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Radiation Protection in Fluoroscopy

Fluoroscopic Privilege Certifying Exam

Disclosures

Yale New Haven Health System has no financial disclosures and receives no commercial support for this cme online activity

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Disclaimer

This material is intended to provide an overview and education to practitioners who utilize fluoroscopy with the objective of ensuring both patient and operator safety and minimization of radiation exposure.

Please consult any fluoroscopy policies and procedures at local YNHHS affiliated hospitals for additional information.

This module will utilize SI units for all fluoroscopy equipment output and patient dose values.

Useful conversion factors:

1 Gy = 100 rad

1 R (Roentgen) = 0.00877 Gy = 8.77 mGy

1 R/min = 8.77 mGy/min

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Minimizing patient and staff exposure in Fluoroscopy procedures

It is Yale New Haven Health's responsibility to keep our patients safe. When using fluoroscopy equipment, special attention must be paid to the radiation dose to which patients are exposed.

Fluoroscopy procedures involving radiation exposure include:

- General Fluoroscopy
- Urology
- Endoscopy
- Mobile C-arm
- Interventional Radiology
- Cardiac Cath labs

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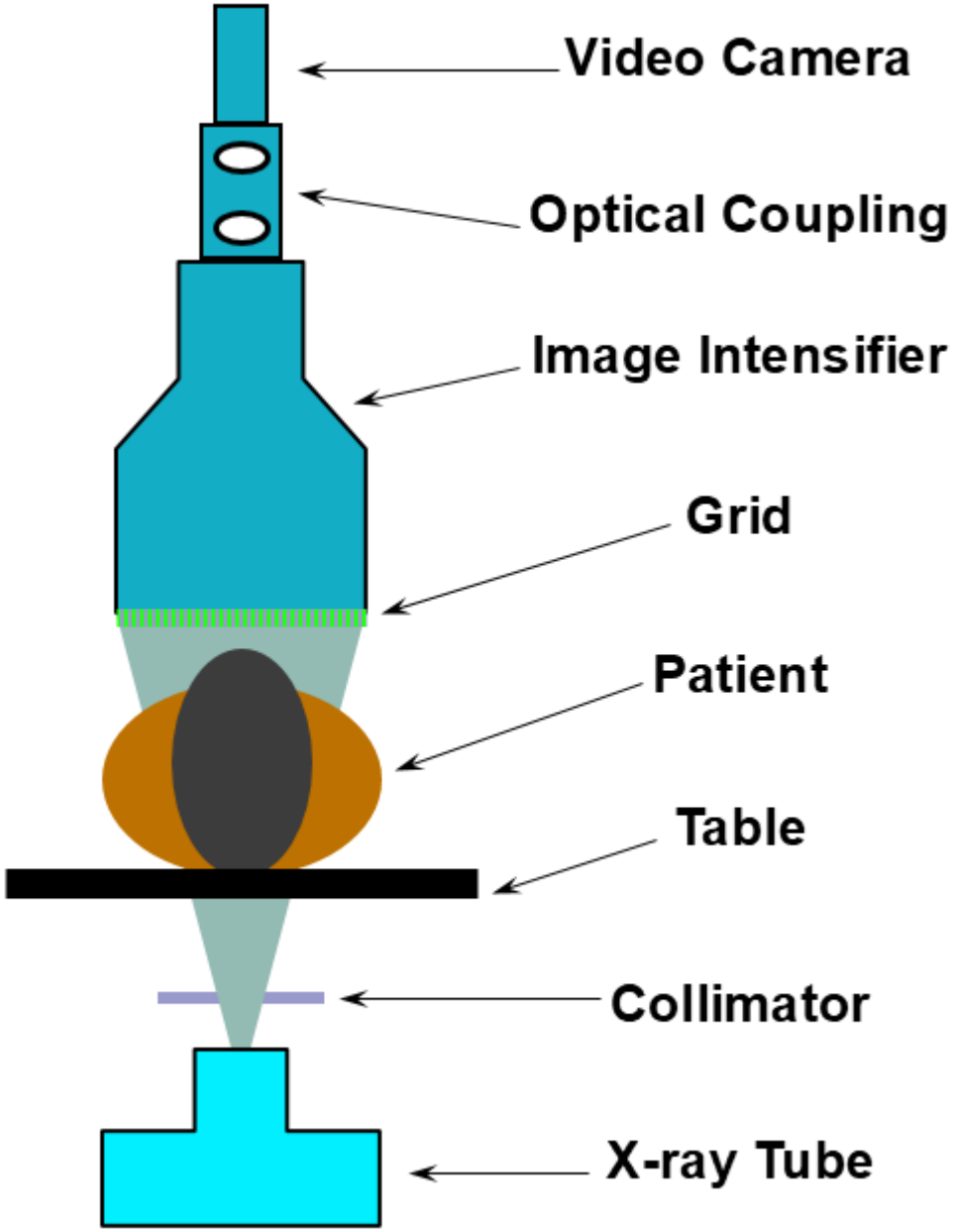
Recognize Fluoroscopic Imaging Chain using Image Intensifier



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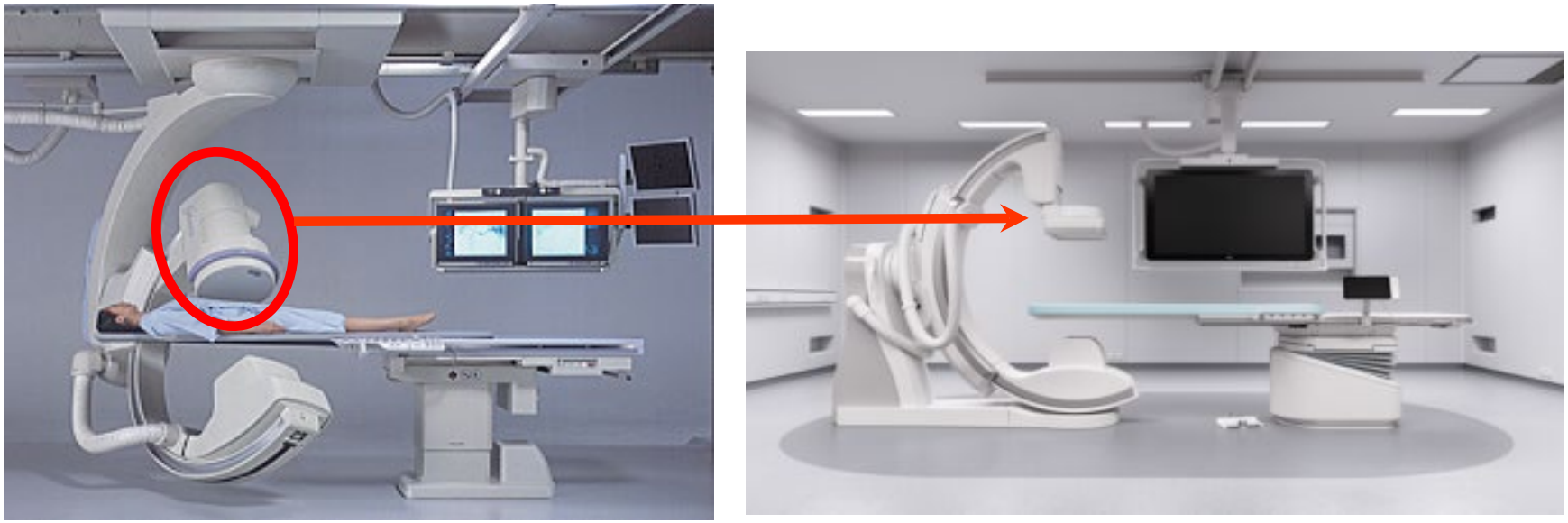
Modern Fluoroscopy system using Flat Panel Detector instead of Image Intensifier

