
# 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

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## 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?

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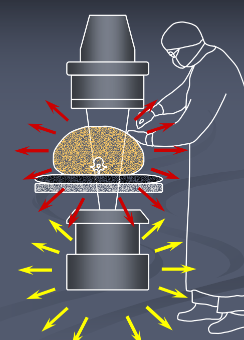
## Stray Radiation Sources

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



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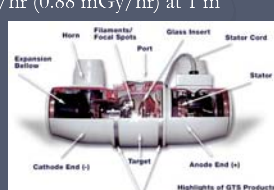
## X-Ray Tube Leakage

- 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)

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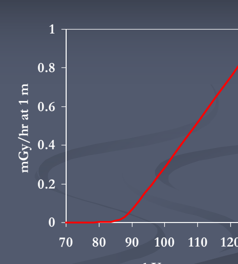
## X-Ray Tube Leakage

- 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

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## 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

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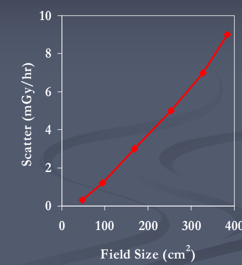
## Scatter vs Field Size

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

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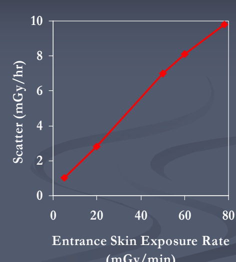
## Scatter vs Entrance Exposure

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

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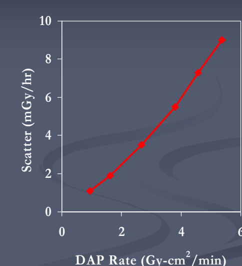
## Scatter vs DAP

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

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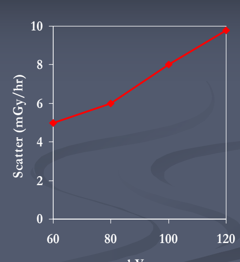
## Scatter vs kVp

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

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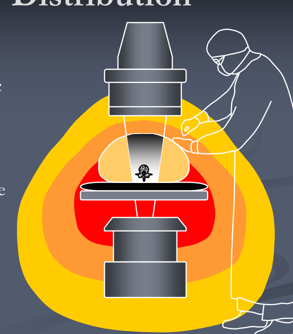
## Scatter: Distribution

- 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



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## Scatter: Distribution

- 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

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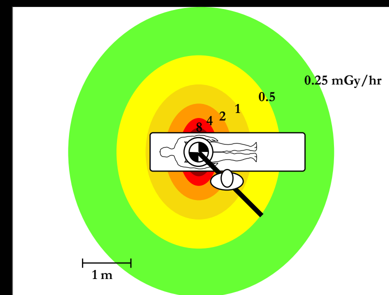
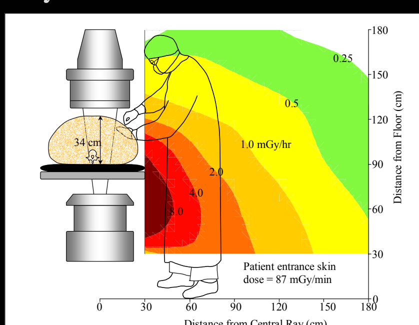
## Stray Radiation: Horizontal Profile




## Stray Radiation: Vertical Profile




## 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?

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## Occupational Exposure Reduction

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

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## 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

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## Radiation Safety: Operator

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

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## Radiation Safety: Operator

- 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

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## Radiation Safety: Operator

- 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

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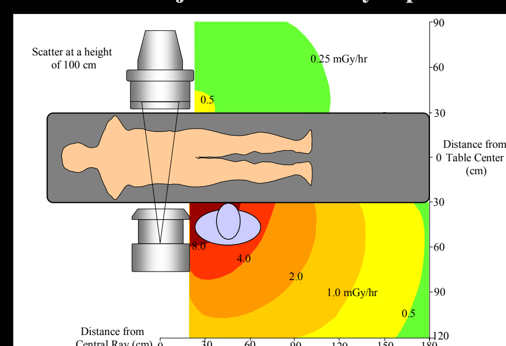
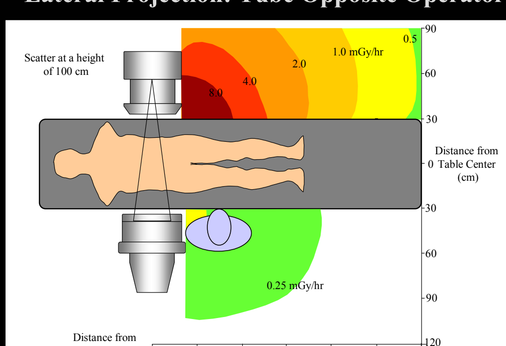
## Lateral Projection: Tube by Operator




