Radiation Safety

Introduction

These notes review the fundamental principals of radiation protection, radiation dose limits and some of the precautions and risks associated with the different imaging modalities in the hospital.

Time, Distance and Shielding

The three principle methods by which individual radiation exposure can be reduced are time, distance and shielding.

Time: Reducing the time around the radiation source reduces your exposure. For example, most radiation exposure technologists receive is scatter radiation from the patient. Reducing fluoroscopy "on" time will proportionally reduce scatter exposure to the technologist during GI, angio, or other invasive procedures. “Fluoro” time can be reduced using pulsed (rather than continuous) flouro, image hold (an electronic feature used for localization and planning), and activating the fluoro only when viewing the monitor.

Distance: The exposure rate from radiation decreases as the distance from the source squared. This relationship between exposure and distance is called the inverse square law. For example, if one doubles the distance from the source of radiation the exposure rate is reduced to one fourth (1/4) its initial value. Scatter radiation exposure, the most common type of exposure you will receive in diagnostic radiology, is reduced to 1/1000 the exposure the patient is receiving if you stand one meter (approximately 3 feet) from the patient. All personnel should stand as far away from the xray source and the patient as possible during x-ray procedure without compromising the procedure.

Shielding: The purpose of radiation shielding is to protect individuals working with or near x-ray machines from radiation caused by the operation of the machine. Personnel shielding is accomplished using 0.5 mm lead (Pb) equivalent aprons (and thyroid collars), portable chest shields, pull-down shields, and leaded drapes on fluoroscopy equipment.

Therefore, wear lead aprons at all times when in the room with fluoroscopy. A lead apron will reduce your exposure by approximately 95%. For example, if your exposure to radiation is 10mR/hr at a given distance without any shielding, wearing a lead (Pb) apron will reduce this to 0.5 mR/hr.

> Shielding: Pb apron 0.5 mm stops 99.9% of x-rays at 75 kVp and 75% of 100 kVp x-rays.
>
> Pb aprons are not as effective for high-energy 140 keV Tc-99m gamma photons; only approximately 70% of the photons are attenuated.

Dose Limits: Dose limits are intended to limit the risk of stochastic effects such as cancer and genetic effects and to prevent deterministic effects such as cataracts, skin damage, and sterility. When radiation is measured there are different terms used depending on whether they are considering radiation coming from a radioactive source, the radiation does absorbed by a person, or the risk that a person will suffer health effects (biological risk) from exposure to radiation. Like many measurement situations, there is an international system (System International) and a more common “conventional” system used in the US. Emitted radiation is measured using a conventional unit **Curie (Ci)** or the SI unit **becquerel** (Bq)**.** The radiation does absorbed by a person is measured conventionally using the unit **rad** or the SI unit **gray** (GY). The biological risk of exposure to radiation is measured using the conventional unit **rem** or the SI unit **sievert** (Sv). One Gy = 100 rad and one Sv = 100 rem.

Current National Council on Radiation Protection (NCRP) recommended dose limits:

Occupational Dose Limits

Annual limit (whole body)	50mSv	5 rem/yr

Annual dose limits for tissues and organs		
Lens of the eye	150mSv	15 rem/yr
Skin, hands, feet and other organs	500 mSv	50 rem/yr
Cumulative	10 mSv (1 rem) x Age	
<u>Embryo/fetus</u>		
Total dose equivalent	5 mSv	0.5 rem
Monthly dose equivalent	0.5 mSv	0.05 rem
<u>General Public (annual) – excluding medical</u>		
Effective dose limit, continuous or frequent	1 mSv	0.1 rem
Effective dose limit, infrequent	5 mSv	0.5 rem

Personnel Dosimetry: Personnel radiation exposure must be monitored for both safety and regulatory considerations. The two most common devices for monitoring exposure are the film badge and thermoluminescent dosimeter (TLD). The film badge is the most widely used dosimeter in diagnostic radiology. It consists of small sealed film packet that is placed inside of a plastic holder. The plastic holder consists of a number of metal filters that allow the energy range of the radiation to be identified. The amount of film darkening is proportional to the amount of radiation exposure. Most film badges can record dose from 10 mrad (mrem) to 1500 rad for photons and 50 mrad to 1000 rad for beta radiation. Film badges are processed monthly with a vendor who provides a permanent record of radiation exposure.

Thermoluminescent dosimeters (TLDs) are commonly used as extremity dosimeters. A lithium fluoride (LiF) chips is the most commonly used TLD material. The exposed chip limits light when heated; the amount of light is proportional to the exposure. LiF TLDs have a dose response range of I mrem to 10^5 rem and are reusable.

Why should I wear a film badge?

Personnel likely to exceed 10% of dose limits listed above must be monitored. Film badges allow your employer to track e ... equipment malfunction can be ... s.

Where do I wear a ...

If only one badge i ... ollar. If two are assigned, one sho ... for hands and glasses or goggles ...

