Chapter 8: Fluoroscopic Imaging Systems

Slide set of 95 slides based on the chapter authored by A. Kyle Jones 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 principles of the construction and operation of fluoroscopic imaging systems

Slide set prepared by K.P. Maher following initial work by S. Edyvean

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8.1 INTRODUCTION

Fluoroscopic Imaging: real-time radiographic imaging

Plain Radiography: good SNR, poor **Temporal Resolution**

Fluoroscopy: poor SNR, good Temporal Resolution

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8.2 FLUOROSCOPIC EQUIPMENT

Components:

- High Voltage Generator
- X-Ray Tube (XRT)
- X-Ray Image Intensifier (XRII)
- Video Camera

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8.2 FLUOROSCOPIC EQUIPMENT
8.2.1 The Fluoroscopic Imaging Chain

XRII converts:

low intensity X-ray photon fluence

to

high fluence of **Visible Photons**

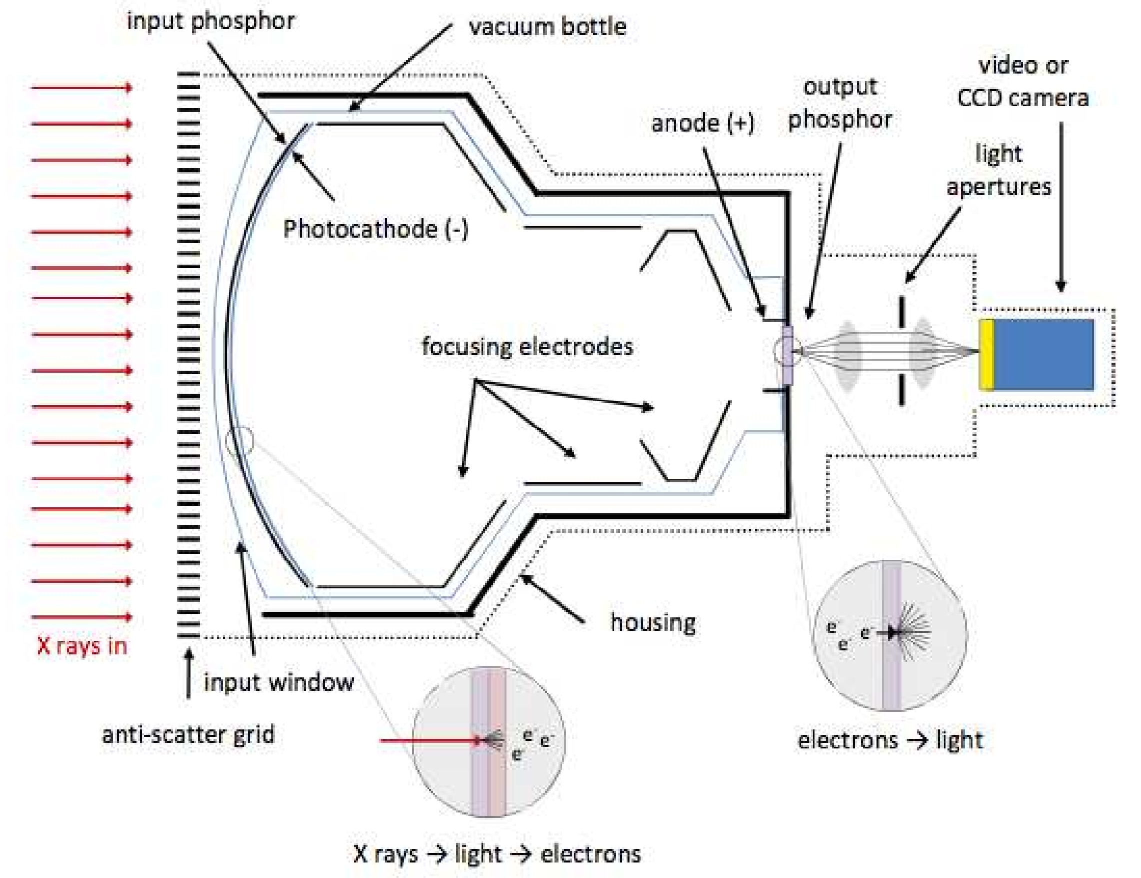
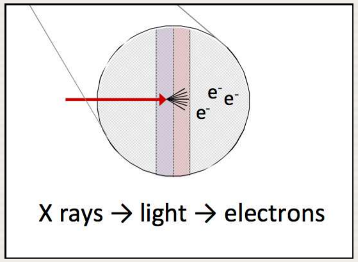


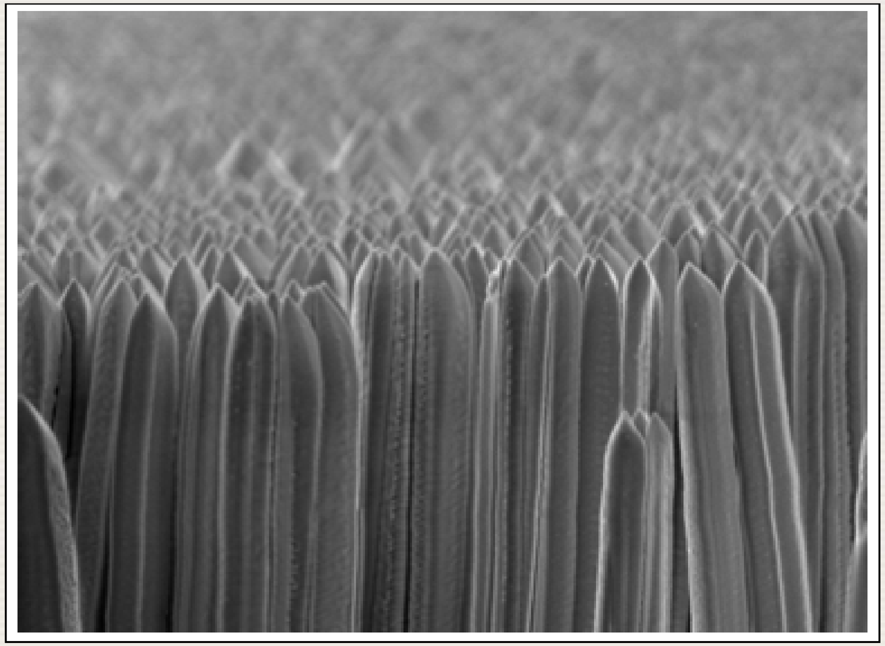
FIG. 8.1. Basic structure of an X ray image intensifier