## Lateral Projection: Tube Opposite Operator




## Radiation Safety: Operator

- 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

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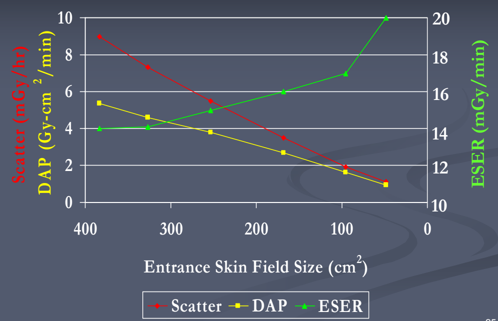
## Scatter vs Field Size

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## 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

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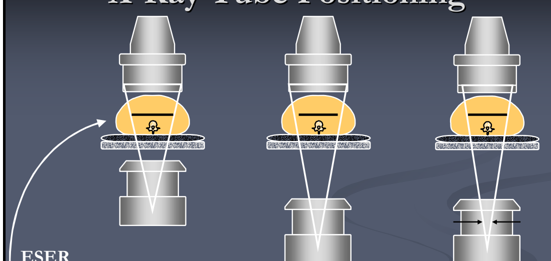
## X-Ray Tube Positioning



| | | | |
|---|---|---|---|
| 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 |

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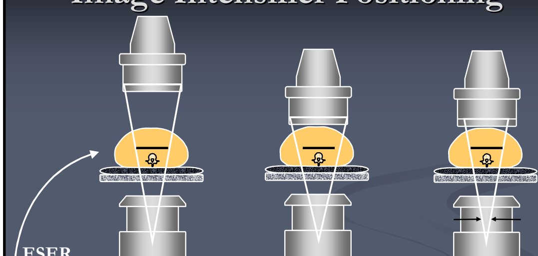
## Image Intensifier Positioning



| | | | |
|---|---|---|---|
| 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 |

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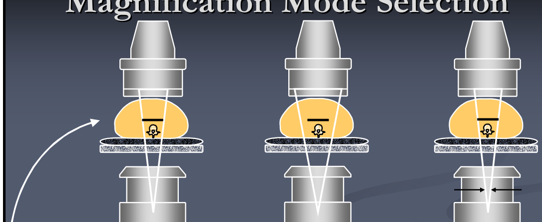
## Magnification Mode Selection



| | 20-cm FOV | 28-cm FOV | 28-cm FOV |
|---|---|---|---|
| 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 |

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## Radiation Safety: Operator

- Use movable shielding devices
  - ceiling-suspended shield
  - tableside shield
  - undertable shield

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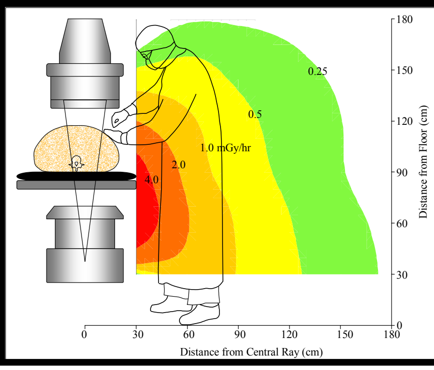
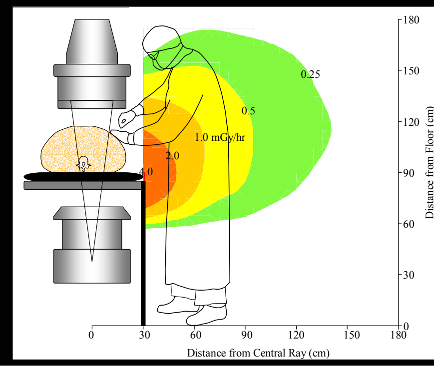
## Scatter Levels without Shielding




## Scatter Levels with Undertable Shielding




## Occupational Exposure Reduction

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

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## 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

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## 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

