Radiation Safety in Computed Tomography

OUTLINE

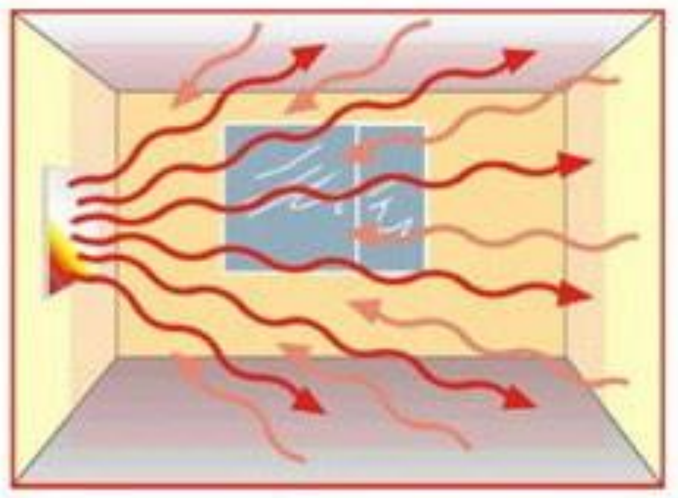
- What is Radiation
- Background Radiation
- Concern with CT Exposures
- A.L.A.R.A.
- Personnel Monitoring
- Radiation Safety
- Radiation Risks

What is Radiation ?

- **Radiation is Energy that comes from a Source and travels through space and may be able to penetrate various materials.**

What is Radiation ?

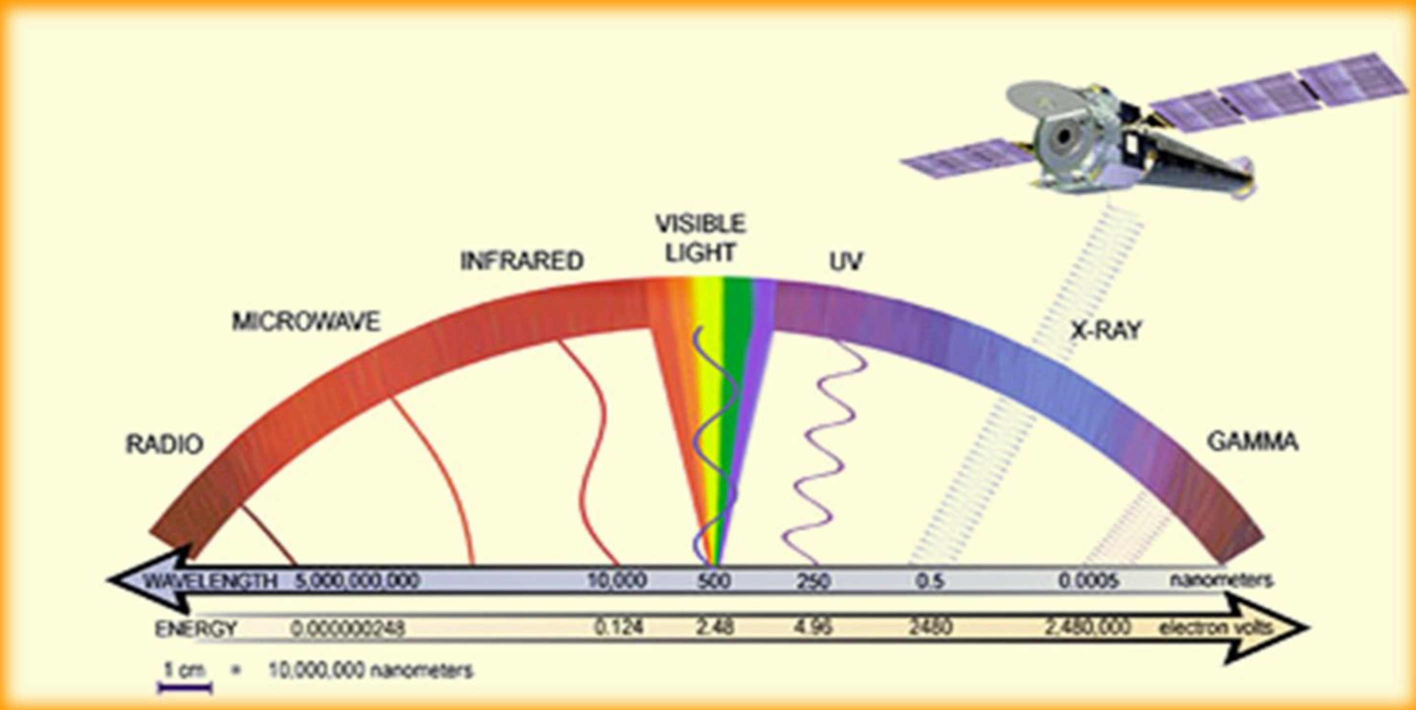
- For example, an electric heater operates by heating metal wires and the wires radiate that energy as heat (infrared radiation)



