

RADIATION SAFETY MANUAL

FOR THE

FLUOROSCOPIST

PROVIDENCE

REGIONAL

MEDICAL

CENTER

EVERETT

April 2006

WHY THIS MANUAL?	1
CHAPTER 1: RADIATION PHYSICS	2
X-RAY PRODUCTION	2
INTERACTIONS OF X-RAYS WITH MATTER	3
DIVERGENT NATURE OF RADIATION	5
DESCRIPTION OF RADIATION EXPOSURE	6
CHAPTER 2: GENERAL FLUOROSCOPY CONCEPTS	7
FLUOROSCOPY SYSTEM DESCRIPTION.....	7
AUTOMATIC BRIGHTNESS CONTROL.....	7
IMAGING MODES	7
FIELD SIZE AND COLLIMATORS.....	8
MAGNIFICATION MODES	9
LAST IMAGE HOLD.....	10
CHAPTER 3: FLUOROSCOPY RADIATION ENVIRONMENT	10
PATIENT EXPOSURE PROFILE.....	10
OPERATOR EXPOSURE PROFILE	11
CHAPTER 4: RADIOBIOLOGY	12
BIOLOGICAL EFFECTS OF RADIATION	12
RADIATION SENSITIVITY	13
DETERMINISTIC EFFECTS	14
STOCHASTIC EFFECTS.....	15
PRENATAL EFFECTS	16
CHAPTER 5: CASE STUDIES OF RADIATION INJURY	17
NON-SYMPTOMATIC SKIN REACTIONS.....	17
SYMPTOMATIC SKIN REACTIONS	17
PA FLUOROSCOPY.....	17
STEEP FLUOROSCOPIC ANGLES.....	19
MULTIPLE PROCEDURES	20
POSITIONS OF ARMS.....	20
SKIN SENSITIVITY	22
INJURIES TO PERSONNEL	22
CHAPTER 6: REDUCING RADIATION EXPOSURE	22
REDUCE USE TIME	22
INCREASE DISTANCE	23
ROOM LIGHTING	23
X-RAY TUBE POSITION	24
REDUCE AIR GAPS	24
MINIMIZE USE OF MAGNIFICATION.....	25
COLLIMATE PRIMARY BEAM	26
USE ALTERNATE PROJECTIONS.....	26
OPTIMIZING X-RAY TUBE VOLTAGE.....	27
USE OF RADIATION SHIELDS.....	27
USE OF PROTECTIVE EQUIPMENT	27
CHAPTER 7: RADIATION STANDARDS	29
MEDICAL DOSE LIMITS	29
OCCUPATIONAL DOSE LIMITS.....	29
ALARA PHILOSOPHY	30
RADIATION MONITORING	30
PROVIDENCE EVERETT MEDICAL CENTER - RADIATION SAFETY PROGRAM.....	31
REFERENCES	31
APPENDIX A: NATURAL SOURCES OF RADIATION EXPOSURE	33
APPENDIX B: SUMMARY SHEET FOR REDUCING RADIATION EXPOSURE TO STAFF AND PATIENT	36

WHY THIS MANUAL?

The use of X-ray fluoroscopy has increased dramatically in recent years and is spreading beyond the radiology department. Advances in medical technology have resulted in the development of more powerful X-ray machines used during complex procedures requiring extensive use of fluoroscopy. The use of such equipment by personnel who have not received specialized training in the proper use of radiation creates the potential for excessive radiation exposure to personnel and patients. Inadequate training combined with increased radiation outputs, higher X-ray tube heat capacities, and real-time digital image acquisition and storage can produce patient doses that induce serious skin damage.

Procedures Involving Extended Fluoroscopy Exposures

Radiofrequency cardiac catheter ablation
Percutaneous transluminal angioplasty (PTCA, PTA)
Vascular embolization
Stent and filter placement
Thrombolytic and fibrinolytic procedures
Percutaneous transhepatic cholangiography
Endoscopic retrograde cholangiopancreatography (ERCP)
Transjugular intrahepatic portosystemic shunt (TIPS)
Percutaneous nephrostomy, biliary drainage, or stone removal

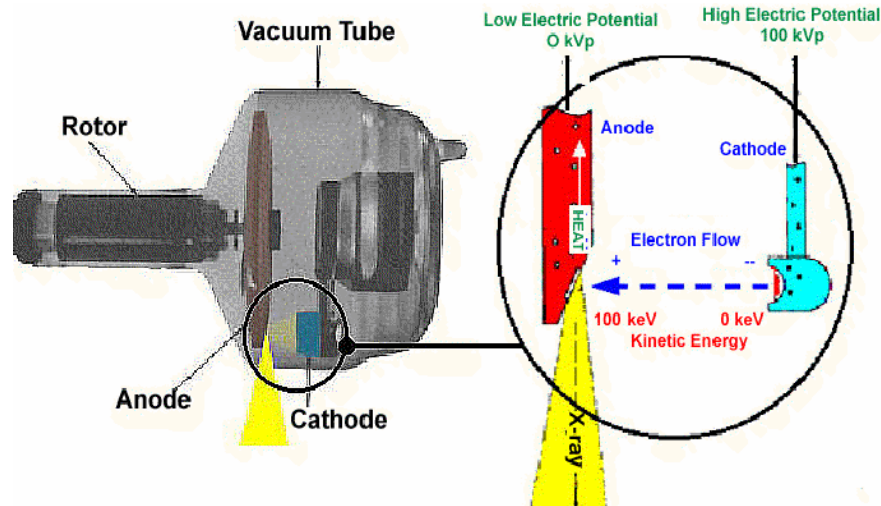
The risk of adverse radiation effects originating from a medically necessary procedure is almost always offset by the benefit received by the patient. However, in order to improve the benefit-risk tradeoff for these procedures, it is incumbent on the operator to explore the reasons behind radiation effects that have occurred and to seek means by which to avoid them or reduce their severity for future cases.

This manual is written as a primer for non-radiologist physicians who use fluoroscopy equipment in their practice of medicine. It covers some basic principles of radiation physics, biology, and radiation safety in order to provide an understanding of the optimal utilization of fluoroscopy, while minimizing exposures to the patient, operators, and their colleagues.

CHAPTER 1: RADIATION PHYSICS

X-ray Production

X-rays are produced when high velocity electrons are decelerated during interactions with a high atomic number material, such as the tungsten target in a X-ray tube. An electrically heated filament within the X-ray tube generates electrons that are then accelerated from the filament to hit the tungsten target by the application of a high voltage to the tube. The electron speed can exceed half the speed of light before being rapidly decelerated in the target.



The quantity of electron flow, or current, in the X-ray tube is described in units of milliamperes (mA). The maximum kinetic energy of the accelerated electrons is defined in terms of kilovolts peak potential (kVp). For the mobile C-arms and the dedicated R/F rooms, fluoroscopy at Providence Everett Medical Center is usually performed using 2 to 10 mA current at a peak electrical potential of 75 to 125 kVp. The tube currents associated with the Interventional Radiology and CVL imaging systems can rise to as much as 200 mA when being operated in the pulsed mode.

The rate of X-ray production is directly proportional to the electron flow. Higher mA values indicate more electrons are striking the tungsten target, thereby producing more X-rays. Increasing kVp attracts more electrons from the filament, also increasing the rate of X-ray producing. However, this relationship is not directly proportional. Changing X-ray tube current does not effect the ultimate image (video screen, X-ray film) contrast, while changing tube voltage does (see next subsection). The total number of X-rays produced at a set kVp depends directly on the product of the mA and exposure time and is typically described in terms of mA-s.

Only a small fraction of the energy imparted by the decelerating electrons is converted into X-rays. Most of the energy is transformed into heat that must be dissipated in order for the X-ray tube to continue functioning. With high usage, X-ray production may be delayed until this excess heat is adequately removed.

Once generated, the X-rays are emitted in all directions in a fairly uniform manner. The lead housing surrounding the X-ray tube limits X-ray emission through a small opening or port. The resulting primary beam of useful radiation is shaped by additional lead shutters, or collimators, that can be adjusted to provide different beam shapes or sizes. Also, the energy range of the primary radiation beam can be changed by adding additional filtration (e.g., 0.1 mm copper) in front of the port.

Interactions of X-rays with matter

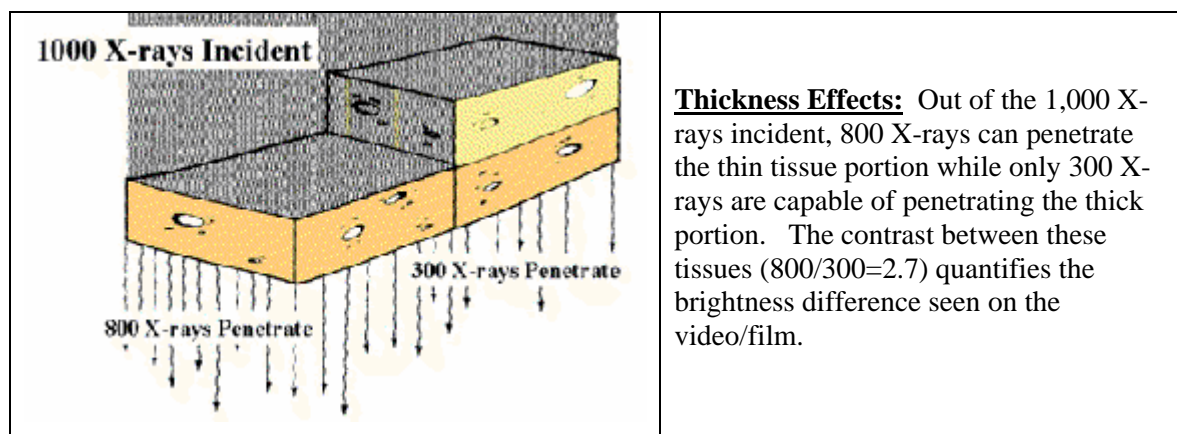
X-rays have several fates as they traverse tissue. The most important interactions are:

	<ul style="list-style-type: none"> • No interaction; X-ray passes completely through tissue and into the image recording device. • Complete absorption; X-ray energy is completely absorbed by the tissue. No imaging information results. • Partial absorption with scatter; Scattering involves a partial transfer of energy to tissue, with the resulting scattered X-ray having less energy and a different trajectory. Scattered radiation tends to degrade image quality and is the primary source of radiation exposure to operator and staff.
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The probability of radiation interaction is a function of tissue electron density, tissue thickness, and X-ray energy (kVp). Dense material like bone and contrast dye attenuates more X-rays from the beam than less dense material (muscle, fat, air). The differential rate of attenuation provides the contrast necessary to form an image.

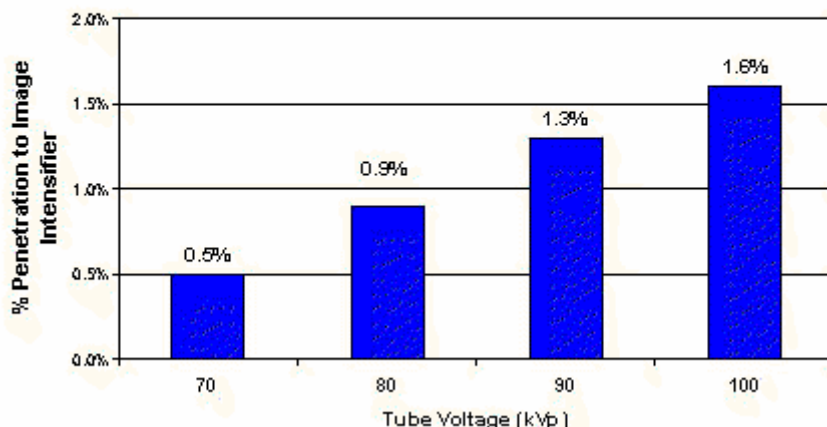
<p>Density Effects: Assume 1,000 X-rays strike the following body portions. The number of X-rays reaching the recording media (film, TV monitor) directly affect the image's brightness.</p> <p>900 X-rays are capable of penetrating the soft tissue (less dense), while only 400 penetrate the bone (more dense). The contrast between bone and soft tissue ($900/400 = 2.25$) quantifies the brightness difference seen on the video/film.</p>	
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As tissue thickness increases, the probability of X-ray interaction increases. Thicker body portions remove more X-rays from the useful beam than thinner portions. This effect must be compensated for while panning across variable tissue thickness to provide consistent information to the image-recording device. All fluoroscopic systems at PEMC have the necessary electronic systems (ABC, ABS) to adjust the x-ray parameters rapidly to the changing tissue composition during panning.