Image Intensifier replaced with Flat Panel Detector



33cm for Angio

22cm for Cardiac

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Overview

Physicians performing fluoroscopically guided procedures should be aware of the potential for serious radiation-induced skin injury. Occasionally this is an unavoidable consequence of the time required to perform complex procedures. Some of this, however, can be minimized through a better understanding of how the equipment works and how some operational procedures affect the total skin dose.

Following is a summary of desirable techniques to optimize Fluoroscopy use and reduce dose to patient and operator. The tutorial includes slides which add detail to this discussion.

Introduction

Significant **patient dose reduction** can be achieved by proper use of the fluoroscopic unit, and many of these dose reduction measures will also produce higher quality images. The **most common operator error** when using C-arm units (where the operator can vary the distance from the x-ray tube to the skin entry point) is to place the x-ray tube too close to the patient skin. Because dose reduction is proportional to the square of the tube-focal-spot-to-skin distance, moving the tube housing closer to the patient can greatly increase the patient skin dose, and will also result in blurring of the image

The image intensifier (or digital detector) should be lowered to come as close as practical to the patient's skin and maximize the gap between the x-ray tube and the skin. Even for a fixed fluoro unit (tube fixed under unit's table such that tube to skin distance is fixed) lowering Image Intensifier will lower skin dose.

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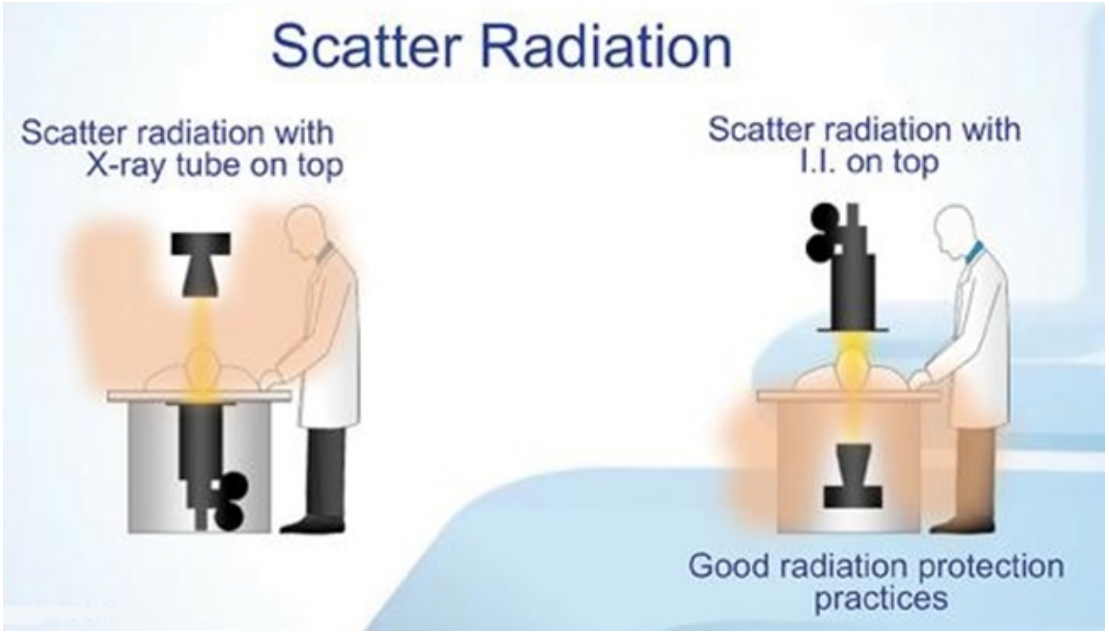
X-ray Tube Position



- **Position the X-ray tube under the patient not above the patient.**
- **The largest amount of scatter radiation is produced where the x-ray beam enters the patient.**
- **By positioning the x-ray tube below the patient, you decrease the amount of scatter radiation that reaches your upper body.**

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Collimation

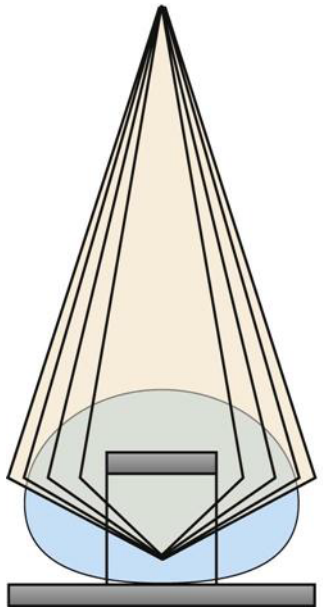
Closing the collimators down to irradiate only the tissue of interest will reduce the area and volume of tissue irradiated, and will improve the image contrast by reducing the amount of radiation which scatters back into the intensified image. Magnifying the image by selecting a smaller field size (e.g. 6” vs 9”) will markedly increase patient dose to the smaller area, so should only be used when necessary to visualize small objects. For those units with selectable kVp and automatic exposure control, raising the kVp of the beam will improve penetrability of the x-rays and markedly lower patient dose at the expense of a small loss in image contrast.

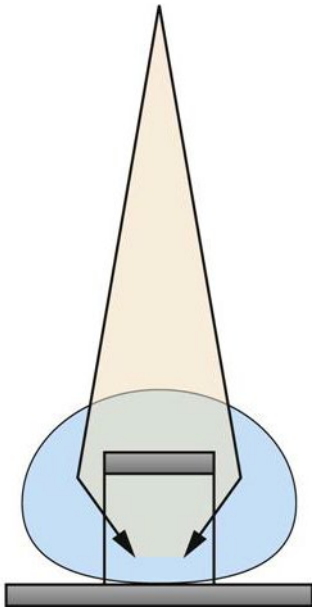
Directing the beam through the patient at an oblique angle will raise radiation dose due to increased tissue thickness, which results in automatic higher tube current, while the skin surface is forced closer to the x-ray tube in the fixed-dimension C bracket.

