Radiation Safety for New Medical Physics Graduate Students

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Background and Purpose of This Training

- This is intended as a brief introduction to radiation safety from the perspective of a Medical Physicist.
  - Have a healthy respect for radiation without an undue fear of it.

- The learning objectives are:
  - To point out the sources of ionizing radiation in everyday life and at work.
  - To present an overview of the health effects of ionizing radiation.
  - To show basic concepts and techniques used to protect against exposure to ionizing radiation.

- Further training in Radiation Safety can be found at: https://ehs.wisc.edu/radiation-safety-training/

Outline

- Ionizing Radiation
  - Definition, Quantities & Units
- Levels of Radiation Exposure
  - Background & Medical
- Health Effects of Radiation Exposure
  - Stochastic & Deterministic
- Limits on Radiation Exposure
- Rationale for Exposure Limits
- Minimizing Radiation Exposure
  - Time, Distance, Shielding, Containment

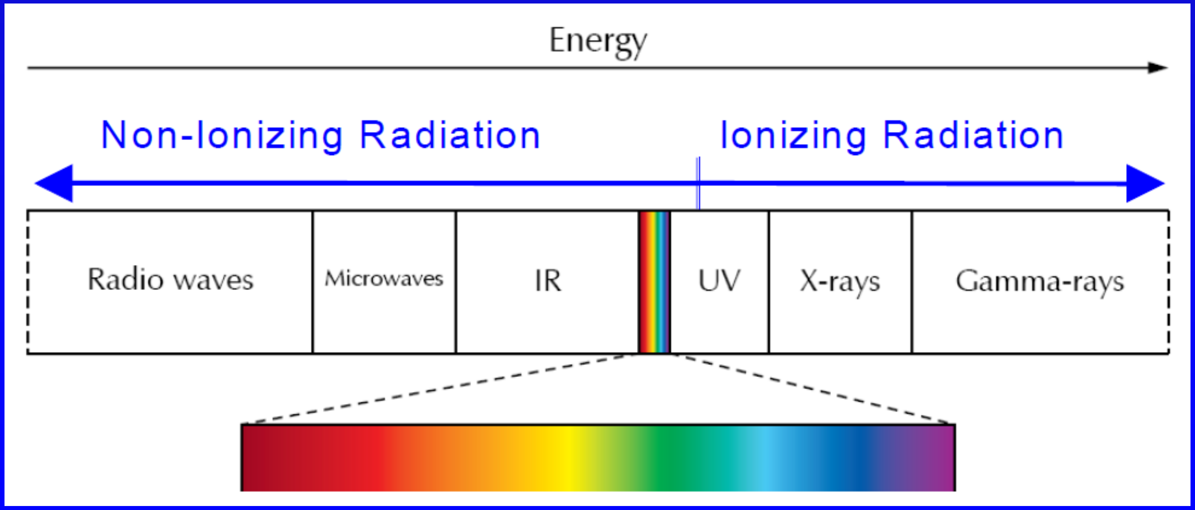
Definition of Ionizing Radiation

- **Radiation can be thought of as energy in motion.**

- Electromagnetic radiation is pure energy that moves at the speed of light in the form of photons and includes: radio waves; microwaves; infrared, visible and ultraviolet light; x-rays and γ-rays. A key difference between these forms of electromagnetic radiation is the amount of **energy** that each photon carries.

- Some ultraviolet light, and X-rays and Gamma-rays have **enough energy to remove electrons from atoms** as they are absorbed, forming positive and negatively charged ions. These forms of radiation are called **ionizing radiation**.

- Radio waves, microwaves, infrared and visible light do not have enough energy to ionize atoms. These are all forms of **non-ionizing radiation**.



