INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE CENTRATOM TRIESTE

SMR.803 - 10

TRAINING COURSE ON DOSIMETRY AND DOSE REDUCTION TECHNIQUES IN DIAGNOSTIC RADIOLOGY

(16 - 25 MARCH 1994)

"IMAGE RECEPTORS"

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These are preliminary lecture notes, intended only for distribution to participants.

IMAGE RECEPTORS

JIM MALONE.

IMAGE RECEPTORS

- Film
- Fluorescent Screen
- Image Intensifier
- Image Intensifier / TV System
- Other, Including CT / Amber etc.
- Multiformat / Laser Imagers

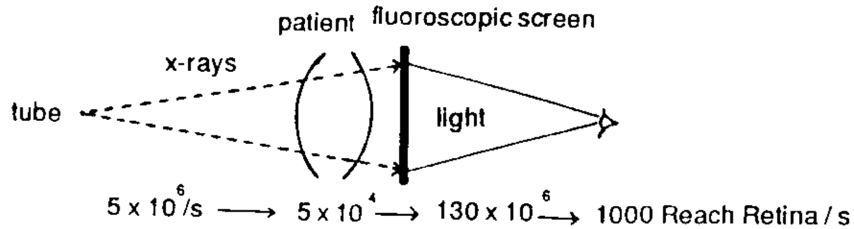
NRPB / RCR (1990)

- 26% of collective dose due to GI examinations involving fluoroscopy
  (Barium Meals / Enemas)

- Add all Special / Interventional Procedures

Statistical Quality Direct Fluoroscopy

Depends on no. of light photons in image



Eye is weakest point in chain:

Pupil presents narrow viewing angle
Loss of photons in eye
Failure of retina to respond 100% etc.

Solution to problem:
Cannot increase dose indefinitely
Can increase light reaching eye by amplification with image intensifier

Cones can be used instead of rods
By adding TV camera/monitor viewing distance can be increased (dose)

Why Image Intensifiers ?

- Direct fluoroscopy:
  Light only
  (fluoroscopic screen)
- Light output very low
  (approx. 1/10,000 as bright
  as viewing box)
- Dark Adaptation Required
- High dose rates
- Poor images:
  low resolution
  low statistical quailty

Visual Processes

<u>Daylight Vision (photopic):</u>

Cones used
Greatest density in fovea
Colour vision
High acuity
Good contrast Perception

<u>Night Vision (Scotopic):</u>

Rods used
Peripheral distribution
No colour
Sensitive blue / green light
Sensitive to edges, movement
Low acuity

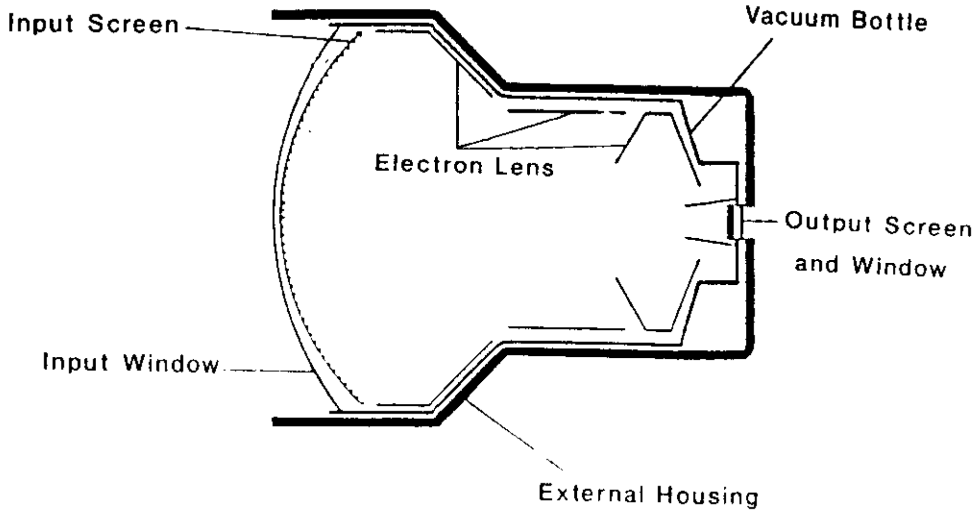
EQUIPMENT TYPES

- Fluoroscopy with Image Intensifier II/TV
- Fluoroscopy with II and 100 mm film
- Fluoroscopy with II and 35 mm cine film
- Fluoroscopy with II/TV and Digital Cardiac System
- Fluoroscopy with II/TV and DSA
- Fluoroscopy with II/TV and General Purpose Digital

EXAMINATION TYPES

- General Purpose Barium Studies
- Venography and other Common Procedures
- Angiography and DSA
- Special Cardiac and Neurological Procedures
- Interventional Procedures

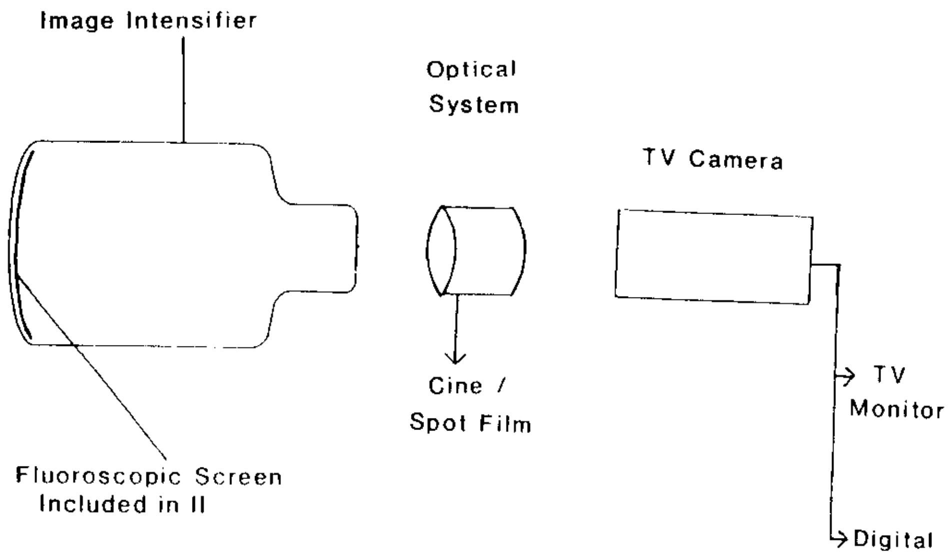
Typical structure of an x-ray Image Intensifier



Principles of operation

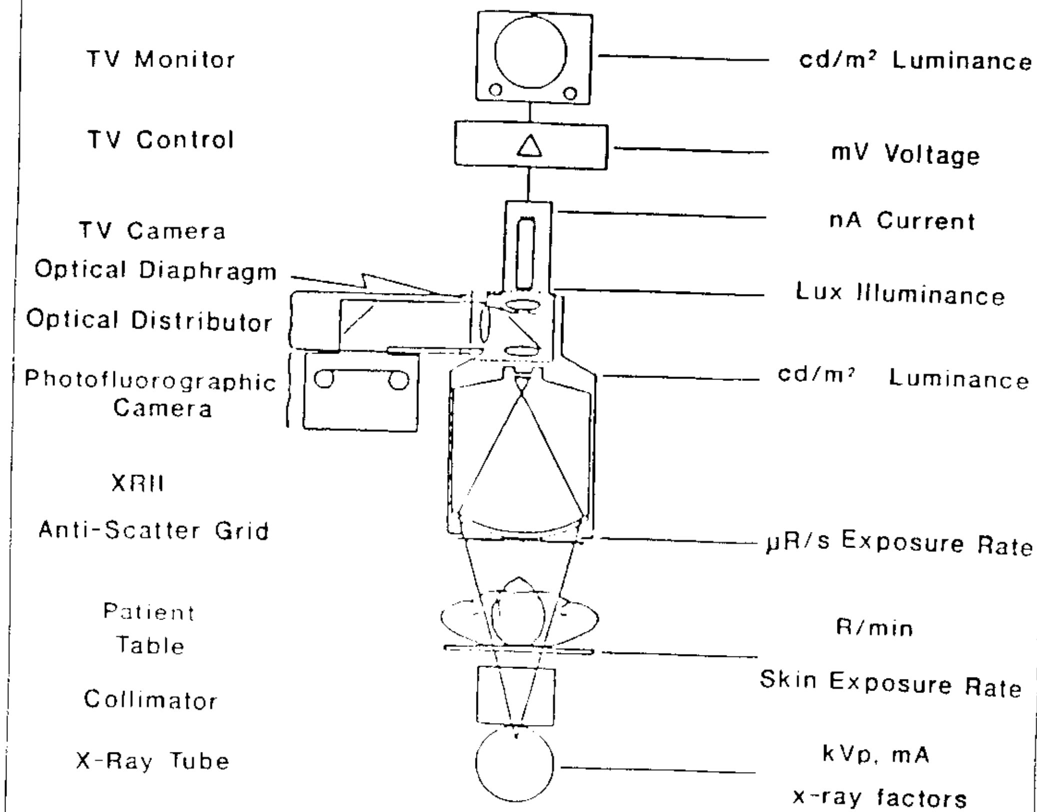
- X-rays leaving the patient's body penetrate the INPUT WINDOW
- X-rays strike INPUT FLUOROSCOPIC SCREEN and form a light image of the patient
- Light photons hitting the PHOTOCATHODE release photoelectrons
- The photoelectons are focussed and accelerated by the electrical field set up by the ANODE and ELECTRODE
- High energy photoelectrons penetrate the thin Al foil to hit the OUTPUT FLUOROSCOPIC SCREEN where they produce a bright, inverted and minified light image

Image Intensifier TV system



Overview of clinical imaging chain

with components identified (left) and measurable quantities and their units of measurement (right)

