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11 - 15 May 2009

Dosimetry for Fluoroscopy Basics

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And its Clinical Implementation
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Dosimetry for fluoroscopy - basics

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Introduction

- Fluoroscopy equipment
- Air-kerma rates and KAP measurement
- Phantom and patient dosimetry

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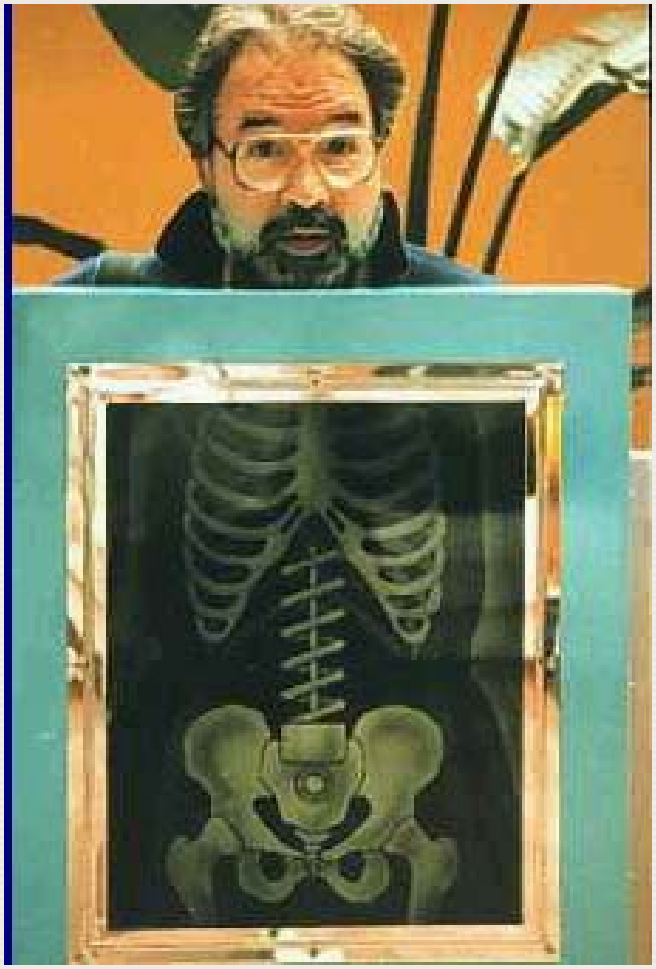
Fluoroscopy: a “see-through” operation with motion



- Used to visualize motion of internal fluid, structures
- Operator controls activation of tube and position over patient
- Early fluoroscopy gave dim image on fluorescent screen
- Physician seared in dark room
- Modern systems include image intensifier with television screen display and choice of recording devices

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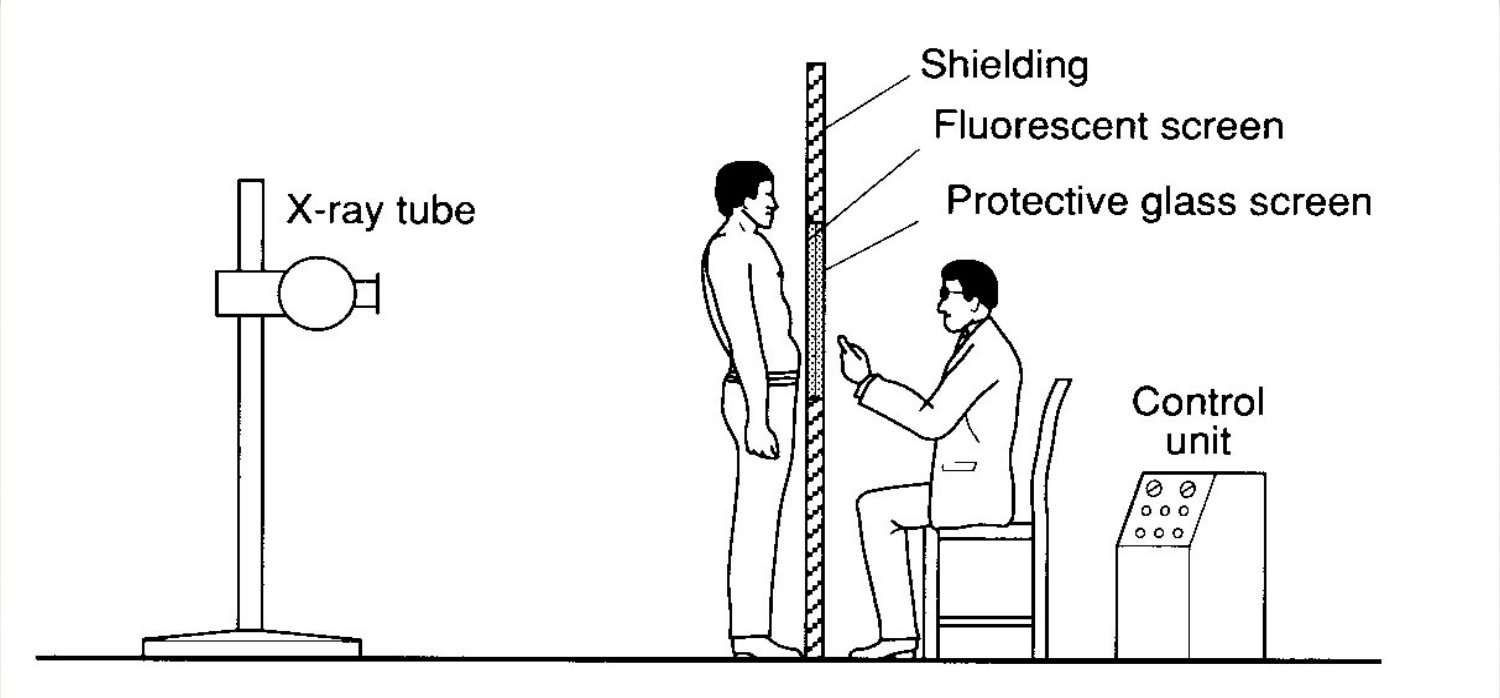
Direct Fluoroscopy: obsolete



In older fluoroscopic examinations radiologist stands behind screen and view the picture
Radiologist receives high exposure; despite protective glass, lead shielding in stand, apron and perhaps goggles

Main source staff exposure is NOT the patient but direct beam

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Older Fluoroscopic Equipment
(still in use in some countries)