8.2 FLUOROSCOPIC EQUIPMENT
8.2.1 The Fluoroscopic Imaging Chain

Input Phosphor converts: X-Rays to Light



Most commonly used phosphor: CsI(Tl) crystals grown in a dense needle-like structure - prevents lateral light spread



Top portion of a ~750 micron thick film of CsI(Tl) demonstrating well separated columnar growth

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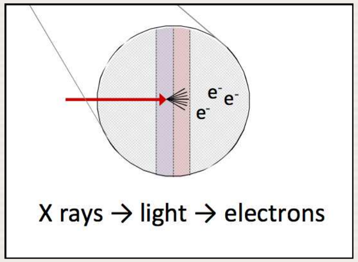
8.2 FLUOROSCOPIC EQUIPMENT
8.2.1 The Fluoroscopic Imaging Chain



Photocathode converts: Light to Electrons

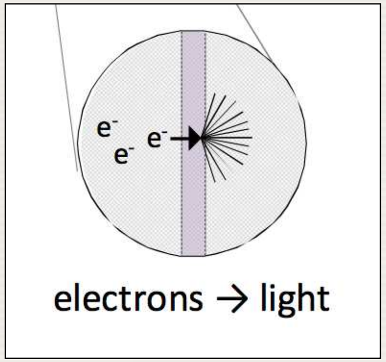
Light photons strike a very thin bi- or multi-alkali photocathode

Electrons:

- **Released** through photoelectric effect
- **Repulsed** from photocathode
- **Accelerated** towards anode by 25-30 kV

8.2 FLUOROSCOPIC EQUIPMENT
8.2.1 The Fluoroscopic Imaging Chain

Output Phosphor converts: Electrons to Light



Electron beam focused by electrodes onto a thin powder phosphor

e.g. ZnCdS:Ag (P20)

Incident Air Kerma Rate (IAKR): 15-40 µGy/min

40 cm FOV XRII

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Intensification - two mechanisms:

- **Electronic** (or **Flux**) **Gain** - KE gained by electrons from acceleration (~50 typically)
- **Minification Gain** - reduction of large X-ray image at Input Phosphor (e.g. 40 cm) to a smaller diameter Output Phosphor (e.g. 2.5 cm)

$40^2/2.5^2 = 256$

Brightness Gain = (Electronic Gain).(Minification Gain)

ranges from **2,500-7,000** in practice

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Conversion Factor: also used to express gain

definition:

Ratio of **Luminance** at the output phosphor to the **Incident X-ray Air Kerma Rate** at the input phosphor

typically 9-27 $cd.m^{-2}/\mu Gy.s^{-1}$

Optical System couples XRII to video camera

includes:

- **Collimating Lens** to shape the divergent light from the Output Phosphor

- **Aperture** to limit the amount of light reaching the video camera

- **Lens** to focus the image onto the video camera

Video Camera captures the XRII output image,

and

converts it to an analogue electrical signal that conforms to a recognized video format (e.g. NTSC/PAL/SECAM)

Older Video Cameras - Photoconductive target scanned by electron beam

Modern Video Cameras - Charge-Coupled Device (**CCD**)

Photoconductive Video Cameras

e.g.

TARGET MATERIAL	CAMERA NAME
Sb_2S_3	Vidicon
PbO	Plumbicon
CdSe	Chalnicon

collectively known as ‘Vidicons’

Photoconductive Video Cameras

Resistivity of the photoconductive target changes based on the amount of light striking it

Creating a **Latent Image** of the XRII output phosphor

As the **Electron Beam** is scanned rapidly across the target, its intensity is modulated by this latent image

The resulting small current is **integrated** across a large resistance and converted to a voltage that is **amplified**

Photoconductive Video Cameras

Fundamental characteristics include:

LAG

- Describes the **Speed** of response of the video camera to a changing signal
- High lag can result in blurred images of moving objects, but noise will be reduced through **Temporal Integration**

SIGNAL-TO-NOISE RATIO (SNR)

- Cameras with low SNR contribute to increased noise levels in fluoroscopic images - temporal integration can reduce this
- Maximum SNR is achieved when a video camera is operated near its maximum signal level - important that **Aperture** set accordingly

Photoconductive Video Cameras

Analogue video waveform can be displayed **directly** on a video monitor

Waveform can also be digitized using an **ADC**

Important ADC characteristics include:

- **Bit Depth**
- **Sampling Rate**

Digital images stored in a **Video Buffer**

CCD Video Cameras

A **Solid-State Device** composed of many **discrete** photoconducting cells

Light from the Output Phosphor is converted to electrons in an **Amorphous Silicon** photoconducting layer

The electrons are stored in **Potential Wells** created by applying a voltage between rows and columns of cells

CCD Video Cameras

Stored charge that has accumulated during an exposure is read out using parallel and serial **Shift Registers**

that move charge from column to column and row to row in a

Bucket-Brigade fashion

This creates an analog signal that is **amplified** and output as a video signal or digitized directly

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CCD vs Vidicon

- Absence of **Lag**
- Wider **Dynamic Range**
- Reduce or eliminate **Blooming**, at the expense of Fill Factor and QDE

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Flat Panel Image Receptors

Replacing XRIIs in modern systems

Advantages include:

- Larger **Size**
- Less bulky **Profile**
- Absence of **Image Distortions**, and a
- Higher **QDE** at moderate to high IAKR

Flat panels broaden applications to include **Rotational Angiography** and **Cone-Beam CT**

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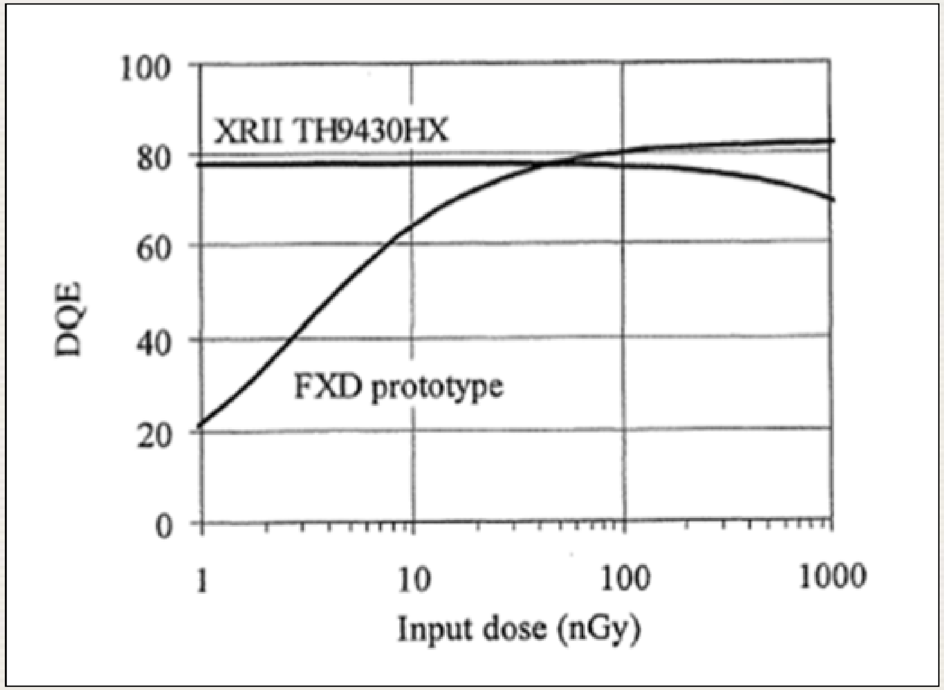
Flat Panel Image Receptors