Units and Measures of Ionizing Radiation – Absorbed Dose & Dose Equivalent

- ## Absorbed Dose
- Units: mGray (mGy) or rad (r)
- The radiation energy absorbed (per unit mass) ***at a point***.
  - Different tissues absorb radiation differently (for example bone absorbs more x-rays than soft tissue so for the same intensity of incident radiation, the absorbed dose in bone tends to be higher).
- Limitations: Absorbed dose does not take into account the amount of tissue exposed, the sensitivity of that tissue or the relative biological effects of different types of radiation.
- Uses: Along with weighting factors, absorbed dose is used for estimating the effect of ionizing radiation on an exposed tissue or organ.
- ## Dose Equivalent
- Units: mSieverts or rem
- Takes into account relative biological effectiveness of different types of radiation.
  - Examples: x-rays W_r = 1.0, α-particles W_r = 20

Units and Measures of Ionizing Radiation – Effective Dose

- ## Effective Dose

- Units: mSievert (mSv) or mrem

- The effective dose is the average dose equivalent to each organ system multiplied by a "tissue weighting factor" (W_T) that takes into account the relative sensitivity of the tissue to radiation damage and how that potential damage would affect the person during their lifetime (and the life of their offspring, considering genetic effects).

- Effective dose cannot be measured directly but must be calculated based on estimates of the absorbed dose to all tissues of the body, and estimates of the effects of ionizing radiation on the body.

- Limitations: Tissue weighting factors depend on the dose and the effect on the tissue. They are only defined for low doses and are averaged over the entire population even though the effect on an individual depends on many factors including age, health condition, etc. There is a lot of uncertainty in the calculation of effective dose.

- Uses: Effective dose can be used to compare relative risks of different types of radiation exposure, e.g. an x-ray imaging procedure vs. natural background radiation, but should not be used (by itself) to estimate the risk of an individual to health effects from a particular radiation exposure.

Tissue Weighting Factors

▪ Red Bone Marrow, Colon, Lung, Stomach, Breast, Remainder Tissues	0.12
▪ Gonads	0.08
▪ Bladder, Esophagus, Liver, Thyroid	0.04
▪ Bone Surfaces, Brain, Salivary Glands, Skin	0.01

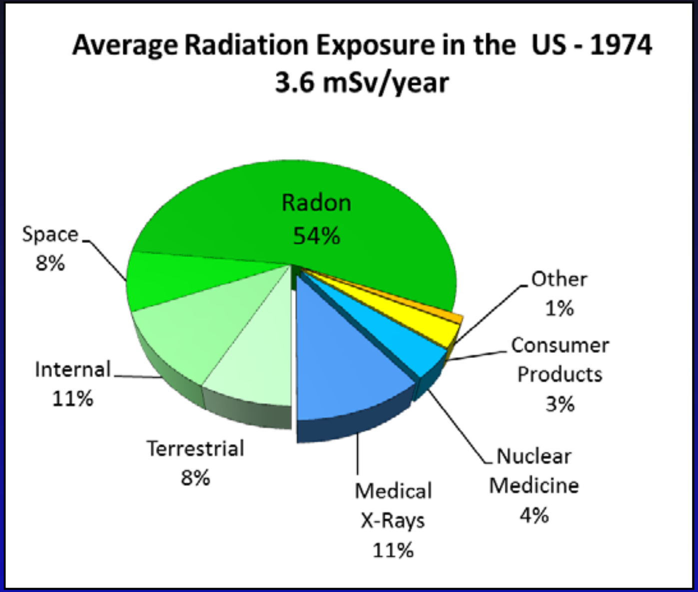
Tissue weighting factors are based on follow-up for many years of populations exposed to higher levels of ionizing radiation than normal.

Levels of Radiation Exposure

- Average Annual Effective Dose in the US:
- **1974:** 3.6 mSv (360 mrem or 1 mrem per day) for non-smokers.
  - 3 mSv from natural sources (This varies widely from place to place.)
  - 0.6 mSv from man-made sources.
- **2006:** 6.2 mSv (620 mrem). 70% Increase due to the increased use of Computed Tomography and Nuclear Medicine.
- For a typical smoker, the average effective dose is 13 mSv (1,300 mrem) per year. Increase due to radioactive polonium and lead in tobacco leaves.
- A round trip coast-to-coast flight: 0.03 mSv.
- A Chest x-ray: 0.10 mSv.
- A Head CT scan: 2 mSv.
- A Body CT scan: 5 to 10 mSv.

