

# Notes on Radiation, Radiation Protection, Effects of Radiation, and Medical uses of Radiation

## Radiation Interactions

### Alpha and Beta

- Particles that lose kinetic energy.
- Distance traveled before coming to rest is the range.
- Some energy lost by collisions with the atoms of a material.
- Some energy lost by ionizing (removing outer electrons) the material, hence “ionizing radiation.”
- Easily shielded with plastic or aluminum.

### Alpha

- Massive, relatively slow.
- Most alpha particles have an energy of about 4 to 5 MeV.
- In air, the range of a 5 MeV alpha is about .5 meter. Only a few mm range in human tissue. By contrast, the range of a 5 MeV proton in air is about 5 meters.
- Due to slow speed, alphas can lose all their energy.

### Beta

- Fast moving, low mass, moderate energy.
- More penetrating than alphas & can lose energy by bremsstrahlung and ionization.
- Range in air several meters, range in human tissue several cm.
- Can be blocked with a small thickness of Al.

### Gamma and X-Rays

- Photons that can transfer their energy to electrons by various processes or by producing electron-positron pairs.
- Amount of attenuation depends on the gamma or x-ray energy and the type of material:  $I = I_0 e^{-\mu x}$
- Very penetrating and more difficult to shield.

### Geiger Tube

- Filled with Gas
- Radioactive particles ionize the gas
- Free electrons attracted to the wire
- Current created that triggers the counter

### Scintillation Counter

- Incoming betas and gammas strike a NaI crystal.
- Visible light emitted.
- Photomultiplier converts the photons into electrical signals.
- Signal sent to counter.

### Film Badge

- Beta, Gamma, and X-rays cause film to darken.
- Gives total accumulated exposure.
- Used by medical practitioners, technologists, dentists, veterinarians, chiropractors or any practice with potential exposure to diagnostic X-rays

### Semiconductor Detectors

- Semiconductor detector releases electrons.
- Freed electrons create pulses.
- Multiple small detectors give image detail (pixels).
- No chemicals, no film.

## Radiation Exposure and Effects on Humans

### Radiation Exposure

- Type of radiation
- Activity of source
- Distance from source
- Amount of time exposed

<b>TYPE</b>	<b>DAMAGE</b>	<b>SOURCES</b>	<b>PROTECTION</b>
ALPHA	Slow, non-penetrating, few mm range in tissue.	Ingested Inhaled	Skin Clothing Respirator
BETA	Penetrating, few cm range in tissue.	Ingested Inhaled Proximity	Aluminum Lead
GAMMA	Extremely penetrating.	Ingested Inhaled Proximity	Lead

<b>Quantity</b>	<b>“New” SI unit &amp; symbol</b>	<b>“Old” Non-SI unit</b>	<b>Conversion factor</b>
Radioactivity	becquerel, Bq	curie, Ci	1 Ci = $3.7 \times 10^{10}$ Bq 1 Bq = 27 picocuries

Absorbed dose    gray, Gy      rad      1 rad = 0.01 Gy  
 "Dose"            sievert, Sv    rem      1 rem = 0.01 Sv  
 (Effective dose)                              1 rem = 10 mSv

**Environmental Radiation Sources**

- Cosmic Rays
- Terrestrial
- Medical Procedures
- Radiation Devices (e.g., smoke detector)
- Smoking
- Internal Radioactivity
- Environmental

Source	Dose (mrem/y)
Cosmic Rays	44
Soil	40
Radon Gas	200 (?)
Internal Body	18
Medical/Dental	73
Fallout	4
Occupational	1
Nuclear Power	.003
Miscellaneous	2
<b>TOTAL</b>	<b>382</b>