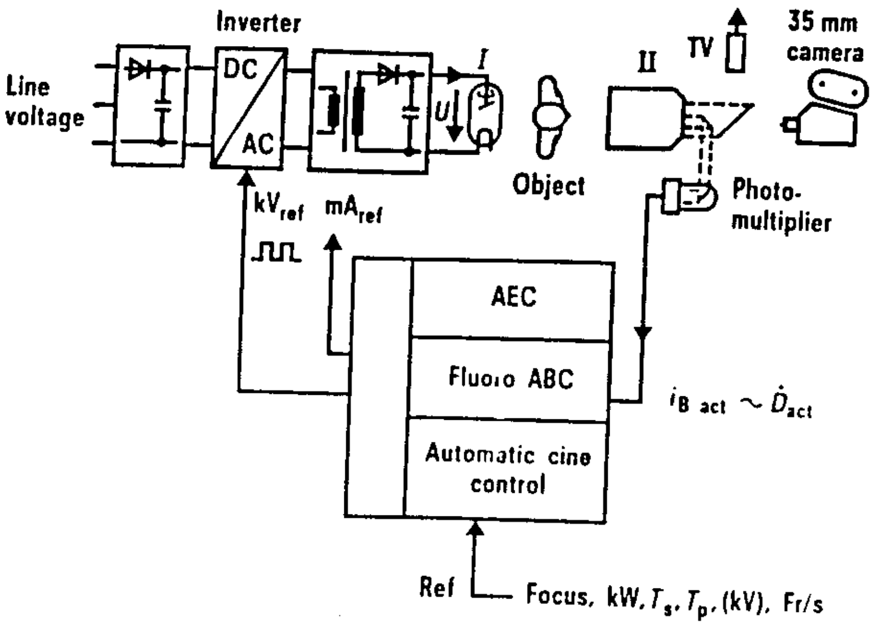


Adapted from Rowlands

AEC cine system for angiocardiography

in cine film or in digital cine mode

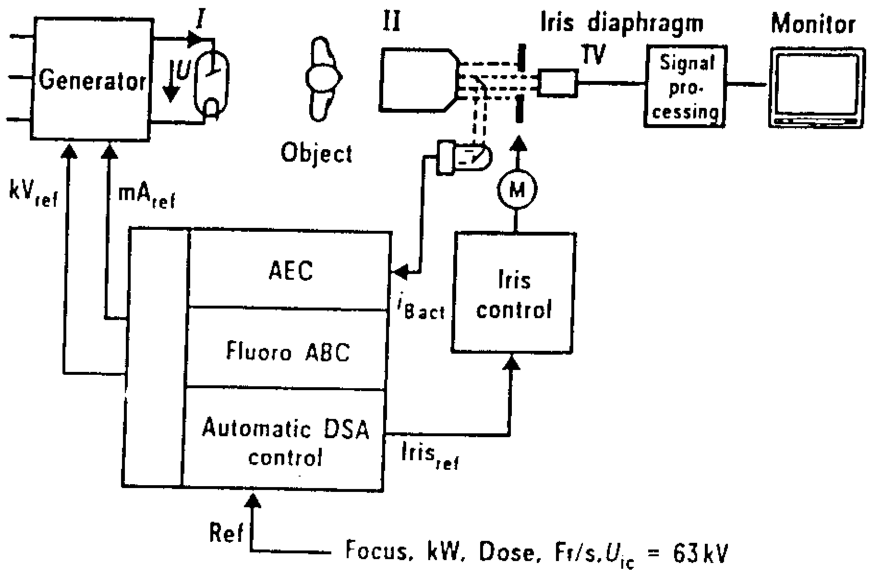
Basic circuit diagram



Adapted from E. Amman (Siemens)

AEC system for Digital subtraction Angiography (DSA)

Basic circuit diagram

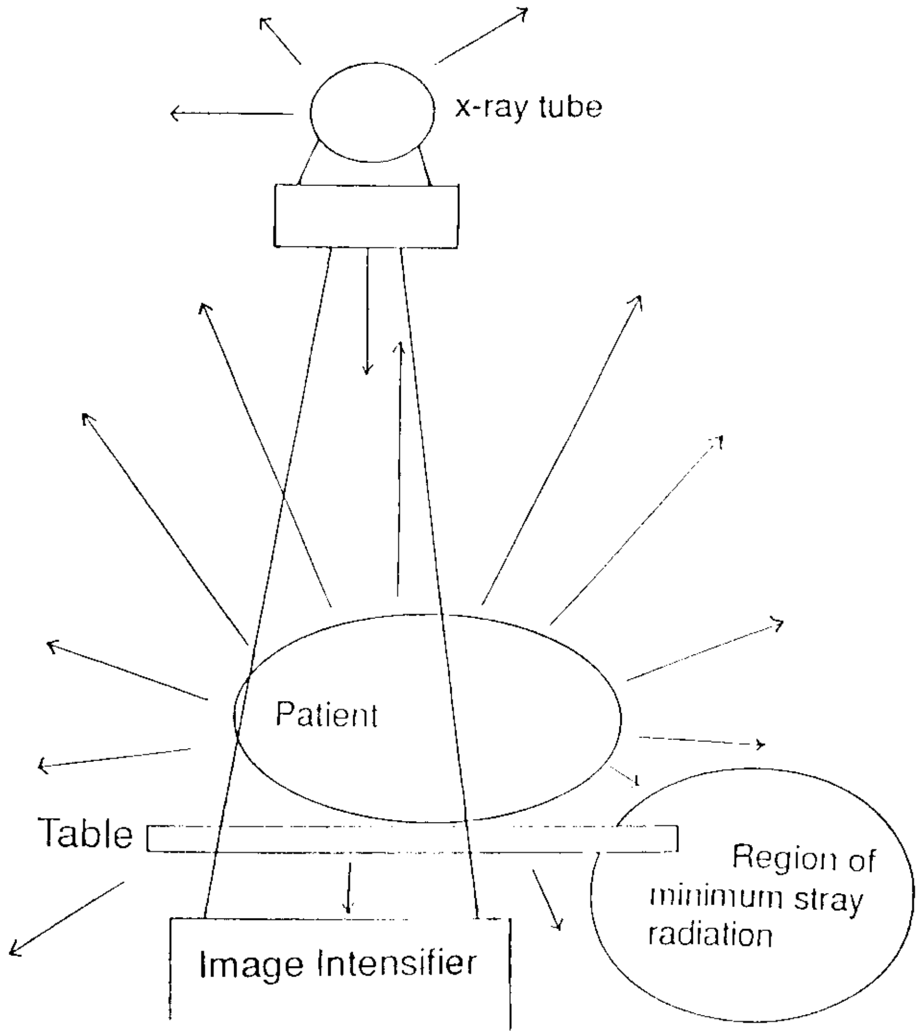


Adapted from E. Amman (Siemens)

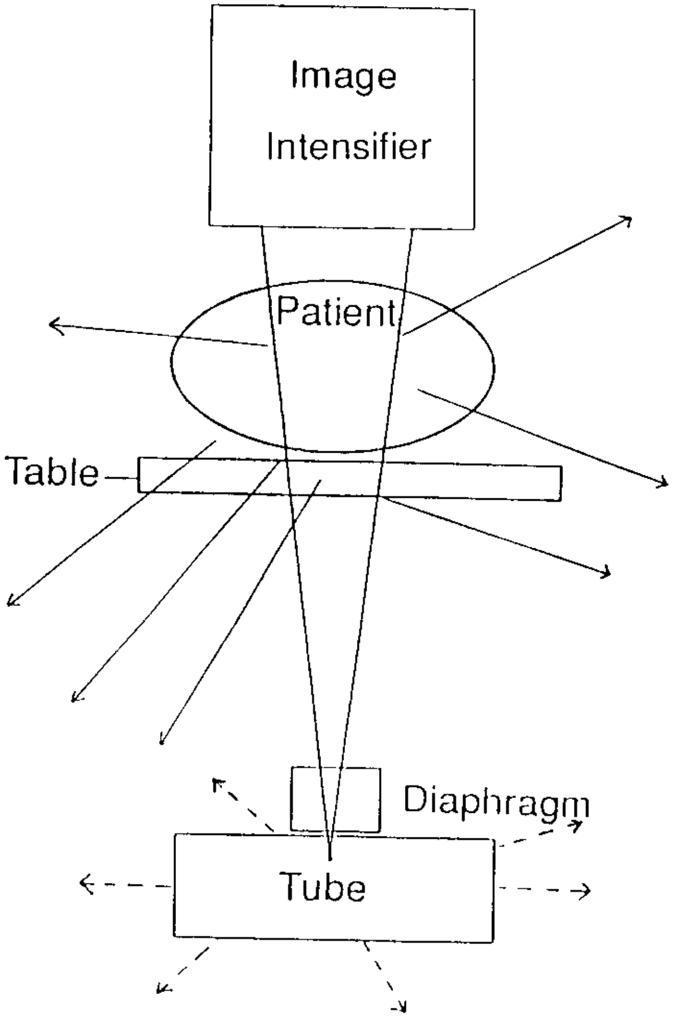
Under couch / Over couch tubes

- Remote Control
- Scatter to head / neck
- Hands in direct beam

Direction and Magnitude of Stray Radiation



Adapted from Keane et al (WHO)



Adapted from Keane et al (WHO)

Input fluoroscopic screen

- Spherical dish of diameter 15 - 60cm
- Material:

  Originally silver activated
  Zinc Cadmium Sulphide ZnCdS:Ag
  Now Sodium activated Caesium
  Iodide preferred CsI:Na

- Several Reasons:
- CsI is vapour deposited on inside surface of II taking form of tightly packed needles hence:
- No need for binder as for ZnCdS (dead space) packing density › 3 times
- Packed needles are like optical fibres - reduces flair
- CsI has higher atomic number
  K edges of Cs (36 keV) and I (33 keV) are better match for x-ray spectrum
- Quantum Detection Efficiency (QDE):
  65% - CsI 20% ZnCdS

