging plate to X-ray is linear.- increased exposure latitude over film-screen.



CR- no toe or shoulder

- Area that receive very little radiation can be enhanced by the computer instead of all the densities clumping around the toe of the D_{log} E curve in film receptor.
- Areas receiving greater exposure can be separated & brought down into visible density range by the computer instead of all clumping around the shoulder of the D_{log} E curve.

Toleration of Overexposure

- Radiation safety for CR system- it has extremely high toleration for pt overexposure.
- dDR does not have D_{max} , instead it has a straight that surpasses D_{log} E curve of film emulsion.
- When film is exposed beyond D_{max} , it actually reverses & begin to get lighter.
- CR imaging plate continues to record exposure & the computer can bring these densities down into visible range.-So, CR can compensate gross overexposure.

- There is **a great danger in permitting personal professional standards to relax & routinely over-exposing all pt with intention of CR system adjusting the histogram to correct exposure.**
- This practice is unethical, violates ALARA radiation protection guidelines, & has to be avoided.

Adequacy mAs

- Adequate mAs is required to activate any digital image receptor.
- Failure to use a high enough mAs setting produces quantum mottle, which produces a grainy.
- This is why a minimum CR sensitivity number is required by many radiologist to ensure they are diagnosing from an image that minimum data requirements of CR system.

- Images that are underexposed will show quantum mottle, even though the density is acceptable, while overexposed image will tend to suffer from low contrast.

Advantages & Disadvantages of CR vs dDR

	Advantages	Disadvantages
CR	•Less expensive •Can be used in portable radiography •Better suited for trauma radiography •Compatible with existing radiographic tables	•Delayed readout •Cassette needed •Plate must be erased and reloaded into a cassette before it can be used again.
DR	•Immediate readout •Cassette free operation •Detector can be re-exposed immediately	•More expensive

IMAGE DISPLAY

Image Display

- Traditionally, film was displayed on an illuminator viewbox.
- Digital images can still be produced on film(hard copy) with a laser printer.
- Advantages of soft-copy display:
  - Multiple viewing of same image
  - Variation of image display parameters (density, brightness, sensitivity & contrast)
  - Reduced no of lost films

Types Image Display

- Hardcopy
- Softcopy

HARDCOPY DISPLAY

Hard Copy display

- Refer to Images that are visualized on film.
- Required for:

1. Physician without soft copy display.
2. Orthopedic image measurements
3. For operating room.

Laser Printer

- Printer produced transilluminated hard-copy film images from computerised digital information.
- Light sources:
  1. Infrared (~780-820 nm)
  2. Solid-state diode (~670-680 nm)
  3. Helium-neon (~633 nm)