Suffer from **Additive** noise sources and therefore perform poorly compared to XRIIs at low IAKR

Typical IAKR for fluoroscopic imaging with a full-FOV flat-panel receptor (30 cm x 40 cm) range from **27-50 µGy/min**



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Video Image Display

Images must be converted from digital to analog form for image display on a viewing monitor

Early television standards determined at least **525** video scan lines of the image were necessary to adequately display moving images

Bandwidth restrictions required scanning two frames or **Video Fields**, each containing one half (262 1⁄2) of the scan lines, in an **Interlaced** fashion to eliminate flicker

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note: NTSC example

Video Image Display

Interlaced scanning provides a refresh rate of

60 Hz

while only requiring the bandwidth of

30 Hz

Progressive scanning video

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note: NTSC example

Video Image Resolution

Spatial resolution limited in the **Vertical** direction by the number of effective lines used to make the image

The effective number of lines is the number of scan lines in the image multiplied by the **Kell Factor**

The Kell factor is an empirically determined factor that describes **Vertical** image degradation

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Video Image Resolution

Causes include:

- Finite size of the scanning **Electron Beam**
- **Low-pass Filtering** of interlaced scan lines in scanned-pixel devices
- Scanned and fixed pixels **not aligning** exactly with a scanned signal

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Video Image Resolution

Kell Factor is device-specific, ranging from

- **0.7** for scanned-pixel video cameras (e.g. vidicon) and display devices (e.g. CRT) to
- **0.9-0.95** for fixed-pixel devices (e.g. CCD cameras) and liquid crystal display (LCD) monitors

In the **Horizontal** direction, resolution is limited by the bandwidth of the video system

In most systems the bandwidth is adjusted to give **Equal Resolution** in both the vertical and horizontal directions

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Radiographic systems use **AEC** devices that automatically adjust radiographic technique factors

most often the mAs

to deliver a

Constant Signal Intensity at the Image Receptor

Similarly in fluoroscopic systems, the AEC controls the **IAKR** to prevent fluctuation in

- Image Brightness and
- SNR

that would make diagnosis or navigation of instruments difficult

8.2.2 Automatic Exposure Control (AEC)

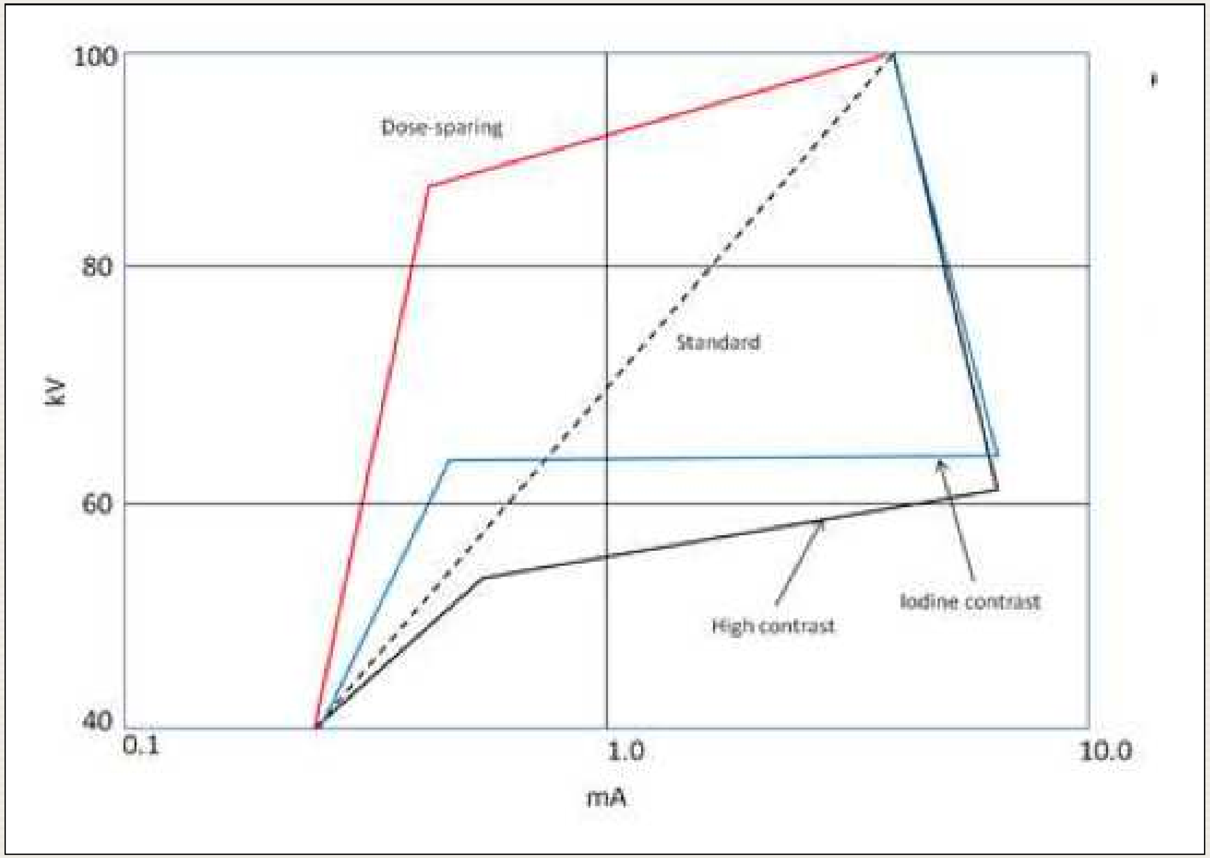
Fluoroscopic AEC may use the signal from a sensor such as a

- **Photodiode** or a
- **Photomultiplier Tube** or
- More commonly the signal from the **Video Camera** or
- **Directly** from a flat panel image receptor

to determine necessary adjustments of fluoroscopic technique factors

The selection of fluoroscopic technique factors follows **predetermined** curves that are stored in the generator