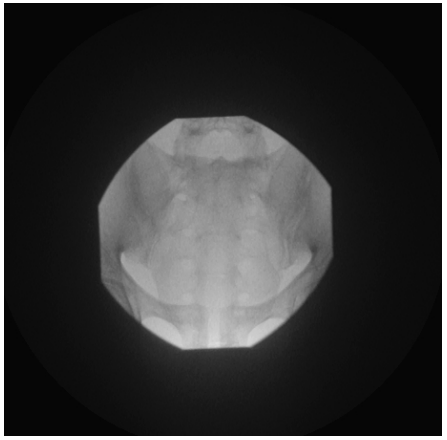
Collimation

Collimate tightly to the area of interest.

- Reduces the patient's total entrance skin exposure.
- Improves image contrast.
- Scatter radiation to the operator will also decrease.





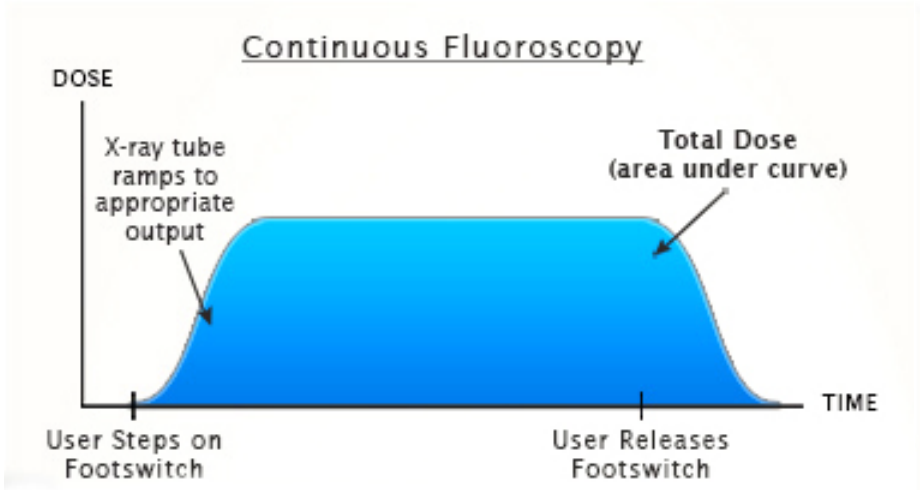


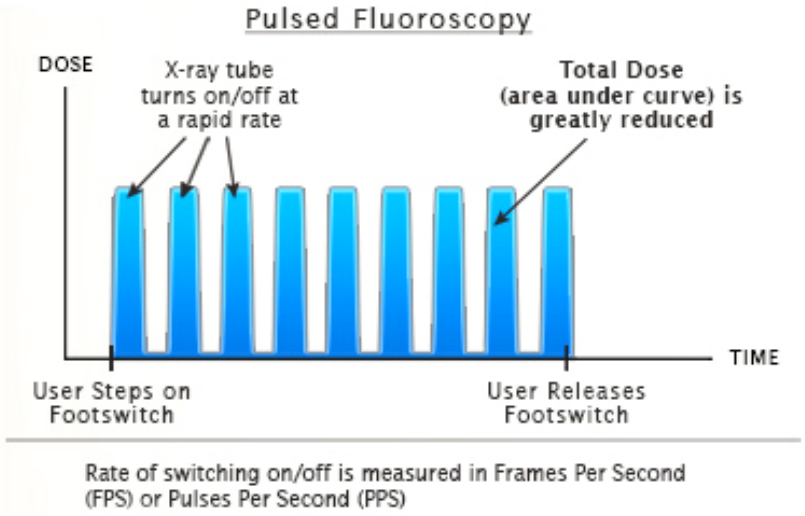
Pulsed Fluoro

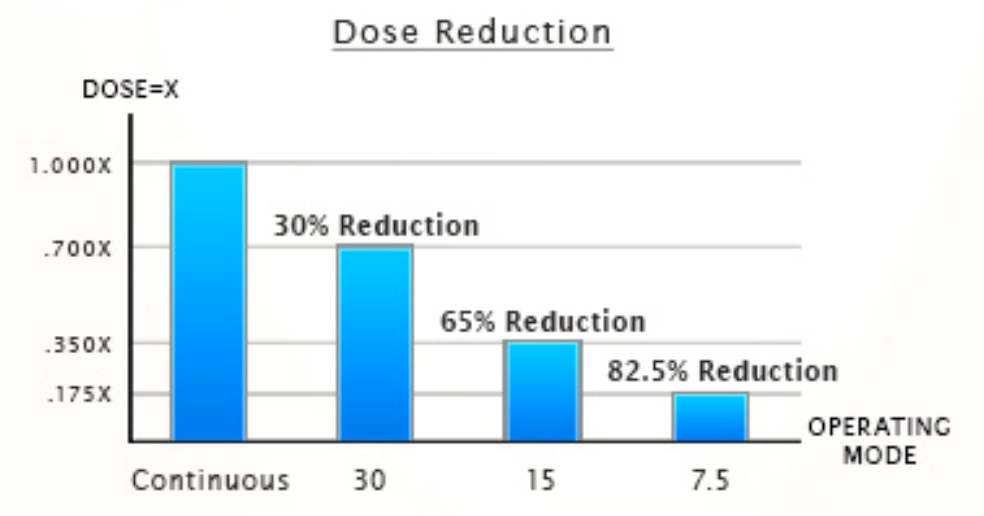
Several **newer units** have the capability of boosting the fluoro output to a higher level for larger patients. Care should be exercised since the dose can increase significantly over normal fluoro. Many of these same units can **pulse the beam on and off several times per second, sparing patient dose** due to turning the beam off between pulses. Image processors on newer units make any image flicker from a low frame rate relatively unobjectionable. All newer units also have a "last image hold" feature which leaves the last fluoro image on the screen after the beam is turned off, allowing one to study the image or discuss it with colleagues without the need to keep the radiation beam on.

Also, any x-ray unit can have its dose rate lowered by a serviceman at the expense of producing a noisier image. Physicians are generally reluctant to make this compromise, except where the tissue is easily visualized due to large objects with high natural contrast (e.g. bones) or artificial added contrast (barium enema, etc).