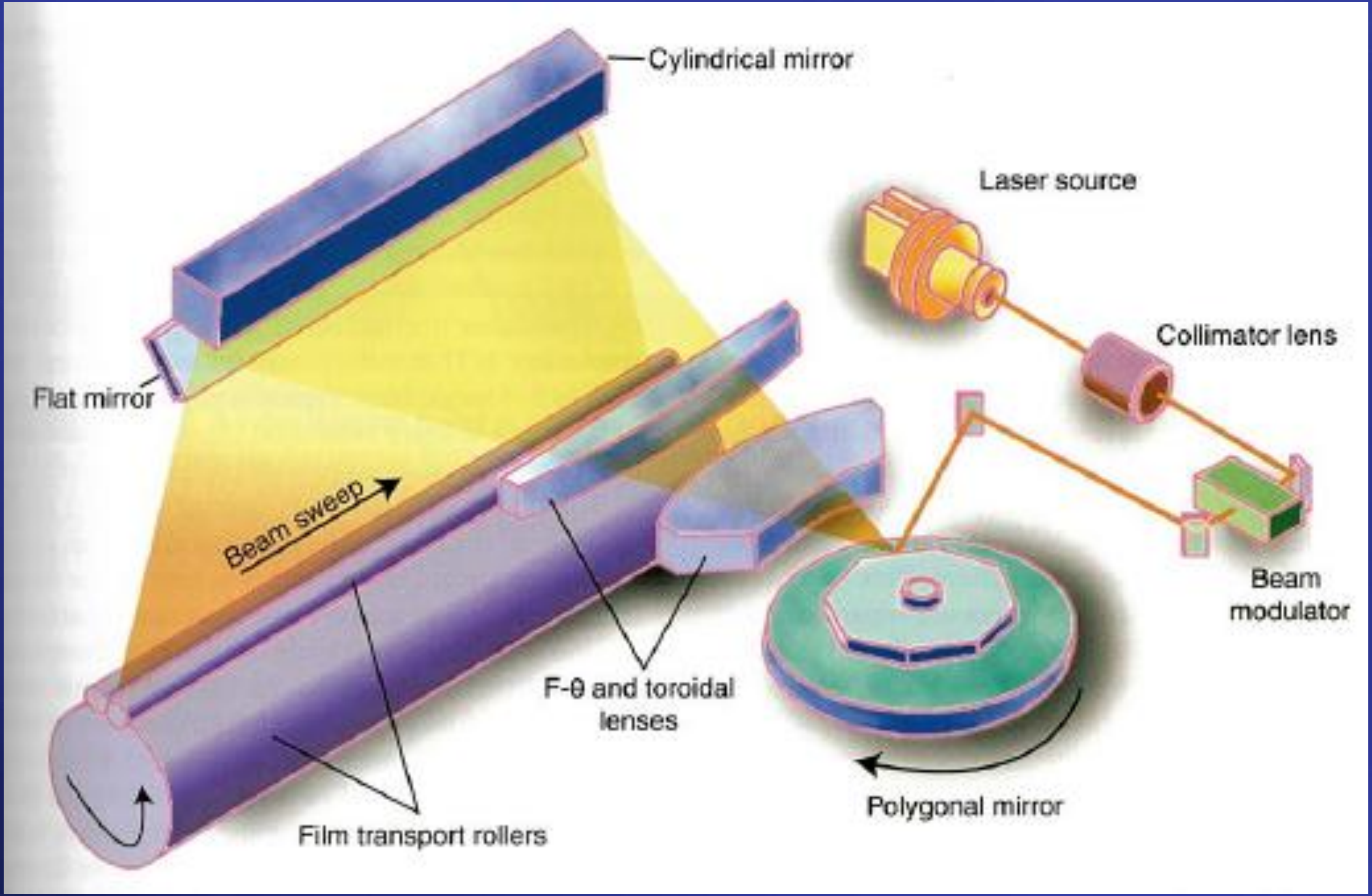
Laser Printer con’t

- Film is exposed line by line in a raster pattern.
- It is then processed either by dry or wet processing method.
- Then, deposited in exposed film receptor bin.

Laser Printer Components

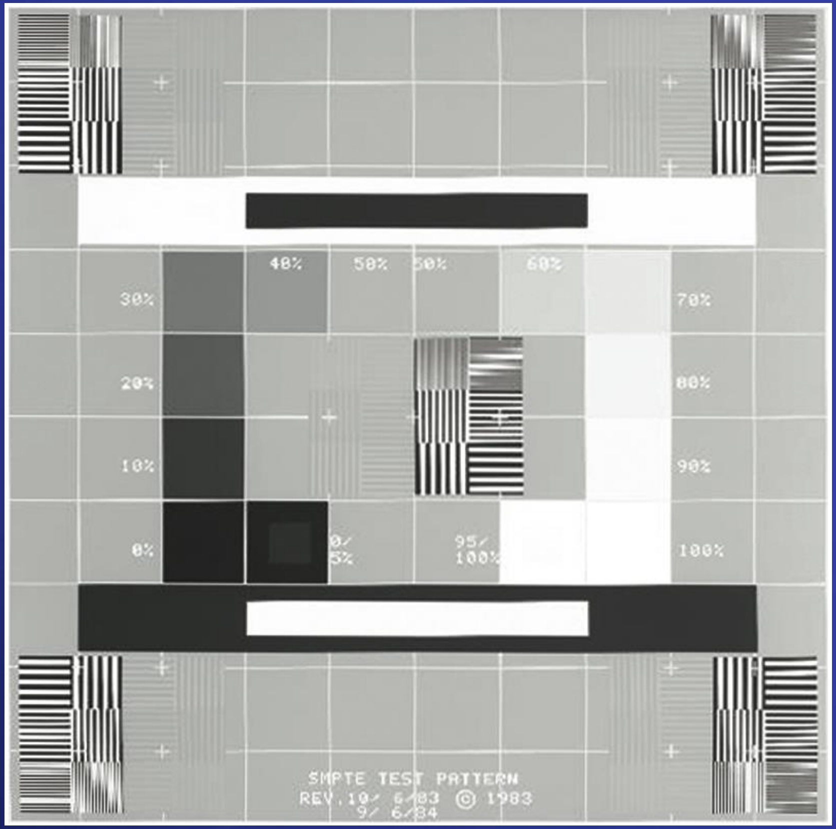
1. Laser source
2. Collimator lens or beam shaping optics
3. Beam modulator
4. Deflecting mirror-shaping lenses
5. Cylindrical reflecting mirror
6. Unexposed film storage
   - With mechanical transport to move film through printer

Diagram film laser camera



Laser Printer Calibration

Calibration film can be printed to check optical density range of the printer.



Laser printer calibration demonstrates full range of density and contrast for that unit.

Wet Laser Film

- Wet processing use silver halide in emulsion.
- Wet laser film designed to be sensitive to either red or infrared wavelengths
- Cannot be exposed to red safelight- fog.
- After laser energy create latent image, it is processed through developer, fixer, wash and drier

Dry processor

- Eliminate the need for chemicals & plumbing required by wet processing- more flexible in printer placement.
- Unexposed dry-processing laser film has shorter shelf life- sensitive to heat & humidity.
- Use thermal processing which involve heat sensitive film with:
  1. **Silver based emulsion**
  2. **Dye microcapsule**
  3. **Carbon-based adherographic printing**

Silver based Emulsion Dry-Processor Film

- Contain silver benhate .
  - Respond to laser light & heat from thermal head.
- Laser light produces latent image centers
- Only the activated silver halide grain develop when heated by thermal head.

Dye Microcapsule Dry-Processor Film

- When exposed to laser light microcapsule become active & permeable to allow developing agent to enter them.
- If film cool, microcapsule impermeable-chemical development process stop.
- High heat during storage-cause increase film density.

Carbon-Based Adherographic Printing

- Film is exposed to gallium arsenide laser.
- Then, carbon particles adhere to exposed area.
- To protect image & keep carbon particles in place, cover sheet is sealed or laminated onto finished film.

SOFT COPY DISPLAY

Soft Copy Display

- Refer to images visualized on monitor, either by flat panel technology or cathode ray tube (CRTs).
- Advantages:
  – Images can be manipulated
  – Images can be viewed in multiple location
  – Images can be distributed to multiple locations
- Diagnostic viewing require monitor with highest spatial & contrast resolution.

References

- Carlton R.R & Adler A.M. (2006).Principles of Radiographic Imaging An Art and a Science, 4th edition. Thomson Delmar Learning: New York.
- Shephard, C.T. (2003). Radiographic Image Production and Manipulation. Mc Graw Hill: New York.
- Carter, C. (2010) Digital Radiography and PACS. Mosby