Usually allows some choices, including a **Standard** curve, **Low Dose** curve, and **High Contrast** curve, e.g.:



The complexity of fluoroscopic AEC increases with advanced applications

where the AEC assumes control over **additional** equipment parameters such as:

- Pulse Length
- Added Filtration
- Variable Aperture Setting

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Electronic Magnification refers to the use of a Focusing Electrode in the XRII to Deminify the fluoroscopic image

by selecting a smaller portion of the **Input Phosphor** to project onto the **Output Phosphor**

Improves the image MTF but also **decreases**:

- Minification Gain and
- Sampling Pitch of the input phosphor, increasing noise

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In practice

the increased noise in a **magnified** fluoroscopic image is compensated for by adjusting the technique factors

to Maintain a Constant Perceived Noise Level in the Displayed Image

In an XRII, the IAKR usually increases as the ratio of the **Areas** of the FOV as the image is magnified

Flat panel based systems also increase the IAKR as the image is magnified in response to changes in the image matrix size

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Subject Contrast is inherently poor in fluoroscopic imaging, especially at the high kV values used to maintain patient dose at an acceptable level

Contrast is greatly improved through the use of

- **Radio-Opaque** markers on catheters and other instruments, and
- Exogenous **Contrast Agents**, e.g. iodine and barium with K- edges of 33 keV and 37 keV respectively

Gadolinium or carbon dioxide may also be used

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Spectral Shaping

The signal from iodine contrast is highly dependent on the X-ray spectrum used to image the contrast agent

Maximal contrast occurs when the polyenergetic X-ray spectrum is optimized to be predominantly just above the K-edge

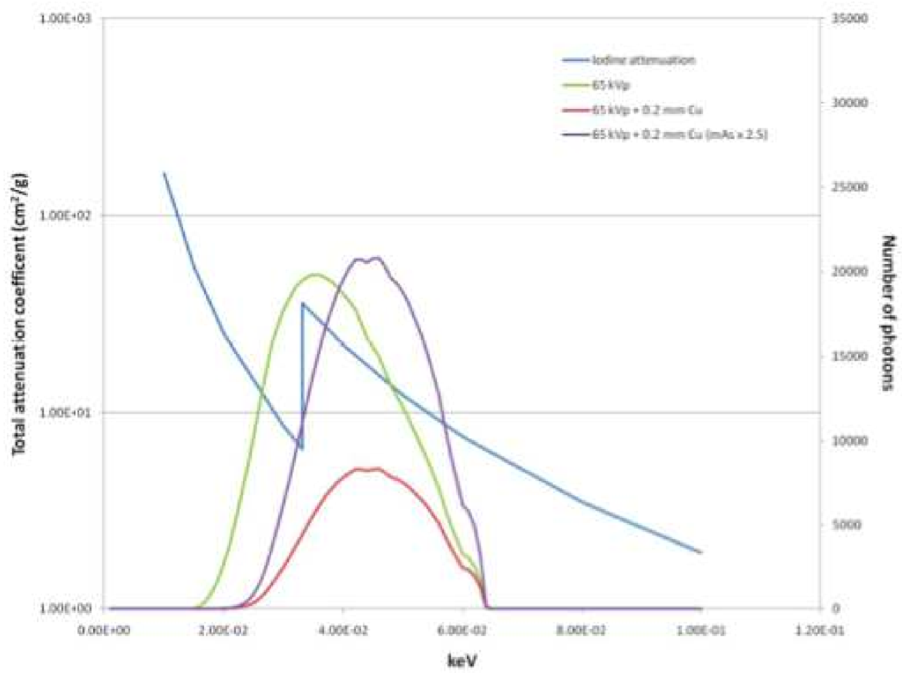

FIG. 8.5 Impact of spectral shaping on iodine contrast.

Spectral Shaping

However the use of such low X-ray energies may lead to

Excessive Patient Dose

requiring:

- Careful selection of kV and
- Appropriate filtration

e.g. **Cu**

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Noise in fluoroscopic images is high, since low IAKR is used to maintain patient dose at an acceptable level

XRII-based fluoroscopic systems are also characterized by **Additive Electronic Noise**

Flat Panel-based fluoroscopic systems suffer from high levels of electronic noise (read noise, specifically)

Their imaging performance is limited by this noise at **low IAKR**

Flat panels therefore require **higher IAKR** than XRII-based systems for fluoroscopic imaging

Conversely, flat panels perform better than XRIIs at high IAKR, such as those used during **Digital Acquisition Imaging**

The appearance of image noise in fluoroscopy is also influenced by **Human Perception**

For example, less noise will be perceived by an observer at high frame rates compared to lower frame rates

Sharpness influenced by several factors, including:

- Display Matrix
- FOV
- Video Camera Matrix
- Focal Spot Size
- Geometric Magnification
- Image Noise
- Motion

Noise interacts with sharpness as it can obscure and blur small details in the image that would normally be visible at a higher IAKR

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Large number of **Signal Conversions** in an XRII also degrade the sharpness

Sharpness with a **Flat Panel** receptor affected by the size of the image matrix compared to the

- Display Matrix and the
- Pixel Size of the receptor

which may vary if pixels are binned at certain field sizes

Artefacts in fluoroscopic imaging usually stem from image distortions caused by components of the image chain

XRIIs suffer from several common image distortions including:

- Veiling Glare
- Vignetting
- Blooming
- Pincushion Distortion
- S Distortion

Flat Panel image receptors are **generally free** from image distortions

Veiling Glare

A contrast-reducing **Haze**

Not unlike the effect of **X Ray Scatter**, that results from the scattering of information carriers within the XRII, including:

- **Electrons** within the electron-optical system and
- **Light Photons** within the glass output window

Veiling Glare

A thick XRII **Output Window** is used that may incorporate

- **Dopants** to absorb scattered light, and
- Sides coated with a **light-absorbing** material

In some cases, the optical coupling system is replaced by a direct **Fibre Optic** linkage

Vignetting

An **Optical Distortion** that produces a fall-off of light intensity or darkening near the edges of an image

Can be caused by a number of factors including deterioration of the video camera

and is also inherent to **multi-element** lenses

Vignetting can be reduced in some cases by restricting the **Aperture Size**

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Blooming

Blooming is caused by the input of signals to the video camera that exceed its **Dynamic Range**

Such large signals cause **Lateral Charge Spreading** within the camera target resulting in a diffuse image that is larger than the original