Sources of Radiation Exposure to the Population of the US

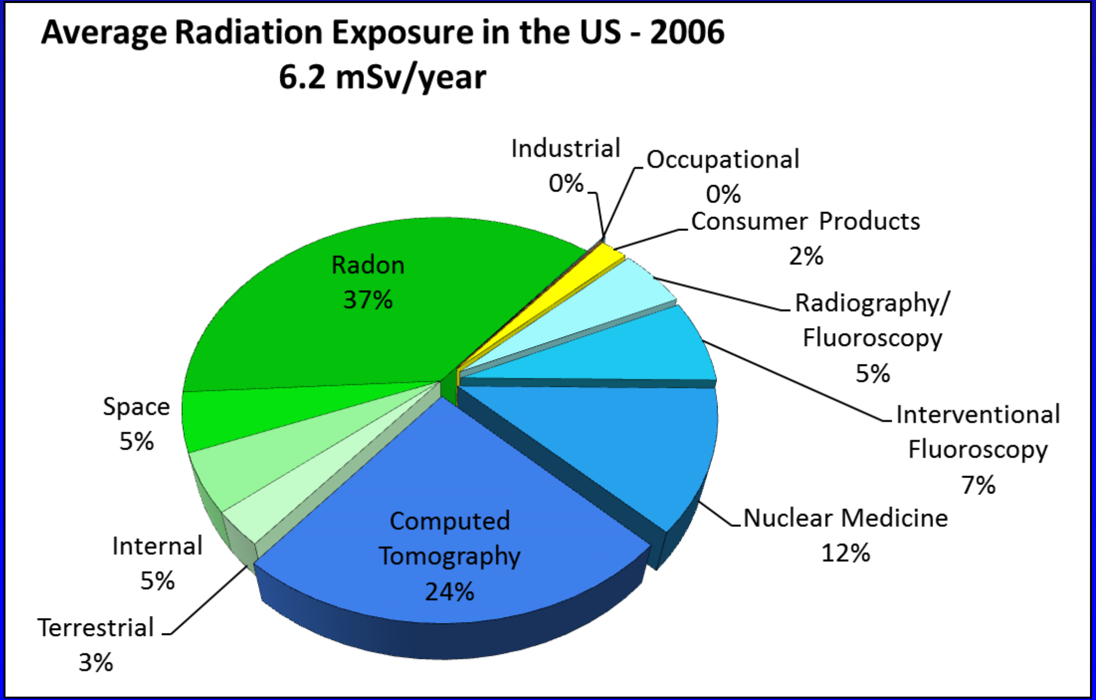
In 1974:



In 1974, approximately 80% of radiation was from natural sources. In 2006, man-made exposures increased to approximately 50% of the total, while natural sources remained nearly constant.

Natural background radiation varies considerably in magnitude in different areas throughout the world. Radon gas is the largest source of natural radiation exposure.

In 2006:



Medical uses of radiation account for the majority of man-made radiation exposures.

Other sources include building materials, commercial air travel, etc.

Tobacco products are also a significant source of exposure but are excluded from these totals.

The Basis For Potential Health Effects of Ionizing Radiation – DNA Damage

- **When atoms are ionized**, the **chemical bonds** holding them to other atoms within a molecule **can be broken**.

- **Broken chemical bonds can alter the structure of molecules**. If a molecule that is **altered** (damaged) through ionization happens to be **DNA**, then it **can potentially have an adverse effect on a person's health** because DNA molecules contain the genetic information needed by cells to make the proteins that enable them to perform their specific functions.

- Since our bodies are continuously exposed to ionizing radiation, as well as many ionizing chemicals, our DNA molecules are constantly being damaged. Thankfully though, **our cells are continuously and very effectively repairing that DNA damage**.

