Radiation Safety Training

MXR THE IMAGING SOLUTIONS COMPANY™

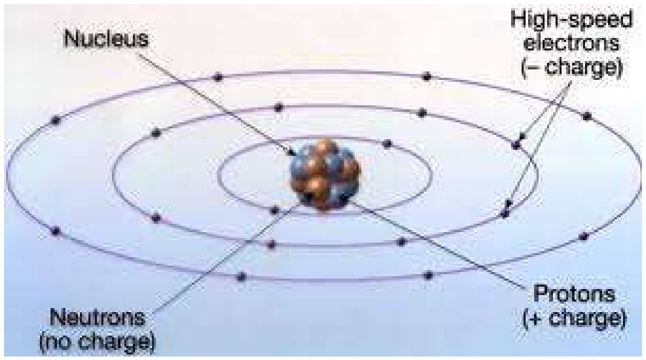
Course Objectives

Objective of this course is to provide a high level review of the following Radiation Safety Topics, focused on ionizing radiation applications in medical imaging:

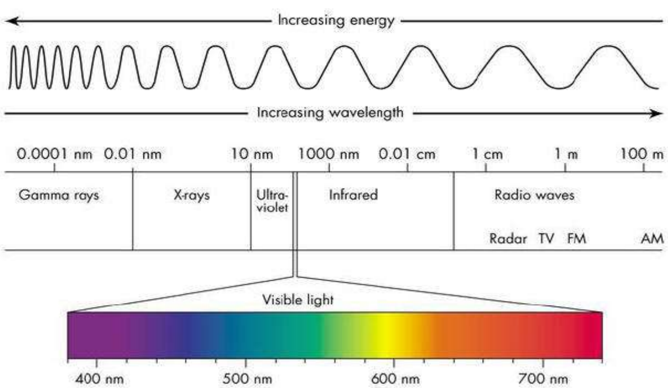
- Introduction to Health Physics and Scientific Fundamentals
- Radioactive Materials
- Biological effects of Radiation
- External Dose Assessment
- Use of Personal Dosimeters

Introduction to Health Physics and Scientific Fundamentals

Structure of an Atom & How it Works



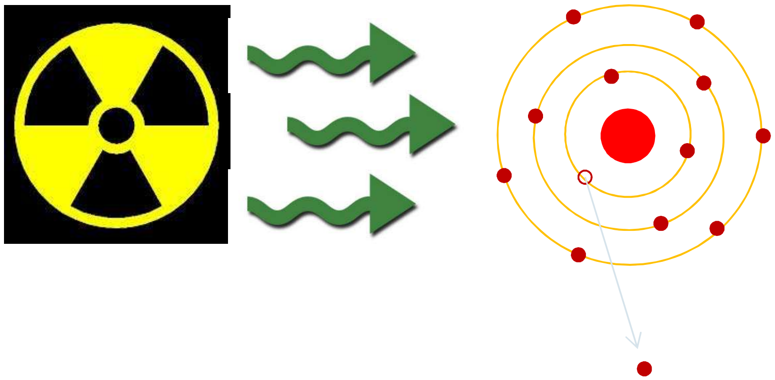
- The atom is a basic unit of matter that consists of a dense central nucleus surrounded by cloud of negativity charged electrons.
- The electrons are bound to the nucleus by electromagnetic forces.



- The atoms that make up our bodies absorb photons as well. Lower energy waves do not possess enough energy to excite any of our electrons. However, x-ray photons do.
- Smaller atoms, like those that comprise our soft tissue, hold their electrons closer to the nucleus so the change in energy between electron orbitals is relatively small. Therefore, when they come in contact with the x-ray photon they will knock an electron away from the atom altogether.
- Larger atoms, like the calcium atoms comprising our bones, have greater energy differences between electron orbitals, so they absorb those x-ray photons instead of getting excited by them.

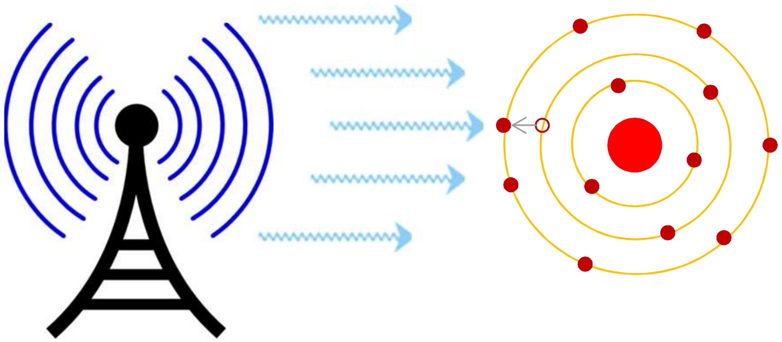
Ionizing Electromagnetic Radiation

- Ionizing electromagnetic radiation consists of photons possessing enough energy to completely free electrons from atoms.
  - Compton Scattering
- When one or more electrons are gained or lost a positive or negative charged ion is produced.
- The types of ionizing radiation we will encounter are x-rays mainly produced by x-ray generating equipment, and radioactive material. Radioactive materials can produce α (alpha) particles, β^- particles (electrons), β^+ particles (positrons), and γ (gamma) rays.