Higher kVp X-rays are less likely to interact with tissue and are described as more "penetrating." Increasing kVp, thereby generating more penetrating radiation, reduces the relative image contrast (or visible difference) between dense and less dense tissue. Conversely, less radiation dose results to the patient since less X-rays are absorbed. The following figure illustrates this effect. The X-rays that do not reach the image recording device are either absorbed in the patient (patient radiation dose) or are scattered throughout the exam room (staff radiation dose)

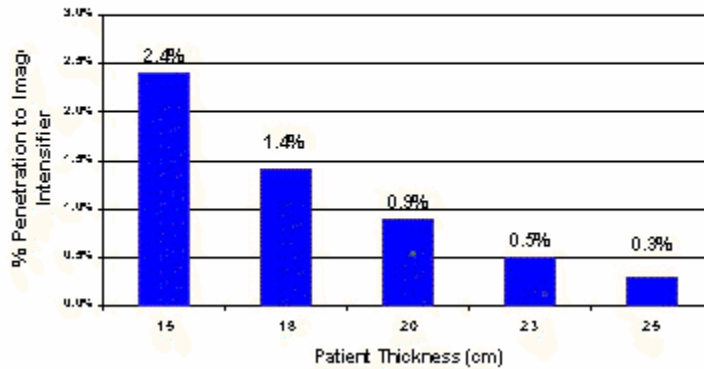
**X-Ray Penetration Vs Tube Voltage
20-cm Thick Patient**



The following figure illustrates the effect of patient thickness on X-ray penetration. For a typical procedure involving a 20-cm thick patient and a X-ray tube voltage of 80 kVp:

- 1 percent of the X-rays reach the image-recording device (e.g., image intensifier, film), yielding useful information
- 99 percent of the X-rays generated are either absorbed within the patient (patient radiation exposure) or are scattered throughout the examination room (staff radiation exposure).

X-Ray Penetration Vs Patient Thickness
80 kVp Tube Voltage



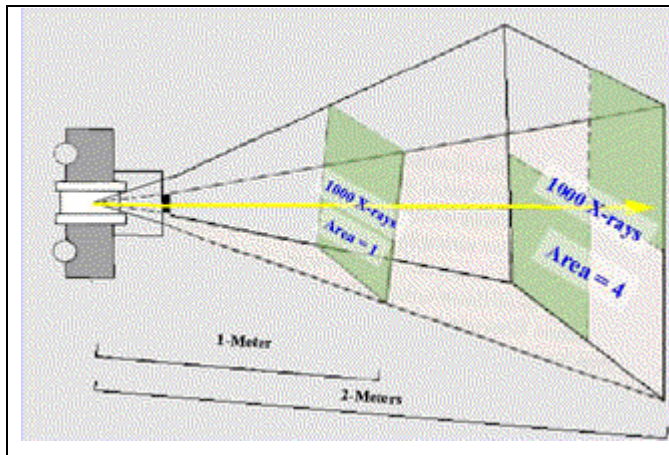
Divergent Nature of Radiation

The primary beam X-rays travel in straight but divergent directions as they exit the X-ray machine. The degree of divergence increases with distance away from the X-ray origin (tungsten target). Consequently, the number of X-rays traveling through a unit area decreases with increasing distance. Likewise, radiation exposure decreases with increasing distance since exposure is directly proportional to the number of X-rays interacting in a unit area.

The inverse square law describes the degree of radiation exposure reduction caused by divergence:

$$X_A \propto X_B \cdot \left(\frac{D_B}{D_A} \right)^2$$

where X_A is the radiation exposure rate at distance D_A . This relationship indicates that doubling the distance from a radiation source decreases radiation exposure by a fourth. Conversely, halving the distance increased exposure 4 times.



Inverse-Square-Law

1-Meter Distance: 1,000 X-rays pass through a unit area. The amount of X-rays per unit area is 1,000.

2-Meter Distance: With increasing distance, the beam diverges to an area 4 times the original area. The same 1,000 X-rays are evenly distributed over the new area (4 times the original). Thus the amount of X-rays per unit area is 250 or 1/4 the original. The resulting radiation exposure is 1/4 less.

Application of inverse square law principles can yield significant reductions in patient and operator radiation exposure.

Example 1:

An operator normally stands 1 meter away from the patient during cineangiography. The exposure rate at this point is 15 mrem/min and total cineangiography time is 2 min. What is the reduction should the operator stand 1.2 meters away?

Solution 1:

The original exposure was 30 mrem (15 mrem/min for 2 min). The new exposure would be:

$$X_1 \propto 15 \cdot \left(\frac{1.0}{1.2}\right)^2 \cdot 2 \propto 20.8 \text{ mrem}$$

A 31% percent reduction in radiation exposure is achieved in this example.

$$(30 - 20.8) / 30 = 31 \%$$

Description of Radiation Exposure

There is a myriad of terms describing radiation and radiation exposure. This is often confusing even to those quite familiar with radiation physics. Terms which the physician should be aware of include those that:

- Describe X-ray machine radiation output;
- Describe patient radiation exposure; and
- Describe personal radiation risk



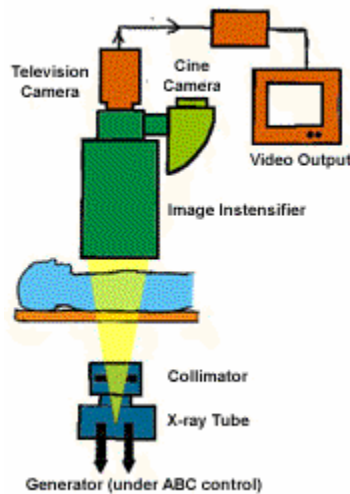
X-ray machine output is described in terms of Entrance Skin Exposure (ESE) and is the amount of radiation delivered to the patient's skin at the beam's entrance point. ESE may also be described as "table-top dose." Most X-ray machine regulations are defined in ESE. The older units of ESE are *Roentgens*, while the exposure rate would be *Roentgens per minute* [R/min]. {Recognizing Wilhelm Roentgen, the discoverer of X-rays, pictured left} The newer SI unit for exposure is *coulombs per kilogram* [C/Kg], where **1R = 0.000258 C/Kg**.

Patient radiation exposure is described in terms of radiation dose. Radiation dose is the energy imparted per unit mass of tissue and has the units of *rad* (Radiation Absorbed Dose). The newer SI unit is the *Gray* [Gy]. Immediate biological effects caused by radiation are described in terms of the *rad* or *Gray*. Note that **1 Gy = 100 rad**. Also, at energies used in diagnostic radiology, 1 R of radiation exposure produces an absorbed dose in tissue of approximately 0.87 rad.

Occupational radiation exposure is also described in terms of radiation dose equivalent, where the unit used is called the *rem*. *Rems* are synonymous with risk, with increasing *rem* equivalent to increasing probability of latent health effects. For the case of fluoroscopy, the risk of long-term effects from 1 *rad* of patient dose is equivalent to 1 *rem* (i.e., **1 rad = 1 rem**). For the newer SI units, the radiation dose equivalent unit is *Sievert* [Sv]. For fluoroscopy, **1 Gy = 1 Sv**.

CHAPTER 2: GENERAL FLUOROSCOPY CONCEPTS

Fluoroscopy System Description



Modern fluoroscopy imaging systems consist of the X-ray tube producing X-rays, captured by an Image Intensifier (II), which converts the X-ray energy into light. The light output is then optically distributed to a closed-circuit video system ultimately producing a "live" image on a video monitor. The light output can also be distributed to a spot film or cinematography recording systems, though the output must be greater for these imaging modalities. In newer systems a solid state imaging receptor plate (IP) converts x-rays directly into digital electrical signals, which are then distributed electronically to viewing monitors and storage devices.

Radiation exposure during fluoroscopy is directly proportional to the length of time the unit is activated by the foot (or hand) switch. Unlike regular X-ray units, fluoroscopic units do not have an automatic timer to terminate the exposure after it is activated. Instead, depression of the foot (or hand) switch determines the length of the exposure, which ceases only after the foot (or hand) switch is released.

Fluoroscopy machines are equipped with a timer and an alarm that sounds at the end of 5 minutes. The alarm serves as a reminder of the elapsed time and can then be reset for another 5 minutes. The Washington Department of Health requires total elapsed fluoroscopy time be recorded for every procedure.

Automatic Brightness Control

Modern fluoroscopy machines produce images with an II or IP that captures the radiation exiting the patient. The II brightens the image level sufficiently so that the TV tube can display the image on a video screen. The machine can be operated in either a manual mode or in an automatic brightness control (ABC) mode.

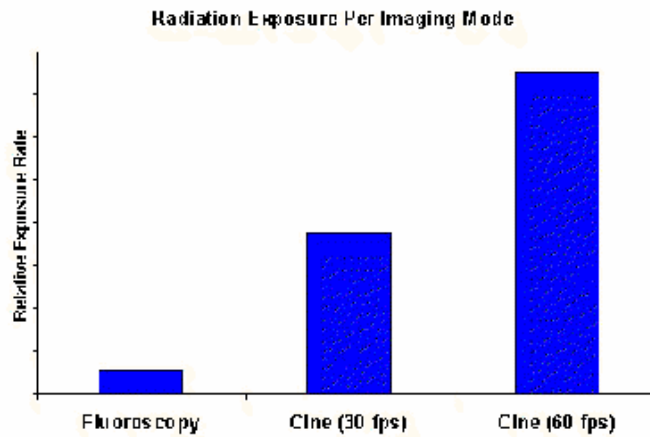
The radiation exposure rate is independent of the patient size, body part imaged and tissue type when manual mode is used. However, the image quality and brightness are greatly affected (often adversely) by these factors when the operator "pans" across tissues with different thickness and composition. For this reason, most fluoroscopic examinations are performed using ABC.

ABC mode was developed to provide a consistent image quality during dynamic imaging. When using ABC, the II output is constantly monitored. Machine factors are then adjusted automatically to bring the brightness to a constant, proper level. When the brightness level is too low (or too high), the ABC increases (or decreases) the mA, kVp, or both, depending on the method devised by the device manufacturer. For newer IP based systems, additional image information is manipulated by the system hardware and software to provide different image formats, depending on the procedure being performed.

Both patient and operator factors influence the number of X-rays reaching the II. The ABC compensates brightness loss caused by decreased II radiation reception by generating more X-rays (increasing radiation exposure) and/or producing more penetrating X-rays (reducing image contrast).

Imaging Modes or Fields

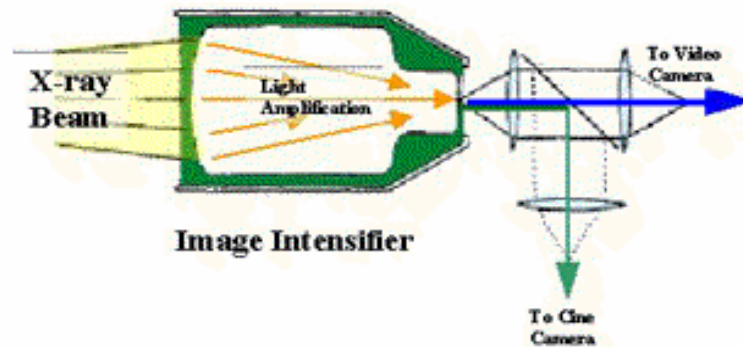
'Normal' (or 'full') mode is used in the majority of fluoroscopy procedures. The radiation output is sufficient to provide video images for guiding procedures or observing dynamic functions. The typical exposure rate at the X-ray beam entrance into the patient (ESE, or Entrance Skin Exposure) is 2 to 3 R/min [20 mGy/min].