Health Effects from Unrepaired DNA Damage

- **Only in very rare cases are altered DNA molecules not repaired.** When that happens, usually the cell dies and is replaced. However, if a cell with altered DNA does survive, in some cases it may lose the ability to regulate its growth and proliferation. **This can lead to certain kinds of cancers**, which are essentially tissues growing out of control.
- **Surviving sperm and egg cells with DNA damage can also pass on the altered DNA to our offspring as genetic abnormalities.**
- If the number of cells that are killed or damaged is very extensive (at very high doses of radiation) the structure or function of tissues and organs can be compromised, leading to effects such as skin reddening, hair loss, loss of thyroid function, cataracts, etc.

Latency Period and Dose Rate Dependence of Radiation Effects

- Latency period – 24 hours to 40 years, depending on the effect. Nothing happens right away.

- Dose rate effect – A single large exposure in a short time period has a greater effect than small exposures over time.
  - Much of the radiation damage to DNA can be repaired by cells, if not too extensive.
  - Most of the repair to DNA occurs within about 6 hours so high doses can be repeated at 24 hour intervals, with reduced effect.

Health Effects From **Low** Doses of Ionizing Radiation

- The following are all low doses of ionizing radiation that occur in the medical setting:
  - doses to patients and staff from natural background radiation,
  - doses to patients from all diagnostic x-ray imaging procedures,
  - doses to patients undergoing most x-ray image guided interventional procedures, and
  - doses to staff working in the vicinity of x-ray machines

- **Low Dose Effects –** Adverse effects from low doses of radiation are thought to be caused by unrepaired DNA damage that does not kill the cell, but causes it to become cancerous or to pass on the damaged DNA as a genetic defect.

- Potential **health effects** that can occur at **low doses** of ionizing radiation are **cancer or genetic abnormalities**.

- Since these effects may be caused by only a single or small number of DNA molecules that are damaged but not repaired, the severity of the effect does not depend on the radiation dose. Rather, ***the chances of an effect occurring increases as the radiation dose increases. These effects are called "Stochastic Effects".***

- The chances of these effects being caused by radiation are very small at radiation doses that are normally encountered in everyday life, the workplace, or from x-ray imaging procedures.

Risks From **Low** Doses of Ionizing Radiation Compared to Other Risks

- **Cancer and genetic abnormalities are much more likely to be caused by factors other than ionizing radiation.**

- In the US, approximately 44% of the population will eventually develop cancer during their lifetime. The lifetime risk of fatal cancer in the US is approximately 22%. The vast majority of those cancers are caused by factors other than ionizing radiation.

- For example, a typical x-ray technologist may receive a total work related radiation dose of 1,000 mrem over their entire career. Although it's too small to be measured, the best estimate for that technologist's increased risk of a fatal cancer from a lifetime of radiation exposure at work is about 0.05%. On average, this would mean an increase from about 22% to around 22.05% risk for a fatal cancer.

- In comparison, the risk of dying in a fatal crash riding 42,000 miles in a vehicle is also equal to 0.05%.

- *Interesting fact: The average work-related radiation dose for airline crews is 3,000 mrem per year from flying high in the atmosphere where ionizing radiation from outer space is more intense.*

Risks From **Low** Doses of Ionizing Radiation – Genetic Effects

- Radiation induced genetic effects
  - There is a high incidence of spontaneous mutations.
    - Normal incidence of abnormalities per 1,000,000 live births is 110,000 (11%).
    - A dose of 1,000 mrem increases the abnormality rate per million by 22 to 110 abnormalities. This is a 0.02% to 0.1% increased chance of an abnormality.
  - The dose at which the rate of abnormalities is doubled in humans is approximately 200,000 mrem.
  - *Note: Radiation induced genetic effects have never been unequivocally demonstrated in any human, including the atomic bomb victims. Estimates of human genetic effects are derived from animal studies.*

Health Effects From **High** Doses of Ionizing Radiation

- The following are all high doses of ionizing radiation that occur in the medical setting:
  - doses to radiotherapy patients, and
  - doses to some patients undergoing long, difficult x-ray image guided interventional procedures.

- **High Dose Effects – High doses of radiation have the potential to kill a significant fraction of the cells in a tissue.** This loss of cells can compromise tissue function or structure, resulting in adverse health effects.