Pulsed Fluoroscopy







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Radiation induced injuries

Often a procedure will produce as much **radiation dose to the skin** from associated recorded spot images as from the fluoroscopy portion itself, such as fluoro plus cine in the cardiac catheterization lab, and fluoro plus digital frame acquisitions in radiology interventional special procedures. For these cases the skin dose from each contribution should be added to obtain a total dose. Typical dose rates from all contributions are measured annually by a medical physicist and fluoro outputs are posted on each image intensifier.

For a given amount of radiation, **small children are more sensitive** to harmful skin effects than adults. Fortunately, their small size means less radiation is needed, and automatic fluoro units will automatically reduce radiation levels resulting in lower skin doses for the same procedure compared to an adult. There is no difference in skin sensitivity between males and females. The determinant of radiation induced skin injury is the total amount of dose received by skin at the peak exposed location.

Varying the entry point of the radiation beam, when practical, will spread the radiation over more skin and reduce the likelihood that any one area will be overexposed. For high radiation dose procedures, radiation induced skin reactions should be included on the list of possible complications on the patient consent forms. Be aware that recent exposures from previous exams can also contribute to the totals and may need consideration.

Radiation induced injuries

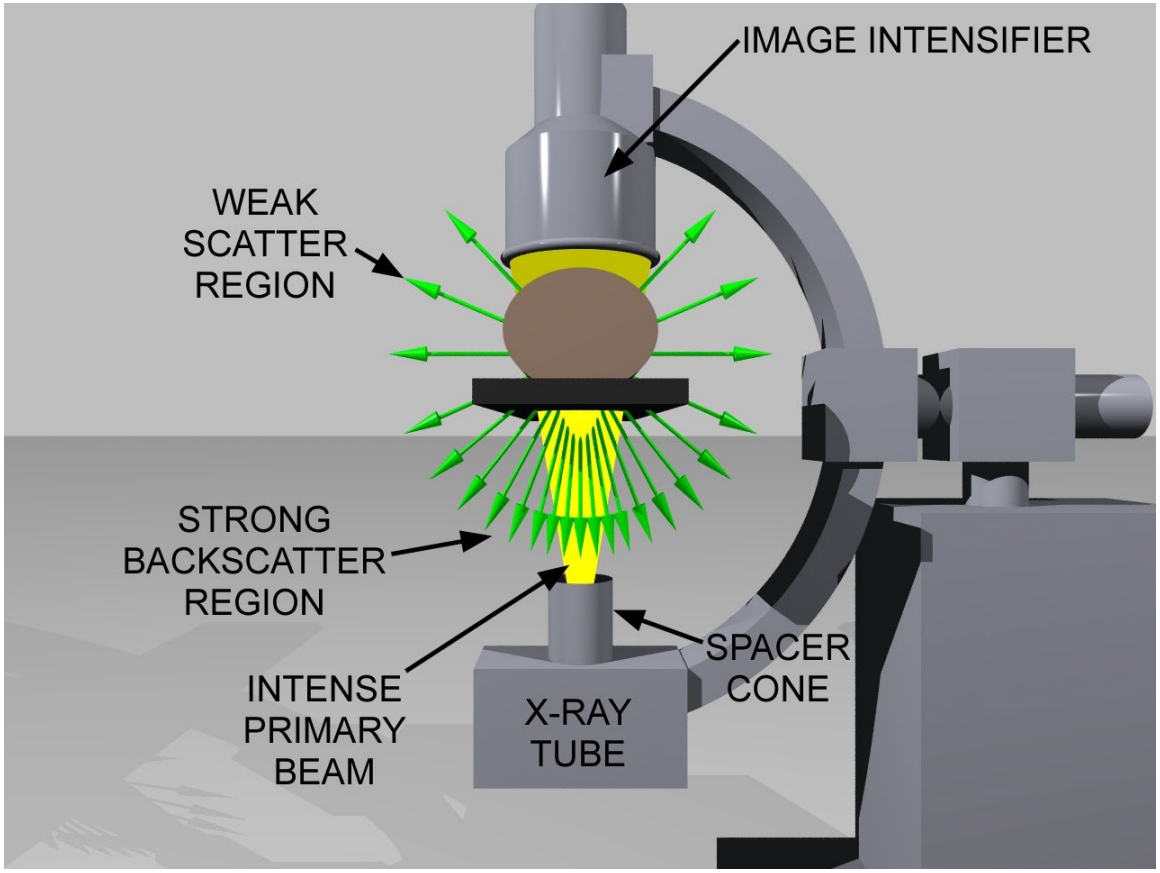
Radiation induced injuries from fluoroscopy are generally not immediately apparent. Other than the mildest symptoms, such as transient erythema, effects of radiation may not appear until weeks following the exposure, when the fluoroscopist has lost contact with the patient. Early transient erythema occurs after exposure to as little as 2 Gy (Grays) of radiation. It will appear in several hours, peaks at about 24 hours, and fades in several days. For doses exceeding 6 Gy, this will be followed by the main erythema effect which usually appears at 10 days, peaks at 2 weeks, and fades around 4 weeks after irradiation.

Permanent epilation will occur at slightly higher doses, around 7 to 8 Gys. On equipment with optional high level radiation exposure rate feature, serious effects could occur after 45-60 minutes of exposure, and may have a delayed appearance of about 10 weeks. For higher exposures, these injuries can continue to progress to more serious effects many months later.

Operator & Staff Exposures

The **absorbed radiation dose to hospital personnel** in the procedure room is directly proportional to the dose the patient receives. At one meter, a person will absorb about 0.1% of the patient dose due to scatter, and a smaller additional contribution due to leakage through the side of the tube housing. The most common 0.5 mm lead equivalent aprons used by the staff during fluoroscopy attenuate 95% of the scattered radiation to the shielded torso, vs 80% for the lightweight 0.25 mm aprons. After a lead apron, leaded thyroid shields and eyeglasses provide additional protection in descending order.

Operator & Staff Exposures



Scatter radiation from the patient is the highest at the primary beam entry side of the patient (x-ray tube side) and least at the image intensifier side.