Staff in DIRECT beam
Even no protection

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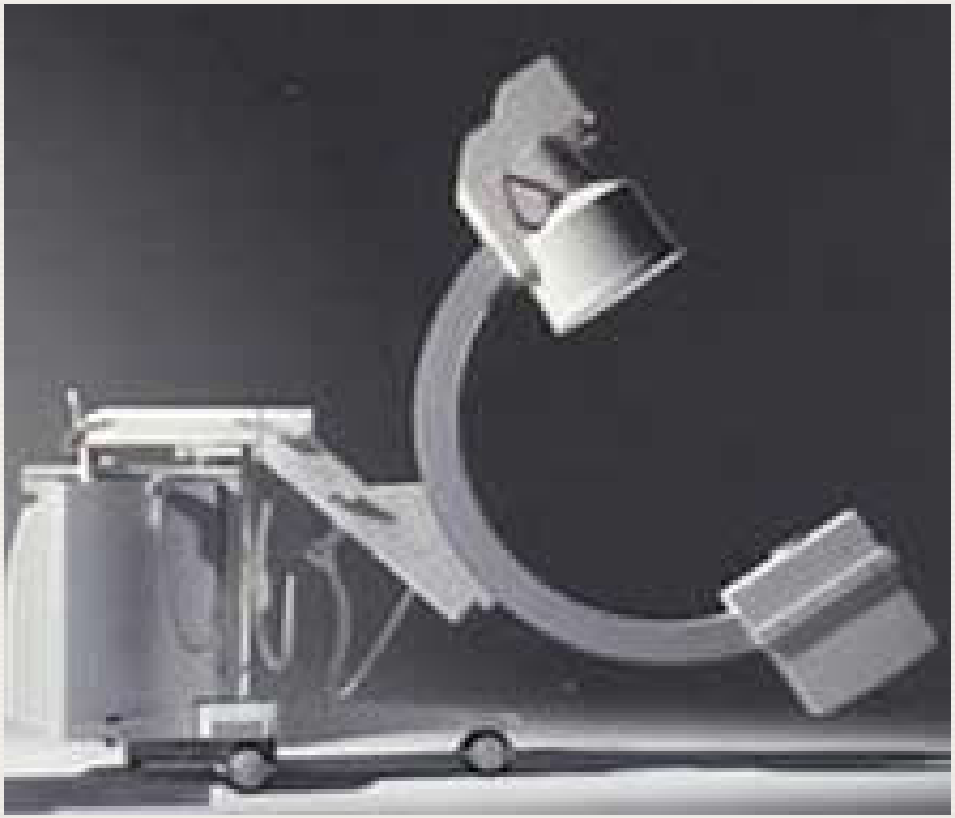
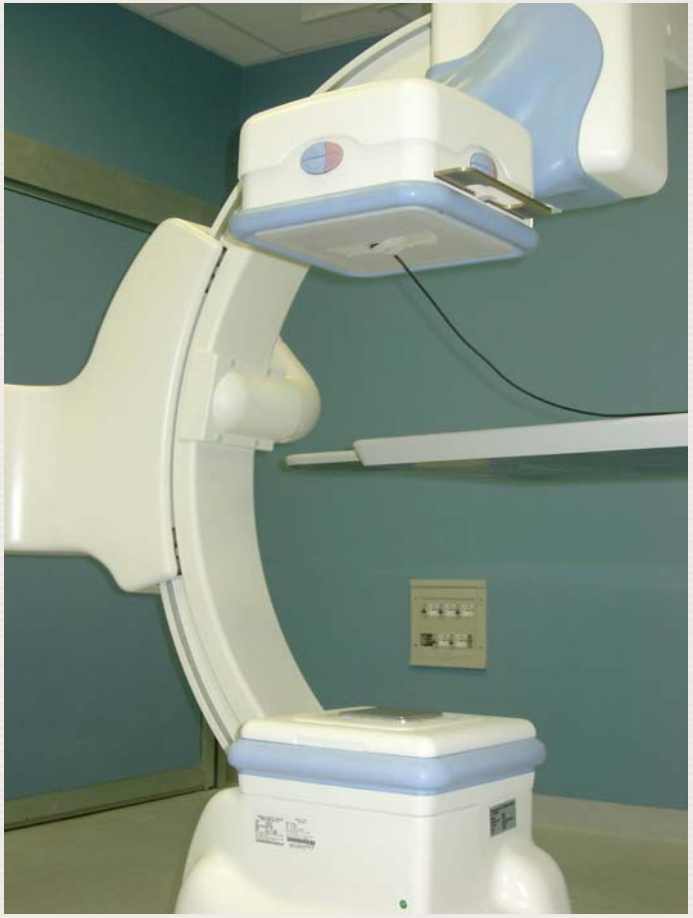
New Fluoroscopic Equipment





Direct fluoroscopy

- AVOID USE OF DIRECT FLUOROSCOPY
- Directive 97/43Euratom Art 8.4.
  - In the case of fluoroscopy, examinations without an image intensification or equivalent techniques are not justified and shall therefore be prohibited.
- Direct fluoroscopy will not comply with BSS App.II.25
  - "… performance of diagnostic radiography and fluoroscopy equipment and of nuclear medicine equipment should be assessed on the basis of comparison with the guidance levels

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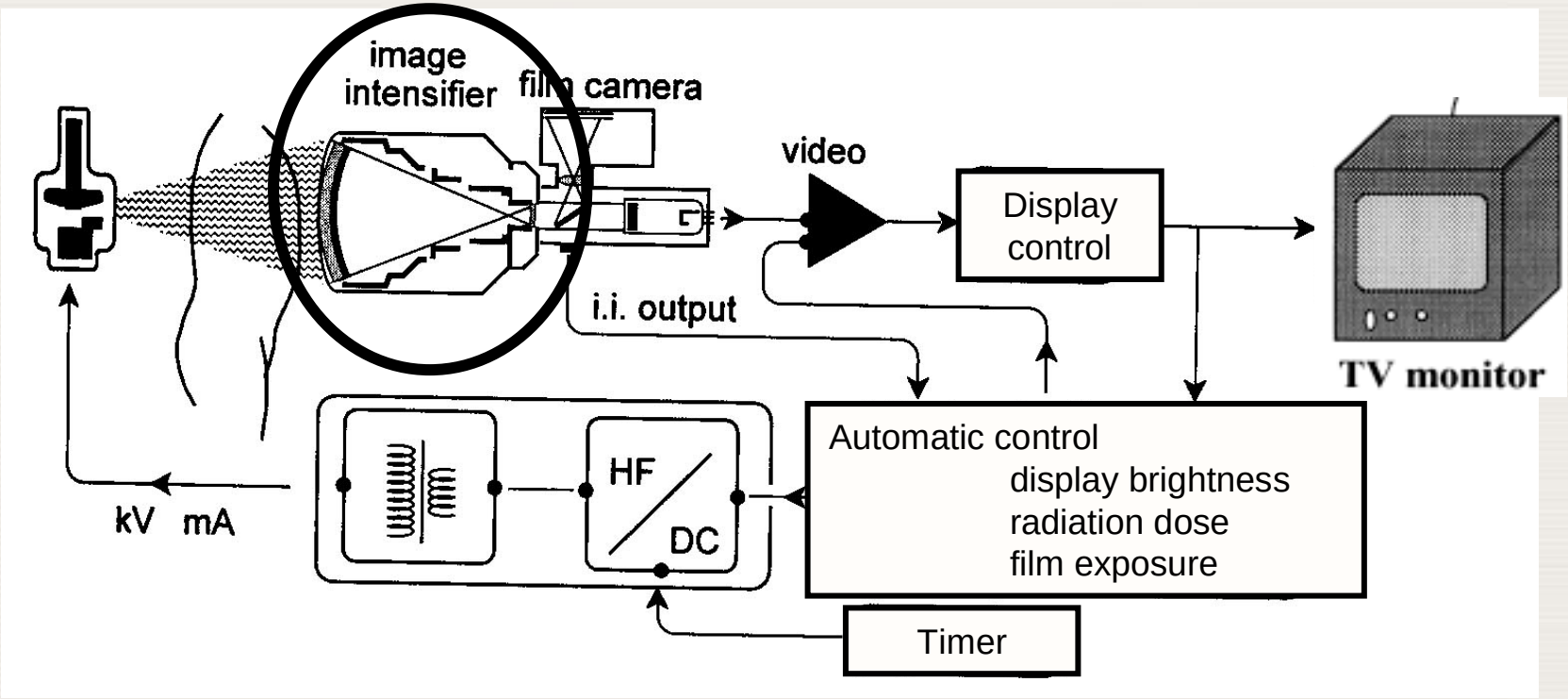
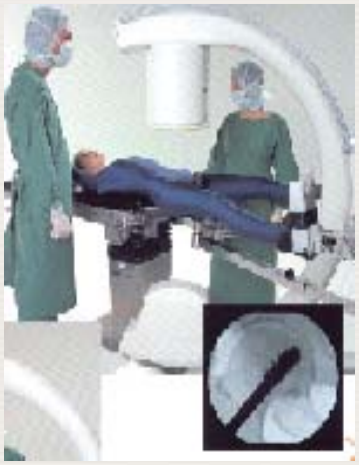
Modern fluoroscopic system components



Different fluoroscopy systems

- **Remote control systems**
  - Not requiring the presence of medical specialists inside the X Ray room
- **Mobile C-arms**
  - Mostly used in surgical theatres.



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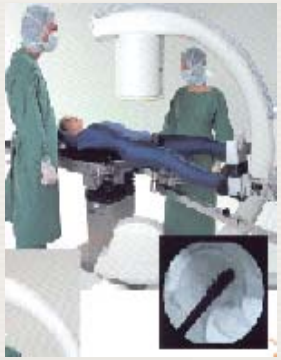
Different fluoroscopy systems

- **Interventional radiology systems**
  - Requiring specific safety considerations.