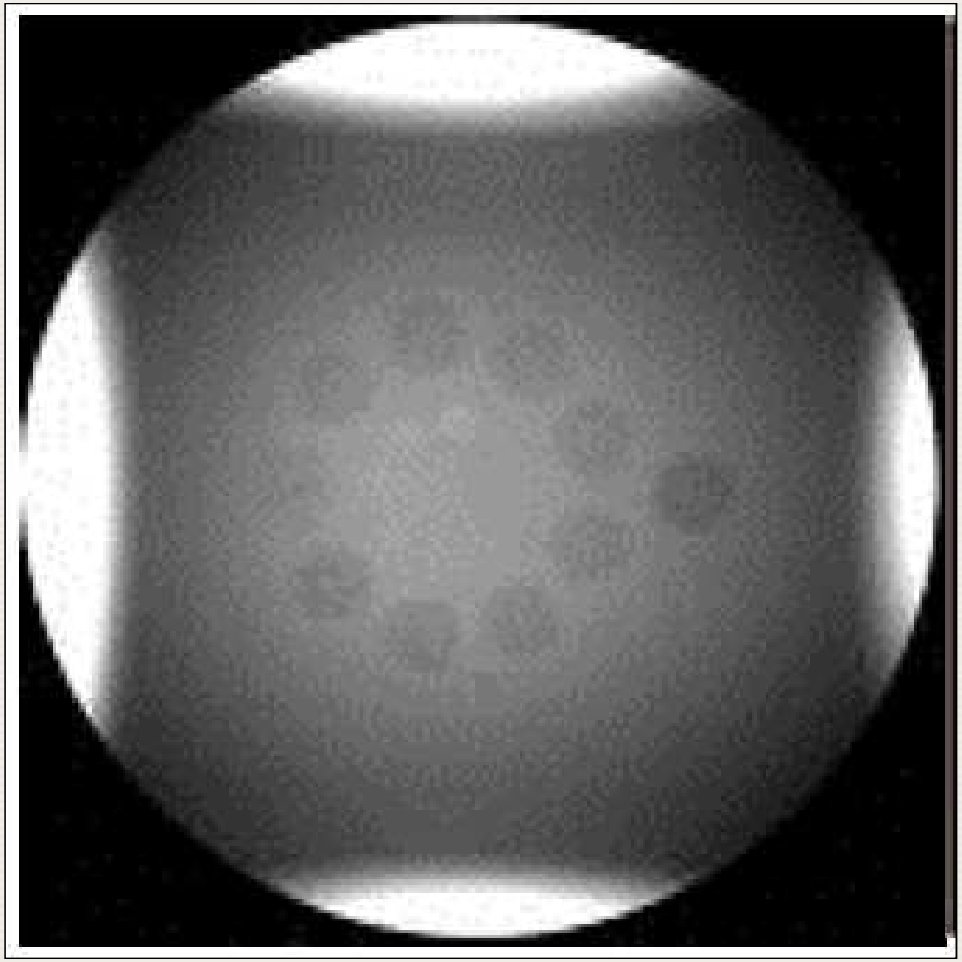
Can be minimized through the use of tight X ray beam **Collimation**

Has largely been eliminated in CCD cameras

Pincushion Distortion

Pincushion Distortion causes enlargement of the fluoroscopic image near the edges

- Results from the curvature of the input phosphor
- More severe for large fields of view



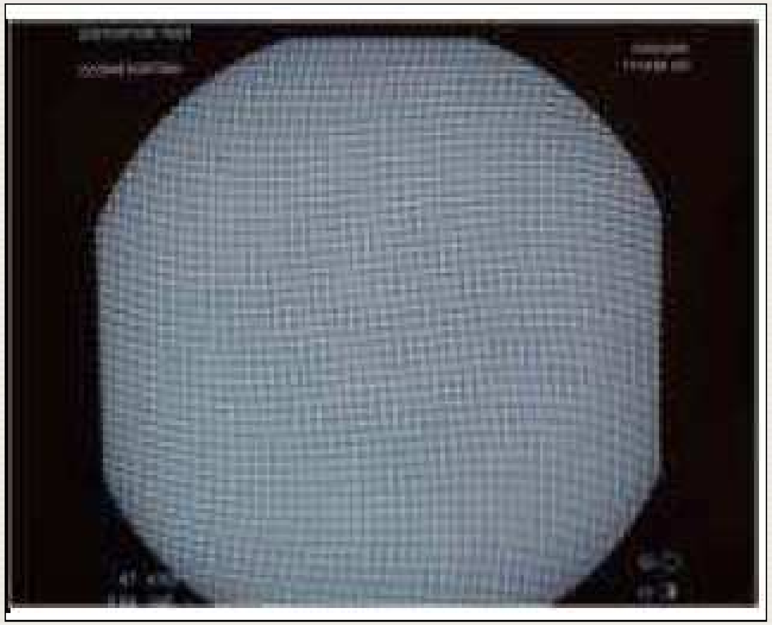
S Distortion

S distortion causes straight objects to appear curved

Results from presence of an **External** magnetic field

Common sources: the Earth (5×10^{-5} T), fringe fields from nearby MRI units (0.1-0.5 mT) and steel support structures and reinforcement

S distortion can be minimized by proper site planning and by encasing the XRII in a high-susceptibility metal

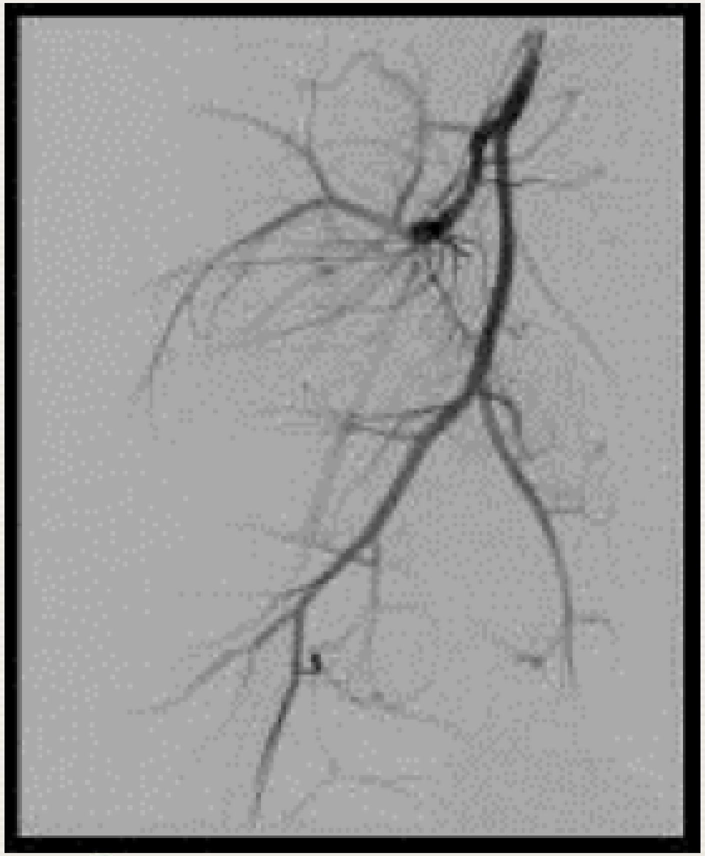


Digital Acquisition Imaging refers to a mode of operation in which high-quality images are recorded and stored for analysis