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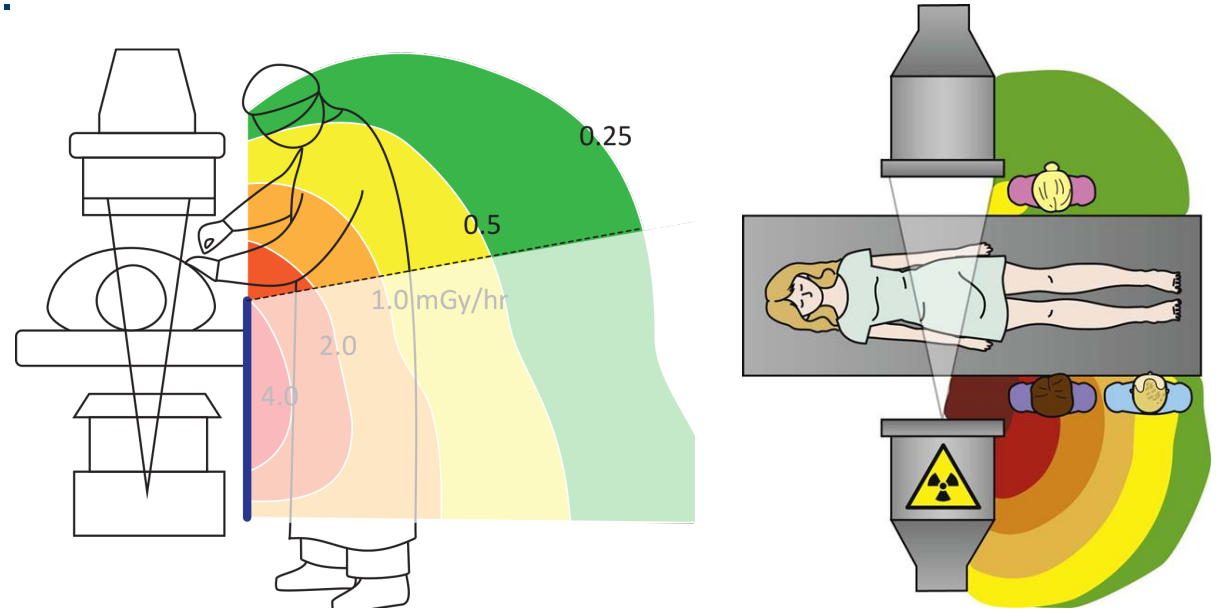
C-Arm Positioning

C-Arm positioning greatly influences the amount of scattered radiation affecting the fluoroscopist. Whenever possible, the C-Arm should be positioned with the image intensifier above the patient and the x-ray tube below, directing scatter toward the operator's feet instead of the head, since the highest scatter component is the scatter reflected from the primary beam initial impact on the patient. When fluoroing across the patient, the operator should be positioned on the same side of the patient as the image intensifier, not the x-ray tube side.



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Equipment Warnings & Feedback

Recent federal regulations applicable to fluoro equipment manufactured after June 10, 2006, will add a warning label to the equipment warning that the equipment may be dangerous to the patient and the operator unless it is operated and maintained properly. The long-present 5-minute timer on fluoro units will now be joined by an accumulated time readout to constantly remind the operator of the total fluoro time involved in the procedure as it progresses. In addition, all newly manufactured fluoro systems must automatically monitor the dose rate entering the patient's skin and continuously display the dose rate plus the cumulative skin entry dose to the patient throughout the procedure.

YNHHS Requirements

YNHHS requires non-radiologist physicians using fluoroscopy be trained in radiation safety in fluoroscopy and in proper use of the equipment. After satisfactorily acquiring training non-radiologist physicians must apply for and be granted privileges to perform fluoroscopy in the medical center.

In many States, updated regulations have formalized earlier commendations to keep track of fluoro times skin cumulative dose by mandating fluoro logs for all machines for recording all patient exposures, keeping track of the type of procedure, the practicing physician, the total fluoro time, cumulative and number of spot images involved. Fluoro times, cumulative dose and number of spot / cine images must be recorded in patient records, and if the data indicate a possibility of a skin dose above 5 Gy, the procedure must be reviewed in detail to determine the best estimate of the skin entry dose, record it in the patient's record for review at the relevant committee responsible for radiation safety at each YNHHS affiliated hospital.

Radiation Injury in Diagnostic Radiology

- **Stochastic Effects** (from low radiation levels, low dose rate)
  - Carcinogenesis, mutations, teratogenesis
  - Probabilistic
  - Carcinogenic : the main concern in radiology
  - Low from low radiation doses
  - Long term
  - Can't be eliminated but should be reduced

- **Deterministic Effects** (higher radiation doses)
  - Involve organ or tissue damage
  - Has a dose threshold before it occurs
  - Higher doses mean increased severity
  - Short term or late effect
  - Must be avoided in radiological procedures

Radiation Injury in Diagnostic Radiology

- **Stochastic Effects** (from low radiation doses)
  - **Carcinogenesis**

    No dose threshold but very low @ diagnostic doses
  - **Germ-cell mutagenesis**

    No effect @ mean gonadal dose below 360 mGy
  - **Teratogenesis**

    Threshold dose ≈ 100s of mGys → No radiogenic abortions or congenital defects @ Dx doses
  - **Childhood Cancer**

    ~50% increase in incidence of childhood cancer per 10 mGy in utero, but total incidence (300 vs 200 per 10^6 births) very low

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Radiation Skin Injury in Diagnostic Radiology

TABLE II. Chronology and Severity of Tissue Reactions From Single-Delivery Radiation Dose

Single site (Gy) acute skin dose	Prompt (<2 weeks)	Early (2–8 weeks)	Mid term (6–52 weeks)	Long term (<40 weeks)
0–2	No observable effects expected			
2–5	Transient erythema	Epilation	Recovery from hair loss	None expected
5–10	Transient erythema	Erythema, epilation	Recovery; high doses cause prolonged erythema and permanent partial epilation	Recovery; higher dose cause dermal atrophy/induration
10–15	Transient erythema	Erythema, epilation; dry/moist desquamation	Prolonged erythema permanent epilation	Telangiectasia; dermal atrophy/induration
>15	Transient erythema; Very high dose causes moist desquamation edema/ulceration	Erythema, epilation	Dermal atrophy with secondary ulceration; atrophy/induration; High dose dermal necrosis surgical repair likely	Telangietasia; dermal Late skin breakdown

Modified: Balter S. Fluoroscopically guided interventional procedure: A review of radiation effects on skin and hair. NCRP SC 2–3, Feb 2010.