    In interventional radiology the surgeon can be near the patient during the procedure.



- **Multipurpose fluoroscopy systems**
  - They can be used as a remote control system or as a system to perform simple interventional procedures

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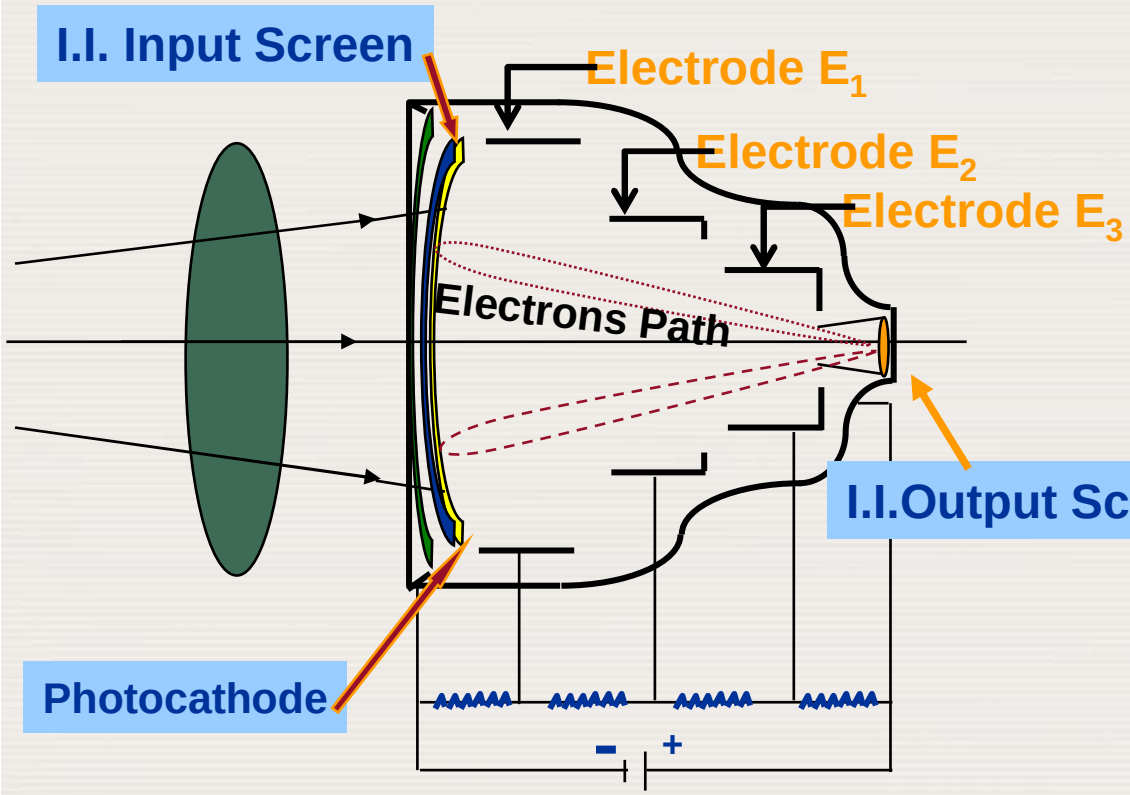
The image intensifier (I.I.)



- **Input screen**: conversion of incident X Rays into light photons (CsI)
  - **1 X Ray photon creates ≈ 3,000 light photons**
- **Photocathode**: conversion of light photons into electrons
  - **only 10 to 20% of light photons are converted into photoelectrons**
- **Electrodes** : focalization of electrons onto the output screen
  - **electrodes provide the electronic magnification**
- **Output screen**: conversion of accelerated electrons into light photons

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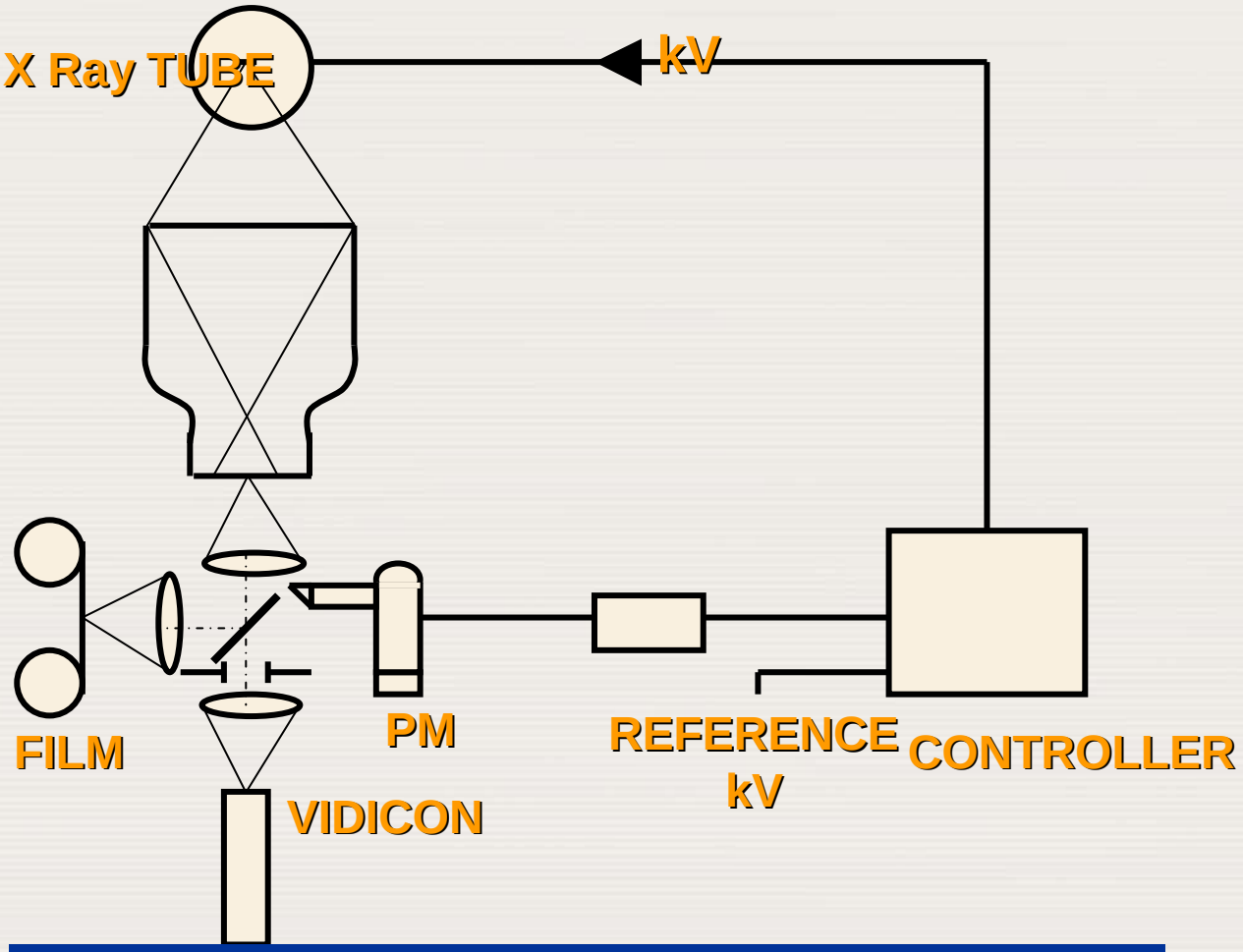
Image intensifier systems