IAKRs are **higher** in digital acquisition mode than in fluoroscopic mode by approximately an **Order of Magnitude**

In order to avoid saturation of the video camera for systems using an XRII, the signal from the image intensifier may be reduced through the use of the **Variable Aperture**

DSA is a technique in which sequential (**Fill**) images that include a contrast agent are subtracted from a **Mask** image that includes only the anatomical background



This subtraction reduces **Anatomical Noise** and increases the contrast of the blood vessels in the subtracted images

Both the mask and fill images undergo a **log-transform** before subtraction

The final result is an image in which the signal in the contrast-filled vessels depends only on the amount of contrast in the vessel, and not on the background

As noise sums in **Quadrature** when images are combined

the noise level in the **subtracted** image is higher by a factor of **1.4** than the noise level in the **constituent** images

This increase in noise implies that DSA will require **Higher Exposures** than digital acquisition imaging if similar image noise levels are to be maintained

Mask Averaging can be used to reduce the exposure requirements for DSA imaging

Major source of **Artefacts** in DSA: patient motion between the capture of the mask and fill images

These motion artefacts can **obscure** contrast-filled vessels

These types of artefacts can be reduced retrospectively in some cases through the use of processing techniques such as manual or automatic **Pixel Shifting** of the mask image or **Remasking** through the selection of a different mask frame for subtraction

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Roadmapping

An **Adjunct** imaging mode used to create a **Map** of vascular anatomy that aids the **Navigation** of catheters

A roadmap can be generated by using a

- stored image of a **Contrast-Filled** vessel or
- in a more complex fashion by using the **Peak Opacification** in each image pixel obtained from a series of post-injection images

The roadmap image can either be displayed **alongside** the live image on another monitor, or **overlaid** on the live fluoroscopic image

Peripheral Runoff Imaging

Follows a **Bolus** of contrast as it travels from the injection site into the peripheral vasculature, most often in the legs

Many angiographic systems operate in a stepping mode for **Runoff** procedures, sequentially stepping along the patient's body, acquiring images at each step

Images **overlap** by some amount, often 1/3, to ensure seamless anatomical coverage

Peripheral Runoff Imaging

This type of study requires the use of **Compensating Filters** to

Equalize image receptor exposure around the patient's legs

Compensating filters can either be:

- **External** to the system, such as wedges or forms placed around the patient's legs, or
- **Internal** in the form of wedge-shaped metal filters either attached to the outside of the collimator or contained inside the collimator

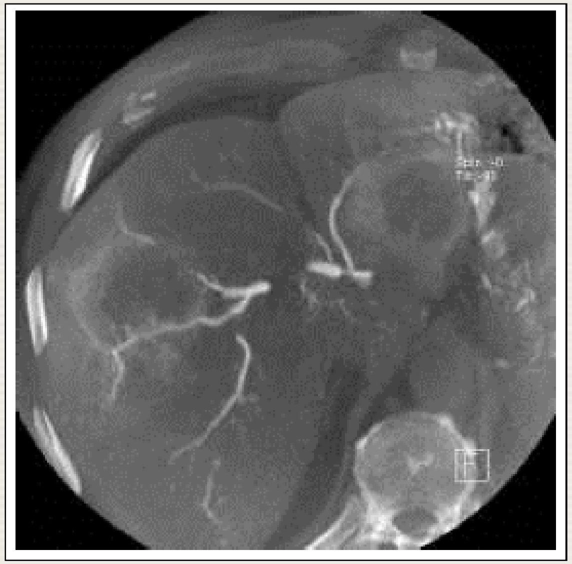
Rotational Angiography

An adjunct imaging mode used most often in vascular, interventional, and neurointerventional radiology

A series of **basis images** are acquired as a C-arm rotates around the patient

The basis images can be viewed as a cine loop, and are often used to reconstruct cone-beam CT images

- The images can be reconstructed in axial, coronal, and sagittal planes, or in arbitrary curved planes
- MIP images are often generated to better visualize iodine contrast in small vessels
- Some manufacturers offer the capability to perform 3D rendering using the CT images, and to perform subtracted rotational angiography



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Rotational Angiography

An **Adjunct** imaging mode used most often in vascular, interventional and neurointerventional radiology

A series of **Basis Images** are acquired as a C-arm rotates around the patient

The Basis Images can be:

- Viewed as a **Cine Loop**, and are
- Often used to reconstruct **Cone-Beam CT** images

8.5 APPLICATION-SPECIFIC DESIGN

Fluoroscopic imaging systems can be **configured** in several ways

Most common is the configuration in which the XRT is located **under** the patient table and the XRII and auxiliary imaging equipment on a movable **tower** above the patient table

Lead curtains hang from the XRII tower and shield the operator from stray radiation scattered from the patient

This configuration is commonly used for **Genitourinary** (GU) and **Gastrointestinal** (GI) imaging

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8.5 APPLICATION-SPECIFIC DESIGN

8.5.1 Remote Fluoroscopy Systems

Commonly used for GI procedures, including Ba swallow and Ba enema examinations utilizing a configuration with the XRT located **above** the table and the XRII assembly below the table

The system can be **rotated** to:

- **Achieve** other necessary projections or to
- **Distribute** contrast agents within a patient