The Food and Drug Administration (FDA) regulates the construction of all fluoroscopy systems. For routine fluoroscopy applications, the FDA and the Washington Department of Health limits the maximum ESE rate to 10 R/min [100 mGy/min] at specified distances from the II or IP.

The use of higher radiation rates ("boost", HDF, or "fluoro+" modes) is acceptable in situations requiring high video image resolution. ESE rates of up to 20 R/min is permitted for short durations. Special operator reminders, such as audible alarms, are activated during these elevated ESE fluoro modes.

Cineangiography involves exposing cinematic film to the II output, providing a permanent record of the imaged sequence. The II output required to expose cinematic film is much higher than the level needed for video imaging. As such, X-ray production must be increased to adequately expose the cinematic film. Consequently, dose rates during cine recording are usually 10 to 20 times higher than normal fluoroscopy (i.e., ESE of 90 R/min or greater). For this reason, judicious use of cineangiography is required.



Field Size and Collimators

The maximum useful area of the X-ray beam, or field size, is machine specific. Most fluoroscopy systems allow the operator to reduce the field size through the use of lead shutters or collimators.

Irradiating larger field sizes increases the probability of scatter radiation production. A portion of the increased scatter will enter the II, degrading the resulting video image. Prudent use of collimators can also improve image quality by blocking-out video "bright areas," such as lung regions, allowing better resolution of other tissues.

<p style="text-align: center;">Benefits from using collimation</p> <p>Limiting beam size by using the collimators provides benefits to both patient and image.</p> <ul style="list-style-type: none"> • Less tissue is subject to radiation exposure, reducing patient risk and also scatter production. • Reducing scatter radiation improves image quality since scatter only contributes noise to the image. 	
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Collimator use also reduces the total volume of tissue irradiated. The subsequent benefit-risk ratio is improved when irradiation of tissue with little diagnostic value is avoided.

Magnification Modes

Many fluoroscopy systems have one or several magnification modes. Magnification is achieved by electronically manipulating a smaller radiation II input area over the same II output area. A reduction in radiation input subsequently results, lowering image brightness. The ABC system, in turn, compensates for the lower output brightness by increasing radiation production and subsequent exposure to patient and staff. For some fluoroscopic systems, however, this dose increase is lessened by increasing the gain of the video camera instead of the radiation input. This, however, results in an image with more noise.

<p>Under Normal mode, there is little magnification with the whole beam used to generate a bright image.</p> <p>Under Mag 1 mode, a smaller beam area is projected to the same II output. The resulting object size is larger, but the image is dimmer due to the less beam input.</p> <p>The ABC system would sense the brightness loss and either boost machine X-ray output, increase tube voltage, or a combination of both.</p>	
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The following Table illustrates the effect of changing Field-Of-View, or magnification modes, for a fluoroscopy system used at Providence Everett Medical Center:

Room 2 at Colby Campus

Philips Pulsera Mobile C-Arm

Mag Mode (Field-Of-View)	ESE (R/min)	% Increase	Mag Mode (Field-Of-View)	ESE (R/min)	% Increase
Normal (40 cm)	2.09	0	Normal (31 cm)	1.90	0
Mag 1 (30 cm)	2.31	10 %	Mag 1 (23 cm)	2.06	8 %
Mag 2 (20 cm)	3.16	51 %	Mag 2 (17 cm)	2.18	15 %
Mag 3 (14 cm)	3.52	68 %			

Last Image Hold

Newer fluoroscopy units are often equipped with a last-view freeze-frame feature and/or video recording. Use of these modes allows the operator to view a static image at leisure, avoiding continuous patient and staff radiation exposure caused by constant fluoroscopy use.

CHAPTER 3: FLUOROSCOPY RADIATION ENVIRONMENT

Patient Exposure Profile

The greatest single source of man-made radiation exposure to the average person in the United States comes from medical irradiation. Medical doses range from a few mrad for a chest X-ray to thousands of rad in the treatment of cancer. The average U.S. citizen gets an effective dose from medical radiation of about 100 mrem per year.

Studies indicate that this exposure level can be reduced by optimizing the use of fluoroscopy (NRC 1989):

Optimizing Action	Potential Dose Reduction Factor
Audio output related to X-ray machine output	1.3
Optimization of Video Camera system	3
Required switching between High (Boost) and Normal modes	1.5
Optimizing Operator Technique	2 to 10

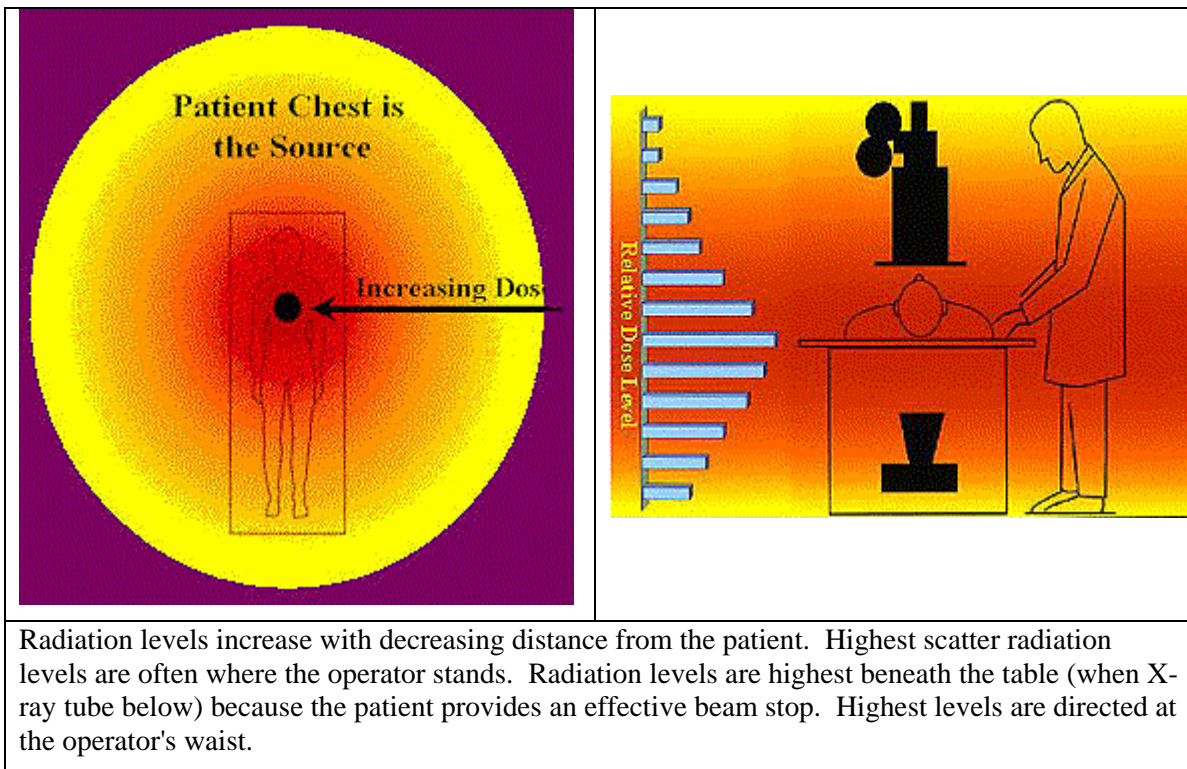
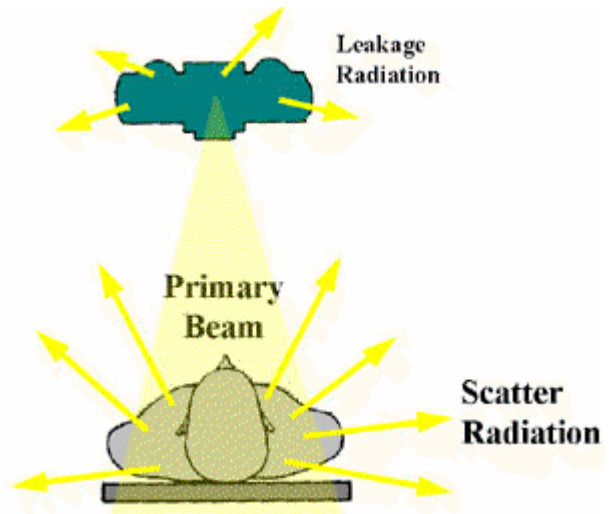
During normal mode fluoroscopy, the average patient ESE is approximately 2 R/min [20 mGy/min]. The level of radiation exposure falls off exponentially with increasing tissue depth due to attenuation and inverse-square effects. Only approximately 1% of the original radiation beam reaches the II for image generation.

The ESE rate from fluoroscopy can be as high as 30 R/min [300 mGy/min] under certain conditions using a high dose rate or "boost" mode if the patient's skin is close to the X-ray tube. During cineangiography, ESE may exceed 90 R/min [900 mGy/min]

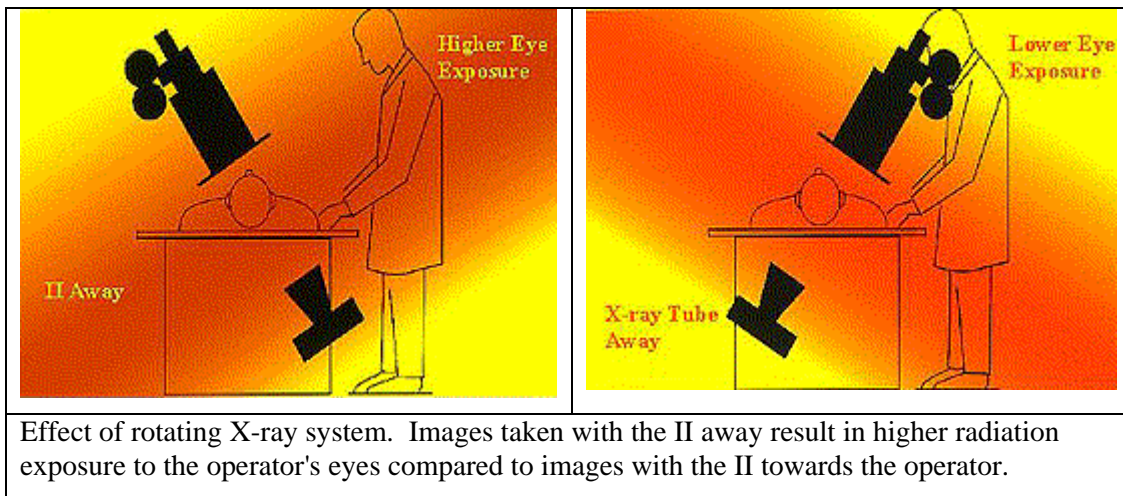
Operator Exposure Profile

The majority of the radiation dose received by the operator (provided the primary beam is avoided) is due to scattered radiation from the patient. After interacting with the patient, radiation is scattered more or less uniformly in all directions.

The intensity of scatter decreases with increasing distance, due to inverse square law effects. Consequently, scatter radiation is highest near its source (X-ray beam entrance point on the patient). Because radiation scattered in the forward direction (into the patient) is subject to further tissue attenuation, radiation levels are significantly lower above the table than below, when the x-ray tube is below the table. This effect is preferable since protective equipment worn by the operator (lead aprons) protects the body regions receiving highest exposure (waist, thighs).