**Physiological Effects of high doses of radiation**

- Hair: Loss of hair quickly and in clumps occurs with radiation exposure at 200 rems or higher.
- Brain: Brain cells won't be damaged directly unless the exposure is 5,000 rems or greater. Radiation kills nerve cells and small blood vessels, and can cause seizures and immediate death.
- Thyroid: susceptible to radioactive iodine. In sufficient amounts, radioactive iodine can destroy all or part of the thyroid. potassium iodide can reduce the effects of exposure.
- Reproductive Tract: Damaged at rem levels as low as 200. Some radiation sickness victims will become sterile.
- Blood System: around 100 rems, the blood's lymphocyte cell count will be reduced, leaving the victim more susceptible to infection. Data from Hiroshima and Nagasaki, show that symptoms may persist for up to 10 years and may also have an increased long-term risk for leukemia and lymphoma.

- Heart: Intense exposure to radioactive material at 1,000 to 5,000 rems would do immediate damage to small blood vessels and cause heart failure and death directly.
- GI Tract: Nausea, bloody vomiting and diarrhea with exposure of 200 rems or more. The radiation will begin to destroy the cells in the body that divide rapidly. These including blood, GI tract, reproductive and hair cells, and harms their DNA and RNA of surviving cells.

<b>Estimated Days of Life Expectancy Lost From Various Risk Factors</b>	
<b>Industry Type or Activity</b>	<b>Estimated Days of Life Expectancy Lost</b>
Smoking 20 cigarettes a day	2370 (6.5 years)
Overweight by 20%	985 (2.7 years)
Mining and Quarrying	328
Construction	302
Agriculture	277
Government	55
Manufacturing	43
Radiation - 340 mrem/yr for 30 years	49
Radiation - 100 mrem/yr for 70 years	34

## **Medical Uses of Nuclear Physics**

### **Positron Emission**

- Positron is the antimatter electron.
- Source emits a positron which immediately annihilates with an electron producing two gammas.
- $\beta^+ + \beta^- \rightarrow 2 \gamma$
- $.511 \text{ MeV} + .511 \text{ MeV} = 2 \gamma$
- Each  $\gamma$  has energy .511 MeV
- Leave the interaction point in opposite directions in order to conserve momentum.
- Gamma's emitted in different directions allowing for two dimensional images.
- Collimators not needed and hence lower dose of radiation can be administered.

### **Positron Emission Tomography**

- Small dosage of a radionuclide combined with a sugar is injected into patient.
- Malignant tumors grow at a faster rate than healthy tissue & the tumor cells use up more of the sugar.
- Radionuclide emits positrons.
- A PET scanner rotates around a patient's head to detect the gamma rays given off by the positron annihilation.
- The computer then uses the measurements of glucose to produce a color coded picture.

<b>Radiopharmaceutical*</b>	<b>Half-life (minutes)</b>	<b>PET Application</b>
Carbon 11 ( <sup>11</sup> C)	20	Amino acid metabolism
Nitrogen 13 ( <sup>13</sup> N)	10	Blood flow (cardiology)
Oxygen 15 ( <sup>15</sup> O)	2	Blood flow
Fluorine 18 ( <sup>18</sup> F)	110	Glucose metabolism

### **CT Scans**

Computed Tomography (CT) imaging, also known as "CAT scanning" (Computed Axial Tomography), was developed in the early to mid 1970s and is now available at over 30,000 locations throughout the world. CT is fast, patient friendly and has the unique ability to image a combination of soft tissue, bone, and blood vessels. CT is the workhorse imaging system in most busy radiology departments and diagnostic centers. Since its invention some 25 years ago, CT imaging has seen massive advances in technology and clinical performance. Today CT enables the diagnosis of a wider array of illness and injury than ever before! Follow the links below to learn more about uses and benefits of computed tomography imaging.

Computed Tomography is based on the x-ray principal: as x-rays pass through the body they are absorbed or attenuated (weakened) at differing levels creating a matrix or profile of x-ray beams of different strength. This x-ray profile is registered on film, thus creating an image. In the case of CT, the film is replaced by a banana shaped detector which measures the x-ray profile.