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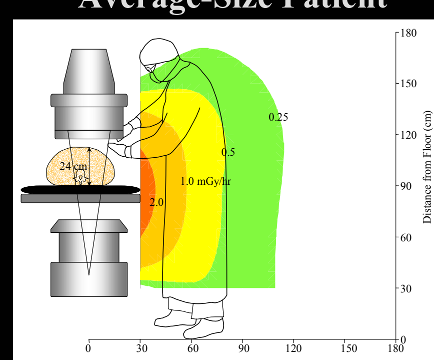
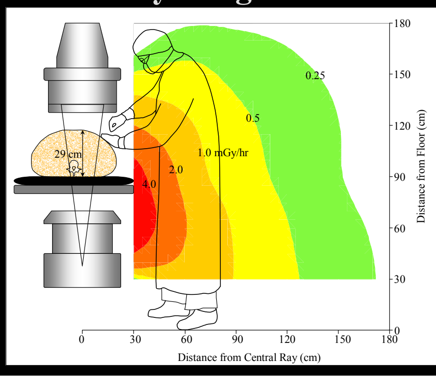
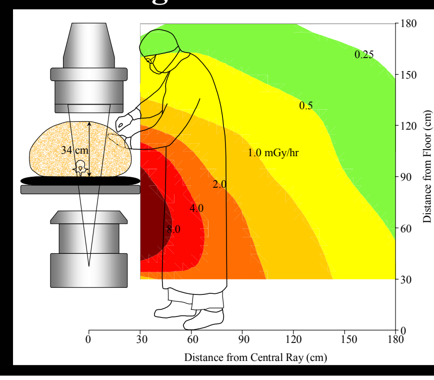
## Average-Size Patient



## Moderately Large-Size Patient




## Large-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%

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## 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

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## Personal Shielding Devices

- Thyroid shields
  - use recommended if monthly collar badge reading exceeds 4 mSv
  - significantly reduces effective dose with minimal inconvenience
- Leaded glasses
  - use recommended if monthly collar badge reading exceeds 4 mSv
  - side shields needed since user does not typically face the exposed patient volume

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## Personal Shielding Devices

- Leaded gloves
  - 0.5 mm lead equivalent shielding recommended if hands must be in the primary beam
  - leaded 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

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## 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

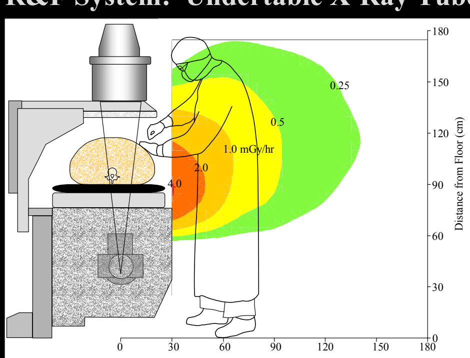


## Radiation Safety: Physicist

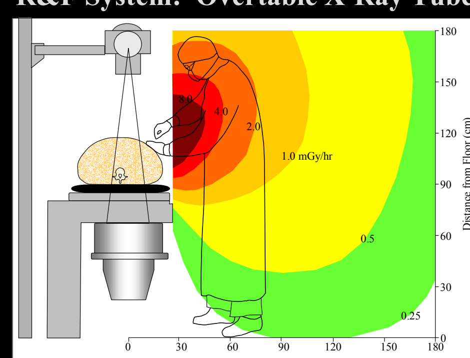
- Ensure fluoroscopic equipment radiation safety design features are considered when specifying a system for purchase
  - R&F systems: undertable x-ray tube configuration results in lower personnel exposure as compared to an overtable x-ray tube configuration (for non-remote applications)



## R&F System: Undertable X-Ray Tube




## R&F System: Overtable X-Ray Tube



## 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

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## 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

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## 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

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## 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

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## 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

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## Learning Objectives

- What is the nature of stray radiation in fluoroscopic procedures?
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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

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## 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

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## Dose Assignment

- Individual state regulations vary
- CRCPD Suggested State Regulations:
  - for single-monitor, $H_E$ = collar reading, or
  - if single-monitor reading > 25% of the dose limit, $H_E = 0.3 \times$ collar reading, or
  - for dual-monitor, $H_E = 1.5 \times$ waist reading $+ 0.04 \times$ collar reading
    - $H_E$ = effective dose equivalent

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## 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 = deep dose reading/21
  - for dual-monitor, $E = 0.5 \times$ waist reading $+ 0.025 \times$ collar reading
    - E = effective dose

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## 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

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## 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

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