Photocathode

- Layer of antimony and one or more alkali metals directly deposited on fluoroscopic screen to a thickness 10 - 30 nm
- Earth potential 0 V
- Number of electrons emitted is proportional to brightness of adjacent input fluoroscent screen

Electron Optics

Electrostatic Focussing

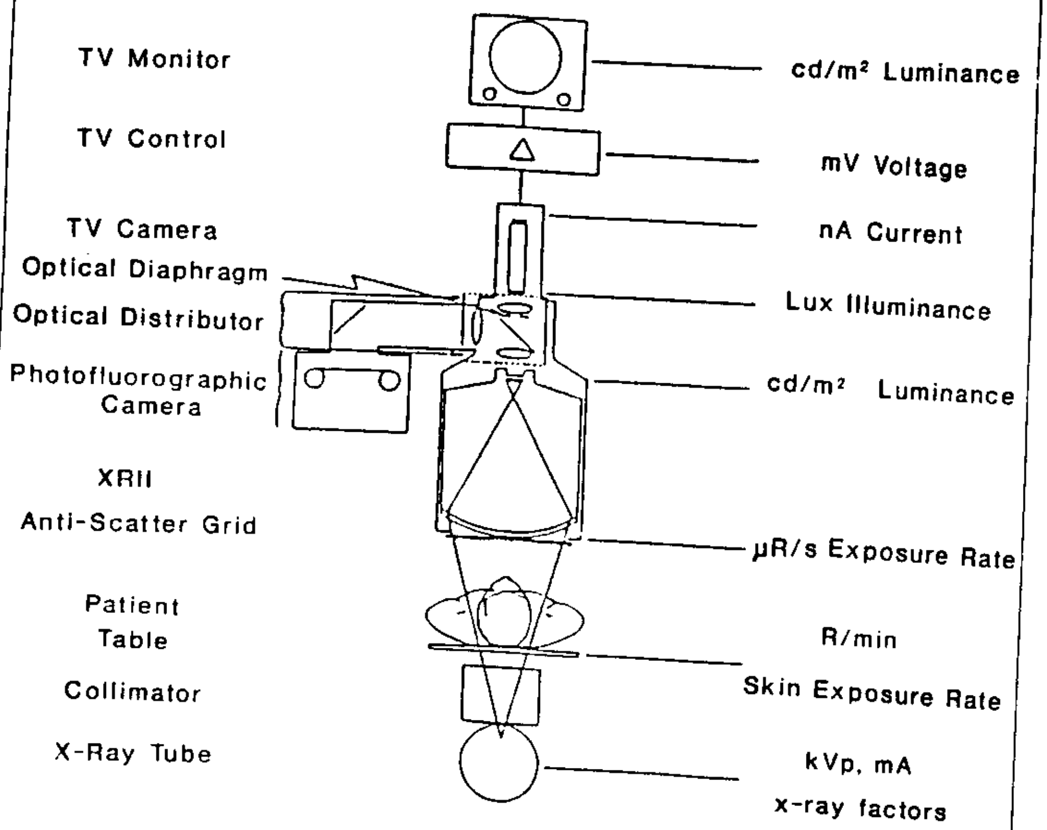
- An axially symmetric electrostatic potential distribution is produced by the ANODE (25 - 35kV) and ELECTRODES. Deviation in the electrostatic field can result in distortions such as pin-cushion effect and astigmatism
- Metal shield to avoid distortion
- Dual / multiple fields / Zoom

Output Phosphor

- ZnCdS(Ag) a few µm thick on the glass exit window of the II
- Diameter 15 - 50 mm
- Aluminium foil backing prevents light going back towards the Photocathode. Also used as electrical connection to Anode

Overview of clinical imaging chain

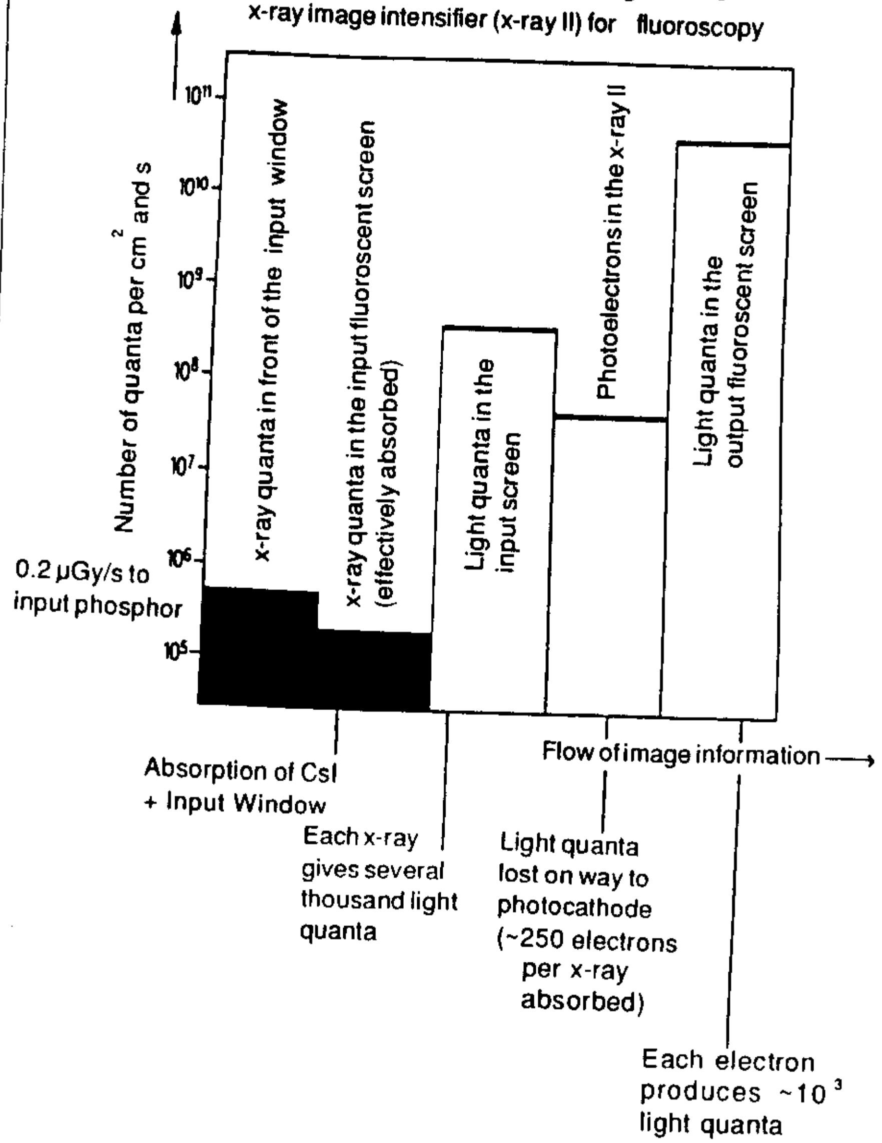
with components identified (left) and measurable quantities and their units of measurement (right)



Adapted from Rowlands

Flux densities of the information-carrying quanta

in the various transformation stages of the x-ray image intensifier (x-ray II) for fluoroscopy



Adapted from original

TV Raster Formats

- 525 line (US)
- 625 line (Europe)
- › 1000 line (High Resolution)

- Aspect Ratio 4:3

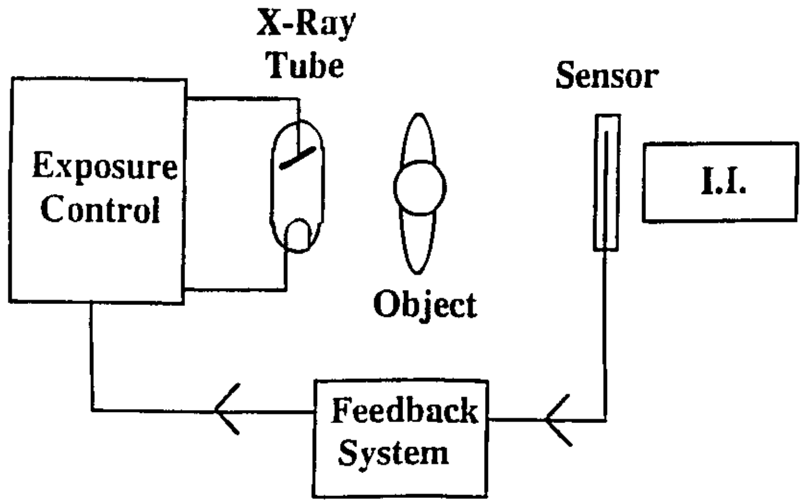
Imaging parameters of various optical image devices used in XRII videofluoroscopy

TYPE	γ	LAG (FIELDS)	RESOLUTION	IMAGE BURN RESISTANCE
VACUUM TUBE VIDICONS:				
Vidicon	0.7	8	Good	Low
Plumbicon	1	1	Poor	High
Saticon	1	2	Excellent	High
Chalnicon	1	6	Good	Medium
Newvicon	1	4	Good	Medium
SOLID STATE DEVICES:				
CCD	1	1	Excellent	Very High
CID	1	1	Excellent	Very High

Typical sensitivities of TV detectors for P20 light

TV DETECTOR	ILLUMINATION FOR 40 dB SNR
Primicon	
Plumbicon	0.8 - 1.0 lux
Saticon	
Standard	0.5 - 0.8 lux
Sb_2S_3 vidicon	
2/3" CCD	0.4 - 0.5 lux
(450,000 pixels)	
Newvicon	0.3 - 0.5 lux
Chalnicon	