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Radiation Injury in Diagnostic Radiology

- **Deterministic Effects** (from high localized radiation doses)

  - **Skin injury**
    - 2 Gy: Threshold
    - >15 Gy: Ulceration, skin repair
  - **Fluoroscopically**
    - guided interventions
    - ~0.1% significant skin injuries (1992-95)
  - **CT overdose**
    - Brain perfusion studies in some stroke pts
    - 3 to 4 Gy overdose (vs 0.5 Gy) to head → Hair loss, Erythema
    - Human error - Incorrect CT parameters
    - No check of displayed CTDI, DLP
  - **3 yr post-coronary angiography & angioplasty studies**
    Shope, Radiographics 1996, Balter et al. Radiology 2010

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Typical Patient Dose in Fluoroscopy

- Equipment design and patient size determine dose rate to the patient
- Typical **dose rate** in the skin from direct beam fluoroscopy is about 20 - 50 mGy/min, **OR HIGHER**
- Occasional, but severe skin injuries could result from prolonged, fluoroscopically guided, invasive procedures

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Occupational Personal Dosimeters (Badges)

- **Yale-New Haven Hospital Policy***
  **the monitoring threshold established below may vary by delivery network*
  - Dosimeters are required for individuals who are likely to exceed 10% (>500 mrem) of the annual limit (5,000 mrem whole body).
  - Dosimeters must be exchanged or processed either Monthly or Quarterly as determined by the Radiation Safety Office

Occupational Limits (annual)

	Deep Dose Eq. (DDE)	Lens Dose Eq. (LDE)	Shallow Dose Eq. (SDE)	Extremity Dose (hands)
NRC (federal)	5,000	15,000	50,000	50,000
CT DEEP (state)	5,000	5,000	30,000	75,000

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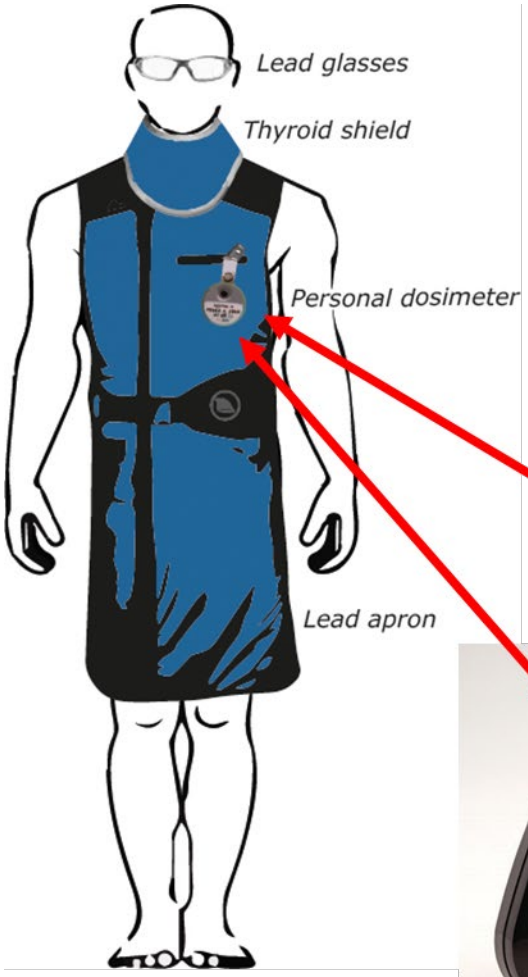
Wearing Your Radiation Monitor



- During fluoro badge must be worn ***OVER*** lead apron (at neck / torso area)
- Only wear dosimeter issued to you.
- Wear your badge whenever working with radiation devices / radioactive materials
- Do ***NOT*** store your badge in a radiation area

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Occupational Personal Dosimeters (Badges)

❖ Exposure Reports

- *Any badge wearer may obtain a copy of their radiation exposure reports by contacting the Radiation Safety Officer and/or their local department badge contact.*

- *Each delivery network is responsible for monitoring radiation exposure to staff & clinical providers. Each delivery network Radiation Safety Committee will develop trigger levels for dose notifications and/or investigations when warranted.*

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Occupational Personal Dosimeters (Badges)

- **Radiation Badge Trigger Levels***
  **the thresholds established below may vary by delivery network*

  - Each ***quarter*** the Radiation Safety Officer reviews all dosimetry results and distributes alerts in accordance with the ALARA Levels
    - ALARA 1 (10%) – Notify User
    - ALARA 2 (30%) – Investigation & Follow-up

Default Levels (per quarter)

	Deep Dose Eq. (DDE)	Lens Dose Eq. (LDE)	Shallow Dose Eq. (SDE)	Extremity Dose (hands)
A1 (10%)	125	125	750	1,250
A2 (30%)	375	375	2,250	3,750

Applicable to YNHH: High Level Fluoroscopy Physicians (e.g. IR / Cardiology / Vascular)

	Deep Dose Eq. (DDE)	Lens Dose Eq. (DDE)	Shallow Dose Eq. (DDE)	Extremity Dose (hands)
A1 (10%)	250	250	750	1,250
A2 (30%)	750	750	2,250	3,750

**DPW (embryo/fetus) → 500 mrem annual or 50 mrem/month*

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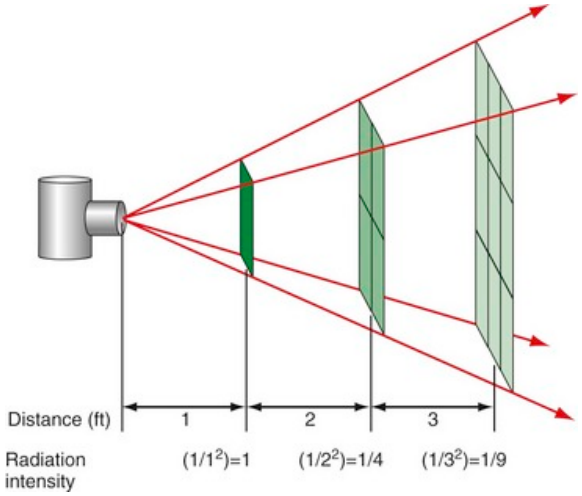
Protection of Personnel

- **Time**
- **Distance**
  - Inverse Square Law
  - Double the distance → ¼ the dose



- **Shielding**
  - Aprons: 0.25 mm or 0.5 mm Lead (Pb) Equivalent
  - Thyroid Collars
  - Lead Glasses
  - Ceiling mounted & rollaway shields

Protection of Patient

- **Time**
  - Take foot off fluoro pedal if physician is not viewing the TV monitor
  - Use last image hold (freeze frame)
  - Monitor Five-minute timer
- **Operation Mode** (Continuous, Pulse, Normal, Medium, Low, High)
  - Use pulsed fluoro instead of continuous fluoro
  - Lower doses can be obtained with less pulses/sec and shorter pulse duration.
  - Low-Dose mode: 40% dose of Normal fluoro
  - Pulsed Low-Dose provides further reduction with respect to Normal Dose continuous mode:
  - Use record mode only when a permanent record is required
  - Record beam-on time for review
  - Record cumulative dose for review

Protection of Personnel & Patient

- **DISTANCE**
  - One step back from tableside (double distance):
    - Reduces staff exposure by factor of 4
  - Lateral or Oblique fluoroscopy:
    - 5x less dose if you stand on Receiver (Image Intensifier) side
  - Move Image Int. (panel) close to patient:
    - less scatter (more dose interception by panel)
    - Less patient skin exposure
    - sharper image