GENERAL SCHEME OF FLUOROSCOPY

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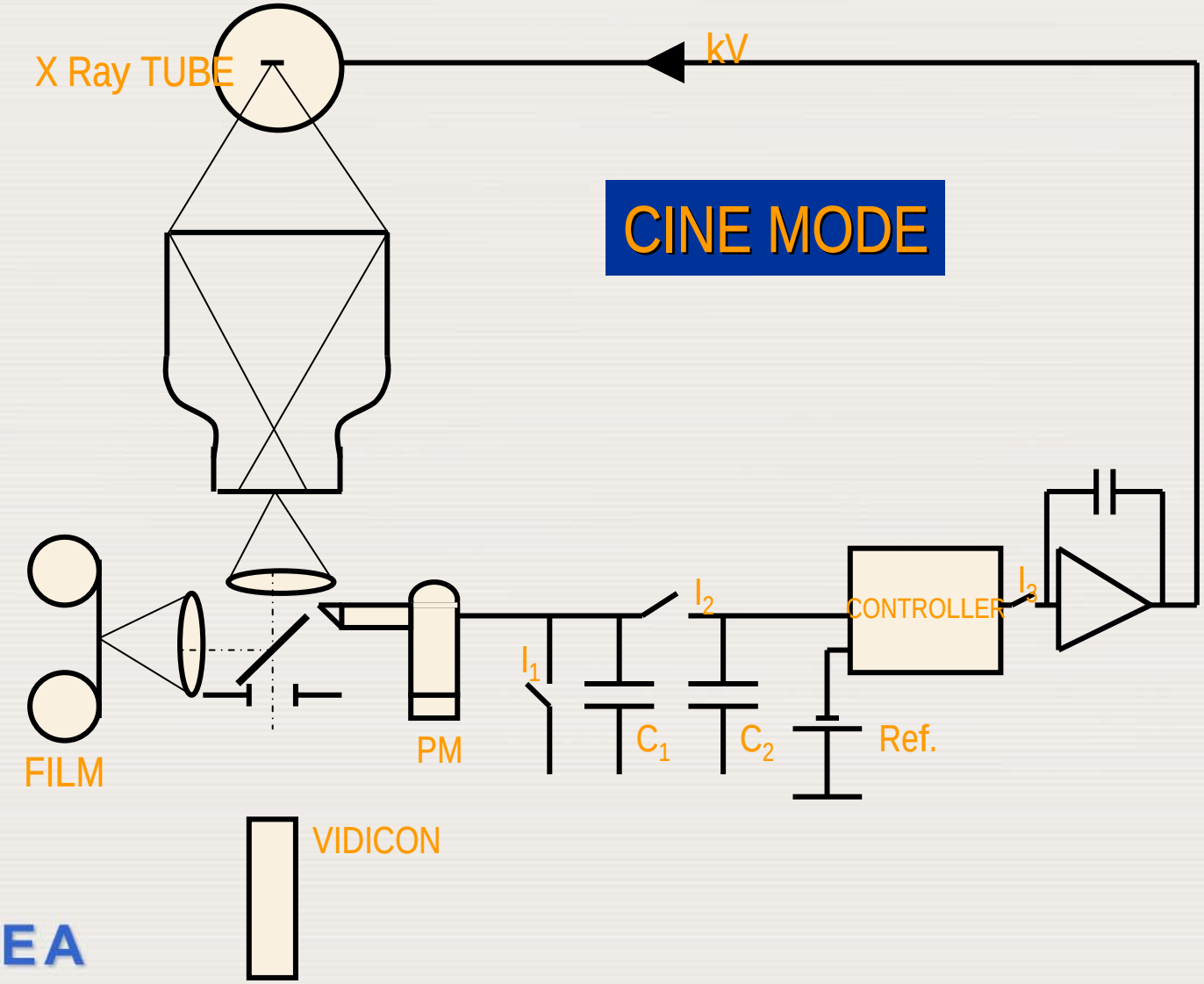
X Ray TUBE
kV
CINE MODE
FILM
PM
I_1
C_1
I_2
C_2
CONTROLLER
I_3
Ref.
VIDICON

Type of TV camera

- **VIDICON TV** camera
  - improvement of contrast
  - improvement of signal to noise ratio
  - high image lag
- **PLUMBICON TV** camera (suitable for cardiology)
  - lower image lag (follow up of organ motions)
  - higher quantum noise level
- **CCD TV** camera (digital fluoroscopy)
  - digital fluoroscopy spot films are limited in resolution, since they depend on the TV camera (no better than about 2 lp/mm) for a 1000 line TV system

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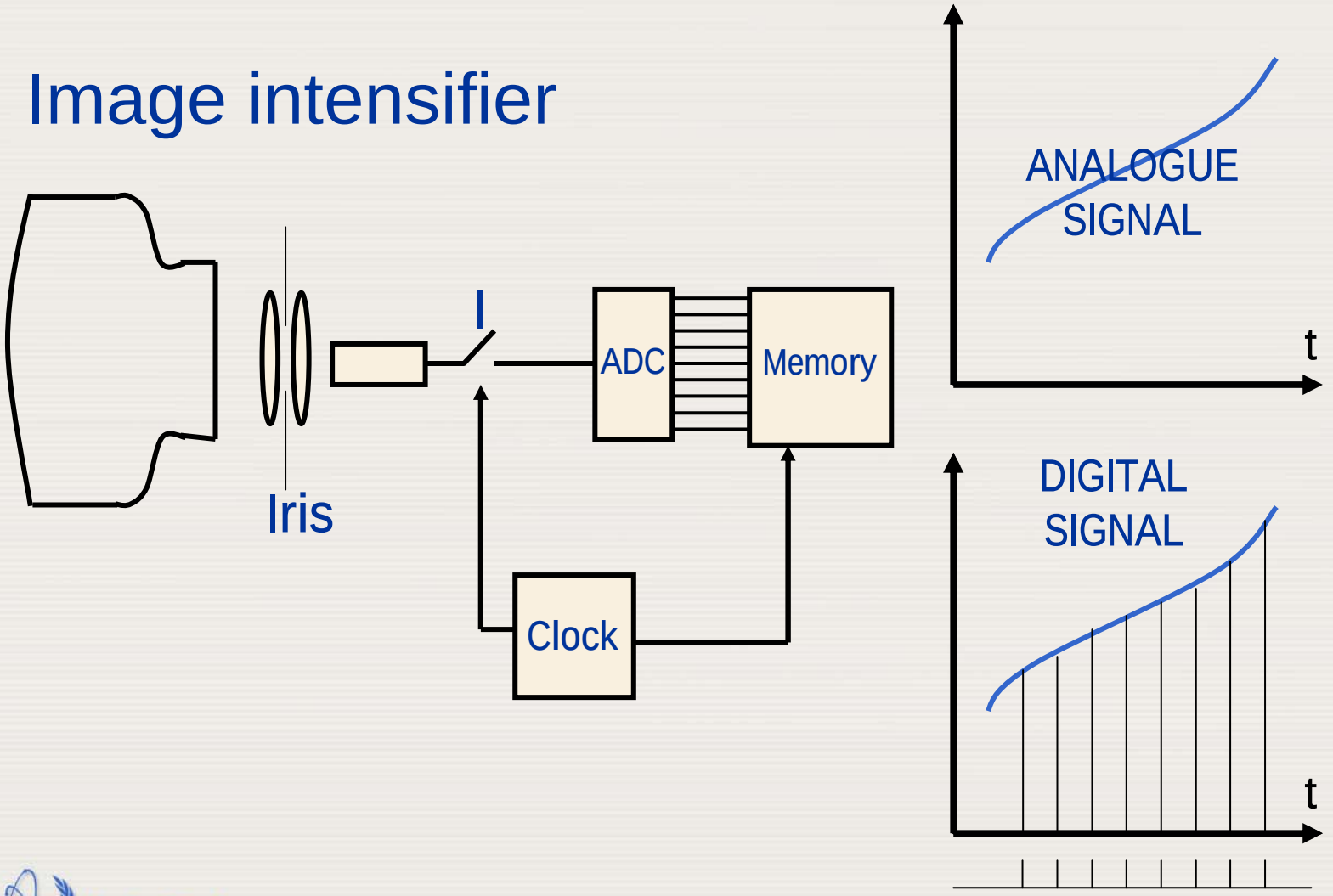
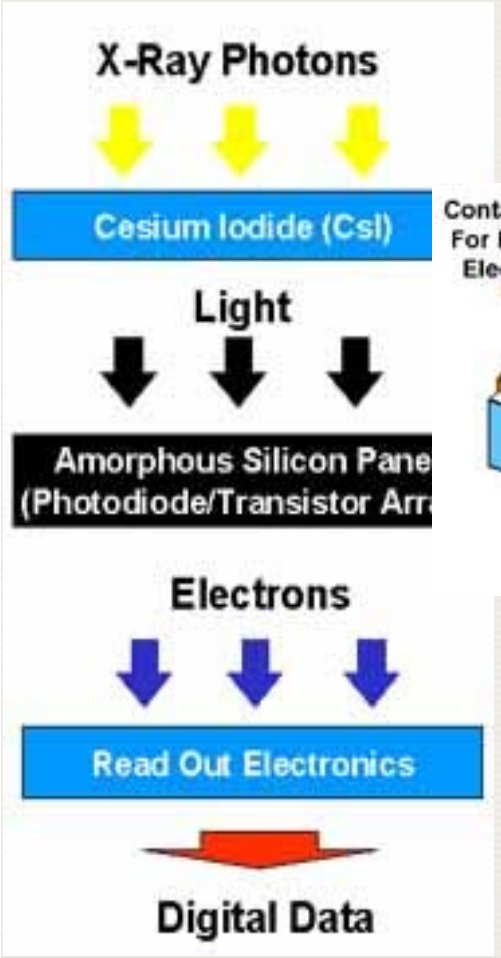
Digital radiography principle