The scatter radiation profile tilts with the X-ray tube should it moved from the posterior-to-anterior (PA) projection. Higher exposure to the operator's head and eyes results during oblique angle projections where the X-ray tube is tilted towards the operator (II is tilted away from the operator). Conversely, radiation exposure is decreased when the X-ray tube is tilted away from the operator (II tilted towards the operator). **When possible, the operator should work on the II side of the table when oblique angles are being imaged.**



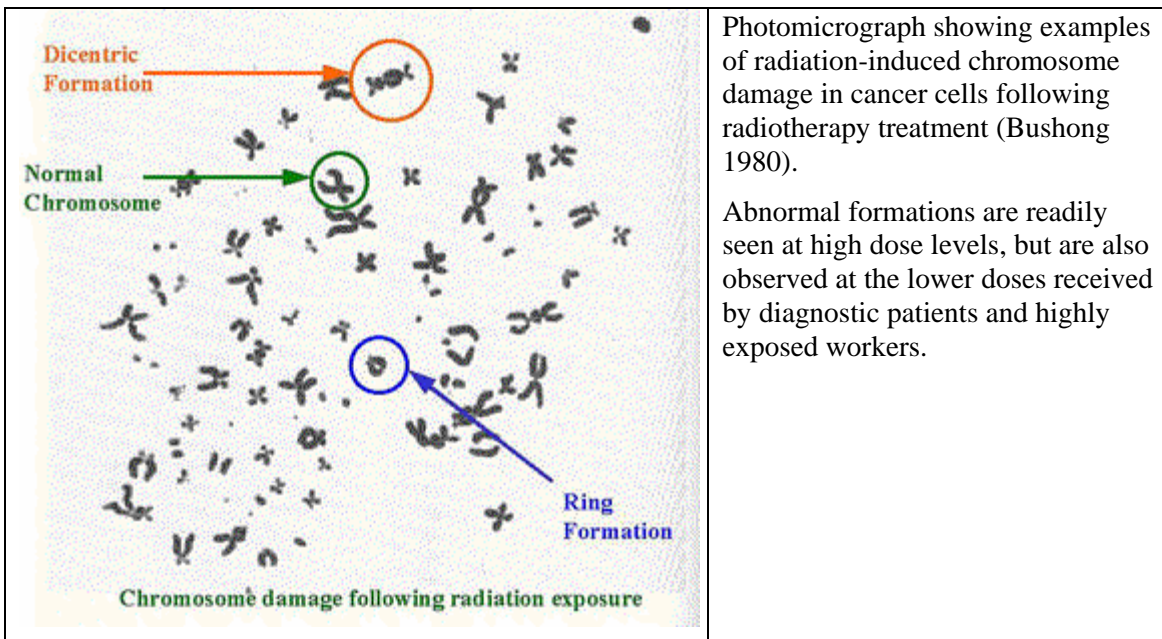
In general, an operator positioned 3 feet from the X-ray beam entrance area will receive 0.1% of the patient's ESE. Staff members positioned further away receive much less exposure due to inverse square law effects. In almost all cases, the operator will receive the highest occupational radiation exposure during the fluoroscopic procedure.

CHAPTER 4: RADIOBIOLOGY

Biological effects of radiation

The lethal dose (LD50) in humans from acute, *whole body radiation* exposure is approximately 450 rads [4.5 Gy]. The temperature elevation in tissue caused by the energy imparted is $\ll 1^\circ \text{C}$. The severe biological response is due to ionizing nature of X-ray radiation, involving removal of electrons from molecular structures.

Atoms ionized by radiation may change chemically, becoming free radicals. These free radicals can damage a cell's DNA. The DNA may also be altered directly by radiation. In either case if the DNA is damaged, several things can happen. The most likely is that the damage will be repaired before the end of the cell's cycle. If not, the cell will probably die. There is some chance that the cell will survive and behave differently because of the damaged DNA. For example, it may become malignant. Large radiation doses may kill many cells causing noticeable damage such as erythema or epilation. Low doses do not cause such significant changes but may produce a malignant change.



Photomicrograph showing examples of radiation-induced chromosome damage in cancer cells following radiotherapy treatment (Bushong 1980).

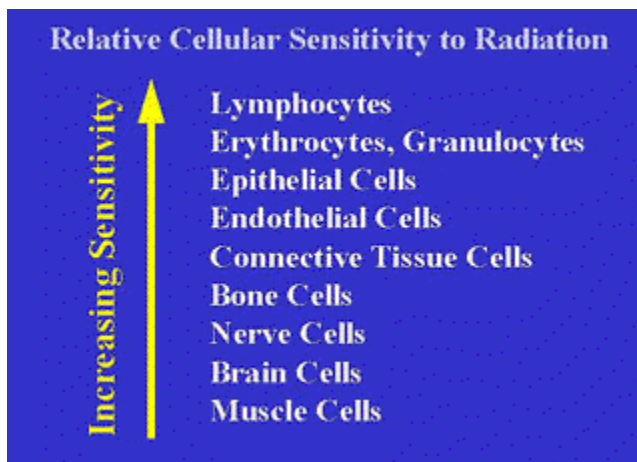
Abnormal formations are readily seen at high dose levels, but are also observed at the lower doses received by diagnostic patients and highly exposed workers.

Human population groups in which radiation effects have been observed (Bushong 1980):

- American Radiologists
- Atom bomb survivors
- Radiation-accident victims
- Marshall Islanders (Atomic bomb fallout)
- Residents of areas having high levels of environmental radiation
- Uranium miners
- Radium watch-dial painters
- Radioiodine patients
- Children treated for enlarged thymus
- Ankylosing spondylitis patients
- Thorotrast patients (contrast containing radioactive material)
- Diagnostic irradiation in-utero
- Volunteer convicts
- Cyclotron workers

Radiation sensitivity

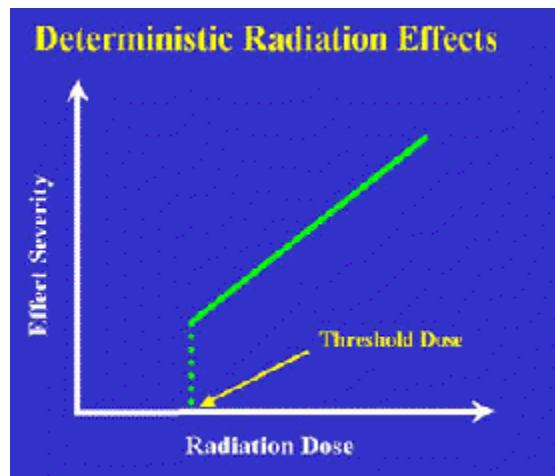
Radiosensitivity is a function of the cell cycle with late S phase being the most radioresistant and G1, G2, and especially mitosis being more radiosensitive. According to the Law of Bergonie-Tribondeau, radiosensitivity is highest in undifferentiated and actively proliferating cells, proportionate to the amount of mitotic and developmental activity that they must undergo. For example, bone marrow is much more sensitive to radiation than nerve cells, which have an extremely long cell cycle. The following list provides a relative ranking of cellular radiosensitivity (Seibert 1996):



The total dose, dose rate, fractionation scheme, volume of irradiated tissue and inherent radiation sensitivity all affect a given organ's response to radiation. Generally, a large total dose, high dose rate, small fractionation schedule (as encountered during fluoroscopy), and large irradiated volumes cause a greater degree of damage. Less biological damage occurs when the radiation dose is fractionated (delivered over several different events as opposed to all at once), as is the condition of most operator/staff exposures. Dose fractionation allows time for cellular repair.

Deterministic Effects

A large number of ionizing radiation effects occur at high doses. These all seem to appear only above a threshold dose. While the threshold may vary from one person to another, it is about 200 rad [2 Gy]. The severity of these effects increases with increasing dose above the threshold. These so-called deterministic effects are usually divided into tissue-specific local changes and whole body effects, which lead to acute radiation syndrome.



Local effects include erythema, epilation, sterility, and cataracts. The first three of these can be temporary at doses of 200 rad or permanent at doses greater than 600 rad [6 Gy]. Above 50 rad [0.5 Gy], a decrease in leukocyte counts can be detected. Most of these deterministic effects are seen within days or weeks after the exposure, but cataracts may appear a few years after exposure.

The following Table provides examples of possible radiation effects to skin caused by typical fluoroscopy exposures. Note that patient and technique factors can substantially increase exposure rates, significantly reducing the time necessary for the subsequent effect.

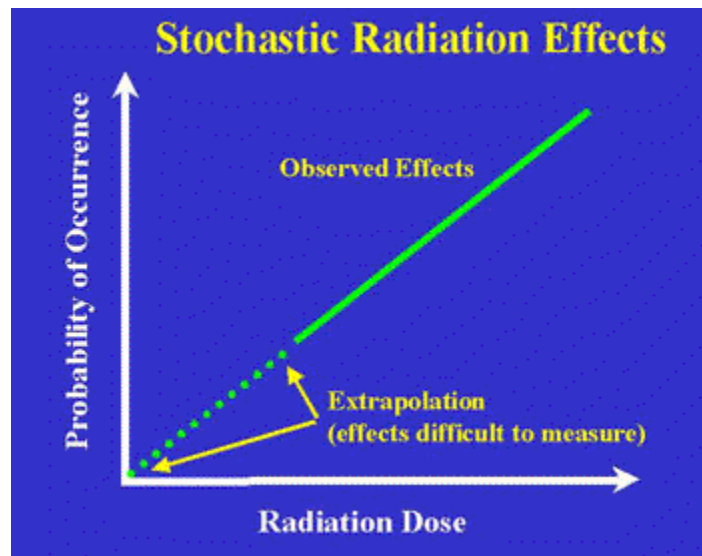
[Specific case studies of radiation-induced skin injury are presented in the next section]

Effect	Threshold (rad) (Gy)	Minutes of Fluoro On-Time @ 5 R/min	Minutes of Cine On-Time @ 30 R/min	Time to onset of effect
Transient Erythema	200 2	40	6	24 hr
Epilation	300 3	60	12	3 wk
Erythema	600 6	120	18	10 day
Pericarditis	800 8	160	24	>10 wk
Dermal Necrosis	1800 18	360	60	>10 wk
Skin Cancer	None Known	N/A	N/A	> 5 yr

Cataract induction is of special interest to fluoroscopy operators since the lens of eye often receives the most significant levels of radiation (provided lead aprons are used). Radiation is known to induce cataracts in humans from single doses of 200 rad [2 Gy]. Higher exposures can be tolerated when accumulated over time. Cumulative exposures of up to 750 rads [7.5 Gy] have resulted in no evidence of cataracts. Personnel exposed to the maximum levels each year would accumulate only 450 rems [4.5 Gy] over 30 years. As such, the risk for cataracts is likely to be small.

Stochastic Effects

Somatic effects induced by radiation may include carcinogenesis. Experimental data suggests a non-threshold linear response to the dose-effect relationship. Equal increases of dose cause a corresponding equal increase in the incidence of the effects. Such effects are also known as stochastic or probabilistic phenomena.



The U.S. National Council of Radiation Protection and Measurements (NCRP 1987) estimates that an exposure of 1 rem to 1 million persons would result in an increase in cancer deaths from 190,000 to 190,400; an increase of 0.2 percent.

There is limited data on the risk estimates for patients exposed during diagnostic procedures. However, studies on patients who have undergone radiation therapy indicate that the incidence for secondary malignancy ranges from 6 to 13 percent. The source of these malignancies are attributed to (Hall 1999):

- Continued lifestyle (e.g., continued tobacco abuse or sun exposure)
- Genetic susceptibility (e.g., familial cancers)

- Treatment-induced second malignancies

Studies with an adequate cohort size clearly indicate an excess of second cancers induced by radiotherapy. Studies suggest that the risks are concentrated in younger patients, the breast is especially sensitive to radiation and that excess cancers develop with a latency of 10 years or more (Hall 1999).