Heat Distribution from Infrared Heater Panel

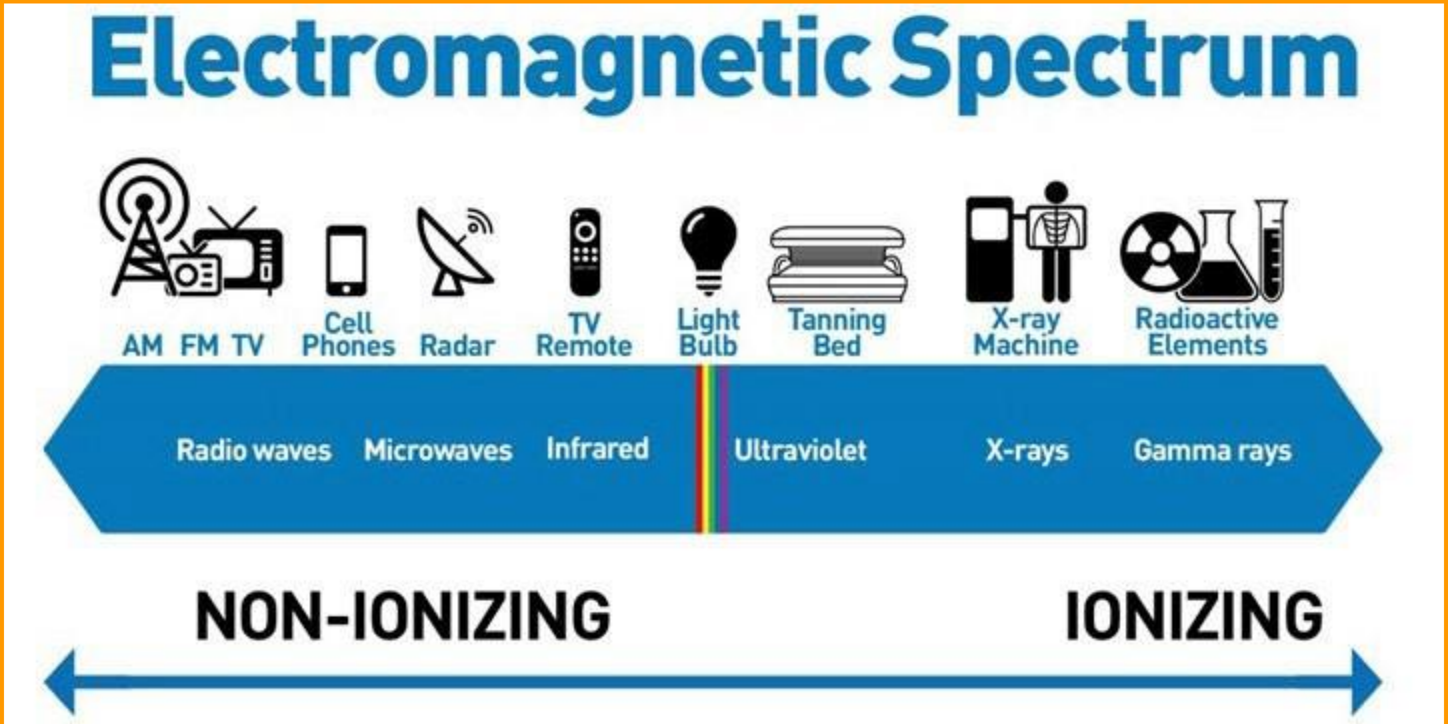
What is Radiation ?