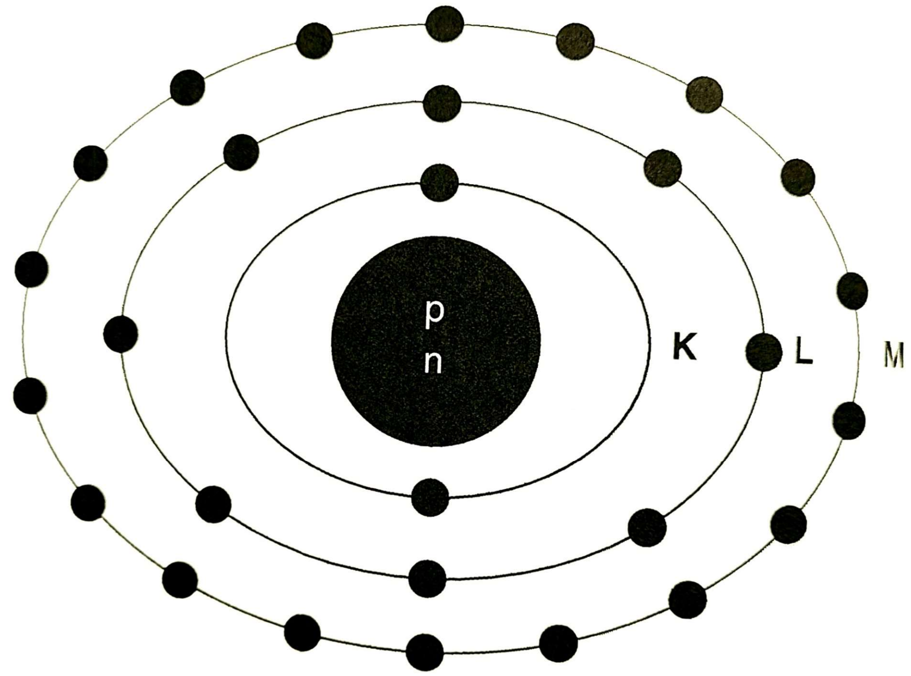
Non-Ionizing Electromagnetic Radiation

- Non-ionizing electromagnetic radiation consists of photons that do not possess sufficient energy to liberate an electron.
- However, non-ionizing electromagnetic radiation may have enough energy to excite electrons, that causes them to move to a higher energy state.
- Examples include near ultraviolet rays, visible light, infrared light, microwaves, and radio waves.



Radioactive Material

- Matter is composed of atoms made up of protons, neutrons, and electrons.
- An atom has a nucleus containing protons and neutrons.
- Electrons rotate around the nucleus.
- The number of electrons is equal to the number of protons.
- The number of protons is known as the atomic number.
- The sum of the protons and the neutrons is the atomic mass number.



Radionuclides

- A stable combination of protons and neutrons in a nucleus makes an atom called a nuclide.
- An unstable combination makes an atom called a radionuclide.
- Radionuclides produce ionizing radiation in charged particle form or in photons.

Nuclide

$$^{19}_{9}F_{10}$$

Mass number

Atomic number (number of protons)

Number of Neutrons

Radionuclide

$$^{18}_{9}F_{9}$$

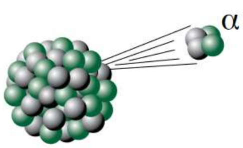
Radionuclides are unstable, and therefore decay by emission of ionizing radiation. There are several types of radioactive decay:

- α – alpha
- β^- – beta negative (electron)
- β^+ - beta positive (positron)
- γ - gamma

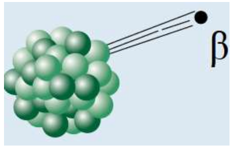
Radioactive Decay

α (alpha) and β (beta) radiation are charged particles with mass.

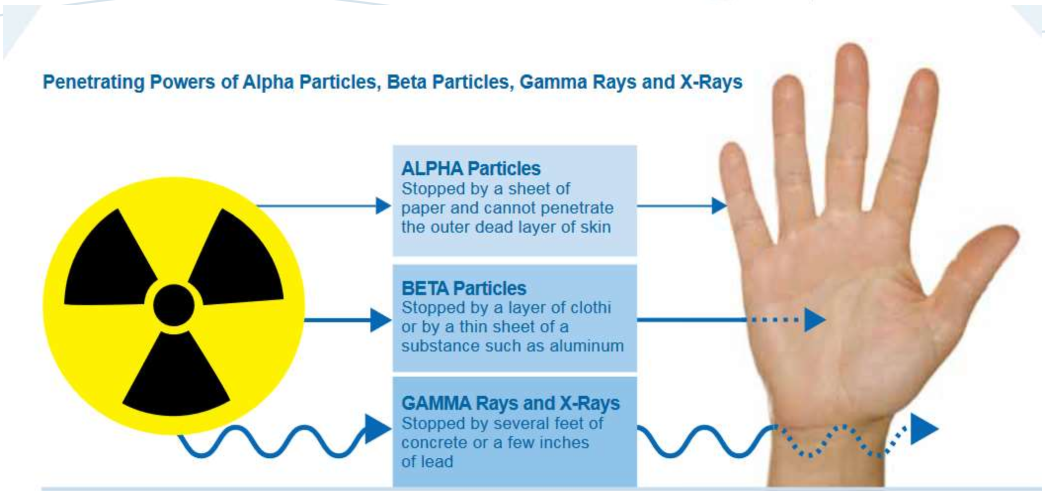
X-ray and γ (gamma) rays are photons without mass or charge emitted as energy.

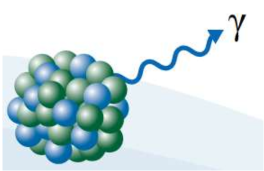


α particles are large, and composed of 2 protons and 2 neutrons (helium nucleus). They have a positive charge, and interact with matter. Because they are large and have a short range, they are easily shielded by paper or skin, but once ingested will cause cellular damage.