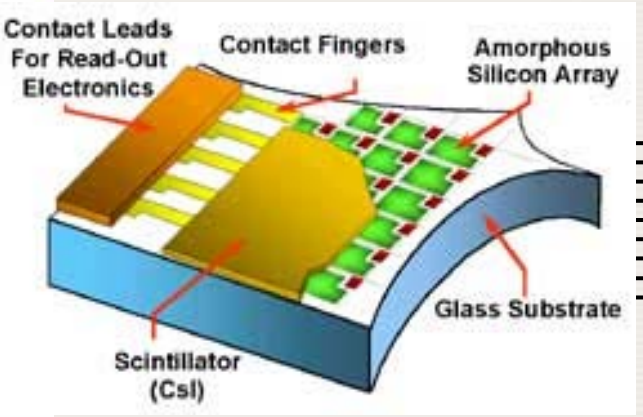
- Image intensifier

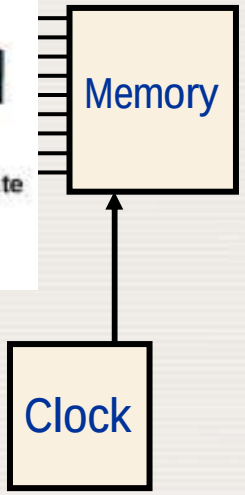


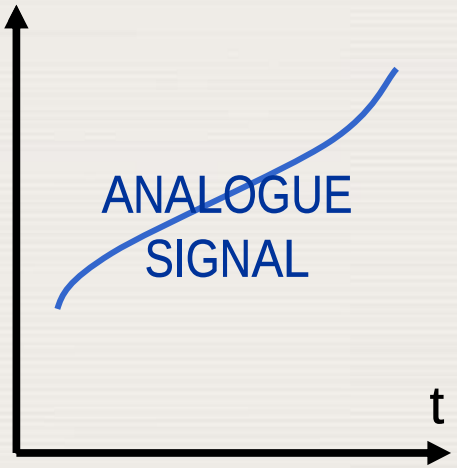
Digital radiography principle

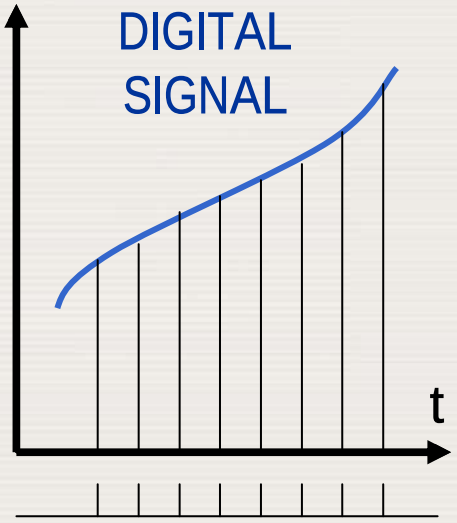
Dynamic Digital Flat Panel











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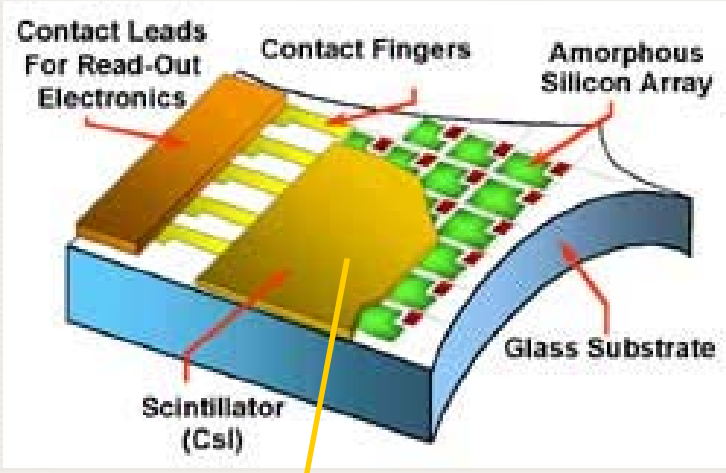
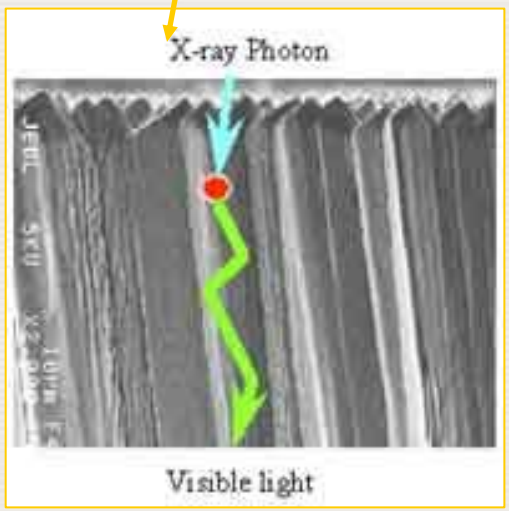
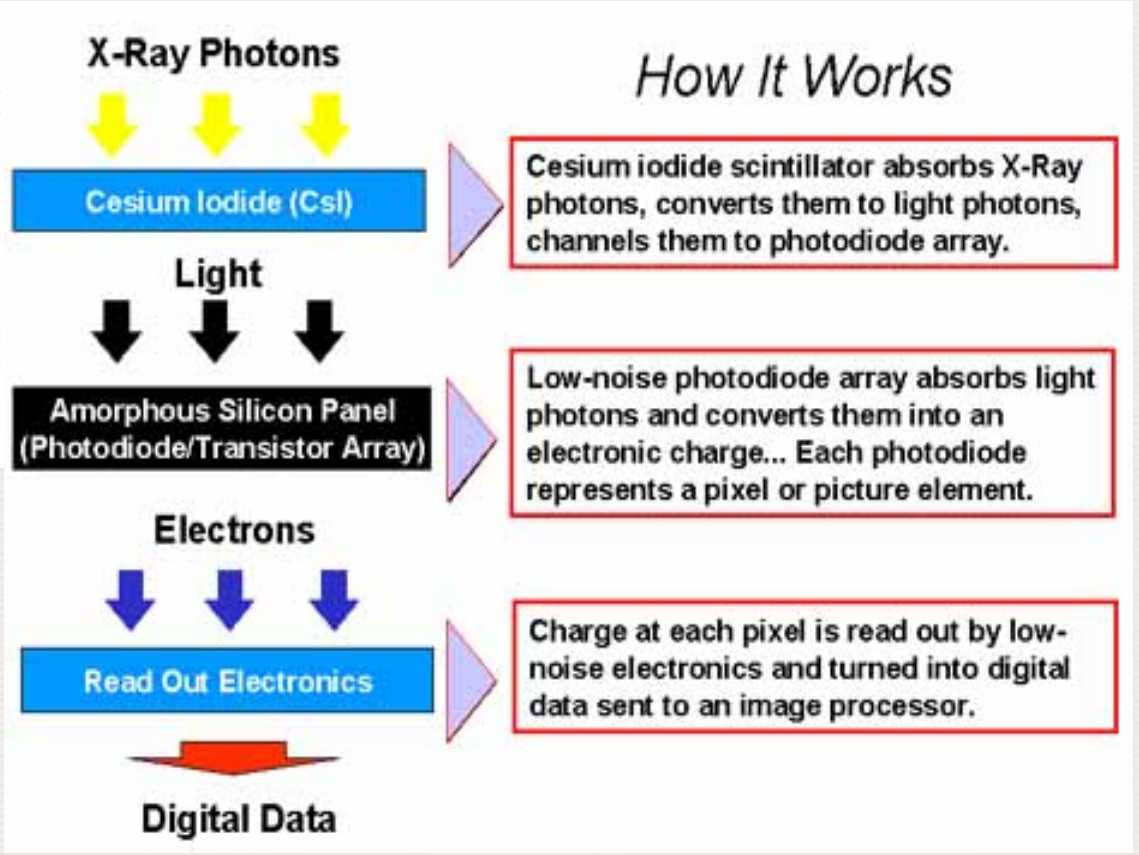
Flat panel technology: indirect conversion