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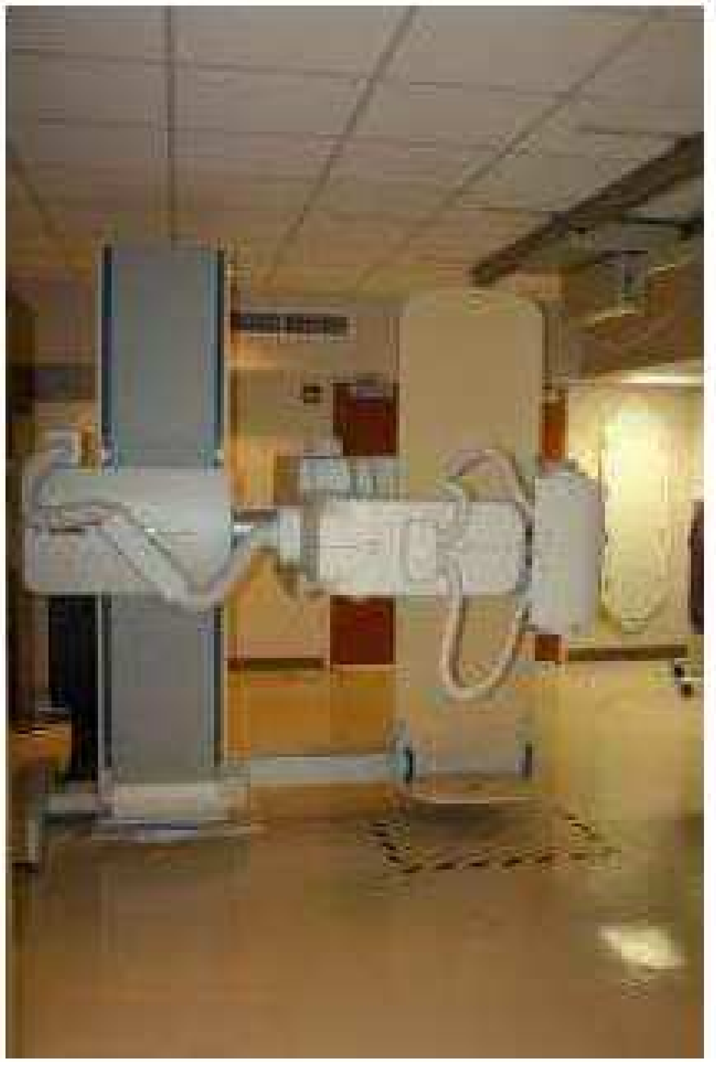
Can also be configured **vertically** for seated examinations, such as the Ba swallow



The **FID** is usually continuously variable between two extremes

A remote-controlled **Compression Cone** may be available for the Radiologist to manipulate air and barium contrast within the patient's abdomen

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There are distinct **advantages** of remote fluoroscopy rooms, namely related to radiation safety

as exposure of the operator and technical staff to

Stray Radiation

is greatly reduced

Vascular and Interventional radiology procedures are usually performed in angiographic suites equipped with **C-Arm Fluoroscopes**

Comprised of a **mechanically-coupled** XRT and image receptor

XRT and image receptor rotate in unison about a point called the **Isocentre** that remains at the centre of the FOV when the C-arm is rotated

The table is often **cantilevered** to allow continuous, unobstructed rotation of the C-arm around the patient during procedures

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Vascular and Interventional suites are equipped with:

- More powerful generators with high heat capacity
- Water or oil- cooled XRTs

Variable **Spectral Shaping Filters** are often included to maximize iodine contrast while maintaining patient dose at an acceptable level

Typical XRII sizes for vascular and interventional labs range from **28-40 cm**

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8.5 APPLICATION-SPECIFIC DESIGN

8.5.3 Cardiology

Interventional cardiology suites also use C-arm fluoroscopes for ease of positioning at a variety of angles around the patient

Cardiology suites can either be **Single-Plane** or **Biplane** systems

Biplane systems use two C-arms that can be independently positioned around the patient for simultaneous digital acquisitions during a single contrast injection

Important since iodinated contrast is **nephrotoxic**, and the total volume of contrast that can be administered is limited by patient body mass

Particularly Critical in Paediatrics

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8.5 APPLICATION-SPECIFIC DESIGN
8.5.3 Cardiology

Image receptors used for Cardiac imaging are smaller than those used for Vascular and Interventional radiology owing to the small size of the heart

A typical XRII size for a cardiac lab is **23 cm**

Some **newer** flat panel-based cardiac catheterization labs incorporate

- Large image receptors (30 x 40 cm) for the primary or **A plane** which make possible adjunct imaging modes such as runoff imaging or rotational angiography
- The lateral or **B plane** is sized for normal cardiac imaging

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Neuroradiology equipment

is very similar to

Cardiology equipment

as the required FOVs are similar

8.5 APPLICATION-SPECIFIC DESIGN

8.5.5 Mobile Fluoroscopes

Mobile Fluoroscopes are fluoroscopes **mounted on wheels** that can be moved between locations

Useful when

- The **expense** of a permanent installation cannot be justified, or when
- Imaging capability is needed **briefly** in several adjacent rooms, for example in the operating room

Often use **shorter FIDs** and **smaller FOVs** than other types of fluoroscopes

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8.6 AUXILIARY EQUIPMENT

Advanced fluoroscopic applications and equipment are changing with the rapid deployment of **Digital** image acquisition devices

Use of **Film** is decreasing and in many cases specialized films are not longer available

In other cases precision mechanical equipment needed for:

- radiographic screen film **Cassette Changers** and
- high speed large format **Film Changer** systems

have become obsolete

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8.6 AUXILIARY EQUIPMENT

8.6.1 Spot Film Device

Used to acquire **Radiographs** during a fluoroscopically-guided procedure

While **Fluoroscopy** is activated:

A radiographic cassette is **retracted** into and held in a **lead-shielded enclosure**

When a **Spot Film** is desired, the cassette is extended automatically in front of the XRII

behind an anti-scatter grid

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After the cassette is exposed, it is

- Ejected and
- **Manually** exchanged for an unexposed cassette

which is retracted into the lead-shielded enclosure until needed

Most spot film devices offer several **Framing** options, including

- Single full-sized image
- Two or four images per film
- etc

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Continuous Fluoroscopy

- the **most basic** form of fluoroscopic imaging
- X-ray beam is on **constantly**, and a video refresh rate of 25 or 30 fps yields a frame integration time of 40 or 33 msec, which can lead to blurring of moving objects

Pulsed Fluoroscopy

- Short **Pulses** of X-rays used

Advantages:

Pulsed Fluoroscopy

- **Lower** radiation dose when fluoroscopic frames are acquired in a fraction of the time used in continuous operation
- X-ray production is needed only immediately prior to the **Readout** of the video cameraImproved **Image Quality** owing to reduction in motion blur because of the reduced integration time
- Pulsed mode operation **freezes** the motion of objects in the image, resulting in sharper images and improved image quality**Reduced** tube loading owing to a lower duty cycle

as low as 5-8%

Pulsed Fluoroscopy

While pulsed fluoroscopy produces **Sharper** images

the reduction in **Temporal Resolution** at low Frame Rates may be unacceptable for rapidly-moving organs

or instruments within the body

Higher Frame Rates provide superior temporal resolution for these cases

Pulsed Fluoroscopy

Grid-Controlled or Grid-Switched XRTs

Pulsed fluoroscopy can be accomplished either by

- Operating the Generator in pulsed mode, or by
- Using a Grid-Controlled or Grid-Switched XRT