  - Source to Skin Distance (SSD) requirements:
    38 cm for stationary fluoroscopes
    30 cm for mobile fluoroscopes

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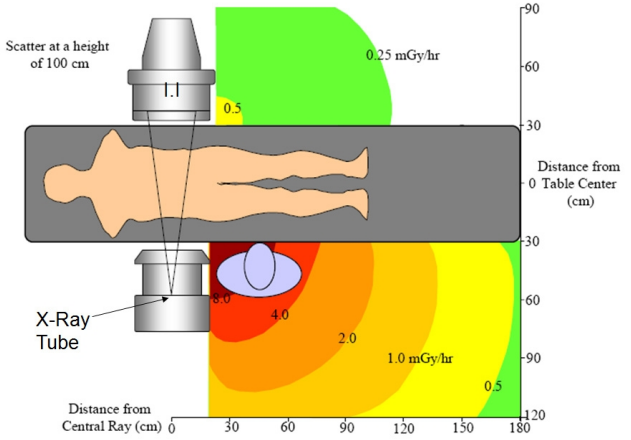
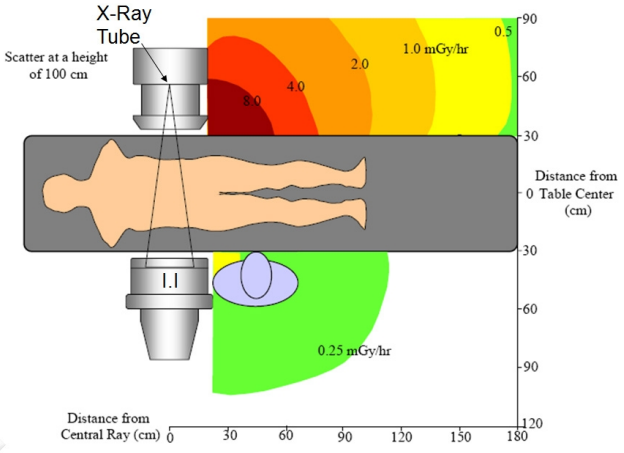
Operator Location and Scatter distribution

The highest operator exposure is near the x-ray tube side of the patient.

Lateral Beam Orientation With the X-ray Source Near the Operator



Lateral Beam Orientation With the Image Receptor Near the Operator



Operator scatter exposure near x-ray tube side is 8 mGy/hr

Operator scatter exposure near II side is 0.5 mGy/hr

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Protection of Personnel

❖ SHIELDING

- Lead aprons - cut exposure by factor of 20
  - distant scatter: 0.25 mm Pb eq
  - direct involvement: 0.5 mm Pb eq
- Proper storage (hanging vs. folding)
- Thyroid collars; eye glasses; wrap around aprons
- Properly used ceiling mounted shields
- Use shielded rooms

PPE – Lead Shielding

- Lead Aprons are required when performing fluoroscopy procedures. *(No exceptions for mini C-arms in Ortho).*
- The Joint Commission requires annual inspection of lead aprons. Each delivery network has a process for inspection.*

*For example at YNHH: Visual indicators are used to demonstrate compliance. ***ALL*** lead aprons ***(including personal physician owned) must be tagged*** in accordance with YNHH Policy. Un-tagged lead aprons are not permitted for use at YNHH facilities.

2018 Testing → **PURPLE** Dot

2019 Testing→ **DARK YELLOW** Dot

PPE – Lead Shielding

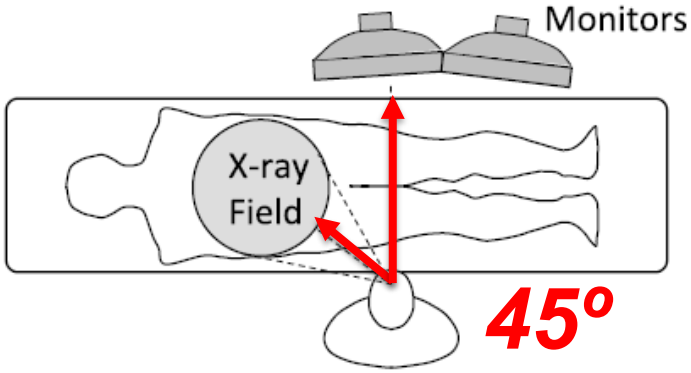
- Eye Protection of different designs. Recommended for staff doing long IR procedures and a larger patient volume

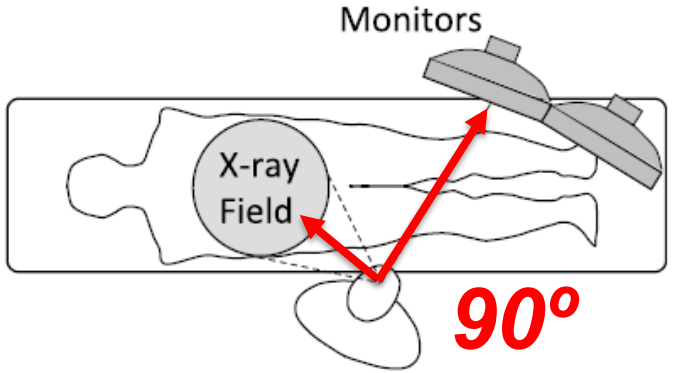
- Highly recommend the use of ***CLASSIC*** style glasses. Increased protection in 90 degree scatter radiation scenario *(see next slide)*.

Classic

Sport Wrap

PPE – Lead Shielding





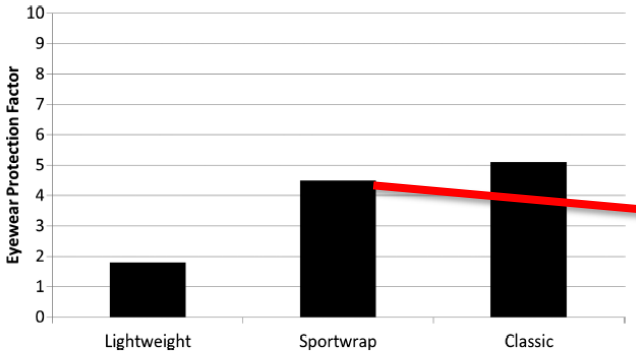


Fig. 4. Eyewear Protection Factors for 45 degree (femoral access) exposure geometry.