- The most common high dose effects are skin reddening and burning, hair loss, loss of thyroid function, cataracts, and loss of fertility.

- **High dose effects occur only above a threshold dose** that depends on the tissues affected. **Below the threshold dose, no observable effect occurs.** As the dose increases above the threshold the number of cells that are lost increases as does the severity of the effect.

- High dose effects are also called deterministic effects.

Threshold Doses for **High** Dose Radiation Effects

- **The threshold doses for all high dose effects are thought to be significantly above the radiation doses allowed for radiation workers or the general public for any non-medical purposes.**
- Occasionally threshold doses for high dose effects are exceeded during complicated image guided interventional procedures. In these cases, the risks of radiation effects are weighed against the significant benefit to the patient from the procedure.
- High doses of radiation, when administered appropriately, can also have therapeutic effects. For example, about half of all cancer patients are treated with high doses of radiation to help control their cancer. High doses of radiation administered to the thyroid can also be used to control thyroid function in patients with hyperthyroidism.

Case from UW-Hospital

Figure 3

a. b.

Figure 3: **(a)** Early erythema and developing moist desquamation in a diabetic woman caused by a localization radiographic exposure. Notice well-demarcated x-ray field and protection of the region of the skin shielded by the lead cross hairs in the field. (Reprinted, with permission from reference 70.) **(b)** Healing of moist desquamation by means of epithelial regeneration, both from epithelial stem cells extending inward from margin of irradiated area and from shadow of the lead cross hairs in the field. (Image courtesy of B. R. Thomadsen, PhD, University of Wisconsin, Madison.)

Example of a Severe Skin Effect from an Interventional Procedure With X-ray Imaging

At 3 weeks

At 6.5 months

Surgical flap

Following ablation procedure under fluoroscopic guidance with arm in beam near the x-ray tube with the spacer cone removed. About 20 minutes of fluoroscopy was used.

Regulatory Limits on Whole Body Radiation Exposure

- *Limits do not include medical exposures.*
- Members of the General Public: 1 mSv (100 mrem) per year above background (effective dose).
- Radiation Workers: 50 mSv (5 rem) in a year *with a lifetime average recommendation of no greater than 10 mSv/year (1 rem/year)*.
- Embryo & Fetus of a Radiation Worker: 5 mSv (500 mrem) total during gestation, no more than 0.5 mSv (50 mrem) per month recommended.
- 150 mSv to lens of eye (New recommendations: 50 mSv max in a single year, no greater than 20 mSv per year averaged over a 5 year period.)
- 500 mSv to extremities, skin, or any individual organ
- *Limits are set at levels comparable to background radiation, well within the range of natural background radiation throughout the world. These are thought to be safe levels.*

Rationale for Regulatory Limits on Radiation Exposure

- Within these limits one expects never to see deterministic (high dose) effects, and the probability of stochastic effects is comparable to the risks associated with working in “safe” industries.

- The risk to any individual at these levels is insignificant but the risk to the population as a whole is perhaps more significant. This is the reason for lower dose limits for the general population than for radiation workers.

Goals of the Radiation Protection Program

- The goals of radiation protection for workers are:
  - **to limit the risk of low dose effects** to a level that is no greater than the risks in other work settings that are considered safe such as offices, factories, etc. and
  - **to prevent any radiation doses** from occurring **that** would **exceed the thresholds for high dose effects.**
- To achieve these goals, all radiation exposures are kept **A**s **L**ow as **R**easonably **A**chievable (ALARA), meaning that reasonable steps should be taken to limit radiation exposure to any individual without compromising the care provided to patients or placing an undue burden on the staff.