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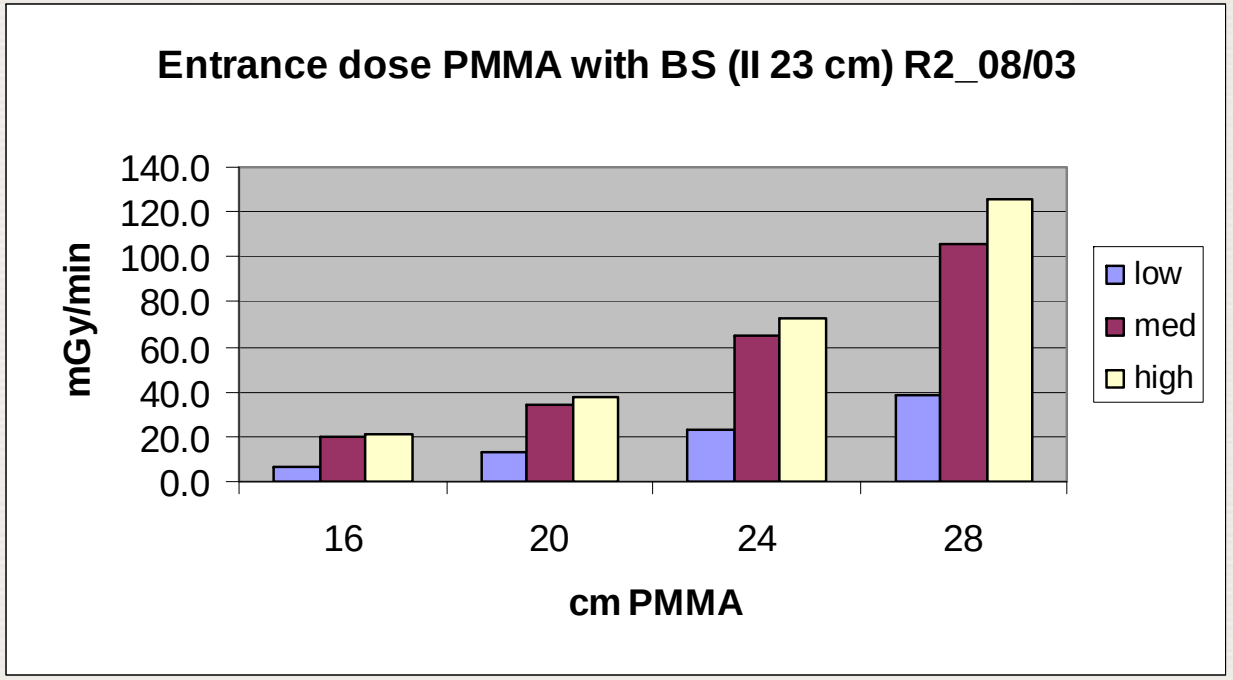
Automatic Exposure Control in fluoroscopy

- kV, mA changes as a function of:
  - Patient body absorption
  - Image quality requested
  - Field of view (FOV)



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IAEA Code of Practice

- Dosimetry in fluoroscopy

Fluoroscopy	Phantom	Entrance surface air kerma rate	Measured directly on a phantom or calculated from the incident air kerma rate using backscatter factors.
	Patient	Air kerma–area product	Maximum skin dose is also measured. As the methods are not standardized they are not included in this Code of Practice.

Dosimetry in fluoroscopy

- Quality assurance
  - Acceptance and constancy test
    - air kerma rate for different acquisition modalities
- Patient dosimetry
  - Comparison with reference levels
    - Air kerma area product
    - Dose analogues: fluoroscopy time and no. of acquired images
  - Organ dose evaluation

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- Entrance surface air kerma rate is the principal quantity to be measured in fluoroscopy using phantoms.
- For measurements on patients, the air kerma–area product, a readily measured quantity closely related to the energy imparted to the patient and to the effective dose, is the recommended dosimetric quantity.

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Incident air kerma & Entrance surface air kerma

The incident air kerma, K_i, is the kerma to air from an incident X ray beam measured on the central beam axis at the position of the patient or phantom surface. *Only the radiation incident on the patient or phantom and not the backscattered radiation is included*.

The entrance surface air kerma, K_e, is the kerma to air measured on the central beam axis at the position of the patient or phantom surface. The radiation incident on the patient or phantom *and the backscattered radiation (**B**)* are included.

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$$K_e = K_i B$$

Measurements using phantoms

- The **entrance surface air kerma rate** is measured using a water phantom or a PMMA phantom.
  - It is important that the detector responds to both direct as well as backscattered radiation.
  - For detectors that do not respond to backscatter, the entrance surface air kerma rate is calculated from the incident air kerma rate and an appropriate backscatter factor. Semiconductor detector systems often possess this property

Equipment

- Diagnostic dosimeter calibrated for beam qualities used in fluoroscopy
- Water phantom of 20 cm thickness and cross-section of 30×30 cm^2;
  - additional water phantom (or PMMA) of 10 cm thickness for simulation of larger patients
- Or 185 cm thick PMMA phantom (correction factor for the different backscatter properties of PMMA)
- Ruler, Thermometer and barometer (for measurements with an ionization chamber)

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Method

- The fluoroscopic unit should be operated under automatic brightness Control (ABC).
- ABC has to be stabilized before measurements
- Measurements for all image intensifier field sizes (FOV), dose rates and automatic brightness control options (image quality) reflecting normal clinical use.
  - The focus to intensifier and focus to chamber distances, tube voltage, tube current and any filtration selected should be recorded for each measurement.
  - The measurements are strongly dependent on the relative positions of the X ray tube, patient entrance surface and image intensifier.