β particles are smaller than α particles, but with greater penetrating power. The can either be negatively or positively charged in the form of electrons or positrons. The particles themselves are easily shielded, but when they interact with matter, they can produce γ photons, which are much more penetrating.





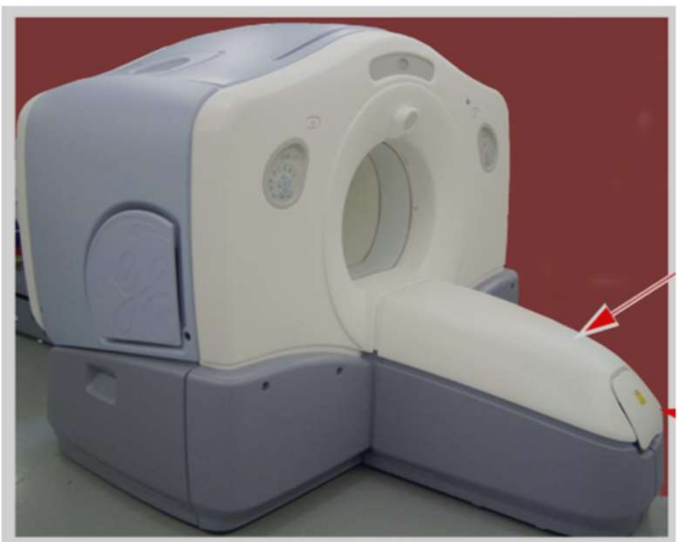
γ rays are high energy photons that penetrate through the body and are only stopped by very dense and thick substrates. They can cause ionizations which damage tissue and DNA.

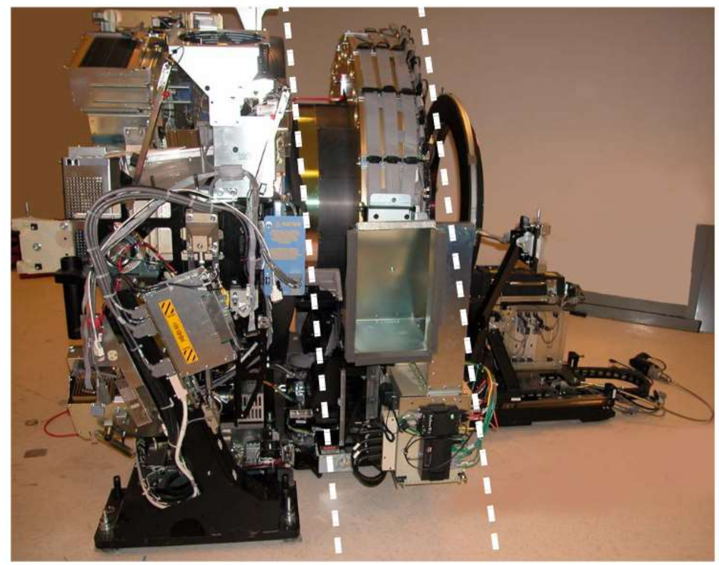
x rays are also pure energy, but lower than γ rays. X rays are most often produced by x ray generating equipment (x-ray and computed tomography). They are also produced by bremsstrahlung, which will be discussed further.

Positron Emission Tomography

The types of ionizing radiation encountered in PET/CT are:

- β^+ (positron) – a positron is a positively charged electron which is antimatter. When antimatter (positron) and matter (electron) collide, an event called an annihilation occurs. The particles are destroyed and converted into two high energy γ photons at 511 kiloelectron volts.
- γ (gamma) photons – The two photons from the positron annihilation emit in opposite directions, which form the basis for PET imaging.
- X-rays are produced by the CT part of the PET/CT system.





CT Gantry (Typical H3 Shown) PET Image Ring PET Trailer

PET Radiation Safety Considerations

ALARA (As Low As Reasonably Achievable) and Time, Distance, and Shielding apply to PET radiation safety. There are some additional considerations:

- Bremsstrahlung – Mentioned in a previous slide, bremsstrahlung in the PET frame of reference is consequential gamma emission from positrons passing through a thin high density shield like a lead apron. Lead aprons are often used to shield parts of the body that do not need to be imaged during x-ray imaging, and are also used sometimes during CT imaging. Lead aprons should not be used during PET imaging due to the consequent production of gamma rays when positrons penetrate the lead apron.
- Liquid sources – only PET trained personnel might handle liquid radioactive sources. Liquid sources can spill and contaminate those who handle them, or the area where the source is spilled. Special precautions are indicated for spills which require specific training. In the event there is a spill of liquid radioactive material, contact the RSO or Authorized User. Contact information will be on the next slide.
- Sealed sources – are handled by PET trained personnel. They are wipe tested when received at Nationwide to ensure that no removable contamination is present. Because the sources are sealed, they cannot spill or contaminate people or an area unless broken. Once wipe-tested, ALARA and Time, Distance and Shielding are the safety measures indicated.

Radioactive Sources

The radioactive sources on our license are:

- Fluorine 18 (F-18) – This comes in the form of FDG which is fluorodeoxyglucose. It is the F-18 infused glucose solution used in PET imaging and calibrations. This is a liquid source and is delivered in a syringe. It has a half-life of about 2 hours, which means its activity decreases by half every 2 hours.
- Germanium 68 (Ge-68) – This comes in the form of a sealed pin source and is kept on the PET system source loader when in use. It is only used for calibration. It has a half-life of about 9 months, and is good for about 2 half-lives.
- The sources are kept in the hot lab, located near the PET test and training bays at Nationwide. The sources are locked or accounted for at all times.