Minimizing Radiation Exposures

- The basic principles of radiation protection:

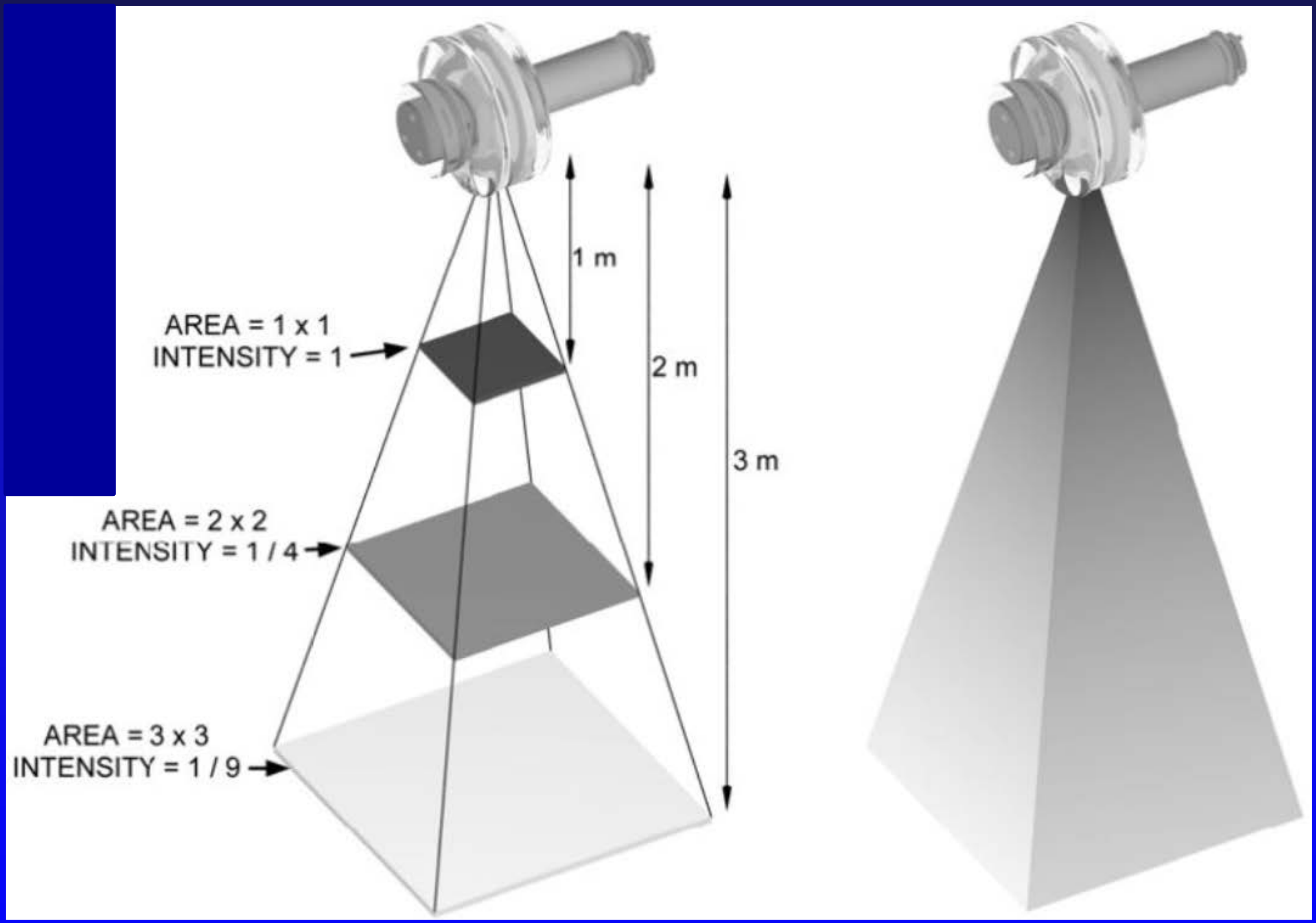
- Time
  - Minimize the time that you are exposed to radiation.
- Distance
  - Maximize the distance between you and the radiation source.
- Shielding
  - Put an effective shield (lead for x-rays, other materials for particles) between you and the radiation source.

- Containment (if working with radioactive materials)
  - Keep radioactive materials contained.

Time

- If you cut the amount of time that you are exposed to radiation in half, your dose is also cut in half.
- X-ray machines only produce radiation when an exposure switch is activated.
- Radioactive materials emit radiation all the time, so to use time for radiation protection, they should only be removed from effective shielding for short periods of time.
- Radioactive materials that are ingested will produce exposure until they are cleared biologically or decay away.