Basic AEC System



US DHHS / FDA

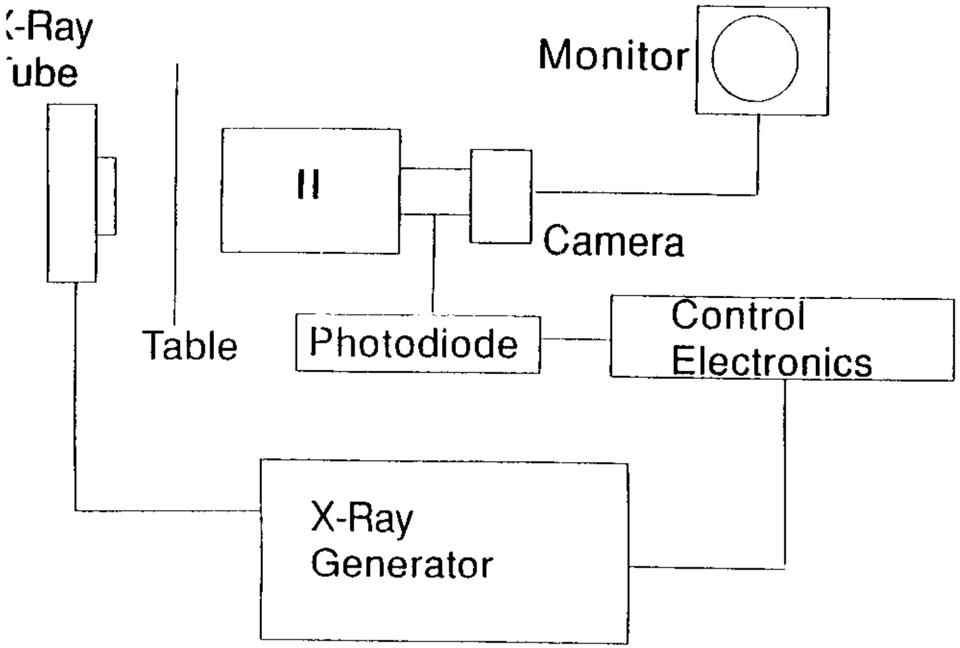
Automatic exposure control means a device whicl automatically controls one or more technique factors in order to obtain at preselected location(s a required quantity of radiation

[Suggest AERC : Automatic Exposure Rate Contro

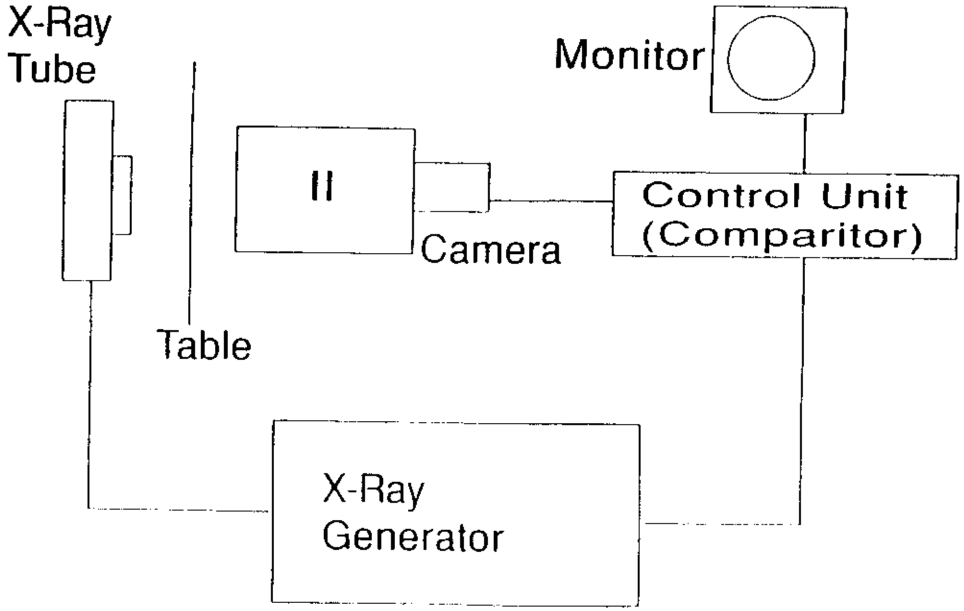
(Federal Register: 3rd May 1993)

Note: Approach now not used in practice

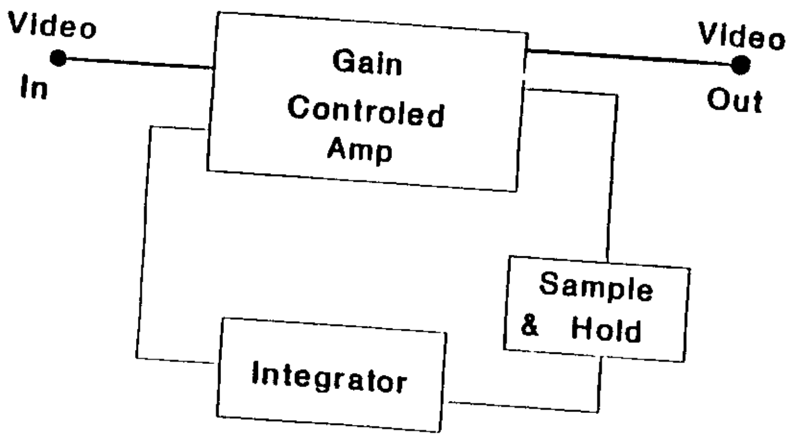
AEC System using light levels at the output phosphor in the Image Intensifier



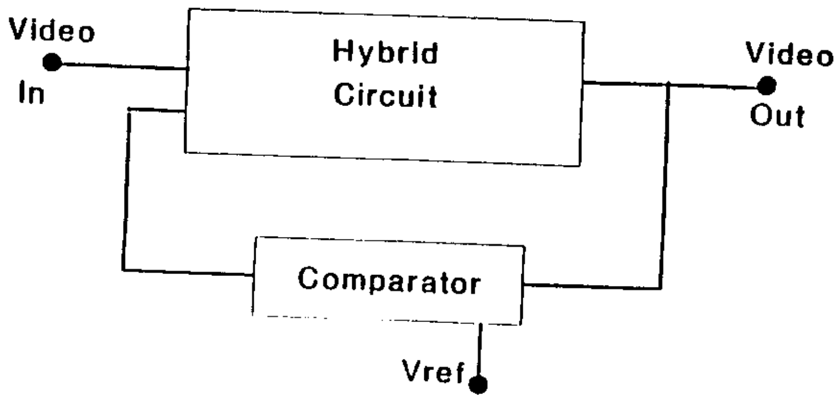
AEC System using video voltage in the TV system



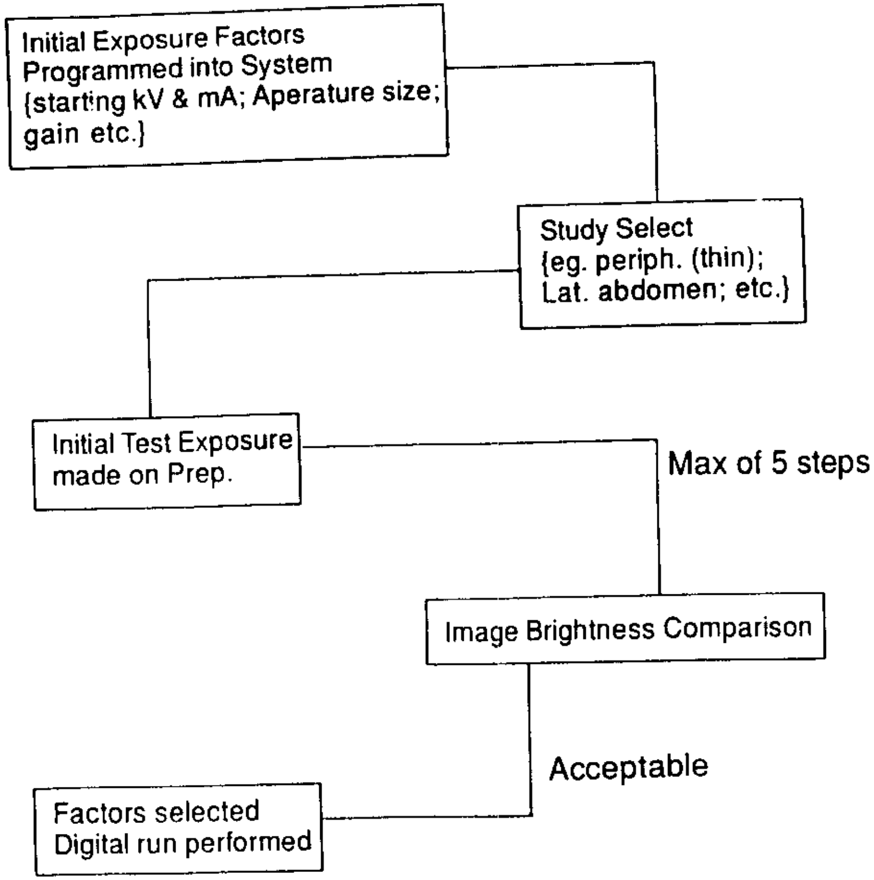
Automatic Gain Control (AGC) for a DSA system