RSO – Radiation Safety Officer

- Mike Davis – (414) 841-8072

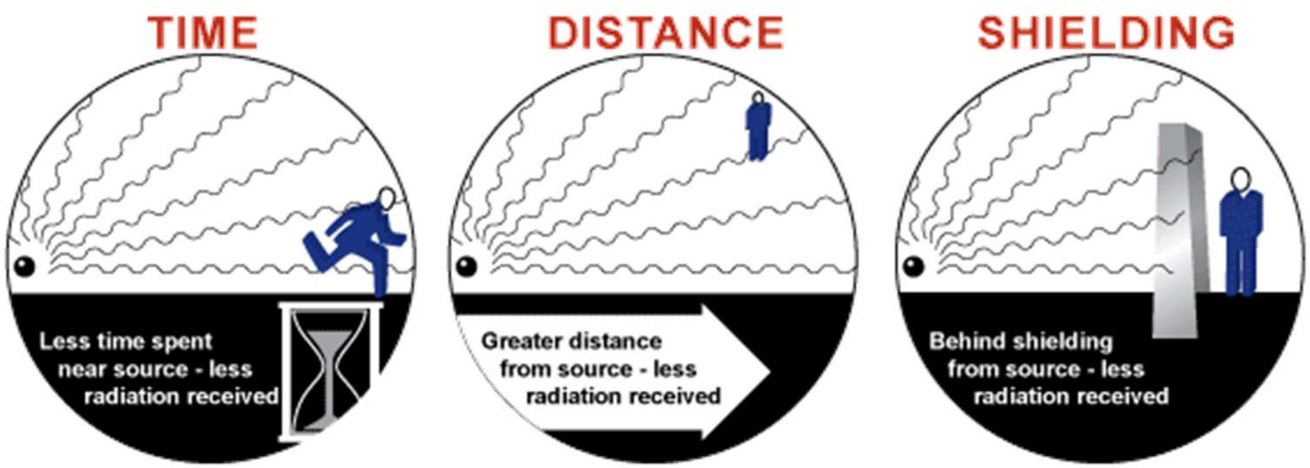
AU – Authorized User

- Tavish McGregor– (801) 674-2668

Radiation Protection Practices

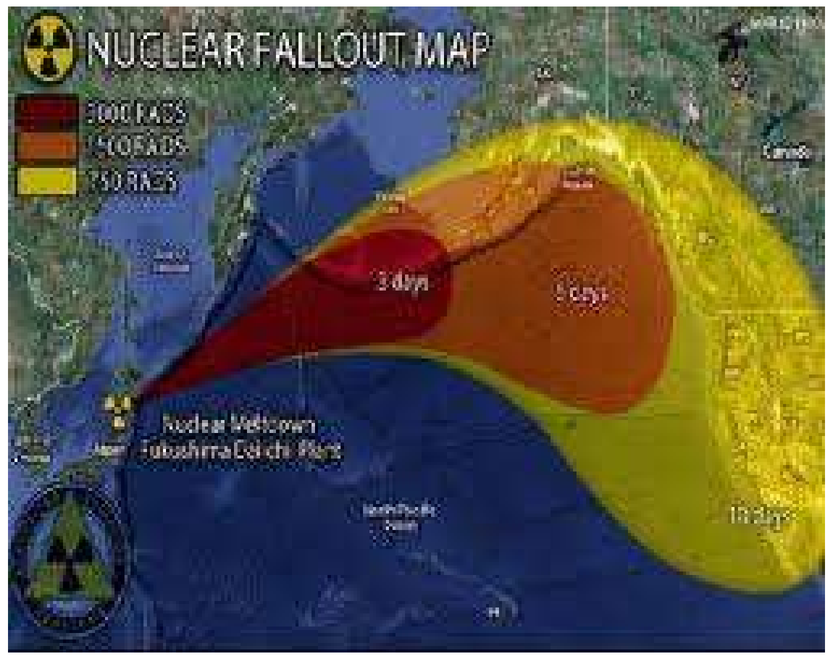
3 ways of controlling exposure to radiation

- Limiting the time spent near the radiation source
- Increasing the distance away from the source
- Using shielding to stop or reduce the level of radiation