Cancer risk estimates from lower radiation exposures are difficult to determine because of the high incidence of malignancy in the general, unexposed population. The effects from lower radiation exposures (such as those encountered occupationally) are extrapolated from observations made at fairly high doses (Upton 1999). The validity of this extrapolation is constantly being re-evaluated. Current guidelines maintain that current risk estimates are the best available for the purpose of establishing acceptable radiation exposure limits.

Unlike deterministic effects, stochastic effects are assumed to be unaffected by dose fractionation. The total risk to an individual is continually increased with increasing radiation exposure. For radiological workers, small savings in radiation exposure realized by altering technique can result in significant reductions in personal risk when integrated over a working lifetime:

Annual Dose		30 year total dose		Incremental Fatal Cancer Risk
rem	Sv	rem	Sv	
0.5	0.005	15	0.15	0.6%
1	0.01	30	0.30	1.2%
2	0.02	60	0.60	2.4%
5	0.05	150	1.50	6%

Radiation exposure can cause chromosomal damage that may be "repaired" with an incorrect sequence and subsequently be passed on to the next generation (genetic effects). Radiation does not cause new types of mutations, but simply increases the incidence of certain mutations above their natural rate of occurrence. Controlled studies of genetic effects are only available from animal models. The 7 million mice, "Megamouse" project revealed the following conclusions (Lam 1992):

- Different mutations differ significantly in the rate at which they are produced by a given dose.
- There is a substantial dose rate effect with no threshold for mutation production.
- The male was more radiosensitive than the female. The males carried most of the radiation induced genetic burden.
- The genetic consequences of a radiation dose can be greatly reduced by extending the time interval between irradiation and conception. Six months to a year is recommended.
- The amount of radiation required to double the natural and spontaneous mutation rate is between 20 to 200 rads [0.2 to 2.0 mGy].

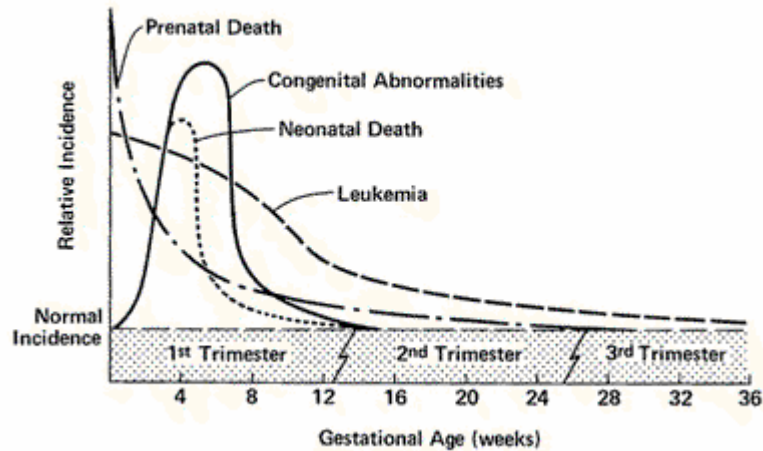
Prenatal Effects

Animal studies have shown that the embryo and fetus are more sensitive to the effects of radiation than the adult. There are three general prenatal effects observed that are dependent upon the dose and stage of fetal development:

- Lethality.
- Congenital abnormalities at birth.
- Delayed effects, not visible at birth, but manifested later in life.

250 rads [2.5 Gy] or more delivered to a human embryo before 2 to 3 weeks of gestation will likely result in prenatal death. Those infants, who survive to term, generally do not exhibit congenital abnormalities.

Irradiation of the human fetus between 4 to 11 weeks of gestation may cause multiple severe abnormalities of many organs.



Irradiation during the 11th to 15th week of gestation may result in mental retardation and microcephaly. After the 20th week, the human fetus is more radioresistant, however, functional defects may be observed. In addition, a low incidence (one in 2000) of leukemia has been observed in individuals who received prenatal radiation.

Medically indicated procedures involving radiation are appropriate for pregnant women (Brent 1999). However, such procedures should be avoided if alternate techniques are available or measures should be taken to minimize patient/fetal exposure. Considering legal complications resulting from non-optimal prenatal radiation exposure, it is strongly suggested that physicians consult with a Board-Certified Radiologist before performing fluoroscopy on potentially pregnant patients.

CHAPTER 5: CASE STUDIES OF RADIATION INJURY

Non-Symptomatic Skin Reactions

Patients may not be aware of skin changes that take place as a result of lengthy fluoroscopic procedures (Wagner 1999):

- Physical examination one year following coronary angioplasty identified a 1 x 2.5 cm-depigmented area with telangiectasia on the patient's left shoulder. Total fluoroscopy time: 34 minutes.
- One year after PTCA involving 66 minutes of fluoroscopy, a 10-cm diameter hyperpigmented area with telangiectasia was evident on the patient's right shoulder.

These skin changes were in areas not visible to the patients and were only identified upon physical examination.

Symptomatic Skin Reactions

The circumstances leading to symptomatic radiation induced changes are varied. Case reports are grouped according to common factors in order to identify the reasons for radiation-induced effects.

PA Fluoroscopy

The posteroanterior (PA) orientation of the fluoroscope, when properly configured with the image intensifier down close to the patient, is probably the least problematic with regard to ESE rate. However, extended fluoroscopy usage has resulted in reports of skin damage. The following case study illustrates this effect (Shope 1995).



On March 29, 1990, a 40-year-old male underwent coronary angiography, coronary angioplasty and a second angiography procedure (due to complications) followed by a coronary artery by-pass graft. Total fluoroscopy time estimated to be > 120 minutes. The image shows the area of injury six to eight weeks following the procedures. The injury was described as "turning red about one month after the procedure and peeling a week later." In mid-May 1990, it had the appearance of a second-degree burn.

Appearance of skin injury approximately 16 to 21 weeks following the procedures with small-ulcerated area present.



Appearance of skin injury approximately 18 to 21 months following procedures, evidencing tissue necrosis (and close-up of injury area)





Appearance of patient's back following skin grafting procedure

Additional reported cases of radiation-induced injury (Wagner 1999):

- Following a transjugular intrahepatic portosystemic shunt (TIPS) procedure involving 90 minutes of fluoroscopy, a discharged patient developed erythema and discoloration on his back. One year after the TIPS procedure an ulcer developed, which did not heal, and two years later it was 4-cm in size. A split thickness skin graft from the right buttock was performed.
- Following a TIPS procedure lasting 6 hours and 30 minutes (no indication of total fluoroscopy time), a 16- x 18-cm hyperpigmented area developed on the patient's back and progressed over a period of several months into a central area with ulceration. After 14 months a split thickness skin graft was performed leaving a depressed scar at the surgical sight.

These case studies indicate that extensive use of fluoroscopy can induce severe skin damage, even under the most favorable geometries.

Steep Fluoroscopic Angles

When the fluoroscope is oriented at a lateral or an oblique angle, two factors combine to increase the patient's ESE rate. The first is that a thicker mass of body tissue must be penetrated. The second is that the skin of the patient is closer to the source because of the wider span of anatomy (Wagner 1999).

- A PA oblique angle using a C-arm involved 57 minutes of fluoroscopy. Twenty-four hours later the patient reported a stabbing pain in his right thorax. Three days later an erythema developed which evolved into a superficial ulcer. At two and half months after the procedure the area was approximately 12-cm x 6.5-cm and described as a brownish pigmented area with telangiectasia, central infiltration and hyperkeratosis.
- A PA oblique angle was employed during a catheter ablation procedure involving 190 minutes of fluoroscopy. A symptomatic discoloration was noted several days after the procedure on the patient's left upper back. In the next few weeks the area had become painful and was draining. At seven weeks the area was approximately 7- x 14-cm in size and described as a rectangular erythema with ulcers. After treatment, there was a gradual lessening of tenderness with reepithelialization, leaving a mottled slightly depressed plaque.
- A steep PA oblique angle through the right shoulder was employed involving 51 minutes of fluoroscopy. Fourteen days after the procedure, an erythema appeared on the right shoulder that progressed into moist superficial ulcer with poor healing. This degenerated into a deep muscular ulcer requiring a myocutaneous skin graft approximately 14 months after the procedure.

The temporal progressions of these effects are consistent with high levels of acute exposure to x-ray radiation. The temporal differences in the responses are due in part to the levels of radiation received, but are also likely due to variations in radiation sensitivity amongst the patients.

Steep angled views, especially in large patients, often require penetration of large masses of tissue and dense bone, creating situations in which x-ray output rates are driven near or at the maximum (10 R/min or 0.1 Gy/min).

Multiple Procedures

Although intervals between procedures should permit the skin to recover, healing might not be complete. This may lower the tolerance of the skin for further procedures (Wagner 1999):

- A patient underwent two PTCA procedures about one year apart. Skin changes appeared approximately three weeks after the second procedure. At seven weeks a cutaneous ulcer had developed over the right scapula and healed without grafting.
- A patient underwent two unsuccessful cardiac ablations involving approximately 100 minutes of fluoroscopy in a lateral oblique orientation. Approximately 12 hours after the second attempt, an erythema developed in the right axilla. At one month the area was red and blistering. At two years the area was described as a 10 x 5cm atrophic indurated plaque with lineal edges, hyper- and hypopigmentation, and telangiectasia. The patient was described as having difficulty raising her right arm.
- Three PTCAs were performed on the patient, the last two completed on the same day approximately 6 months after the first procedure. The total fluoroscopy time was approximately 51 minutes. Erythema was noted immediately after the last procedure. This progressed from a prolonged erythema with poor healing into a deep dermal necrosis. The patient underwent a successful split thickness skin graft two years after the last procedure.
- Past treatment of pulmonary tuberculosis often resulted in many patients undergoing extensive exposure to fluoroscopy. These patients had a demonstrated high incidence of breast cancer.

Previous procedures can lower the skin's tolerance for future irradiation. Prior to commencing any lengthy fluoroscopic procedure, the patient's medical history should be reviewed. The skin of the patient should be examined to ascertain if any skin damage is apparent should the patient have a history of lengthy fluoroscopic examinations. Direct irradiation of damaged areas should be avoided when possible.

Positions of arms

Keeping arms out of the x-ray beam during some procedures can be a difficult objective. Careful attention must be given to providing the arms with a resting position that will not restrict circulation but will at the same time maintain the arms in an area that is outside the radiation field (Archer 2000).

A middle-aged woman had a history of progressively worsening episodes of arrhythmia. A radiofrequency electrophysiological cardiac catheter ablation was scheduled to treat the condition. The procedure employed 20 min of beam-on time for each plane of a bi-plane fluoroscope. Prior to the procedure the separator cones were removed so that the fluoroscopic c-arms could be easily rotated around the patient. The separator cone is a spacer attached to the tube housing designed to keep the patient at a reasonable distance from the x-ray source. This is done specifically to avoid the high skin-dose rates that can be encountered near the tube port.



The patient's arms were originally placed at the patient's side but the right arm later fell into a lower position directly in front of this x-ray tube. However, personnel were not aware of this change because sterile covers were draped over the patient. The right humerus was directly in the beam at the port. Because the separator cones were removed, the arm was only about 20–30 cm from the focal spot. With the soft tissue and bone of the arm directly in the beam, the automatic brightness control drove the output to high levels at the surface of the arm. The cumulative dose probably exceeded 2500 rads [25 Gy].

The patient was released from the hospital the day after the procedure. At the time there were no complaints regarding her arm and no indication of erythema. About three weeks after the procedure, a bright erythema was demonstrated.



The condition worsened and at five months a large ulcer the size of the collimated x-ray port developed.

At eight months a debridement was performed and a surgical flap was put in place.
(Images before and after surgical flap)



The separator cone ensures that a minimal distance between the X-ray source and the patient is maintained (inverse square law effects). For some X-ray machines, the separator cone is designed to be

removable in order to provide more flexibility in positioning for some special surgical procedures (e.g., portable C-arms). There is a risk of very high dose rates to the skin surface when it is removed.