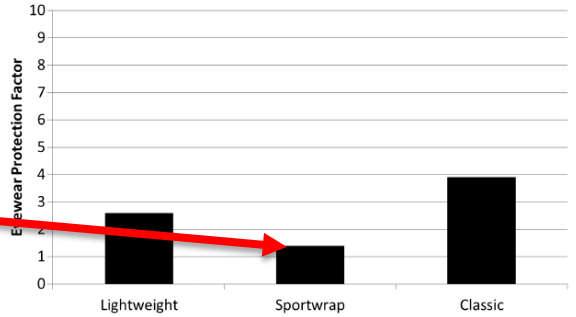


Fig. 5. Eyewear Protection Factors for 90 degree (GI procedure) exposure geometry.

Table 2. Measured eye doses and calculated eyewear protection factors.

	Average eye dose (μSv)			Eyewear protection factor		
Eyewear	0 degree	45 degree	90 degree	0 degree	45 degree	90 degree
None	980	380	350	1.0	1.0	1.0
Lightweight	380	215	135	2.6	1.8	2.6
Sportwrap	120	85	245	8.2	4.5	1.4
Classic	105	75	90	9.3	5.1	3.9

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PPE – Lead Shielding

Other additional lead shielding equipment in high level fluoroscopy labs:

A. Ceiling suspended
B. Table Skirt
C. Rollaway

A

B

C

Safety in Fluoroscopy

- Familiarity with specific fluoro units
  - high level control
  - typical patient doses

- Factors influencing dose:
  - patient size
  - kVp, mA and time
  - tube - patient distance (SSD)
  - Image Intensifier - patient distance
  - use / non-use of grid vs. patient dose
  - image magnification vs. patient dose
  - x-ray field collimation
  - obliques vs. perpendicular views

Safety in Fluoroscopy

- Minimize cine & high-dose fluoro
- Patient's medical history
  - past history
  - record fluoro times on patient files
  - identify skin areas irradiated
  - monitor patient doses
  - patient counseling; consent forms
- State regulations on fluoro practice

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Safety in Fluoroscopy

- Standard Operating Procedures
  - each clinical protocol / procedure
  - modes of operation, image recording
  - emphasis on minimizing duration
  - risk / benefit on a case-by-case basis

- Equipment quality control
  - periodic PMs
  - prompt calibrations
  - post radiation output values
  - check aprons, shields, gloves annually

Typical patient exposures: Portable C-Arms (e.g., OEC Diasonics 9800)

Table-top Dose Rate (mGy/min)

Field Size	Small Pt	Avg Pt		Large Pt	Max Dose	
Open	2.6	6.1	16.5	11.3	43.5	126.2
Mag-1	3.5	7.8	17.4	17.4	41.8	120.1
Mag-2	4.4	11.3	27.0	21.8	40.0	117.5
Mode:	*normal*	*normal*	***BOOST***	*normal*	*normal*	***BOOST***

1 R/min = 8.7 mGy/min

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Notable Changes: FDA regs.

For equipment manufactured after 10 June 2006:

Warning Label – “WARNING: This x-ray unit may be dangerous to patient and operator unless safe exposure factors, operating instructions and maintenance scheduled are observed.”

Timer: audible signal every 5 min of irradiation time until reset

AND

Irradiation time display at fluoroscopist’s working position:

- means to reset display at zero for new exam/procedure

Last Image Hold (LIH) after exposure termination

- indicate if LIH = radiograph or ‘freeze-frame’ image

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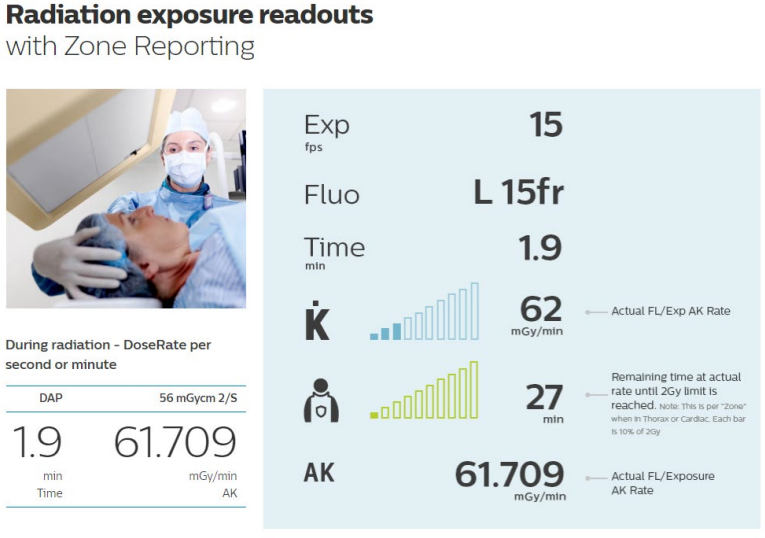
Notable Changes: FDA regs.

Air Kerma Ratio (AKR) and Cumulative AK (CAK) display:

- AKR: dose rate at the point of entrance of beam into patient
- displayed continuously at fluoroscopist's working position
- AKR (mGy/min, mGy/sec, µGy/sec)
- CAK (mGy)
- both displays must be distinguishable
- means exist to reset for new exam / procedure

Dose Area Product (DAP) displays:

- dose x area at skin covered by radiation
- mGy.cm2, µGy.cm2



Patient Dose Evaluation

- For each fluoro machine, maintain a log of each use containing: Patient ID, type of exam, date of exam, fluoro time, number of spot films, and operators name
- If fluoro times indicate possibility that skin entry dose may have exceeded 5 Gy, procedure must be reviewed in detail to determine max skin entry dose.
- Review includes patient description, part of anatomy involved, max fluoro time on any specific area, percentage of mag views, spot films, dose levels delivered.
- If skin entry dose exceeds 5 Gy, note in patient record, notify Radiation Safety Committee

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Minimizing Risks from Fluoroscopic X-rays

1. Remember that dose rates will be greater and dose will accumulate faster in ***LARGER*** patients
2. Keep the tube current as low as possible
3. Keep the kVp as high as possible to achieve the appropriate compromise between image quality and low patient dose
4. Keep the X-ray tube at maximal distance from the patient
5. Keep the detector / image intensifier as close to the patient as possible
6. Don't overuse the magnification mode of operation
7. Remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patient
8. Always use tight collimation
9. Personnel ***must*** wear protective lead aprons, use shielding and know how to position themselves and the machines for minimal exposure
10. Keep beam-on time to an absolute minimum!

    - The Golden Rule

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Additional Resources

International Atomic Energy Agency (IAEA) Radiation Protection of Patients (RPOP) [link]

Image Gently Alliance [link]

Image Wisely Alliance [link]

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END

Please Complete the Following for this Fluoroscopy CME Course:

1. Post-test (score of at least 80% is required to pass)
2. CME Course Evaluation

Click HERE to Start!

Note: You will be required to sign into your Yale CME Profile.
If you do not have a profile, you will be asked to register.

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