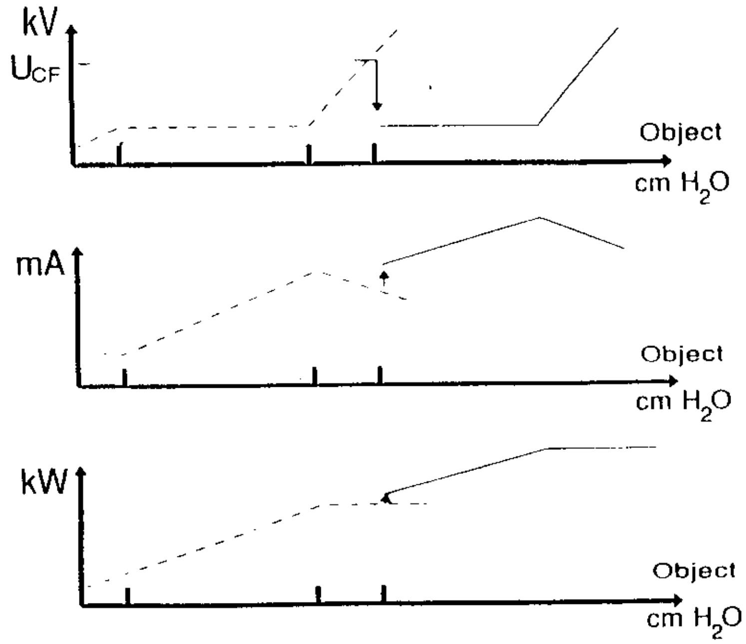
Automatic Gain Control (AGC) for a Myelography system



Exposure Selection for a DSA System

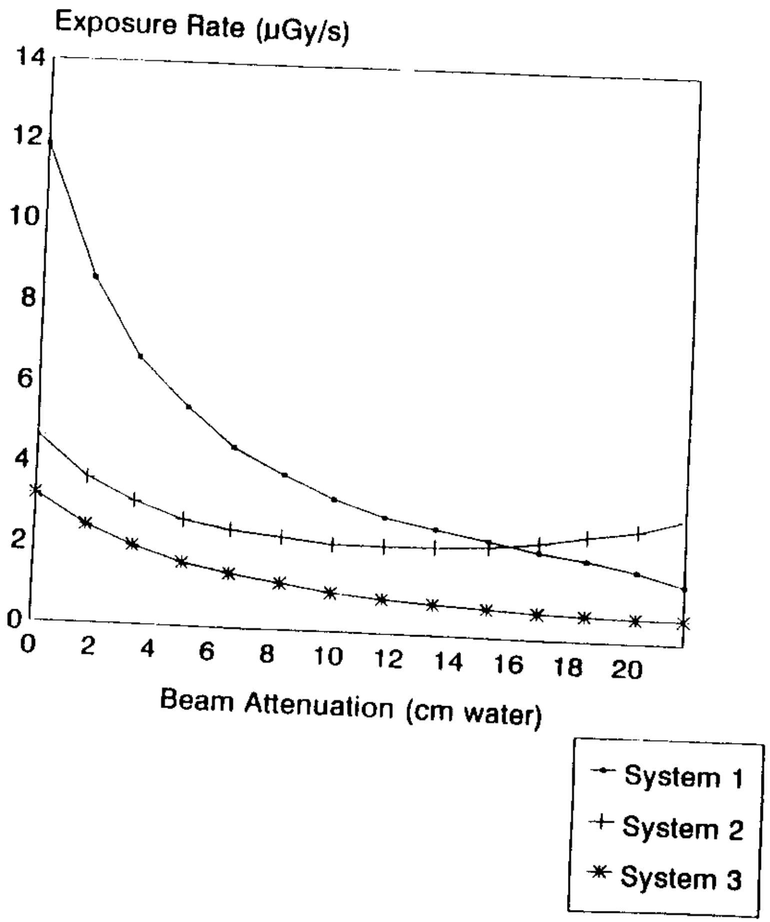


Method of operation depending on object transparency

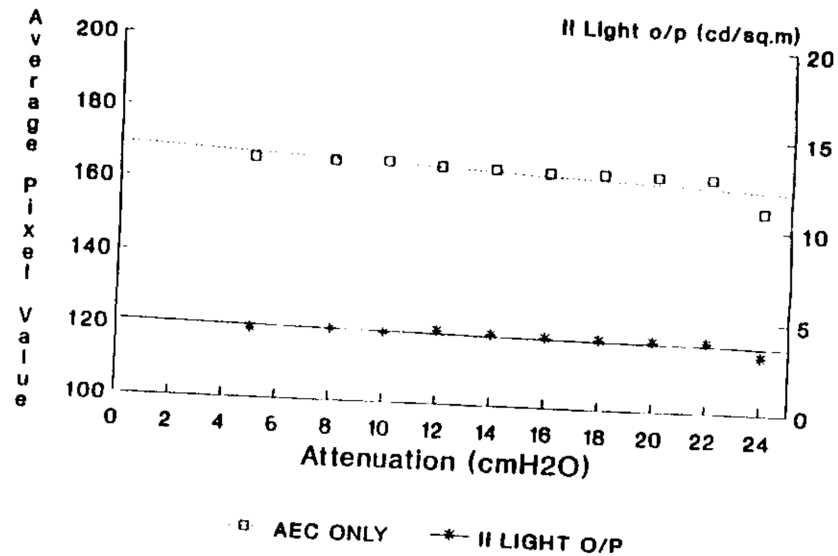


Adapted from E. Amman (Siemens)

Entrance Air Kerma Rate (µGy/s) at the grid as a function of beam attenuation for three AEC systems

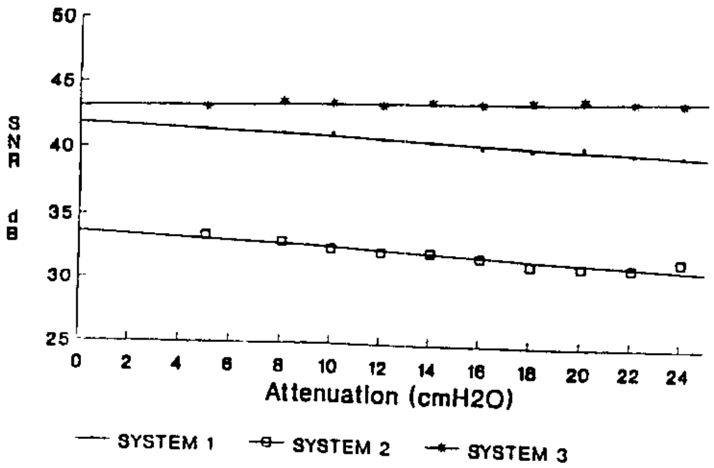


Light from the output phosphor of the Imag Intensifier and corresponding pixel values a function of beam attenuation

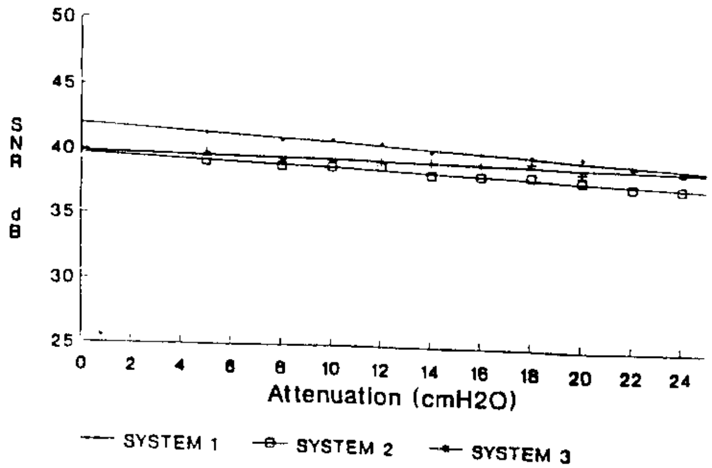


Signal to Noise ratio as a function of beam attenuation for (a) AEC and AGC, and (b) for AEC only

(a) SNR (AEC+AGC)



(b) SNR (AEC ONLY)



Levels of QA

- Acceptance Tests
- Regular QA
- Constancy Tests
- External Audit
- Write-off of Equipment

Performance Specification

- Field size and modes ✓
  Distortions ✓
  Uniformity o
- QDE / Efficiency o
  Conversion Factor / Gain o (✓)
  [Video Signal] o ✓
- Contrast Ratio o
  [Contrast / Monitor settings] ✓
- Leeds Noise ✓
  Leeds Contrast Detail ✓
- Resolution ✓
  Signal to Noise Ratio o
  Wiener Spectra o

Other Measurements

- Noise
- Uniformity
- SNR
- Wiener Spectra
- Gx
- Structural Noise
- AEC / ABC / Exposure Selectic
- Protocol Evaluation

Gain / Conversion Factor

- INTENSIFICATION FACTOR
  2 Components:
  Minification
  Added Electron energy
- MINIFICATION:
  There is an increase in brightness due to reduction in size between input and output screens
  e.g:

Input Diameter	Output Diameter
=33cm	=3.3cm
(Approx. 12")	(Approx. 1")

  Area is deccreased by 100 =>
  Brightness increased by 100
- ADDITIONAL ENERGY:
  Brightness increases by x 100 (approx.)
- Light quanta from output screen
  Light quanta reaching photocathode
- Total Gain = 100 x 100 = 10^4

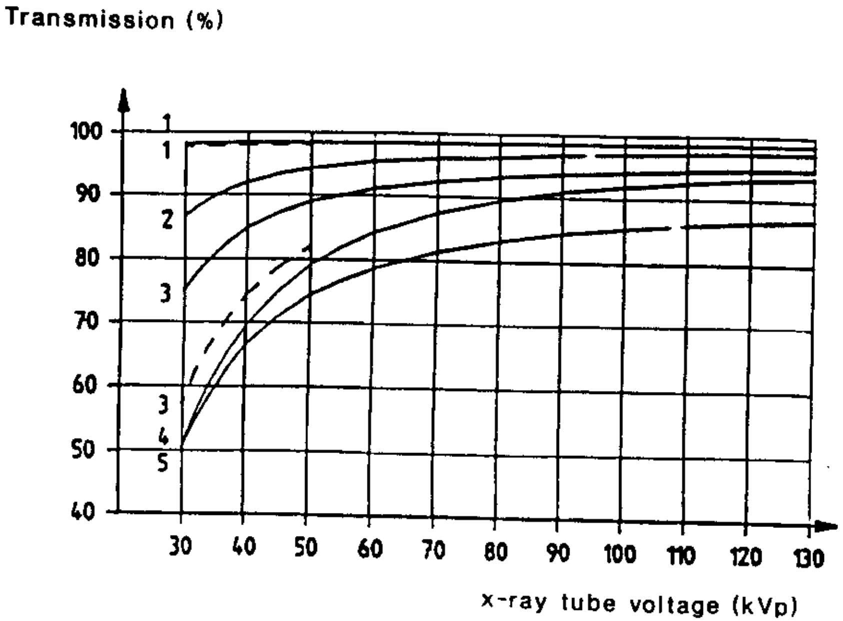
Conversion Factor (Gx)

- X-ray to light conversion efficency:
- Gx = Output Luminance $cdm^{-2}mGy^{-1}s$
  Input Dose Rate
- Typical value modern CsI II =
  1 - 3 $cdm^{-2}mGy^{-1}s$

Quantum Detection Efficiency QDE

- % of photons incident upon image receptor (input phosphor) which are converted to light
- QDE for Modern CsI screen = 65% (approx.)