Skin sensitivity

Some patients may be hypersensitive to radiation due to pre-existing health conditions (Wagner 1999).

- Erythema developed after diagnostic angiography and liver biopsy. Skin necrosis requiring rib resection evolved in the same patient after a TIPS procedure. The wound remained open for five years before a successful cover was put in place. Investigation into the events revealed that the patient suffered from multiple problems, including Sjögren's syndrome and mixed connective tissue disease.

Injuries to personnel

The following are modern-day examples of how improper use of the fluoroscope can lead to injuries in personnel (Wagner 1999).

- Hands of physicians have incurred physiologic changes indicative of high cumulative doses of chronic low-dose-rate irradiation. Brown finger nails and epidermal degeneration are typical signs. These changes were the result of years of inserting hands into the x-ray field with the x-ray tube above the patient.
- Four cases of radiation-induced cataract have been reported in personnel from procedures utilizing the x-ray tube above the patient orientation.

Doses accumulated to hands and eyes from frequently using the fluoroscope with the tube above the patient can be extremely high. Only routine application of proper radiation management techniques will be effective at avoiding such high doses.

CHAPTER 6: REDUCING RADIATION EXPOSURE

Reduce Use Time

Radiation exposure during fluoroscopy is directly proportional to the length of time the unit is activated by the foot switch. Reductions can be realized by:

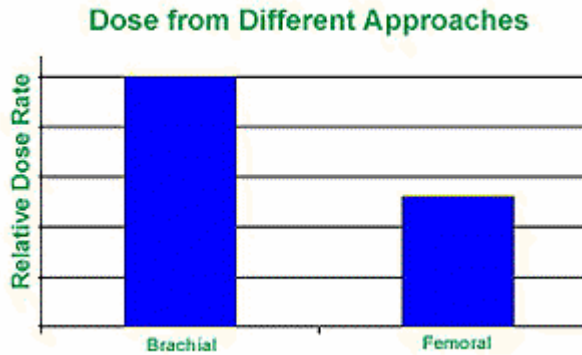
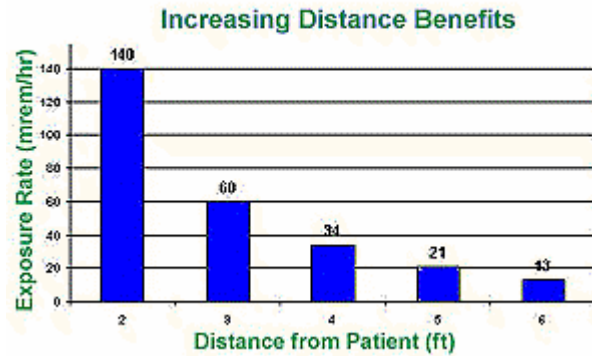
- Not exposing patient while not viewing the TV image;
- Pre-planning images. An example would be to ensure correct patient positioning before imaging to eliminate unnecessary "panning;"
- Avoiding redundant views;
- Operator awareness of the 5-minute time notifications.

Fluoroscopy's real-time imaging capabilities are invaluable for guiding procedures or observing dynamic functions. However, there is no advantage over conventional X-ray techniques when viewing static images. Use of Last-Image-Hold features, when available, allows static images to be viewed without continuously exposing patient and operator to radiation.

Human eye integration time or recognition time of a fluoroscopy image is approximately 0.2 seconds. Therefore, short "looks" usually accomplish the same as a continuous exposure. Prolonged observation will not improve the image brightness or resolution (Seifert 1996).

Increase Distance

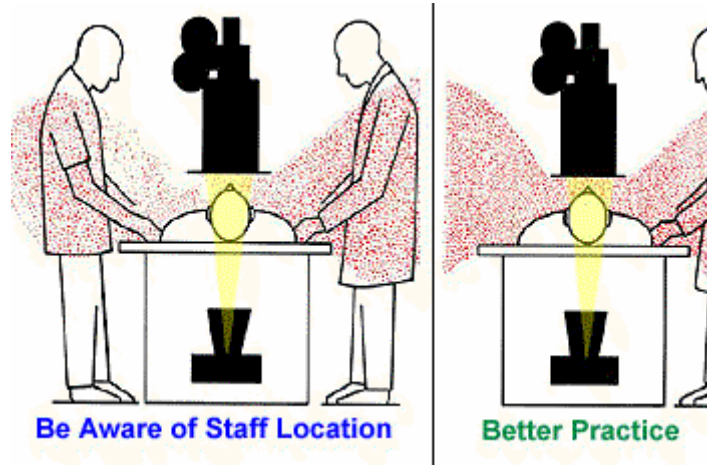
Example One in Chapter 1 illustrated the benefits obtained from a small increase in operator distance from the patient. Personal technique should be self-evaluated periodically to identify whether opportunities for increasing distance exist. Standing one step further away from the patient can cut the physician's exposure rate by a factor of 4 (AAPM 1998).



In percutaneous transluminal techniques, using the femoral approach rather than the brachial approach yields distance benefits to the operator.

Substantial increases in operator distance may be realized through remote fluoroscopy activation whenever automated contrast injectors are used.

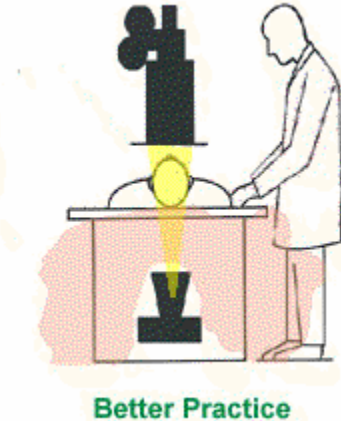
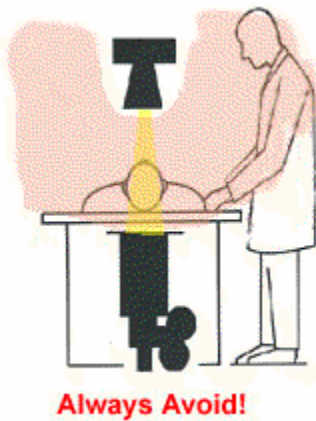
Many procedures require staff to intermittently interact with the patient near the fluoroscopy system. The operator can reduce staff exposure by delaying fluoroscopy until these activities are completed and/or by alerting these personnel when imaging; especially during high dose rate modes like cineangiography.



Room Lighting

Provisions should be made to eliminate extraneous light that can interfere with the fluoroscopic examination. Room lighting should be dim to enhance visualization of the video image. Excessive light can decrease the ability of the eye to resolve detail. Measures taken to improve detail often involve increasing patient/staff exposure.

X-ray Tube Position

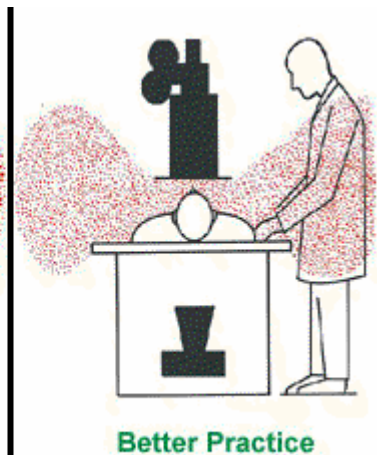
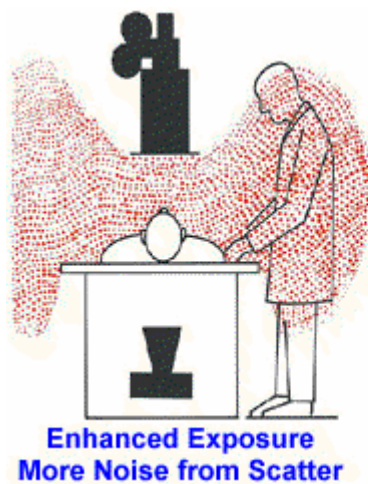


All fluoroscopy examinations should be performed with the X-ray tube underneath the examination table. Whenever possible, the operator should avoid the X-ray tube side of the table when imaging oblique or lateral images.

On some systems (portable C-arms, cardiac systems), the operator must be aware of the X-ray tube-to-patient distance. Positions closer can lead to extremely high patient exposures due to Inverse-Square-Law effects (case study). Minimizing the air gap between the II and the patient typically ensures that this distance is maintained.

Reduce Air Gaps

Keeping the II as close to patient's surface as possible significantly reduces patient and operator exposures. The II will intercept the primary beam earlier and allow less scatter to operator and staff. In addition, The ABC system would not need to compensate for the increased X-ray tube to II distance caused by the air gap. **The presence of an air gap will always increase patient/operator radiation exposure.**



Care should be taken whenever image view angles are changed during the procedure (e.g, changing from an ANT to a steep LAO). The II is often moved away from the patient while changing X-ray tube position. Large air gaps can result if the table or II height remains unadjusted:

Example 2:

After changing views, a 10-cm air gap between II and patient is inadvertently left behind. What is the increase in radiation exposure to a 20-cm thick patient positioned with the table 30 cm away from the X-ray source, assuming the ABC compensates by increasing mA only.

Solution 2:

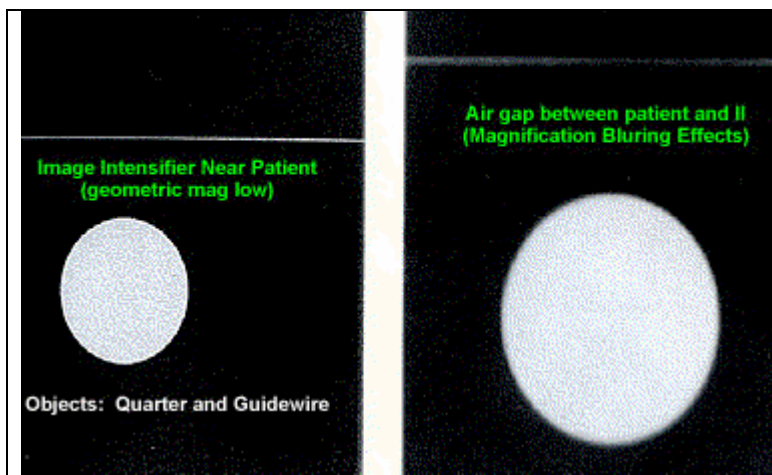
Assuming the air gap could have been eliminated by moving II closer, and that the brightness loss follows the inverse square law:

$$\frac{X_1}{X_2} \propto \left(\frac{D_2}{D_1} \right)^2 \propto \left(\frac{30 + 20 + 10}{30 + 20} \right)^2 \propto 1.44$$

The brightness level with the air gap is only 69% of the zero air gap brightness. The ABC system compensates for brightness loss by producing 31% more X-rays. The exposure rate to the patient and staff is subsequently increased by 31%.

In the case of portable C-Arm systems, eliminating the air gap ensures that the table top is as far away as possible from the X-ray tube, minimizing radiation exposure to the patient's skin. Note that the separator cone should always be re-positioned before commencing fluoroscopy on portable C-arm systems.

Reducing air gaps between patient and II also reduces image blur. Blurring of the image is caused by geometric magnification caused by air gaps:



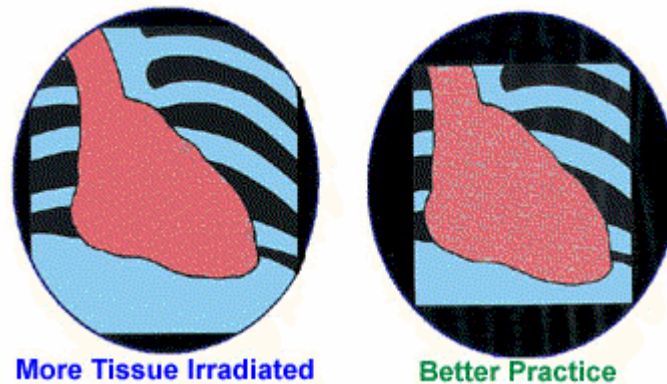
Gaps between patient and II enhance geometric magnification. The objects will appear larger with increasing gap size. However, note that image edges are more fuzzy. The degree of "fuzziness" will increase with increasing air gap.