Radiation Intensity Fall-off with Distance From the Source



Radiation intensity falls off as 1/distance from the source squared.

The dose rate is very high close to the x-ray source.

Distance and Shielding

- In an x-ray room, to effectively use distance and shielding to protect yourself, you need to be able to identify the sources of radiation and their locations.
- There are 3 sources of radiation within an x-ray room.

3 Sources of Radiation within an X-ray Room

- Primary Beam
  - Between the X-ray tube and image receptor (across the opening of the C in a C-arm fluoroscope)
  - Only a patient should be exposed to the primary beam (unless lead gloves are worn).
  - Very high radiation dose rate, limited in size.
- Scattered Radiation
  - The patient (or a phantom) is the most significant source of scattered radiation.
  - The surface of the patient closest to the x-ray tube produces the most scatter.
  - *Scatter is the greatest source of exposure for staff.*
- Leakage Radiation
  - A small amount of radiation “leaks” out in all directions from the x-ray tube when it is on.

Scattered Radiation From the Patient

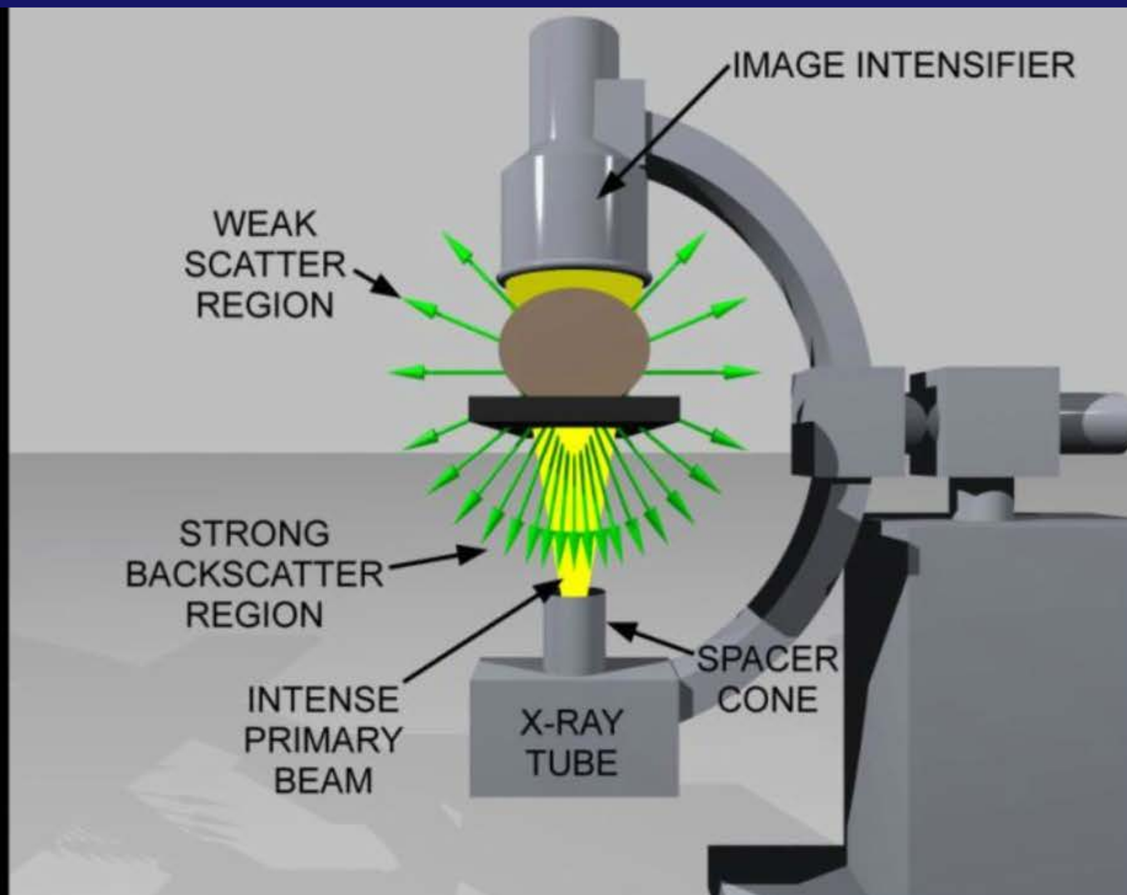


Figure 55: Depiction of the scattered radiation emitted from a patient during a C-arm procedure. There is strong backscatter towards the x-ray tube source and reduced forward scatter towards the image receptor because the patient absorbs much of the scatter produced inside the patient.

Shielding

- Lead is very effective at absorbing x-rays, so **using leaded devices such as lead aprons, thyroid shields, leaded glasses and moveable lead shields is a good way to protect yourself from ionizing radiation**.
- These devices typically absorb at least 97%of the x-rays falling on them. The shield forms a shadow with very low radiation intensity behind it.
- As with distance, it is important to **put the shielding between yourself and the source of radiation (the patient)**. Aprons that have only front panels are not effective when your back is turned to the patient.