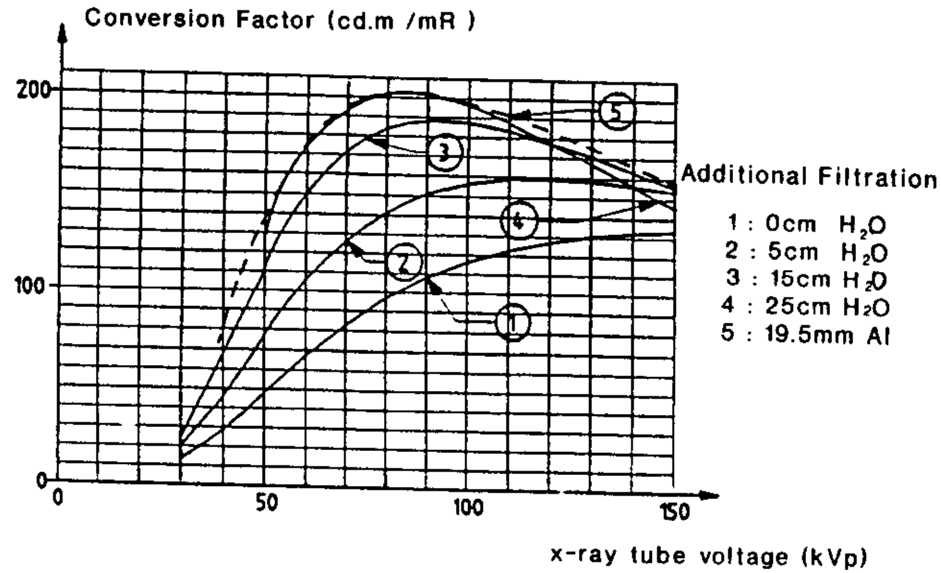
Useful x-ray transmission of various input windows as a function of x-ray tube voltage



1: 0.5mm Be window or substrate
2: 0.4mm Al substrate
3: 0.8mm Al window
4: 0.25mm Ti window
5: 2.7mm borosilicate glass window

Adapted from de Groot (Thomsons)

Variation of the conversion factor with x-ray tube voltage for different patient filtrations

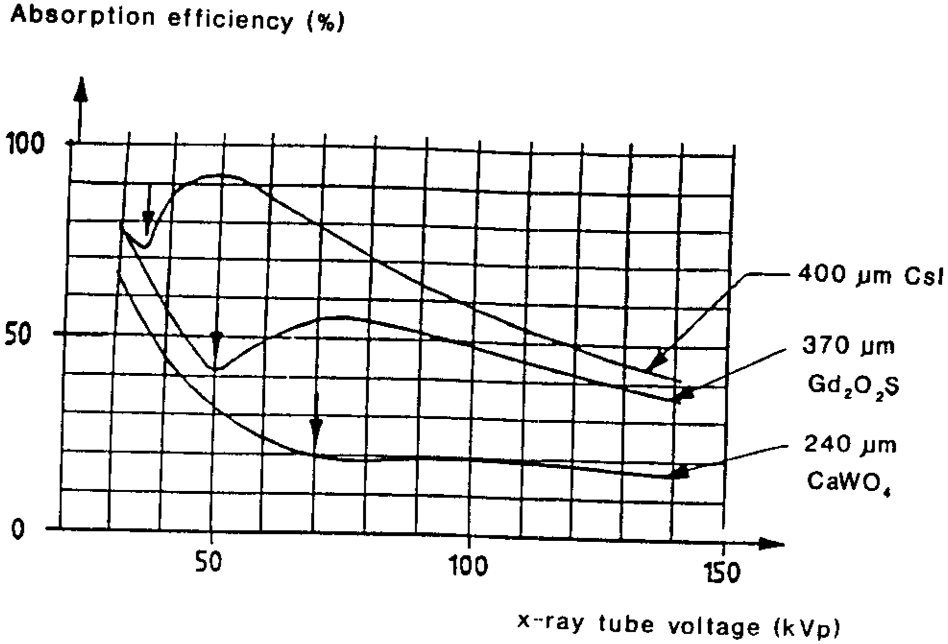


All spectra have 2.5mm Al inherent filtration

Adapted from de Groot (Thomsons)

Useful energy absorption efficiencies of frequently used scintillator screens.

The $CaWO_4$ and Gd_2O_2S curves refer to screen pairs.
The relative densities for CsI, $CaWO_4$ and Gd_2O_2S are assumed to be 0.85, 0.40 and 0.43 respectively



lapted from de Groot (Thomsons)

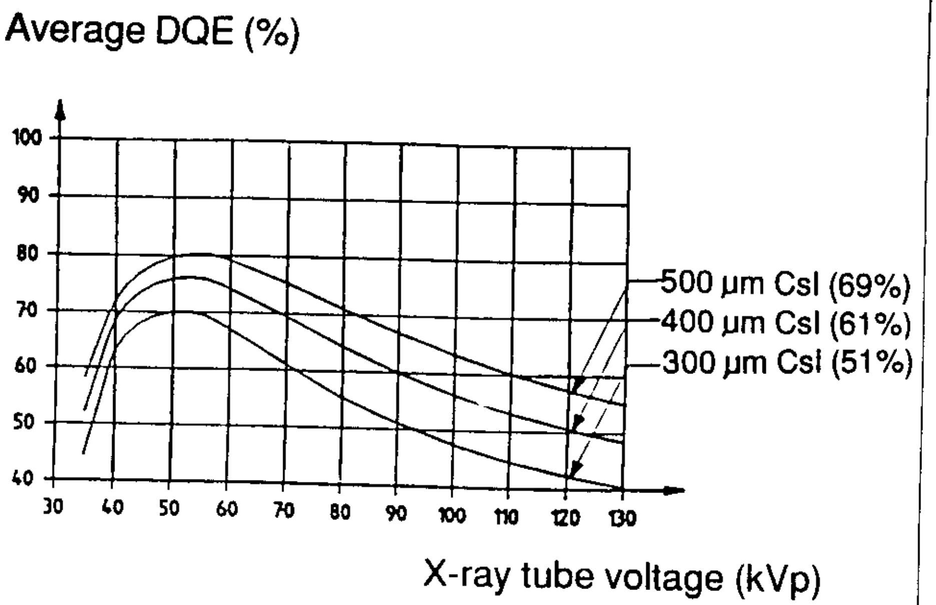
Conversion table between the various units used to express the conversion factor

	cdm^{-2}/mRs^{-1}	$cdm^{-2}/\mu Gs^{-1}$	$cdm^{-2}/\mu Ckg^{-1}s^{-1}$
1 cdm^{-2}/mRs^{-1} =	1	115	388
1 $cdm^{-2}/\mu Gys^{-1}$ =	87	1	338
1 $cdm^{-2}/\mu Ckg^{-1}s^{-1}$ =	258	296	1
1 ftL/mRs^{-1} =	343	394	133

Adapted from de Groot (Thomsons)

Variation of the averaged DQE

with x-ray tube voltage and with 25cm of H_2O filtration for different values of the CsI layer thickness. The values in parentheses give the DQE at 59.5 keV. Relative density of CsI : 0.85

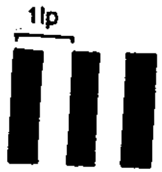


Window + substrate: 1.2 MM Al
Filtration: 25 cm H_2O

Adapted from de Groot (Thomsons)

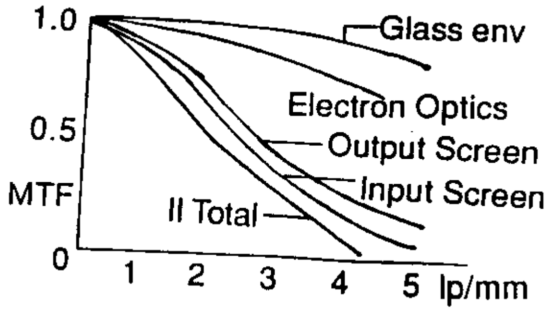
Resolution

- Can be expressed in two different ways:
- LINE PAIRS PER MILLIMETRE (lp/mm):



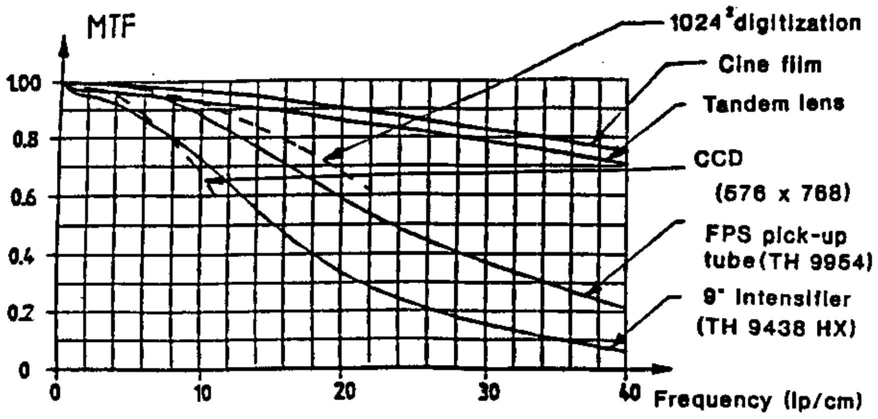
e.g. 0.5mm lead strips with 0.5mm gaps =1lp/mm