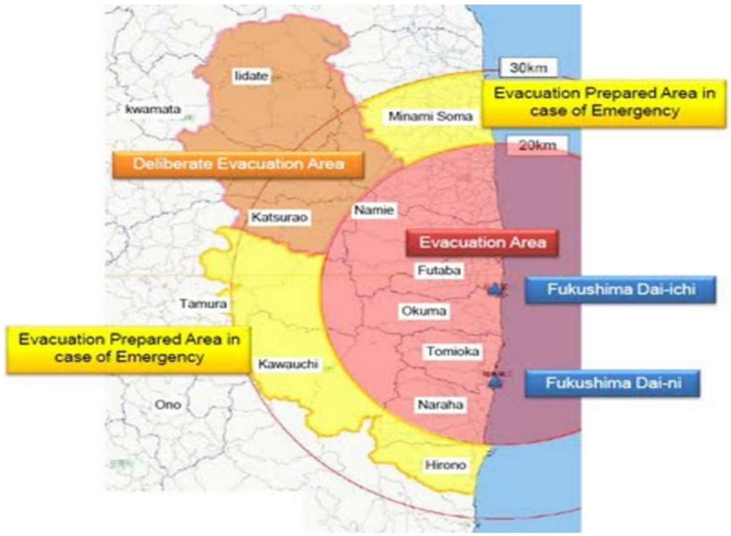
Time

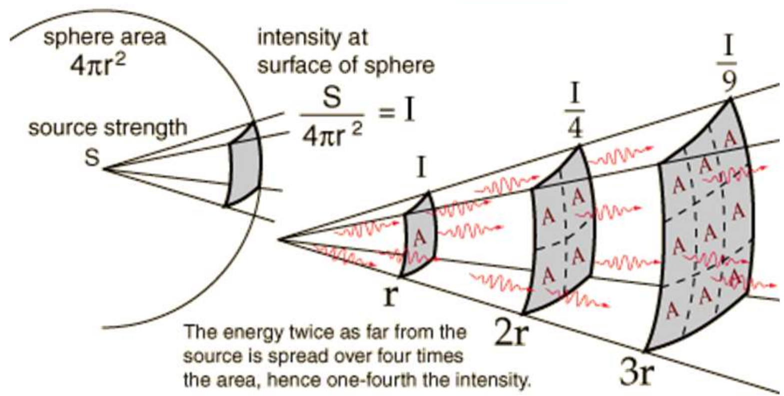
- Radiation dose is directly proportional to the time spent in the radiation
- A person should not stay near a source of radiation any longer than necessary
- Dose = (Dose Rate)(Time)
  - ➢ Both absorbed dose and effective dose are dependent on time



Distance

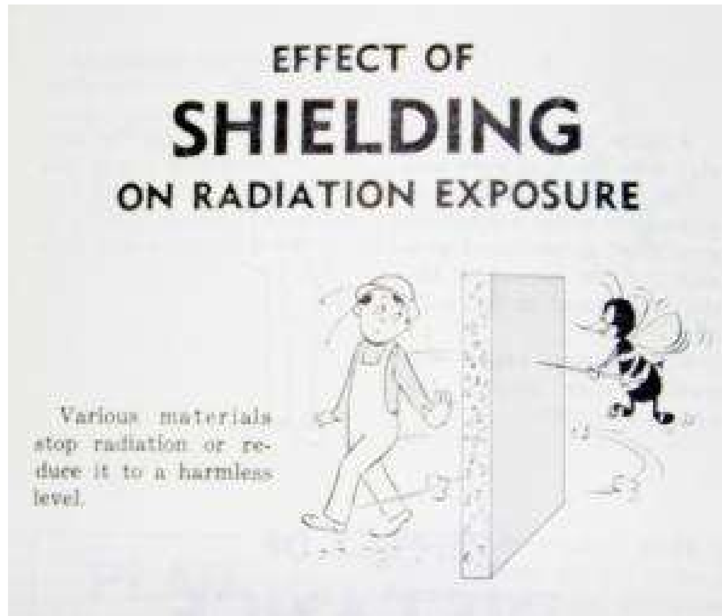
- Increasing distance from the source of radiation will reduce the amount of radiation received
- As radiation travels from the source, it scatters and becomes less intense
  - Standing near a fire
- All measures of exposure will drop off by the inverse square law





Shielding

- Placing something between the radiographer and the source of radiation
- In general, the more dense the material the more shielding it will provide
  - Leaded glass and lead aprons



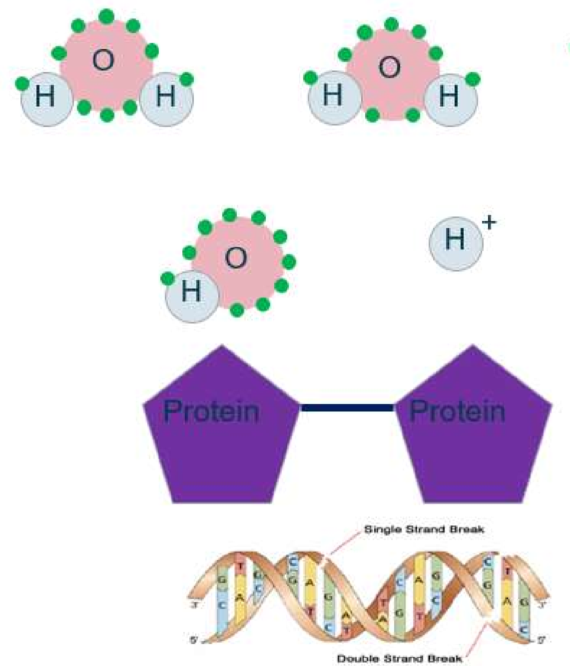
ALARA

- Current guidelines are based on the very conservative assumption that there is no safe level of exposure.
- This assumption has led to the general philosophy of not only keeping exposures below recommended levels but also maintaining all exposure, “as low as reasonably achievable” (ALARA).
- ALARA means that every reasonable effort must be made to keep the dose to workers and the public as far below the required limits as possible.

Biological Effects of Radiation

Ionizing Radiation Effect on Cells

- Ionizing radiation affects tissue on a cellular level by breaking chemical bonds and altering the molecular structures.
- Despite many years of research, there is still an element of doubt regarding the critical cell targets (i.e. what cell structures must be damaged by radiation to kill it).
- Radiation damage results from damage to biological molecules, particularly DNA, from ionization and excitation events, ultimately resulting in cell transformation or death.
- Transformation can be fatal or can lead to expression of disease later.