- Lead aprons are not effective at the high energies used for radiation therapy, and are less effective for high energy gamma rays used in nuclear medicine.
- The best shielding is provided by moveable lead shields. Lead drapes on the x-ray table, portable lead panels with clear leaded windows, and clear lead Acrylic shields are some examples of these. They contain more lead than aprons and absorb an even higher percentage of the radiation scattered from the patient.


Keep detector close to patient.
Collimate.
Position shield in between patient and operator.
Radiation safety cap.
Radiation safety glasses (with side panels).
Lead skirt and vest with thyroid collar.
Movable lead skirt.
Disposable shielding.

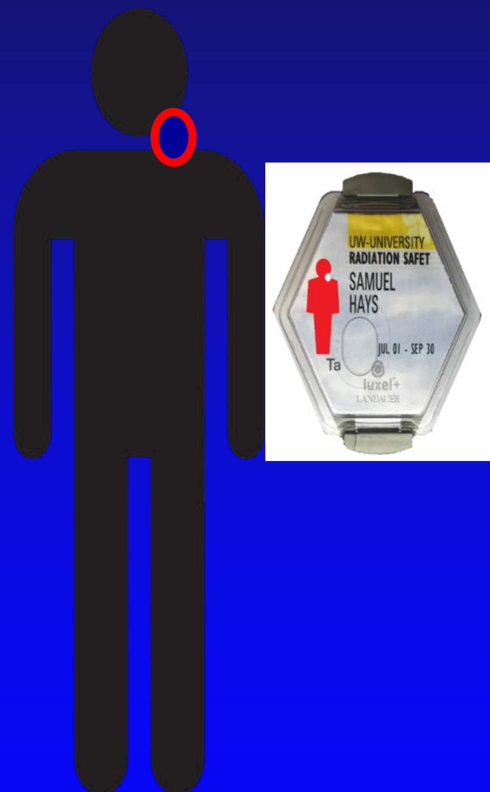
Use of Personnel Dosimeters

Personnel dose monitoring is required (Wisconsin Administrative code DHS 157.25):

- whenever there is a good chance that a worker will receive a dose higher than 10% of the annual dose limit for radiation workers. (i.e. 5 mSv per year effective dose.)
- for anyone working within 2 meters of operating medical fluoroscopic equipment while it is activated
- for a declared pregnant woman likely to receive, in one year, a dose in excess of one mSv.

What badges are issued?

Where should I Wear the Dosimeter?



Check Your Own Results

1. Go to **www.wisc.edu** and search for “**Radiation Safety**”

> RADIATION SAFETY – ENVIRONMENT, HEALTH & SAFETY – UW
>
> We provide the following services: Policy and standard development related to **radiation safety** regulatory matters with a focus on cost containment. University of ...
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2. Or go directly to **ehs.wisc.edu/radiation-safety/**
3. Click on the “Dosimetry” link
4. Follow instructions for UW Hospital
5. You’ll need your badge ID number (on back of your badge)