- MODULATION TRANSFER FUNCTION (MTF):
- Is a measure of sharpness in a noise free situation

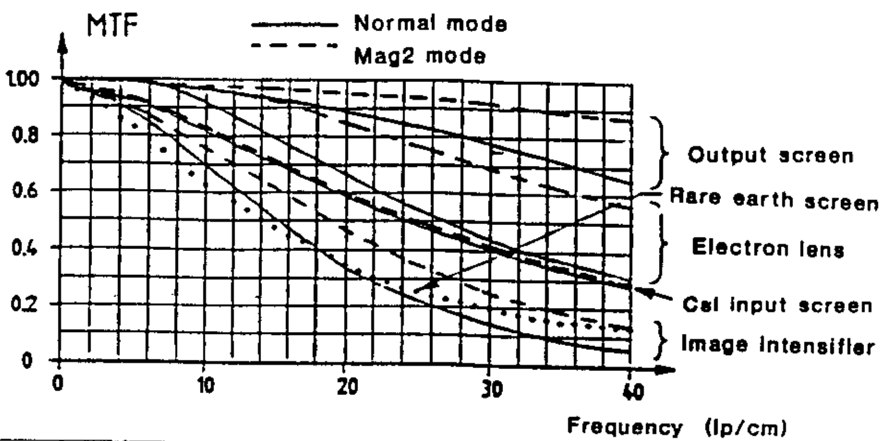


- Typical value for II resolution = 4lp/mm
- Much of this performance is lost at edge of field and by TV camera

MTF comparison of the various components in a high resolution 9" imaging chain



MTF contributions of the different components in a 9" image intensifier



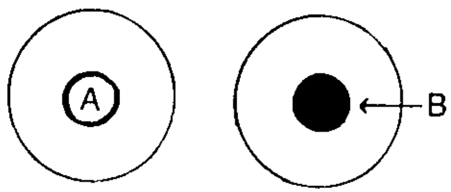
Adapted from de Groot (Thomsons)

Degradation of Resolution in TV system

- Is very significant
  e.g:
  TV = 500 lines (approx.)
  Image = 250 mm
  Resolution = 2 lines /mm (approx.)

Contrast Range / Ratio

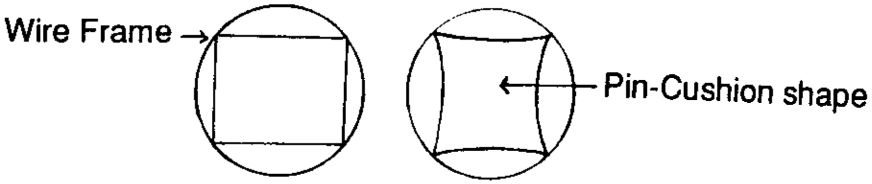
- Luminance over area at centre of output is measured
- Lead disc about 1/10th of the area of the field placed in front of the input screen and luminance measured again



- Contrast Ratio = Luminance A/B
- Typical value = 10 : 1
  15-20 : 1 (Modern Systems)

Spatial Distortions

- Non-uniform electron focusing can occur especially at the edges of the beam. This results in 3 effects:
- Geometrical distortion at edges



- The centre of the screen is brighter than the edges (vignetting)
- The resolution is better at the centre than at the edges

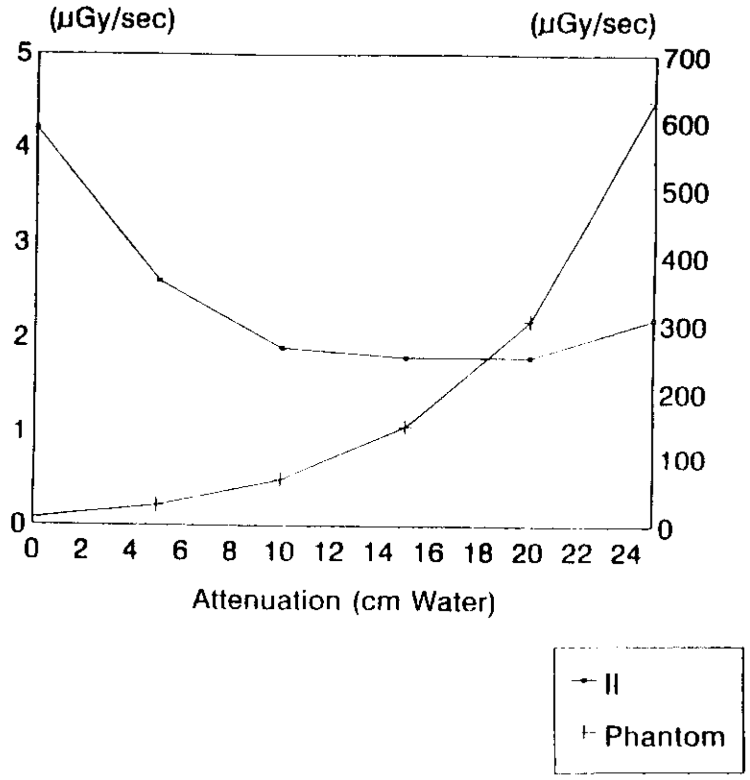
Lag

- Lag (Persistence of luminance after irradiatior is over) is not a problem in modern Image Intensifiers (< 1ms decay).
- Lag was a problem in older systems (30-40 m and still is in TV cameras

Examples of Recommended Performance Levels from UK/US National Sources

SOURCE	EXPOSURE LEVEL
UK GUIDANCE NOTES (16)	
AEC not mandatory.	
Patient Entrance Dose should not	
normally exceed / exceed	5 / 10 cGy/min
adequate image at	1 cGy/min
US: FDA/DHHS (3)	
AEC required under certain	
circumstances and patient entrance Air	
Kerma less than	5 cGy/min
High dose mode allowed	-----

Entrance Air Kerma Rates (µGy/s) for patient and Image Intensifier as a function of beam attenuation



Examples of Recommended Performance Levels from Literature

SOURCE	EXPOSURE LEVEL
Typical Sources in Literature	Air Kerma / Frame
(Air Kerma at Image Receptor)	uGy / Frame
Conventional Fluoroscopy	1 - 4 (10)
Cine Fluoroscopy	10 - 40
100 mm Photospot Camera	50 - 150
Digital Cardiac Cine	10 - 20
Digital Photofluorography / Fluoroscopy	75 - 400
DSA	(300) 1000 - 2000 (7000)

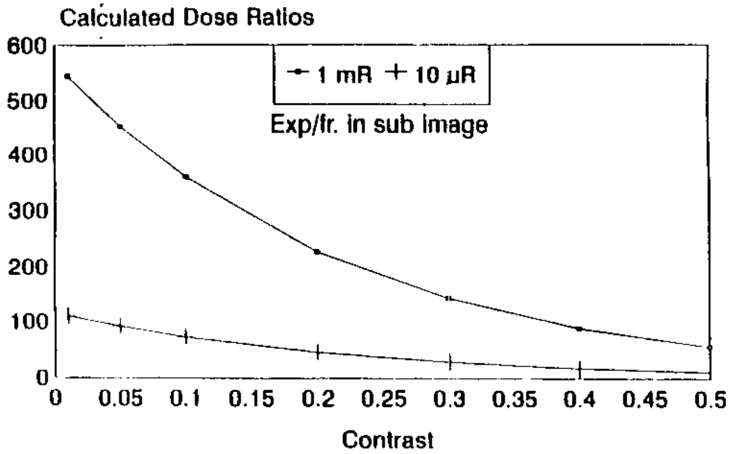
(Unusually large / small values in brackets)

Typical IIIERS Values

IMAGING MODE	IIIERS
Fluoroscopy	75 - 100 μR/s
100 nm Photospot Camera	100 μR/fr
35 mm Cine Camera	10 - 15 μR/fr
Digital Fluoroscopy	75 - 100 μR/fr
Digital Photofluoroscopy	75 - 100 μR/fr
DSA	500 - 1000 μR/fr
Digital Cine DSA	10 - 15 μR/fr