Minimize Use of Magnification

Use of magnification modes significantly increases radiation exposure to patient, operator, and staff for most fluoroscopic imaging systems. (See Chapter 2) Magnification modes should be employed only when the increased resolution of fine detail is necessary.

Collimate Primary Beam

Collimating the primary beam to view only tissue regions of interest reduces unnecessary tissue exposure and improves the patient's overall benefit-to-risk ratio. Optimal collimation also reduces image noise caused by scatter radiation originating from outside the region of interest (See Chapter 2).

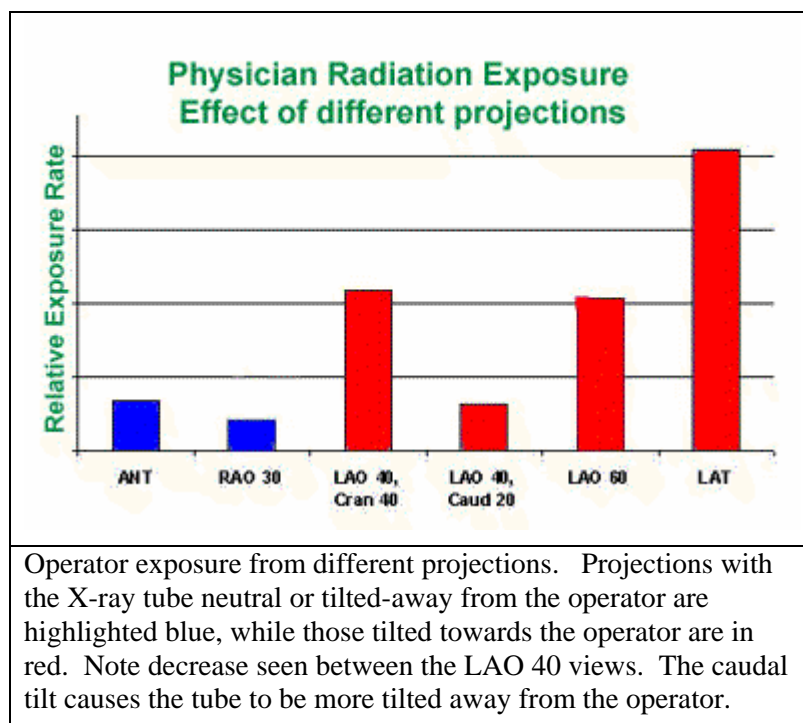


A good rule of thumb is that fluoroscopy images should not be totally "round" when collimators are available for use.

Use Alternate Projections

Steeply angled oblique images (e.g., LAO 50 with 30 cranial tilt) are typically associated with increased radiation exposure since:

- X-rays must pass through more tissue before reaching II. ABC compensates for X-ray loss caused by increased attenuation by generating more X-rays;
- Steep oblique angles are typically associated with increased X-ray tube to II distances. The ABC compensates for brightness loss caused by inverse square law effects by generating more X-rays.
- Oblique views may bring the X-ray tube closer to the operator side of the table, increasing radiation exposure from scatter.



When possible, use alternate views (e.g., ANT, LAO with no tilt) when similar information can be obtained. The physician can reduce personal exposure by re-locating himself when oblique views are taken. For example, dose rates can be reduced by a factor of 5 when the physician stands on the II side of the table (versus X-ray tube side) during a lateral projection (AAPM 1998).

Optimizing X-ray Tube Voltage

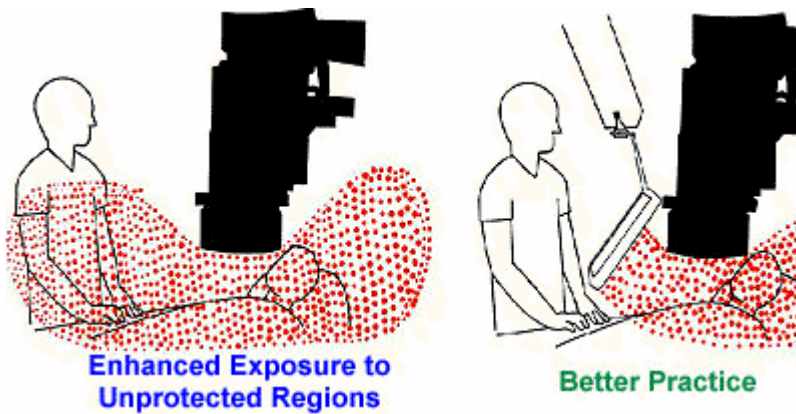
Selection of an adequate kVp value will allow sufficient X-ray penetration while reducing the patient's dose rate. In general, the highest kVp should be used which is consistent with the degree of contrast required (high kVp decreases image contrast).

Providence Everett Medical Center has many resources available (e.g., Clinical Application Specialists, Staff Radiologists, Medical Physicists) to assist the operator in optimizing the fluoroscopy image while minimizing patient exposure.

Use of Radiation Shields

Use of radiation shielding is highly effective in intercepting and reducing exposure from scattered radiation. The operator can realize radiation exposure reductions of more than 90 percent through the correct use of any of the following shielding options. Shields are most effective when placed as near to the radiation scatter source as possible (i.e., close to patient).

Many fluoroscopy systems contain side-table drapes or similar types of lead shielding. Use of these items can significantly reduce operator exposures. Many operators have had little difficulty incorporating their use, even during procedures requiring multiple re-positioning of the system.



Ceiling-mounted lead acrylic face shields should be used whenever these units are available, especially during cardiac procedures. Correct positioning is obtained when the operator can view the patient, especially the beam entrance location, through the shield.

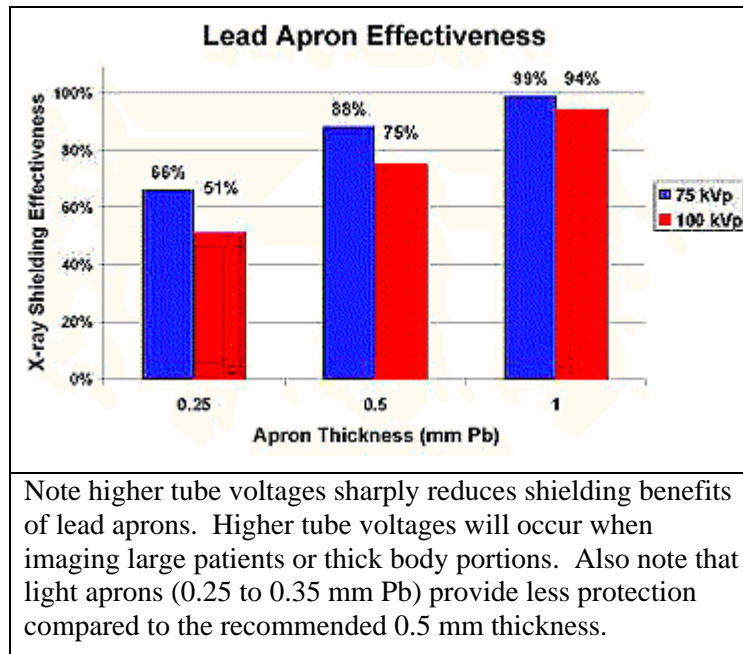
Portable radiation shields can also be employed to reduce exposure. Situations where these can be used include shielding nearby personnel who remain stationary during the procedure.

Use of Protective Equipment

Use of leaded garments substantially reduces radiation exposure by protecting specific body regions. Many fluoroscopy users would exceed regulatory limits should lead aprons not be worn. Operator and nearby staff (within 3 meters) are required to wear lead aprons whenever fluoroscopes are operated at Providence Everett Medical Center.



Lead aprons do not provide total protection from radiation. An approximate 90% reduction in radiation exposure is obtained from wearing a lead apron. It should be noted that this effectiveness is reduced when more penetrating radiation is employed (e.g., ABC response to thick patients). Two piece lead apron systems are recommended since they provide "wrap-around protection" and distribute weight more evenly on the user. So called "light" aprons should be scrutinized to ensure that adequate levels of shielding are provided.



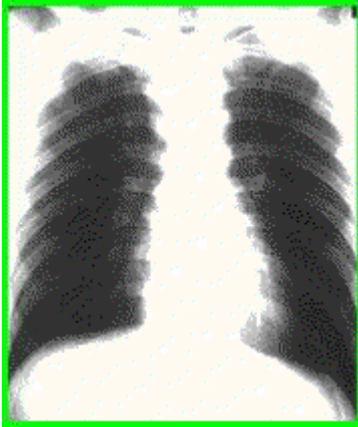
Thyroid shields provide similar levels of protection to the individual's neck region. Thyroid shield use is recommended for operators who use fluoroscopy extensively during their practice.

Optically clear lead glasses are available that can reduce the operator's eye exposure by 85-90% (Siefert 1996). However, due to the relatively high threshold for cataract development, leaded glasses are only recommended for personnel with very high fluoroscopy workloads (e.g., busy Radiology and Cardiology Interventionists). Glasses selected should be "wrap-around" in design to protect the eye lens from side angle exposures. Leaded glasses also provide the additional benefit of providing splash protection.

Leaded gloves provide similar protection to the user's hands. However, trade-offs associated with use include loss in tactile feel and increased encumbrance. For these reasons, use of leaded gloves is left to the operator's discretion. To minimize radiation exposure to the hands, the operator should:

- Avoid placing his hands in the primary beam at all times;
- Place hands only on top of the patient. Hands should never be placed underneath the patient or table top during imaging;
- Consider using leaded gloves if hand placement within the X-ray beam is necessary or positioned nearby for extended periods of time.

CHAPTER 7: RADIATION STANDARDS



Medical Dose Limits

Medical radiation exposures are intended to provide direct benefit to the patient. When the exposure is justified and the use optimized, the dose is considered as low as is compatible with the medical purposes. As such, regulatory bodies have not defined dose limits for medical procedures.

Occupational Dose Limits

The Washington State Department of Health has established upper limits on the amount of radiation that occupationally exposed personnel can receive. The following table provides the dose limits currently in effect [WAC 246-221-010]

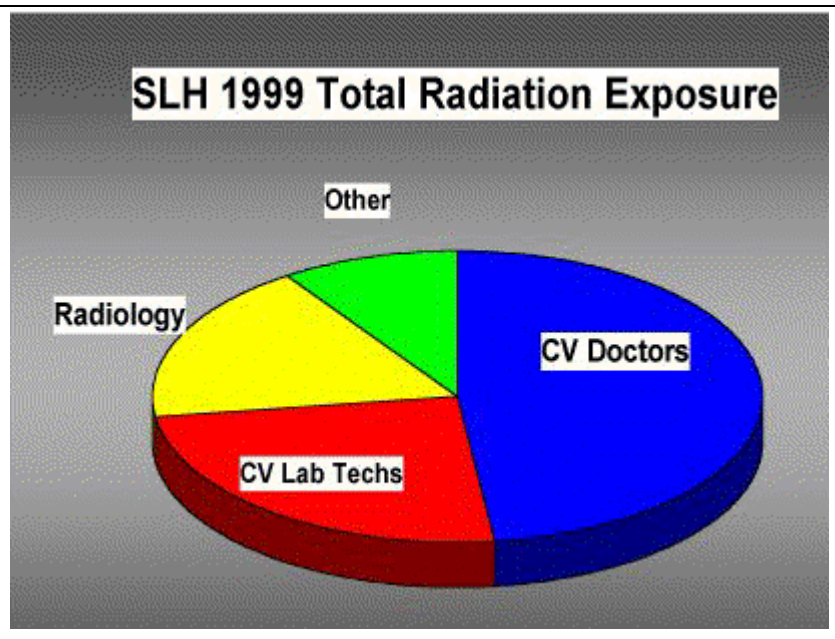
Occupational dose limits For Adults	Annual Maximum Dose	Quarterly Maximum Dose
Total Effective Dose Equivalent Whole body	5 rem 0.05 Sv	1.25 rem 12.5 mSv
Shallow Dose Equivalent To the Skin or any Extremity	50 rem 0.5 Sv	12.5 rem 125 mSv
Lens (Eye) Dose Equivalent	15 rem 0.15 Sv	3.75 rem 37.5 mSv
Deep Dose Equivalent to any other individual organ or tissue	50 rem 0.5 Sv	12.5 rem 125 mSv

The U.S. Nuclear Regulatory Commission also allows a lens of eye dose limit of 15 rems per year and a skin dose limit of 50 rems per year.

