Personnel Protection During Fluoroscopic Procedures
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Medical Physicist’s Role
- Procedure room design
- Movable and personal shielding device selection
- Fluoroscopic equipment selection
- Fluoroscopic system optimization
- Personnel exposure monitoring
- Personnel exposure investigation
- Radiation safety training

Learning Objectives
- What is the nature of stray radiation in fluoroscopic procedures?
- What can be done to reduce occupational exposure?
- What regulations must be followed regarding personnel radiation exposure?

Stray Radiation Sources
- X-ray tube leakage
- Scatter from patient and objects exposed to the primary beam

X-Ray Tube Leakage
- Part 1020.30 (k) Leakage radiation from the diagnostic source assembly:
  - not to exceed 100 mR/hr (0.88 mGy/hr) at 1 m
  - measured at maximum kVp (125-150 kVp) and maximum continuous mA (3-5 mA)

Leakage radiation is negligible compared to scatter
- Typical amount of leakage radiation for fluoroscopy of an average adult abdomen:
  - 5 μGy/hr at 1 m
Scatter

- Number of scattered x-rays depends on:
  - the patient entrance skin exposure rate
  - the patient entrance skin area
  - the beam energy
- Typical scatter value:
  - 0.1% of incident exposure at 1 m for a 23-cm FOV
  - for an entrance skin exposure rate of 20 mGy/min, scatter at 1 m is 20 μGy/min or 1.2 mGy/hr

Scatter vs Field Size

- For constant entrance exposure rate and constant kVp, scatter is proportional to the exposure field size

Scatter vs Entrance Exposure

- For constant field size and constant kVp, scatter is proportional to the entrance skin exposure rate

Scatter vs DAP

- For constant kVp, scatter is proportional to the dose-area-product rate (DAP)

Scatter vs kVp

- For constant field size and constant entrance skin exposure rate, scatter increases with kVp

Scatter: Distribution

- Scatter intensity is higher on the entrance side of the exposed volume
  - primary beam most intense on the entrance side
  - forward scatter is heavily attenuated
The entrance skin port should be considered the major radiation source for occupational exposure.

For actual imaging situations, the scatter distribution is also affected by:
- attenuation from unexposed tissue to the side
- attenuation from the table and pad
- shielding by image intensifier, equipment supports, lead shielding devices

### Scatter: Distribution

### Stray Radiation: Horizontal Profile

### Stray Radiation: Vertical Profile

### Learning Objectives

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### Occupational Exposure Reduction

- What can operators do?
- What can assisting personnel do?
- What can medical physicists do?

### Radiation Safety: Operator

- Minimize fluoroscopy beam-on time
  - use short taps of fluoro instead of continuous exposure
  - use 5-min fluoro-on time warning to maintain awareness of total fluoroscopy time
  - utilize last-image-hold for image study, discussion and teaching
  - develop workflow procedures with ancillary personnel so that there is no fluoroscopic exposure when they need to be close to the patient
Radiation Safety: Operator

- Increase distance from the patient
  - GE: “spoon” palpation device
  - vertebroplasty: PMMA injection device
  - other interventional devices: forceps

Remove the grid when possible
- reduces patient entrance skin exposure and scatter by about a factor of 2
- reduction in image contrast is minimal for small patients and body parts
- procedures requiring a large separation between the patient and image intensifier

Position yourself on the x-ray beam exit side of the patient when possible
- Scatter intensity is lower on the image intensifier side as compared to the x-ray tube side
- For C-arm fluoroscopy,
  - frontal projections: place the x-ray tube under the table
  - lateral and oblique projections: place the x-ray tube on opposite side of the patient

Collimate tightly to the area of interest
- reduces the entrance skin exposure area
- improves image contrast
- entrance skin exposure may increase
- scatter will decrease with collimation as long as there is a decrease in DAP rate
- similar result for wedge-shaped beam filters
Scatter vs Field Size

Entrance Skin Field Size (cm²)

ESER (mGy/min): 22 18 18
DAP rate (Gy-cm²/min): 4.8 4.8 4.3
Scatter rate (mGy/hr): 6.3 6.1 5.2

Image Intensifier Positioning

ESER (mGy/min): 36 18 20
DAP rate (Gy-cm²/min): 5.3 4.6 2.9
Scatter rate (mGy/hr): 6.6 6.5 3.6

Magnification Mode Selection

ESER (mGy/min): 35 18 20
DAP rate (Gy-cm²/min): 4.5 4.6 2.7
Scatter rate (mGy/hr): 6.4 6.5 3.8

Radiation Safety: Operator

- Use optimal imaging chain geometry
- General imaging guidelines
  - place the x-ray tube as far as possible from the patient
  - place the II as close as possible to the patient
  - use magnification modes sparingly
- Adherence to these guidelines
  - reduces patient entrance skin exposure
  - increases spatial resolution
  - decreases scatter, but only when collimation is used
- Use DAP rate as a guide to estimate scatter

- Use movable shielding devices
  - ceiling-suspended shield
  - tableside shield
  - undertable shield
Occupational Exposure Reduction

- What can operators do?
- What can assisting personnel do?
- What can medical physicists do?