The long **HV Cables** used in many fluoroscopic rooms are characterized by significant **Capacitance**

As a result, power **continues** to be applied to the XRT after the generator switches off between pulses

Pulsed Fluoroscopy

Grid-Controlled or Grid-Switched XRTs

This results in **Unnecessary** patient dose,

and possibly additional motion blurring

A **Grid-Controlled XRT** uses a negatively-biased grid near the filament to stop the flow of electrons from the cathode to the anode

preventing **unwanted** X-ray production between radiation pulses

Pulsed Fluoroscopy

and the Human Visual System

Since the **Temporal Response** of the human visual system has a typical integration time of **~0.1 second**

it has the capacity to **Integrate** several pulsed images

Consequently fluoroscopic images **appear noisier** as the pulse rate decreases for the same IAKR per frame

When changing from one pulse rate to another, the **IAK per pulse** can be adjusted to account for this phenomenon

8.6 AUXILIARY EQUIPMENT

8.6.3 Recursive Filtering

Fluoroscopic images are inherently **Noisy**

but increasing **IAKR** to reduce noise comes at a penalty of increased **Patient Dose**

Noise reduction can also be accomplished through image processing, including the **Averaging** of images

Recursive Filtering is an image processing technique that combines portions of both the most recent fluoroscopic frame and several previous fluoroscopic frames to reduce noise in the resultant image

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Process can be described mathematically as:

$$frame_{Displayed} = \sum_{i=N-n}^{N} f_i \cdot w_i \; ,$$

where w_i is a prospectively-determined weighting coefficient and f_i is the i^{th} frame in the video buffer

The recursive filter is thus a **Moving Filter** that incorporates information from several frames into the current fluoroscopic frame, reducing noise in the final image

Both quantum (X-ray) noise and additive noise from the video camera or image receptor are averaged

8.6.3 Recursive Filtering

Filter works well **if changes** in the image from one frame to the next are **small**

In anatomical regions where motion is rapid:

Excessive recursive filtering can lead to unacceptable **Induced Lag**

sometimes referred to as **Artificial Lag**

Most modern fluoroscopic systems use motion-detection algorithms or other methods to prevent Induced Lag

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8.7 DOSIMETRIC CONSIDERATIONS IN FLUOROSCOPY

Note that fluoroscopy, particularly when it involves interventional procedures can give rise to both

Stochastic and **Deterministic** (tissue) effects

primarily radiation-induced **Skin Injury** that occurs once a certain dose has been exceeded

The treatment here focuses solely on **Deterministic Effects** from fluoroscopic procedures

any reference to patient dose refers to **Skin Dose**

Dosimetric indicators for skin dose can be

- Direct (**Real Time**) or
- Determined after the irradiation event

Examples:

Direct Indicators: fluoroscopy time, KAP readings, and the cumulative dose

Non Direct Methods: TLD, OSL, or semiconductor detectors and radiographic or radiochromic film

Fluoroscopic Timers

Fluoroscopy Time is commonly used as a **surrogate** for patient dose in fluoroscopy, as it is widely available on fluoroscopic equipment

Far from ideal: ignores many large contributions to patient dose, including digital acquisition imaging

Digital acquisition imaging is frequently, but not always, the largest contributor to patient dose during fluoroscopic procedures

Kerma-Area Product

- Can be **Measured** directly using a KAP meter or
- Can be **Calculated** from known operating parameters

While KAP is an ideal quantity for assessing stochastic risk, it has **limited** application as an indicator of skin dose

However when carefully combined with direct skin dose measures it has been used to determine **trigger levels** for specific procedures to alert operators of possible danger of skin damage

Cumulative Dose or Reference Point Air Kerma

Refers to the cumulative air kerma at the **Interventional Reference Point** (IRP) at any time during a fluoroscopically-guided procedure

The IRP is a point 15 cm back towards the focal spot from the isocentre

and its location does not vary with changes in C-arm angle or FID

Cumulative Dose or Reference Point Air Kerma

The **Cumulative Dose** (CD) is the quantity **most closely** correlated to skin dose in fluoroscopically-guided procedures

as **all contributions** to skin dose (i.e. both fluoroscopic and digital acquisition imaging) are included

Peak Skin Dose (PSD)

Refers to the **highest** dose to any single area of a patient's skin

In practice, **accurate** PSD determination is difficult

It must be considered that the **CD** is measured at a single point in space that may not correlate with the patient's skin surface

Even in the case where the IRP is located exactly on the skin surface, **Backscatter** will increase PSD beyond the indicated CD by 30-40%

Fluoroscopically-guided procedures can result in high **Patient** and **Operator** doses and

radiation safety is a **Critical** component of a fluoroscopic imaging program

In general, the use of **Good Practice** by the operator will result in the

Minimum Patient Dose

required to safely complete a fluoroscopically guided procedure

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Good Practice

refers to the use of

Commonly-Known Techniques

to deliver the

Best Image Quality

at the

Lowest Radiation Dose

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Good Practice

Actions include, but are not limited to:

- **Moving** the patient as far from the X-ray source as practical
- **Placing** the image receptor as close to the patient as possible (i.e. no air gap)
- **Using** the lowest electronic magnification (largest FOV) required to perform the procedure
- **Collimating** the X-ray beam tightly to the anatomy of interest

Good Practice

In addition to good practice:

- All **Dose Reduction Tools** available on the fluoroscopic equipment should be used
- Maintain a **Minimum Distance** between the focal spot and patient using installed spacers
- **Anti-scatter Grids** should be removed when imaging small patients or thin body parts
- Use **Last Image Hold** (LIH) and other digital storage options

8.7.3 Radiation Safety Considerations for Operator Protection

Occupational radiation protection considerations are often variations on the **Three Cardinal Rules** of radiation protection:

- Time
- Distance
- Shielding

Operators and other personnel remaining in the procedure room during fluoroscopically-guided procedures are exposed to **Scattered Radiation** and are at risk for both:

- **Stochastic** effects, including cancer, and
- **Deterministic** effects, namely cataracts

8.7.3 Radiation Safety Considerations for Operator Protection

Non-Essential Personnel should exit the room while the XRT is energized

Persons remaining in the room should wear **Protective Garments**

made of lead or equivalent material

Mobile Barriers and **Suspended Shields** should be used

Note that the **highest** scatter radiation fields occur from the

Patient Entrance Field

Standing **closer** to the image receptor is therefore generally consistent with lower occupational dose levels

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