Why should I wear a film badge?

Personnel likely to exceed 10% of the dose limits listed above must be monitored. Film badges allow your employer to track exposures and alert you to any unnecessary radiation exposure. Each worker has an obligation to follow radiation safety rules. This includes always wearing your film badge when on the job.

Where do I wear my film badge?

If only one badge is assigned, the badge should be worn outside the lead apron on the collar. If two badges are assigned, one should be worn on the wais under the lead apron and the second on the collar on the outside of the lead apron. In this way we can monitor the effectiveness of the shielding and the exposure to unshielded areas such as the head and extremities. Thermoluminescent Detectors (TLDs) can also be assigned for the hands and other areas (eyeglasses) if these areas are routinely in the primary x-ray beam.

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<u>General Purpose R</u>...

Most radiographic exposures are taken from a lead (PB) shielded control area. Exposure to these areas is from scatter radiation and is negligible and less than 0.1 mrem per exposure. A very small amount of technologist or radiologist annual exposure is from general radiography.

Mobile Radiography

Exposures taken with mobile x-ray units should be taken while wearing a 0.5 mm lead (Pb) equivalent apron with the exposure cord extended. The scatter from a routine portable chest x-ray taken at 80 kVp and 4 mAs is negligible at one meter from the patient. Measurements taken during these radiographs indicate exposures less than 0.1 mrem per film. It is highly unlikely that an excessive personnel exposure would be from multiple mobile radiographs.

Computed Tomography

Scatter exposures from CT scanners are most times not measurable in the control area. The largest source of scatter from the finely collimated beam is the patient. Scatter dose measurements taken 1 to 2 feet from the gantry opening are usually 2 to 5 mrads per slice and fall off rapidly with distance. Dose measurements at the foot of the patient table are less than mrad per slice and usually are not measurable at the control room window and door.

Mammography

Mammography radiograph techniques are commonly below 30 kVp. In addition the primary beam is limited to the image receptor (size of the film) and the operator barrier is shielded with at least 0.5 mm lead (Pb) equivalent material. Scatter dose measurement in the control area are usually not measurable.

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C-arm Fluo

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Annual Mammograms

The American College of Radiology (ACR) and American Cancer Society recommends **annual** screening mammograms for women over age 40.

Current data suggest that by the age of 40 there is probably no risk to the breast from irradiation and the benefit of reduced mortality from annual screening far exceeds the risk from radiation. In a population of 1 million women, 1500 cases of breast cancer surface clinically in a year. Without a screening program, the breast cancer fatality rate is

Special Problems with C-Arm fluoroscopy:

Usually no under the table shielding and over the table shielding is present as in conventional fluoro and x-ray. This is because the procedures requiring the c-arm fluoro such as surgery, catheter placement, pacemaker and prosthetic work require flexibility in the placement of x-ray tube.

The procedures mentioned in #1 require the physician and sometimes nurse and x-ray technologists to be close to the primary x-ray field and x-ray tube where the exposures are the highest.

To reduce dose:

- Increase distance from the patient
- Stand near the image intensifier end of the c-arm
- Always wear lead apron

The c-arm should be positioned with the patient as far from the x-ray tube and as close to the image intensifier as possible. This will minimize skin entry dose and optimize image quality.

- Use pulsed fluoro mode and "image hold" options if possible.

Exposure from Nuclear Medicine Patients Administered Radionuclides
Due to the low exposure rates and short half-lives of most **diagnostic** nuclear medicine radiopharmaceuticals there are no precautions for personnel and other patients coming in contact with the nuclear medicine patient. Dose rates are low enough that pregnant personnel should not have to restrict contact with these patients. Patients receiving **therapeutic administrations** of isotopes, e.g., NaI-131, may require special consideration and precautions to minimize exposure to other patients and personnel. Dose measurements from patients administered 20 to 30 mCi of Tc99m radiopharmaceuticals of cardiac stress tests approach 2 to 6 mR/hr approximately 1 meter from the patient.

So what about Annual Mammograms?
The American College of Radiology (ACR) and American Cancer Society recommend annual screening mammograms for women over the age of 40. Current data suggest that by the age of 40 there is probably no risk to the breast from irradiation and the benefits of reduced mortality from annual screening far exceeds the risk from radiation. In a population of 1 million women, 1500 cases of breast cancer surface clinically in a year. Without a screening program, the breast cancer fatality rate is about 50%. A screening program may reduce the fatality rate from breast cancer by 40%, or save about 300 lives.

There are special problems with C-Arm Fluoroscopy!!
Usually no under the table shielding and over the table shield is present with C-arm equipment, like there is with conventional fluoro and x-ray. This is because the procedures requiring c-arm fluoro, such as operations (particularly orthopedic operations), catheter placement, pacemaker and prosthetic work require flexibility in the positioning of the x-ray tube. As a consequence, medical personnel are often close to both the primary x-ray field AND the tube, where the exposures are the highest.