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- 4 geometries
  - Under couch
  - Over couch
  - C-arm
  - C-arm-lat

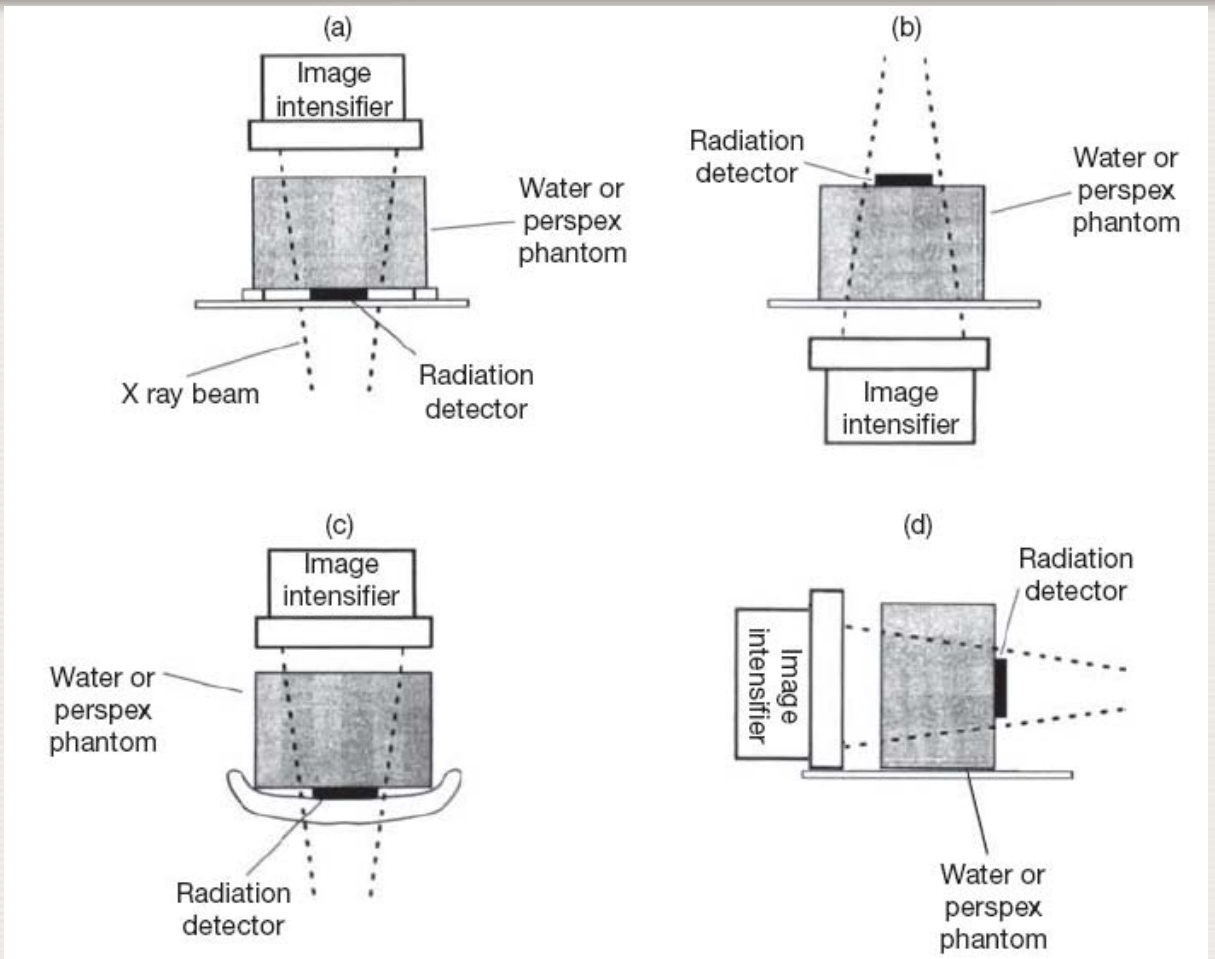
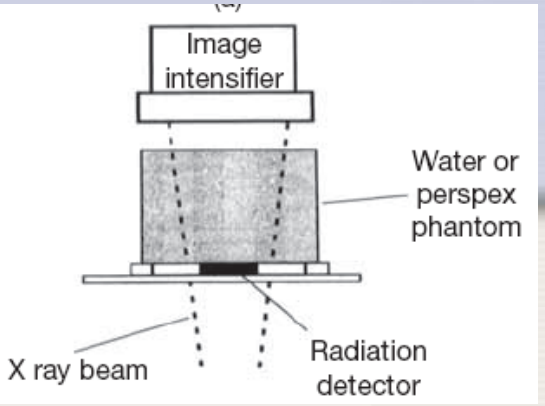


FIG. 8.4. Configuration for measurement of patient entrance surface air kerma: (a) an under couch installation, (b) an over couch installation, (c) a C-arm unit, (d) C-arm unit, lateral exposures or when a couch used clinically is not available (after Martin et al.

Under couch measurement of K_i



1. Use anti-scatter grid if used in the clinical situation
2. The space between the couch and the phantom must be sufficient for positioning the detector
3. Position the detector in contact with the phantom and at the centre of its entrance surface (in the case of back shielded detector position it outside sensitive area of ABC)
4. Position the image intensifier at 100 mm from the exit surface of the phantom
5. Measure and record the focus to intensifier and focus to detector distances.
6. Expose the phantom under automatic brightness control and record the dosimeter reading, *M*, tube voltage, tube current and the exposure settings (FOV, image quality, pulse rate/countinous mode). Repeat the measurement three times
7. Repeat step 6 for all image intensifier field sizes, dose rates and automatic brightness control options in normal clinical use.
8. If a dosimeter with an ionization chamber is used, record the temperature and pressure.

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Other geometries (differences)

- Over couch
  - Set the focus to couch (table top) distance equal to that used in clinical practice. If a standard distance is to be used, set the focus to couch distance equal to 1000 mm
- C-arm & C-arm lateral proj
  - Set the distance between the X ray focus and the image intensifier to 1000 mm (if this distance can be varied).

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Example of under couch measuremetn set-up

Calculation

Entrance surface air kerma rate

- Calculate the mean dosimeter reading from the measurements
- Calculate the entrance surface air kerma rate, K_e, from the mean dosimeter reading

$$\dot{K}_e = \dot{\bar{M}}\, N_{K,Q_0} K_Q K_{TP}$$

  - k_{TP} is the correction factor for temperature and pressure
  - $N_{K,Q0}$ chamber calibration coefficient
  - k_Q factor to corrects for differences in the response of the dosimeter at the calibration quality, Q_0, and at the measurement quality, Q.

T and P temperature and pressure (in ^{o}C and kPa) recorded during the measurement and T_0 and P_0 are their reference values for which N_K,Q_0 is provided.

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Calculation (cont.)

- If PMMA is used

$$\dot{K}_e = \bar{\dot{M}}\, N_{K,Q_0} K_Q K_{TP} \frac{B_{PMMA}}{B_{water}}$$

- If a back shielded detector is used

$$\dot{K}_e = \bar{\dot{M}}\, N_{K,Q_0} K_Q K_{TP} B_{water}$$

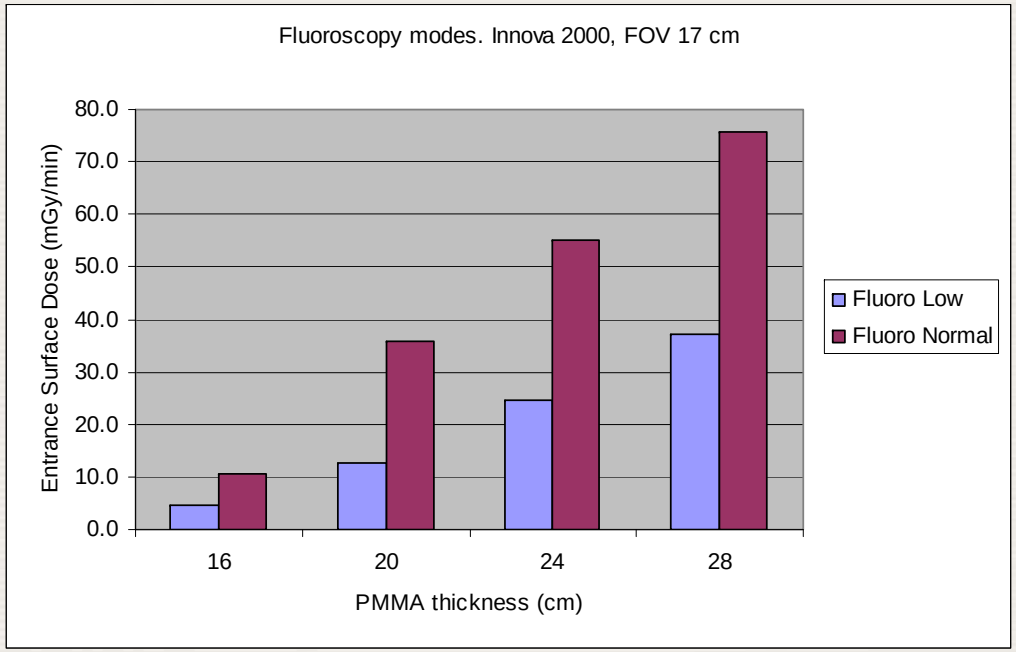
- If needed, the calculated value of *K*e is corrected for a difference between the position of the reference point of the detector and the phantom surface using the inverse square law