In general, these ionizations can:

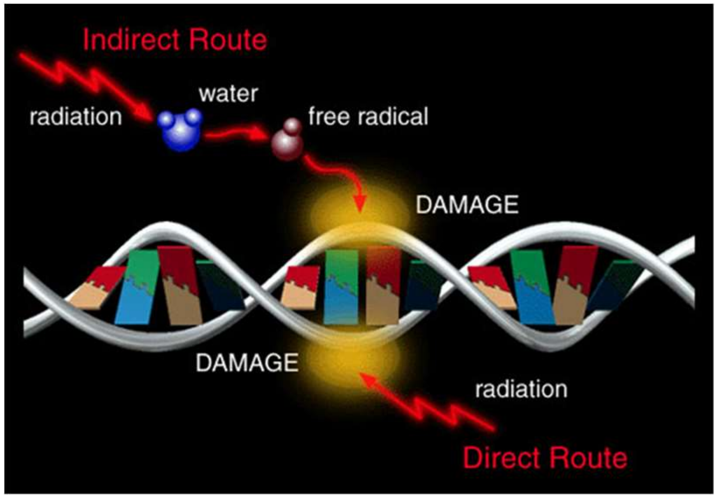
- Break chemical bonds.
- Produce new chemical bonds and cross-linkage between macromolecules.
- Damage molecules that regulate vital cell processes.

Mechanisms of Radiation Damage & Effect on DNA

Radiation damage results from damage to biological molecules, particularly DNA, from ionization and excitation events, ultimately resulting in cell transformation or death.

Transformation can be fatal or can lead to expression of disease later.

- ***Direct Means:*** radiation ionizes or excites atoms contained within the DNA structure itself, initiating a chain reaction that leads to a biological change.
- ***Indirect Means:*** radiation interacts with atoms in the cell (particularly water) breaking chemical bonds and forming free radicals.



Mechanisms of Radiation Damage

Most damage to cells is *indirect*

Indirect damage to cells happens in four stages: Physical, Pre-Chemical, Early Chemical and Late Chemical

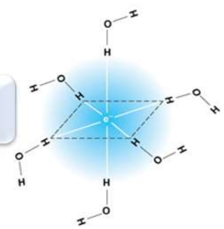
In the Physical Stage, ionized particles collide with H_2O molecules leaving ionized and excited molecules and sub-excitation electrons.

H_2O^+	H_2O^*	e^-_{sub}

This stage plays out in the first 10^{-15} seconds and within a few hundred angstrom of the collision.

Pre-Chemical Stage, between 10^{-15} and 10^{-12} seconds post collision the free electron that was dislodged from the H_2O molecule attracts other H_2O molecules, creating a “hydrated” electron, e^-_{aq}. The hydrated electron dissociates immediately.

$$H_2O \longrightarrow H + OH$$



During the Early Chemical Stage, between 10^{-12} and 10^{-6} seconds post collision, species diffuse and react with each other and with other molecules in solution.

By about 10^{-6} seconds post collision the remaining reactive species are widely separated, further reaction is unlikely.

To estimate any remaining yields during the **Late Chemical Stage**, use standard differential rate equation systems that assume uniform distribution of solutes.

Biologic Effects in Humans

Biologic Effects of radiation exposure in humans comes in two forms:

1. **Stochastic**
   Effect may or may not occur
   Effect can't be directly associated with an exposure event
   Severity of effect is not related to dose
2. **Nonstochastic**
   Effect is always observed if dose threshold reached
   Relationship between effect and exposure event is obvious
   Severity of effect is proportional to dose

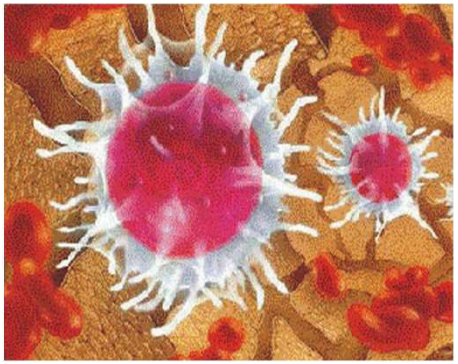
Some Nonstochastics Effects:

Erythema – Reddening of skin
Epilation – Loss of hair
Depression of bone marrow cell division
NVD
Damage to unborn child including:

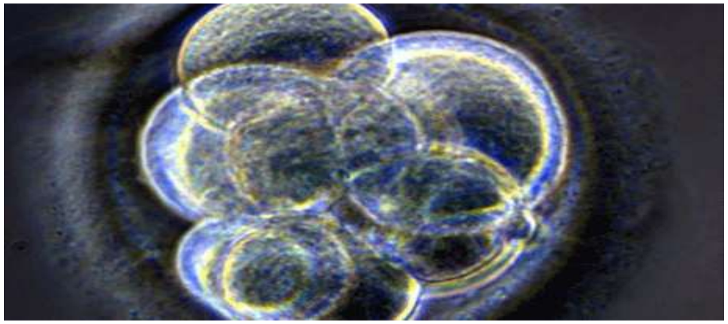
- Deformities
- Microcephaly
- Mental retardation

Radio-sensitivity of Organs

- Organs are more sensitive to radiation if:
  - ➢Cells in the organ have high division rate
  - ➢Cells in the organ have long dividing future
  - ➢Cells in the organ are not overly specialized



Progenitor marrow cells



Fetal cells during rapid division and before significant differentiation

Nonstochastic Effect - Death

Death results from damage first to bone marrow, then to gastro-intestinal system, then to central nervous system.