To reduce the dose:

Increase distance from the patient.
Stand near the image intensified end of the c-arm.
Wear lead aprons – ALWAYS.
Position c-arm with the patient as far from the x-ray tube and as close to the image intensifier as possible (minimizing skin entry dose and optimizing image quality).
If possible, use pulsed fluoro and image hold options.

RADIATION RISK

When compared to activities such as driving a car, boating, or hunting, x-ray examinations are safe or safer than many everyday activities. Note that the probability of death from radiation-induced cancer is much higher for smokers than diagnostic radiology procedures such as cardiac catheterization and lumbar spine radiographs. Please note that the increased risk of death from radiation-induced cancer from radiographic procedures is on the order of 0.1% compared to the normal risk of cancer of 20%.

Probability of Death from Radiation Induced Cancer and Other Causes

Activity (probability is based on one year's activity)		**Probability per 10,000 population exposed per year**
Smoking (all causes)	**30**	**or 3,000/million**
CT of kidneys	12.5	
Smoking (only Cancer)	12.0	
Mining	6.0	
Construction	3.9	
Farming	**3.6**	

Cardiac Catheterization	**3.3**	**or 330 per million**
Driving a car	2.4	
Anesthesiology (elderly patient)	2.0	
Excretory urogram	2.0	
Boating	0.5	
Anesthesiology (all patients)	**0.3**	**or 30 per million**
Hunting	0.3	
Anesthesiology (outpatients)	0.2	
Ionic contrast media	0.2	
AP lumbar spine	**0.06**	**or 6 per million**
Non-ionic contrast media	0.05	
Chest (PA and lateral	**0.02**	**or 2 per million**
Commercial airline flight (one flight only)	**0.002**	**or 2 per 10,000,000**

** Joel Gray. Safety (Risk) of Diagnostic Radiology Exposure. ACR, Radiation Risk - A Primer, 1996*

The National Academy of Sciences/National Research Council Committee on Biological Effects of Ionizing Radiation (BEIR) in their report (BEIR V) stated the single best estimate of radiation induced cancer mortality at low exposure levels is 0.04% per rem. This is in general agreement with the latest risk estimates from the International Council on Radiation Protection (JCRP) of a 0.05% increase per 1,000 mrem. (ANN ICRP22(1) 1991)

However, it should be noted that there is continued active debate on the emerging data on medical exposures to patients who undergo testing with MDCT. The exposures are considerably higher than those detected with conventional spiral or single detector CT. This is especially important for children and women of child-bearing age. Consequently, imaging with MDCT should not be undertaken if not medically necessary and imaging should be done with the understanding that the study will be tailored and programmed for the patient's size and that dose reduction will be used for younger patients.

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Radiation and Pregnancy
Pregnant workers are limited to 500 mrem over pregnancy because fetus is assumed to be 2 to 3 times more sensitive to radiation.

Personnel who may be exposed to radiation should contact the Radiation Safety Officer (RSO) if they are pregnant or planning to become pregnant. Instructions given to workers include information regarding prenatal exposure risks to the developing embryo and fetus. It is important to note that the mother assumes all risk until she specifically declares her pregnancy, in a written and signed statement to her supervisor or RSO.

What are your exposure levels?
Hospital limits your exposure to 1/10 state and NRC limits or 500 mrem/yr (state and NRC allow 5000 mrem/yr); this policy is called ALARA (As Low As Reasonably Achievable)

On the average your background exposure is approximately 110 mrem (0.3 x 365 days).
Occupational exposure (x-ray technologists, nuclear medicine technologists) averages approximately 100mrem.
Film badge reports subtract background.

Nurses in the OR and ER may have considerably less exposure than this, usually at minimum badge readings.
Office staff receives no radiation above background.

Occupational Category	Average annual dose (mrem)
Uranium miners	2300
Nuclear power operations	550
Radiotherapy	260
Nuclear Medicine and Diagnostic Radiology	**100**
Radiology special procedures	1800
Cardiologists (cardiac catheterization)	1600
Adapted from NCRP Report No. 101	

Congenital abnormalities:
Normal incidence of congenital abnormality is 4 - 6 per 100 births (400-600 per 10,000).

The estimated risk from 1,000 mrem during pregnancy increases risk of congenital abnormalities by 0.05% or 5 more per 10,000.

Childhood cancer;
Normal risk is 4.3 per 100,000.

1000 mrem during pregnancy increases risk by 0.023 to 0.025% or 23-58/100,000.

Miscarriage:
Normal risk is 25-50%.
1,000 mrem during pregnancy increases risk by 0.1%.

Sterility:
10,000 mrem causes temporary and 200,000 mrem, permanent sterility in men.
350,000 mrem causes permanent sterility in women.

Cataracts:
lifetime cumulative dose of approximately 400 rem.