Although regulatory limits are defined in terms of rem, radiation exposure at PEMC is reported in units of mrem. **1 rem is equivalent to 1,000 mrem.** The following illustrates where radiation dose typically is being recorded at a typical medical center such as Providence Everett Medical Center:

Radiation Exposure

Location of radiation exposure recorded at a typical hospital in 1999. Almost 70% of all occupational exposure occurred in the Cardiac Catheterization Laboratories.



ALARA Philosophy

The average radiation dose to workers in the United States is about 210 mrem [2.1 mSv] per year (NCRP 1993). In addition, the average radiation dose due to natural sources in the Puget Sound area is about 310 mrem [3.1 mSv]. The risk associated with this exposure is equivalent to the annual risk of accidental death in general industry. Workers receiving higher levels of exposure (i.e., approaching regulatory limits) would be subject to significantly greater risk than those unexposed to radiation. For this reason, regulatory dose limits should be viewed as the maximum tolerable levels. Since stochastic radiation effects, such as carcinogenesis, can not be ruled-out at low levels of exposure, it is prudent to minimize radiation exposure whenever possible. This concept leads to the As-Low-As-Reasonably-Achievable (ALARA) philosophy.

Simply stated, the ALARA philosophy requires that all reasonable measures to reduce radiation exposure be taken. Typically, the operator defines what is reasonable. The principles discussed in this manual are intended to assist the operator in evaluating what constitutes ALARA for his/her fluoroscopy usage.

Radiation Monitoring

Unlike many workplace hazards, radiation is imperceptible to human senses. Therefore, monitoring of personnel exposed to radiation is performed using a radiation dosimeter or "badge." Monitoring is useful to identify both equipment problems and opportunities for improving individual technique (ensuring ALARA). Monitoring also documents the level of occupational exposure.

The State of Washington requires radiation monitoring when individual exposure potentially exceeds 10% of the maximum levels. All activities involving radiation at PEMC have been evaluated with dosimeters being issued to individuals likely to exceed these thresholds. However, a radiation dosimeter will be issued to any fluoroscope operator upon request, for use in monitoring that operator's personal exposure.



PEMC uses a single radiation dosimeter to monitor individual radiation exposure. This dosimeter is worn anywhere between waist and collar. It is important that the dosimeter is placed outside of any protective equipment worn (lead aprons). In other words, staff wearing a lead apron must wear the badge on the collar, outside of the lead apron. Readings from this position provide a estimate of radiation exposure to the eyes. Dose estimates to the individual's whole body are then made using appropriate correction algorithms.

In order to provide an accurate estimate of personal risk, personnel radiation badges are to be used at all times when working with radiation. It is also important to turn in the radiation badges on time. *The accuracy of the readings depends on the timely processing of the dosimeter with the corresponding 'control' dosimeters.* Personnel badge readings turned in late can not be compensated by the 'control' badge readings, thereby causing the personnel badge reading to be higher than would actually be the case.

The Radiation Safety Officer (RSO) or his designee reviews dosimetry records on a quarterly basis and reports the results to the Radiation Safety Committee. Investigations of any exposure exceeding the established standards are performed to determine whether corrective action can eliminate or reduce exposures for all concerned. The circumstances surrounding most cases of excessive radiation exposures are often readily mitigated.

Radiation reports are provided annually to all monitored personnel employed or practicing at Providence Everett Medical Center. In addition, quarterly reporting of radiation exposure is provided for operators and staff using fluoroscopy systems. Also, pregnant staff are provided with monthly badge monitors. Individuals can access their personal records at any time, and written dose estimates are provided upon request. Details associated with Radiation Badge Monitors are provided in PEMC's Policies and Procedures Manuals.

Providence Everett Medical Center's Radiation Safety Program

The Providence Everett Medical Center's administration is committed to ensuring that radiation exposure to its medical staff and employees is ALARA. Full attainment of this goal is not possible without the co-operation of all medical users of radiation devices.

Hospital administration has authorized the Radiation Safety Committee (RSC) to oversee all uses of radiation. The RSC is composed of physicians, physicists, and other professionals who have extensive experience dealing with radiation protection matters. The committee appoints a qualified expert (Radiation Safety Officer or RSO) to administer and over-see its day-to-day activities. Meetings are conducted quarterly and are open to all interested parties. Contact the Medical Imaging office or the RSO for the next scheduled meeting at 8-4100.

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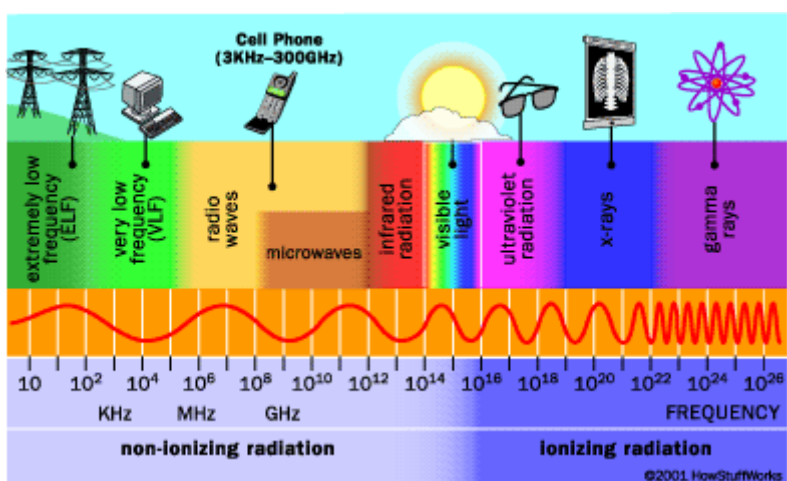
APPENDIX A

Natural Sources of Radiation Exposure

Types of Radiation

There are two basic types of radiation: **Non-ionizing** and **ionizing**. Examples of *non-ionizing* radiation include microwaves and electromagnetic fields. Types of *ionizing* radiation include gamma, beta and x-rays.

Ionizing radiation can't be detected with any of the five human senses. Because of this, special instruments are used to detect radiation and measure radiation levels.



Non-ionizing Radiation: Radiation with **insufficient energy** to produce ions.

Ionizing Radiation: Radiation **energetic enough to damage critical molecules** in the body's cells through direct ionization and the formation of free radicals.

Sources of Ionizing Radiation

Exposure from Natural Background Radiation

Cosmic Radiation - Varies with altitude

(US population average=26 mrem/year)

Seattle (Sea Level)	24 mrem/yr
Denver, Co (1600 Meters)	50 mrem/yr
Leadville, Co (3200 Meters)	125 mrem/yr

Air Travel - Air travel adds 0.5 mrem/hr in flight. Thus, a five hour transcontinental or transatlantic flight would result in a radiation dose of 2.5 mrem. Frequent fliers and crew members might receive a dose of 100 mrem/yr or higher.

(US Population average=1 mrem/yr)

Radionuclides in the Earth - Rock and Soil contain natural radioactivity from long-lived uranium, thorium, etc.

(U.S. Population average=28 mrem/yr)

Denver (Rocky Mountain Area)	63 mrem/yr
Non-coastal Plain	32 mrem/yr
Atlantic and Gulf Coast Plain	28 mrem/yr

Inhaled Radionuclides – Dose is primarily from short-lived decay products of radon-222 in the air, and varies significantly by location and home construction.

(U.S. Population average=200 mrem/yr)

Internally Deposited Radionuclides – Major source: Food and domestic water supply. Mainly ⁴⁰K. Present in the body, primarily in the lean body tissue.

(U.S. Population average=39 mrem/yr)

Exposure from Manmade Radiation Sources

Medical X-rays – U.S. Population average=39 mrem/yr

Extremities	1 mrem
Dental	5 mrem
Chest	10 mrem
Pelvis	44 mrem
Abdomen (kidneys)	56 mrem
Hip	83 mrem
CT (head and body)	111 mrem
Upper GI	244 mrem
Barium Enema	406 mrem

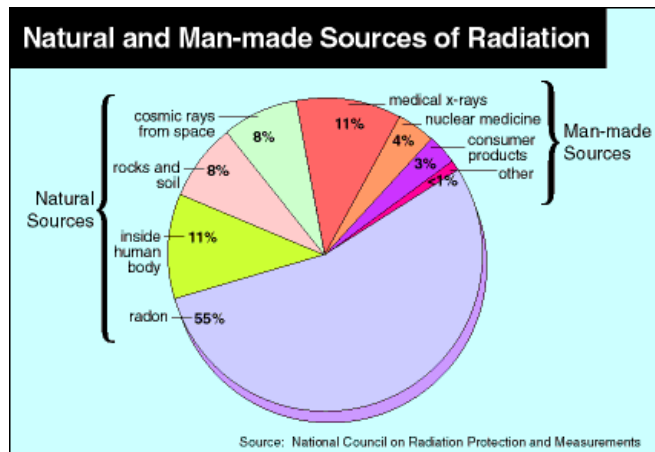
Nuclear Medicine Procedures - US Population average=14 mrem/yr

Pulmonary	150 mrem
Liver	240 mrem
Cardiovascular	710 mrem
Tumor	1220 mrem
Bone	440 mrem
Brain	650 mrem

Consumer Products – U.S. Population average= 10mrem/yr

Smoke Detectors	0.008 mrem/yr
Gas Lantern Mantles	0.2 mrem/yr
Fallout from Nuclear Weapons Testing	0.3 mrem/yr
Road Construction Materials	4 mrem/yr
Natural Gas Cooking Range (radon)	5 mrem/yr
Building Materials	7 mrem/yr
Tungsten Welding Rods	16 mrem/yr
Natural Gas Un-vented Space Heaters	22 mrem/yr
Cigarettes (30/day)	16,000 mrem/yr
Bananas (naturally occurring potassium-40)	trace amounts
Pottery with Red-orange Glaze	varies
Fertilizer	varies

The figure below shows the average annual radiation doses received per capita in the US from **naturally occurring and manmade** sources of radioactivity. The yearly total dose is approximately 300 mrem, with the majority of this dose coming from naturally occurring background radiation. The dose from these sources is NOT part of your occupational dose and is NOT subject to any regulatory limits.



Summary of recommended methods to minimize scatter radiation

Operator-dependent practices

1. MINIMIZE the fluoroscopy on-time
2. Use multiple short fluoro exposures instead of keeping the fluoro on continuously
3. Use the *last image hold* and *frame averaging* features if available
4. Keep the x-ray tube below the patient, and the Image Intensifier above the patient
5. Keep the Image Intensifier as close to the patient surface as possible, and, maintain the source to patient entrance distance as long as practical
6. For most systems, magnification modes should be used only when necessary
7. Collimate the beam to the area of interest
8. Take advantage of the inverse square law and move back from the patient whenever possible and, be aware of staff location during fluoro
9. Select the highest kVp that provides the needed contrast
10. DON'T use high dose or boost fluoro modes unless absolutely necessary and, *use low dose modes* provided with the equipment for initial setup.
11. Dim room lighting to enhance visualization of images
12. Optimize projection views that minimize scattered radiation

Shielding

1. Use lead aprons, thyroid collars, and leaded eye protection
2. Use table side drapes, mobile 'panel' shields, ceiling suspended leaded shields