Lethal dose for humans is 3.5 to 4.5 Gy

$LD_{50/30}$ - Absorbed radiation dose that kills 50% of a population within 30 days of exposure.

Radiation and Stages of Skin Damage

- Human skin is relatively radiosensitive, but not overly.
- Generally, in external exposures, skin receives the highest dose.
- Skin damage is expressed weeks after exposure, after several cycles of cell division.
- High doses can have early erythema that resolve within a few days.

Prodormal Stage

Occurs within hours of exposure and includes early erythema, heat sensations, itching, possibly epilation. Lasts 1-2 days.

Latent Stage

No injury is evident, no symptoms. With increased dose this period becomes shorter.

Radiation and Stages of Skin Damage

Manifest Illness

Occurs after several cycles of cell division

- 2nd stage erythema with heat sensations and edema
- Desquamation or ulceration
- Necrosis

Longer term (10-16 weeks post exposure)

- 3rd wave erythema
- Increasing pain
- Bluish color to skin
- Epilation may subside
- New ulcers, necrosis, thinning of skin may occur

Late Effects that may occur months to years post exposure

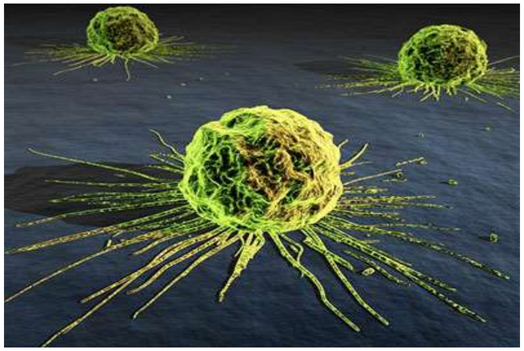
Threshold approximately 10 Gy

- More thinning of dermis layer
- Recurrence of ulcers
- Necrosis
- Deformity
- Skin Cancer

Stochastic and Nonstochastic Effects

Stochastic Effects are probablistic.

- Threshold may not be observed
- Probability of effect increases with dose
- Severity of effect does not increase with dose
- Effect can't be definitively associated with an exposure event



Nonstochastic Effects

1. Gonad exposure can result in sterility
Sometimes temporary in men, but damage occurs at relatively low dose
Usually permanent in women, but happens at higher dose
Cell damage resulting from gonad exposure has significant difference in threshold between male and female

2. Cataract formation threshold has been shown to be as low as 200 rads.
Cataract formation shows strong correlation with exposure to radiation.

Types of Stochastic Effects

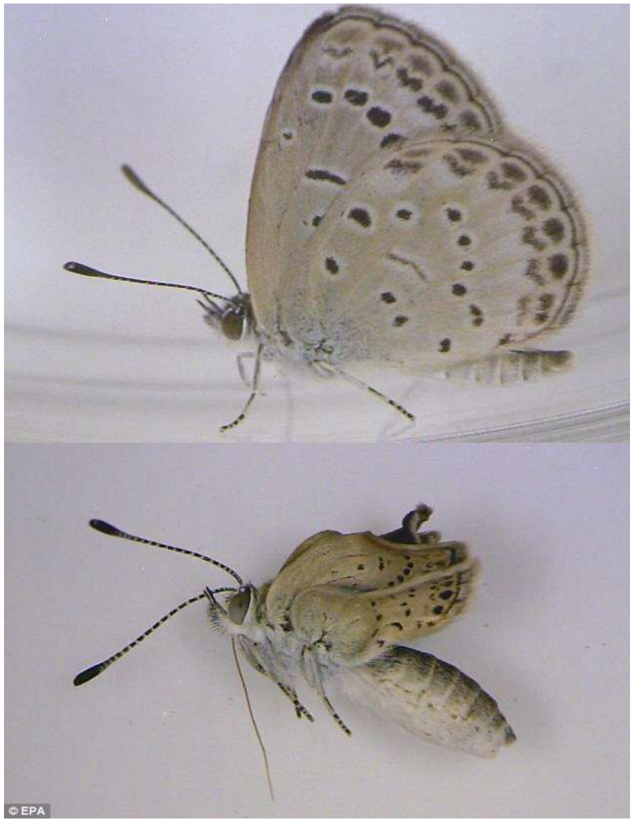
- Cancer Induction
- Genetic Effects appearing in offspring of irradiated individuals

Latent Periods for Stochastic Effects

Latent period is the period of time between exposure and induction of the effect.

Latent period is shortest for radiation induced Leukemia, 5-10 years.

Most solid cancers have latent periods greater than 20 years.



Stochastic Effects

Leukemia is the most likely form of malignancy resulting from whole-body exposure.

Increased leukemia rates have been clearly shown in the following populations:

- Early radiologists
- Japanese bombing survivors
- British children irradiated in utero

Bone Cancer

- Radioactive elements (Radium, Strontium, Barium) are chemically similar to Calcium and are taken up in bone tissue easily.
- Correlation has been shown in animal studies, but no significant increase in bone cancer was seen in Japanese bomb survivor population.

Lung Cancer

- Cumulative Radon exposures are positively correlated to increase in lung cancer.
- Radon exposure and smoking are synergistically related.

Thyroid Cancer

- Thyroid cancer is clearly associated with radiation exposure.
- Early use of X-Ray to treat ring worm and acne in children and teens yielded significant rates of thyroid cancer.

External Dose Assessment

Dose Information

Dose is defined as:

Energy of ionizing radiation absorbed per unit mass of material.