Radiation Safety: Assisting Personnel

- Make sure you are aware of beam-on cues
  - warning lights, audio warnings
- Increase your distance from the patient when possible
- Use movable shielding devices

Radiation Safety: Operator and Assisting Personnel

- Be aware that scatter is significantly higher for large patients as compared to small patients
- entrance skin exposure rate and kVp increases, resulting in higher scatter rates
- image quality decreases, beam on-time may also increase

Average-Size Patient
**Radiation Safety: Operator and Assisting Personnel**
- Select appropriate personal shielding devices
  - Protective aprons
    - Lead equivalent thickness of 0.5 mm recommended, required in some states
    - Wrap-around style needed if side or back faces exposed patient volume
    - Light-weight lead replacements (composites of materials such as barium, tungsten) reduce total weight by 20-30%

**Personal Shielding Devices**
- Proper fit is critical
  - If 2 layers are needed to meet 0.5 mm lead-equivalent requirement, make sure overlap is sufficient
  - Arm holes should not be too wide
  - Neck line should not fall too low

**Personal Shielding Devices**
- Thyroid shields
  - Use recommended if monthly collar badge reading exceeds 4 mSv
  - Significantly reduces effective dose with minimal inconvenience

**Personal Shielding Devices**
- Leaded gloves
  - 0.5 mm lead equivalent shielding recommended if hands must be in the primary beam
  - Ledged surgical gloves provide partial shielding (30-40% attenuation) if hands are in high scatter area
  - Provide minimal protection if hands are in the primary beam: ABC drives up dose rate, protection on one side only
Occupational Exposure Reduction

- What can operators do?
- What can assisting personnel do?
- What can medical physicists do?

Radiation Safety: Physicist

- When constructing or remodeling a fluoroscopic suite, ensure appropriate room design features are incorporated
  - ample procedure room size
  - ample control room size
  - large viewing windows
  - intercom system between procedure room and control room
  - patient table and control area positioned so that no straight-line scatter reaches

Room Design Features

- Operator should be able to view all procedure room entrances from expected operating position
- Adequate structural shielding in walls, doors, and windows
  - consider structural shielding in procedure rooms where mobile C-arms are used routinely
- Movable shielding devices
  - ceiling-mounted shields should be included with fluoroscopic equipment installation

Radiation Safety: Physicist

- Ensure fluoroscopic equipment radiation safety design features are considered when specifying a system for purchase
  - R&F systems: undertable x-ray tube configuration results in lower personnel exposure as compared to an overtable x-ray tube configuration (for non-remote applications)
Equipment Design Features

- Undertable x-ray tube
- R&F systems (with lead II tower drapes attached) are preferable to C-arm configurations
- For biplane systems, a lateral C-arm that can be positioned with the II toward the operator is desirable

Equipment Design Features

- Imaging chain components that allow positioning for optimal geometry
- II can be moved close to the patient
- Eliminate spot-film device if not needed
- x-ray tube located far from the patient
- Removable or retractable grid
- Last-image hold and fluoroscopy frame grab
- Graphic collimator and wedge filter position indicators on last-image hold

Equipment Design Features

- Low dose fluoroscopy settings available
- Pulsed fluoroscopy at 15, 7.5 and lower frames per second
- Image processing: video frame averaging
- Use of spectral beam filtration
- Variable rate digital image acquisition available
- Patient dose indication available to the operator

Equipment Design Features

- Digital acquisition zoom
- Low attenuation tabletop and pad
- Visible exposure warning lights
- Method to disable the fluoroscopy foot pedal to eliminate inadvertent exposure during patient removal or prep

Radiation Safety: Physicist

- Implement and maintain a comprehensive quality control program
- Work with vendor representatives and operators to find optimal image processing and dose settings to meet clinical imaging needs
- Perform regular fluoroscopic equipment performance and radiation safety evaluation
- Perform personal protection device evaluation

Learning Objectives

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Maximum Permissible Doses

- Effective dose (whole body)
  - Annual: 50 mSv
  - Cumulative: 10 mSv × age in years
- Equivalent dose (partial body)
  - Lens of eye: 150 mSv
  - Skin, hands, feet: 500 mSv
- Embryo-fetus: 0.5 mSv/month

Personal Dosimetry

- Single- and dual-monitor methods
  - Single: above protective apron at collar level
  - Dual:
    - Monitor 1. above protective apron at collar level
    - Monitor 2. under protective apron at waist level
- For the dual-monitor method, badges can easily be inadvertently switched
  - Color coding of badges is helpful

Dose Assignment

- Individual state regulations vary
- CRCPD Suggested State Regulations:
  - For single-monitor, \( H_{eq} = \text{collar reading} \), or
  - If single-monitor reading > 25% of the dose limit, \( H_{eq} = 0.5 \times \text{collar reading} \), or
  - For dual-monitor, \( H_{eq} = 1.5 \times \text{waist reading} + 0.04 \times \text{collar reading} \)
  - \( H_{eq} = \text{effective dose equivalent} \)

Dose Assignment

- NCRP Report No. 122 “Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation” 1995
  - For single-monitor, \( E = \text{deep dose reading} / 21 \)
  - For dual-monitor, \( E = 0.5 \times \text{waist reading} + 0.025 \times \text{collar reading} \)
  - \( E = \text{effective dose} \)

Pregnant Workers

- Dose limits apply only after written declaration of pregnancy
- Conceptus dose assignment method
  - Varies with individual state regulations
  - Common method is to wear a monitor under the apron at the waist level
- Prediction of conceptus dose
  - Estimate projected conceptus dose as 10% of collar badge for 0.5 mm lead-equivalent apron
  - Reference: Wagner and Hayman, Radiology 1982; 145: 559

Pregnant Workers

- Prediction of conceptus dose
  - If pregnancy planned, monitor under-apron abdominal exposure prior to pregnancy
- Protection
  - 0.5 mm lead-equivalent aprons are sufficient
  - Wrap-around styles critical if back may face radiation source
  - Specially-designed maternity aprons available
References