TABLE VIII.1. BACKSCATTER FACTORS, *B*, FOR WATER, ICRU TISSUE AND PMMA FOR 21 DIAGNOSTIC X RAY BEAM QUALITIES AND FOR THREE FIELD SIZES AT A FOCUS TO SKIN DISTANCE OF 1000 mm*

Tube voltage (kV)	Filter	Backscatter factor (*B*)									
		Field size	100 mm × 100 mm			200 mm × 200 mm			250 mm × 250 mm		
		HVL (mm Al)	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA	Water	ICRU tissue	PMMA
50	2.5 mm Al	1.74	1.24	1.25	1.33	1.26	1.27	1.36	1.26	1.28	1.36
60	2.5 mm Al	2.08	1.28	1.28	1.36	1.31	1.32	1.41	1.31	1.32	1.42
70	2.5 mm Al	2.41	1.30	1.31	1.39	1.34	1.36	1.45	1.35	1.36	1.46
70	3.0 mm Al	2.64	1.32	1.32	1.40	1.36	1.37	1.47	1.36	1.38	1.48
70	3.0 mm Al +0.1 mm Cu	3.96	1.38	1.39	1.48	1.45	1.47	1.58	1.46	1.47	1.59
80	2.5 mm Al	2.78	1.32	1.33	1.41	1.37	1.39	1.48	1.38	1.39	1.50
80	3.0 mm Al	3.04	1.34	1.34	1.42	1.39	1.40	1.51	1.40	1.41	1.52
80	3.0 mm Al +0.1 mm Cu	4.55	1.40	1.40	1.49	1.48	1.50	1.61	1.49	1.51	1.63
90	2.5 mm Al	3.17	1.34	1.34	1.43	1.40	1.41	1.51	1.41	1.42	1.53
90	3.0 mm Al	3.45	1.35	1.36	1.44	1.42	1.43	1.53	1.42	1.44	1.55
90	3.0 mm Al +0.1 mm Cu	5.12	1.41	1.41	1.50	1.50	1.51	1.62	1.51	1.53	1.65
100	2.5 mm Al	3.24	1.34	1.34	1.42	1.40	1.41	1.51	1.41	1.42	1.53
100	3.0 mm Al	3.88	1.36	1.37	1.45	1.44	1.45	1.55	1.45	1.46	1.57

Fluoroscopy mode: example air kerma rates

Entrance surface air kerma for different fluoro modes and patient thickness



Ionisation chamber to measure phantom entrance surface air kerma rate (K_e)

Uncertainties on K_e

TABLE 8.4. FACTORS WHICH CONTRIBUTE TO THE MEASUREMENT OF UNCERTAINTY IN THE DETERMINATION OF ENTRANCE SURFACE AIR KERMA RATE IN FLUOROSCOPY

Source of uncertainty	Uncertainty ($k = 1$) (%)		
	Scenario 1	Scenario 2	Scenario 3
Measurement scenario (see Table 8.2)	6.3	3.5	2.7
Precision of reading	1.0[a]	0.6[b]	0.6[b]
Uncertainty in measurement position[c]	0.6	0.6	0.6
Uncertainty in detector response to backscattered radiation	3.0	3.0	3.0
Relative combined standard uncertainty ($k = 1$)	7.1	4.7	4.1
Relative expanded uncertainty ($k = 2$)	**14.2**	**9.4**	**8.2**

[a] One single reading taken.
[b] Standard deviation of the mean of three readings.
[c] Corresponding to 2 mm in the positioning of detector at a distance 500 mm from the X ray focus.

Three scenarios which require, from scenario 1 to scenario 3, increasing attention to parameters of measurement.

Measurements on patients

- In examinations using fluoroscopy, irradiation geometry and time vary individually from patient to patient.
- Effects on patient exposures of these variations are captured by the air kerma–area product (P_{KA}),
- KAP is easily measured using a flat transmission ionization chamber (KAPmeter) mounted on the collimator housing.
- The KAP meter does not disturb the examination and gives real time information.
- In the Code of Practice, measurement of the air kerma–area product (P_{KA}) is recommended for monitoring patient exposures in examinations involving fluoroscopy

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Air kerma-area product

The air kerma-area product, P_{KA}, is the integral of the air kerma over the area of the X ray beam in a plane perpendicular to the beam axis, thus

$$P_{KA} = \int_A K(x,y)\mathrm{d}x\mathrm{d}y$$

Unit: Gy m^2

P_{KA} has the useful property that it is approximately invariant with distance from the X ray tube focus.

- when interactions in air and extra-focal radiation can be neglected
- And, the planes of measurement do not include a significant contribution from backscattered radiation from the patient or phantom.

KAP meters

- KAP meter with flat trasparent ionisation chamber

In some systems:

- KAP is calculated from kV, filtration, mAs, diaphragms positions

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Measurement on patient

1. Mount the KAP meter on the exit surface of the collimator housing of the X ray tube. This step is omitted in the case of a built-in KAP meter.
2. Record, if possible, the tube voltage and any other machine parameters (e.g. operating mode chosen, tube current and pulse rate if appropriate) used during the examination.
3. Record the reading, *M*, of the KAP meter.
4. If the operating mode is changed during the procedure, it may be helpful to use recorded KAP meter readings (if available) and machine parameters for each stage.
5. Record the temperature and pressure.

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IAEA Code of Practice: Patient selection

- It is important that the size of a sample of patients is sufficiently large as to avoid large statistical variations of the mean value of the measured quantity.
- Care has to be paid also to the selection of patients according to their anatomical parameters (e.g. weight). A range of 10–50 patients for the sample size can be found in the literature.
- Selection of patients so that the mean weight of the sample lies within 5 kg of 70 kg or within 5 kg of 60 kg in some geographical regions has been shown to be sufficient

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Calculation

- ***Air kerma-area product, P_{KA}***
- Calculate the P_{KA} from the KAP meter reading

$$\dot{P}_{KA} = \bar{\dot{M}}\, N_{P_{KA},Q_0} K_Q K_{TP}$$

  - $_{kTP}$ is the correction factor for temperature and pressure
  - $N_{PKA,Q0}$ chamber calibration coefficient
  - k_Q factor to corrects for differences in the response of the dosimeter at the calibration quality, Q_0, and at the measurement quality, Q.
  - For a total filtration of up to about 3 mm aluminium, this quality can be indicated by the value of the HVL, irrespective of the X ray tube voltage. For beams with stronger filtrations, more comprehensive calibration of the KAP meter may be required.

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Uncertainties

- The uncertainty in the calibration coefficient when the tube voltage and filtration are known and the energy dependence accounted for can be reduced to about 6% at the 95% confidence level.
- IEC 60580 specifies acceptable limits of uncertainty in the response of KAP meters when individual exposure parameters (influence quantities) vary
  - the estimated uncertainty of a measurement with KAP meters is 25% at the 95% confidence interval (k = 2)
  - this corresponds to a single value for the calibration coefficient representing all factors, i.e. all possible doses, dose rates and X ray energies in clinical practice,

    P_{KA} rate (10^{-2} –1.5×10^{4}) $\mu Gy \cdot m^2 \cdot s^{-1}$

    X ray spectrum (50–150) kV, total filtration 2.5 mm Al

Uncertainties

- If a calibration coefficient has only been established for an over couch situation, the insertion of a table with a mattress in the beam reduces the air kerma incident on the patient by up to 15–40%, depending on
  - the HVL of the beam,
  - beam angulations
  - and table construction
- This has to be considered when using the KAP to estimate patient exposure

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KAP meter calibration

- The KAP meters should be calibrated for each stand where they are used.
- Calibrations both in situ and at a standard laboratory are possible.
- Modern radiology departments usually possess a number of machines with KAPs. It is not realistic to calibrate each instrument at the SSDL and for built-in KAP meters this is not even possible.
- The calibration coefficient provided by the manufacturer should be checked before the instrument is used.

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