Units of Dose are in the form Energy/Mass

Units of Dose

Unit	Definition
rad	1 rad = 100 erg/g
Gray	1 Gy = 1 J/kg
Sievert	1 Sv = 1 J/kg

1 Gy = 100 rad

1 Sv = 100 rem

Gray is used for absorption of matter, Sievert is used for absorption of biological tissue.

Sievert is used to express equivalent, effective, and committed dose to biological tissue.

Dose Information

Absorbed Dose

- The rate at which you are being exposed to the source
- Equals the energy deposited per unit mass of the medium
- Absorbed dose depends on the incident radiation and the absorbing material
  - J/Kg, Gy, rad, etc

Equivalent Dose Definition

For a given type and dose of radiation applied to a certain body part of a certain organism, equivalent dose is the whole body dose that has the same probability of inducing cancer in the organism.

Equivalent Dose only defined for human tissue

Radiation Weighting Factors

Conventional quality factors (relative biological effectiveness) to calculate equivalent doses[2]		
Radiation	**Energy**	**Q or RBE**
x-rays, gamma rays, electrons, positrons, muons		1
neutrons	< 10 keV	5
	10 keV - 100 keV	10
	100 keV - 2 MeV	20
	2 MeV - 20 MeV	10
	> 20 MeV	5
protons	> 2 MeV	2
alpha particles, Nuclear fission products, heavy nuclei		20

Equivalent vs. Effective Dose

- Equivalent dose (whole body external exposure)
- Effective dose (partial body external exposure)
- Committed dose (internal exposure)
  - How much radiation you have accumulated overtime
  - The absorbed dose alone is not an adequate indicator of the likely health effects in humans
  - Consideration must also be given to the type of radiation, the dose rate, the affected tissues, and other factors
  - Much more representative of the stochastic risks to human health
    - SV, mrem, etc

Effective Dose

- Uses organ weighting factors to quantify dose from non-uniform exposures.
- Effective dose is used for comparison, addition, etc.

Organ Weighting Factors

Weighting factors for different organs[1]			
Organs	Tissue weighting factors		
	ICRP30(I36) 1979	ICRP60(I3) 1991	ICRP103(I6) 2008
Gonads	0.25	0.20	0.08
Red Bone Marrow	0.12	0.12	0.12
Colon	-	0.12	0.12
Lung	0.12	0.12	0.12
Stomach	-	0.12	0.12
Breasts	0.15	0.05	0.12
Bladder	-	0.05	0.04
Liver	-	0.05	0.04
Oesophagus	-	0.05	0.04
Thyroid	0.03	0.05	0.04
Skin	-	0.01	0.01
Bone surface	0.03	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01
Remainder of body	0.30	0.05	0.12

Why is Dose Assessment important in Radiation Safety?

Limiting dose received by workers (as estimated over a calendar year) will:

- Eliminate possibility of non-stochastic effects.
- Maintain risk of stochastic effects to what is acceptable in other industries.

Radiation workers who may have exposure are monitored for external dose by wearing personal monitoring devices.

Important Units In Radiation Protection

- Millirem (mrem) is a unit used to measure the effect of radiation on the human body.
  - When health risk from radiation is being discussed, millirem is typically used
  - There is no universally applicable conversion constant between these different units, because they measure different things

- "Caution Radiation Area"
  - > 5 mrem in one hour
- "Caution High Radiation Area"
  - > 100 mrem in one hour

Annual Limits

Declared Pregnant Workers and Minors

- 500 mrem annually for persons under the age of 18 years old
- 500 mrem during gestation period
  - If a woman decides to declare her pregnancy, she must do so in writing to her supervisor (the authorized user) and to the radiation safety office. A fetal monitoring badge will be issued.

Maximum Permissible Dose For Occupational Workers

Annual Limits

- Total Effective Dose Equivalent, 5000 mrem
- Sum of deep dose equivalent and committed dose equivalent to any organ or tissue other than the lens of the eye, 50000 mrem
- Dose equivalent to the eye, 15000 mrem
- Dose equivalent to the kind or any extremity, 50000 mrem

Dose Assessment Definition

External Dose Assessment is defined as:

Measurement or Calculation of radiation dose to humans from external sources.

Commonly known as dosimetry

Dosimetry is a means of detecting and measuring dose received by personnel due to their work with ionizing radiation(from x-ray producing machines).

Not protection from exposure, only detection.

Current provider of dosimetry badges is provided by Mirion Technologies.

Dosimeter badges are of LUXEL® Thermoluminescence (TL) type.

They can detect Beta / Photon (X and Gamma) radiation.

Personal and Control Dosimetry Badge

- Personal dosimetry badges from Mirion can be used for whole body/extremity/area monitoring.
- They can be worn in any whole body area(chest, waist, collar, etc.) or extremity(arms, legs, hands, etc.)
- MXR employees who are working in the vicinity of systems that produce ionizing radiation systems must wear their badges.

Personal Dosimetry

- Instadose+ dosimetry badges are issued during the onboarding process. Data from the badges is uploaded quarterly to the Instadose+ website through an app on the users cell phone or by using a hotspot.
- Exposure reports can be found on the Instadose+ website. The Radiation Safety Officer(RSO) can provide you with your quarterly/annual and cumulative MXR exposure counts.

1. Contact the RSO if you suspect you received an excessive or abnormal exposure to ionizing radiation.

2. Contact the RSO or Brenda Peacock if your badge is lost or if your badge (while not being worn) unexpectedly receives an abnormal dose.

MXR RSO Contact Information:
Mike Davis
mike.davis@mxrimaging.com
414-841-8072