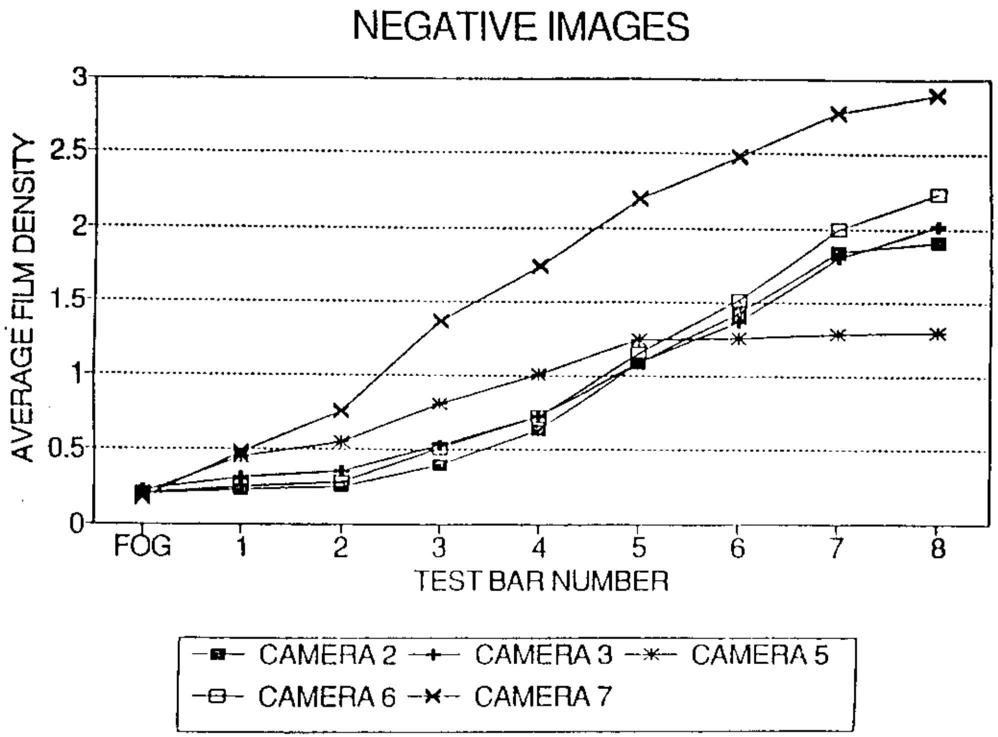
Theoretical Dose Ratios

for equal SNR in subtracted and unsubtracted images)



Ratio = Subtracted Dose / Unsubtracted Dose

Comparison of
Multiformat Cameras



TISSUE OR ORGAN	TISSUE WEIGHTING FACTOR W_T	
	ICRP-26	ICRP-60
Gonads	0.25	0.20
Bone Marrow (Red)	0.12	0.12
Colon	-	0.12
Lung	0.12	0.12
Stomach	-	0.12
Bladder	-	0.05
reast	0.15	0.05
Liver	-	0.05
Oesophagus	-	0.05
Thyroid	0.03	0.05
Sl:in	-	0.01
Bone Surface	0.03	0.01
Remainder	0.30	0.05
	1.00	1.00
Total $(10^{-2}Sv^{-1})$	125	500

1. SPECIFICATION FOR EQUIPMENT FOR GENERAL ROOMS.

1.1. You are requested to, where necessary, complete the following specification in respect of your equipment. Alternatively you may supply detailed technical information to your own format and this will be accepted as the specification, provided it addresses the points raised below.

1.2. Additional information may be included should you wish to do so.

1.3. You may tender for part of the system, or the complete system, or both. The latter may include proposals in which you intend to provide part of the system from other suppliers.

1.4. The tender should include the following:

(i) the equipment listed,
(ii) one year's warranty,
(iii) instruction of hospital staff as users and in maintenance,
(iv) full operator manuals (in English),
(v) full service manuals (in English),
(vi) full software manuals (in English).

1.5. The tender should also include a statement of the cost and terms of the various service contract arrangements offered by your company in respect of this equipment.

1.6. Should you feel that you can fulfill the hospital's needs by providing equipment to an alternative specification you are free to tender accordingly provided you detail the changes involved.

1.7. Values cited for Performance Indicators/Specifications are approximately those required. Please state the actual values that apply in the case of the system you are offering.

Department of Medical Physics and Bioengineering

Federated Dublin Voluntary Hospitals & St. James's Hospital

FORM FOR COMPLETION OF COMMISSIONING OF ROOM/EQUIPMENT.

Room Number:

Inventory Complete: ______ Dept. of Medical Physics & Bioengineering.

Installation Complete: ______ Dept. of Medical Physics & Bioengineering.

Radiation Protection Features to Specification (of Room): ______ Radiation Protection Adviser.

Radiation Protection Features to Specification (of Equipment): ______ Radiation Protection Adviser.

Electrical Safety of Equipment Satisfactory: ______ Dept. of Medical Physics & Bioengineering.

Electrical Safety of Installation Satisfactory: ______ Dept. of Medical Physics & Bioengineering.

Equipment Meets Specification: ______ Chief Physicist.

Satisfactory Patient Investigation Performed: ______ Consultant in Administrative Charge, Diagnostic Imaging Department.

Air Conditioning Functions: ______ Dept. of Medical Physics & Bioengineering.

Additional Comments: ______

Chief Physicist.

1, 2, 3, 5, 6, 8, 9 Required for Payment of Supplier. Date:
Items required for complete commissioning of room.

PLEASE REPLY TO
☐ St. James's Hospital, P.O. Box 580, Dublin 8. Tel. 537941 Fax. 537941 Ext. 264
☐ Federated Dublin Voluntary Hospitals, P.O. Box 795, Dublin 8. Tel. 53238

Department of Medical Physics and Bioengineering

Federated Dublin Voluntary Hospitals & St. James's Hospital

FORM FOR COMPLETION OF COMMISSIONING OF ROOM/EQUIPMENT.

1. Room Number: X201
2. Inventory Complete: [signature] Dept. of Medical Physics & Bioengineering.
3. Installation Complete: [signature] Dept. of Medical Physics & Bioengineering.
4. Radiation Protection Features to Specification (of Room): See below. Radiation Protection Adviser.
5. Radiation Protection Features to Specification (of Equipment): [signature] Radiation Protection Adviser.
6. Electrical Safety of Equipment Satisfactory: [signature] Dept. of Medical Physics & Bioengineering.
7. Electrical Safety of Installation Satisfactory: [signature] Dept. of Medical Physics & Bioengineering.
8. Equipment Meets Specification: Not relevant as it is transfer equipment. Chief Physicist.
9. Satisfactory Patient Investigation Performed: [signature] Consultant in Administrative Charge, Diagnostic Imaging Department.
10. Air Conditioning Functions: [signature] Dept. of Medical Physics & Bioengineering.
11. Additional Comments:

A permanent radiation protection screen is needed for the Cardiac Technicians. Report on Maintenance Contract for this room to follow. [signature]

Chief Physicist.

Items 1, 2, 3, 5, 6, 8, 9 Required for Payment of Supplier Date.
All items required for complete commissioning of room.

and Bioengineering

Federated Dublin
Voluntary Hospitals
& St. James's Hospital

FORM FOR COMPLETION OF COMMISSIONING OF ROOM/EQUIPMENT.

1. Room Number: X315 X318 + Computer Rm 31

2. Inventory Complete:
Dept. of Medical Physics & Bioengineering.

3. Installation Complete:
Dept. of Medical Physics & Bioengineering.

4. Radiation Protection Features to Specification (of Room):
Radiation Protection Adviser.

5. Radiation Protection Features to Specification (of Equipment):
Radiation Protection Adviser.

6. Electrical Safety of Equipment Satisfactory:
Dept. of Medical Physics & Bioengineering.

7. Electrical Safety of Installation Satisfactory:
Dept. of Medical Physics & Bioengineering.

8. Equipment Meets Specification:
Chief Physicist.

9. Satisfactory Patient Investigation Performed:
Patrick J. [illegible]
Consultant in Administrative Charge,
Diagnostic Imaging Department.

10. Air Conditioning Functions:
Dept. of Medical Physics & Bioengineering.

11. Additional Comments:
~~[illegible]~~
System still not completely set up satisfactorily. Withhold at least £10,000.00 from total payment. Major portion of payment should be made.
Chief Physicist.

Items 1, 2, 3, 5, 6, 8, 9 Required for Payment of Supplier Date.
All items required for complete commissioning of room.

PLEASE REPLY TO ADDRESS INDICATED
☐ St. James's Hospital, P.O. Box 580, Dublin 8. Tel. 537941 Fax. 537941 Ext. 264
☐ Federated Dublin Voluntary Hospitals, P.O. Box 795, Dublin 8. Tel. 53238
☐ Meath Hospital, Heytesbury Street, Dublin 8. Tel. 721166 Fax. 532392

WRITING OFF FLUOROSCOPY

EQUIPMENT (1)

* Reviewed the write off of 15 units with a replacement value of ~ £ 4M.

* Experience of writing - off of a larger number of units.

* Comparison of experience in three European countries with different health care systems.

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WRITING OFF FLUOROSCOPY

EQUIPMENT (2) DOSE ASPECTS

* A high input dose - rate at the image intensifier has been frequently used to condemn old units.

* The measurement of input dose - rate on the surface of a patient / phantom has not been used in the write - off process.

* It is relatively easy to condemn high dose fluoroscopy units on the basis of ALARA even in the absence of norms.

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WRITING OFF FLUOROSCOPY

EQUIPMENT (3) IMAGE QUALITY ASPECTS

* Poor image quality has been used to condemn some units
* Serious problems over "acceptable" imaging performance of old units including C-ARMS.
* Often difficult to arrange test conditions comparable with protocol guidelines.
* Gx and 100 mm film speed have proved to be useful measurements.

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WRITING OFF FLUOROSCOPY

EQUIPMENT (4) OTHER COMMENTS

* Units are sometimes condemned for a combination of reasons.
* Balance between Repair / Replacement frequently an issue.
* Reason determining write off seldom derives from Leeds protocols.

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- The Image Intensifier needed a radiation input greater than five times that usually encountered to produce an acceptable image
- The imaging performance was good at the high dose-rate
- The unit would only screen at one tube current of 2.2mA. Whilst it is realised that a control on the partially assembled back panel in the film store can halve the current, this is not regarded as an acceptable solution
- On pressing the footswitch the unit screens for some seconds during which the patient is irradiated, prior to the image on the monitor becoming visible. Similarly, during radiography, radiation is emitted when the exposure switch is in the preparation position, before being advanced to the expose position

Reasons for writing off Fluoroscopy Equipment

Frequently Cited

- High input dose rate at Image Receptor objective
- Image Quality problems, some dose related
- Persistent projected expensive maintenance

Sometimes cited or used

- Gx Measurements
- Considerations arising from ALARA
- Additional objective indices of image quality
- Semi subjective indices of image quality

Not cited

- Patient entry skin dose