A CT scanner looks like a big, square doughnut. The patient aperture (opening) is 60 cm to 70 cm (24" to 28") in diameter. Inside the covers of the CT scanner is a rotating frame which has an x-ray tube mounted on one side and the banana shaped detector mounted on the opposite side. A fan beam of x-ray is created as the rotating frame spins the x-ray tube and detector around the patient (see figure below). Each time the x-ray tube and detector make a 360° rotation, an image or "slice" has been acquired. This "slice" is collimated (focused) to a thickness between 1 mm and 10 mm using lead shutters in front of the x-ray tube and x-ray detector.

As the x-ray tube and detector make this 360° rotation, the detector takes numerous snapshots (called profiles) of the attenuated x-ray beam. Typically, in one 360° lap, about 1,000 profiles are sampled. Each profile is subdivided spatially (divided into partitions) by the detectors and fed into about 700 individual channels. Each profile is then backwards reconstructed (or "back projected") by a dedicated computer into a two-dimensional image of the "slice" that was scanned.

<b>The Evolution of Computed Tomography</b>	
<b>Year</b>	<b>Event</b>
1895	Roentgen discovers x-rays in Wurzburg, Germany.
1917	Radon proves it possible to reconstruct an image from an infinite set of all of its projections.
1956	Bracewell performs practical reconstruction of the sun's image.
1961	Oldendorf, Kuhl, Edwards and Cormack apply reconstruction techniques to medical problems.
1967	Hounsfield develops the first CT head scanner based on x-ray computed tomography.
1970	Hounsfield demonstrates the CT process.
1971	Ambrose installs the first CT scanner at Atkinson-Morley Hospital.
1972	First patient scanned.
1973	Mayo Clinic and Massachusetts General Hospital install the first CT scanners in the United States.
1974	Ledley and colleagues build the first whole-body CT scanner.
1979	Hounsfield and Cormack receive the Nobel prize in Medicine and Physiology.
1989	Spiral/helical CT scanners are introduced.
1998	Multislice CT scanners are introduced.

<b>The Evolution of Positron Emission Tomography</b>	
<b>Year</b>	<b>Event</b>
1895	Roentgen discovers x-rays in Wurzburg, Germany.
1896	Becquerel discovers mysterious emissions from uranium.
1897	Curie terms Becquerel's discovery "radioactivity."
1903	Alexander Graham Bell suggests that sources of radium could be placed in or near tumors.
1931	Harold Urey discovers deuterium.
1932	Carl Anderson discovers the positron.
1933	James Chadwick discovers the neutron.
1935	Georg de Hevesy demonstrates that body tissue exists in a dynamic state, giving up and taking in atoms.
1943	Hevesy is awarded Nobel Prize in Chemistry.
1951	Benedict Cassen and colleagues produce the first clinical nuclear medicine images of the thyroid gland using a scintillation detector (rectilinear scanner).
1952	Gordon Brownell and H.H. Sweet build a positron detector.
1958	Hal Anger invents the scintillation camera.
1961	Allis-Chalmers installs the first cyclotron in the United States at Washington University Medical School in St. Louis, Mo.
1971	Nuclear medicine is officially recognized as a medical specialty.
1974	Michael Phelps and colleagues introduce first PET scanner.

<b>A Comparison of PET and CT Imaging Variables</b>		
<b>Variable</b>	<b>PET</b>	<b>CT</b>
Imaging direct		X
Imaging indirect	X	
Relies on computerized reconstruction	X	X
Displays tomographic images	X	X
Gantry housing data acquisition components	X	X
Image displayed in several anatomical planes	X	X
Images may be fused with other imaging modalities	X	X
Produces tomographic images depicting metabolic activity (physiology)	X	
Produces tomographic images depicting structural anatomy		X
Imaging accomplished by scintillation detection of positron emission	X	
Imaging accomplished by detection of transmitted attenuated x-ray photons		X