There are various components of the electromagnetic spectrum which ranges from low frequency Radio waves to high frequency Gamma and Cosmic Radiation.



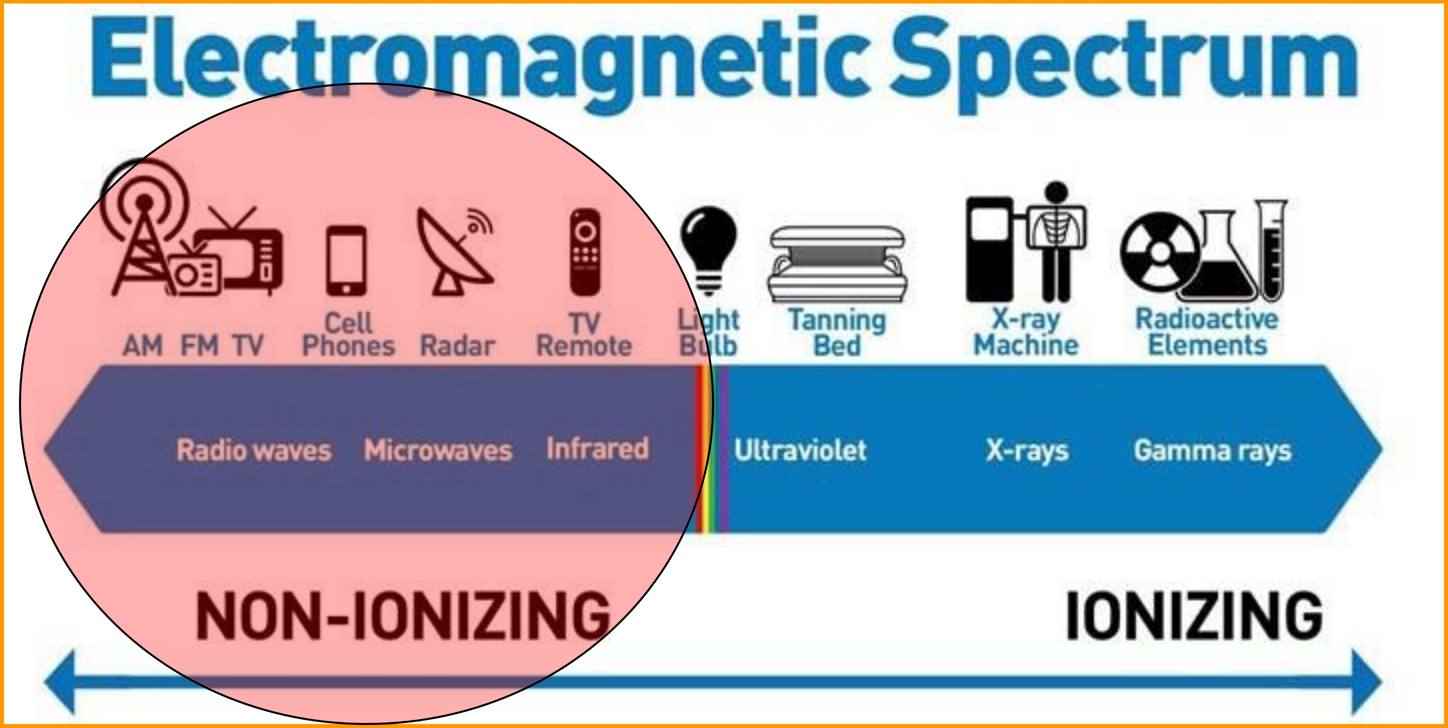
Electromagnetic Spectrum

Radio frequency radiation is a type of electromagnetic radiation, which is a combination of electric and magnetic fields that move through space together as waves. Electromagnetic radiation falls into two categories:



Ionizing Radiation

- Light, Radio and Microwaves are types of radiation that are called NON-IONIZING … which means that they do not produce charged particles.



Non-Ionizing Radiation

- **Routine exposure to non-ionizing radiation is generally perceived as harmless to humans**

Non-Ionizing Radiation

- Sources of NON-IONIZING radiation include Light bulbs, computers, Wi-Fi routers, portable phones, cell phones, Bluetooth devices, FM radio, GPS, and broadcast television

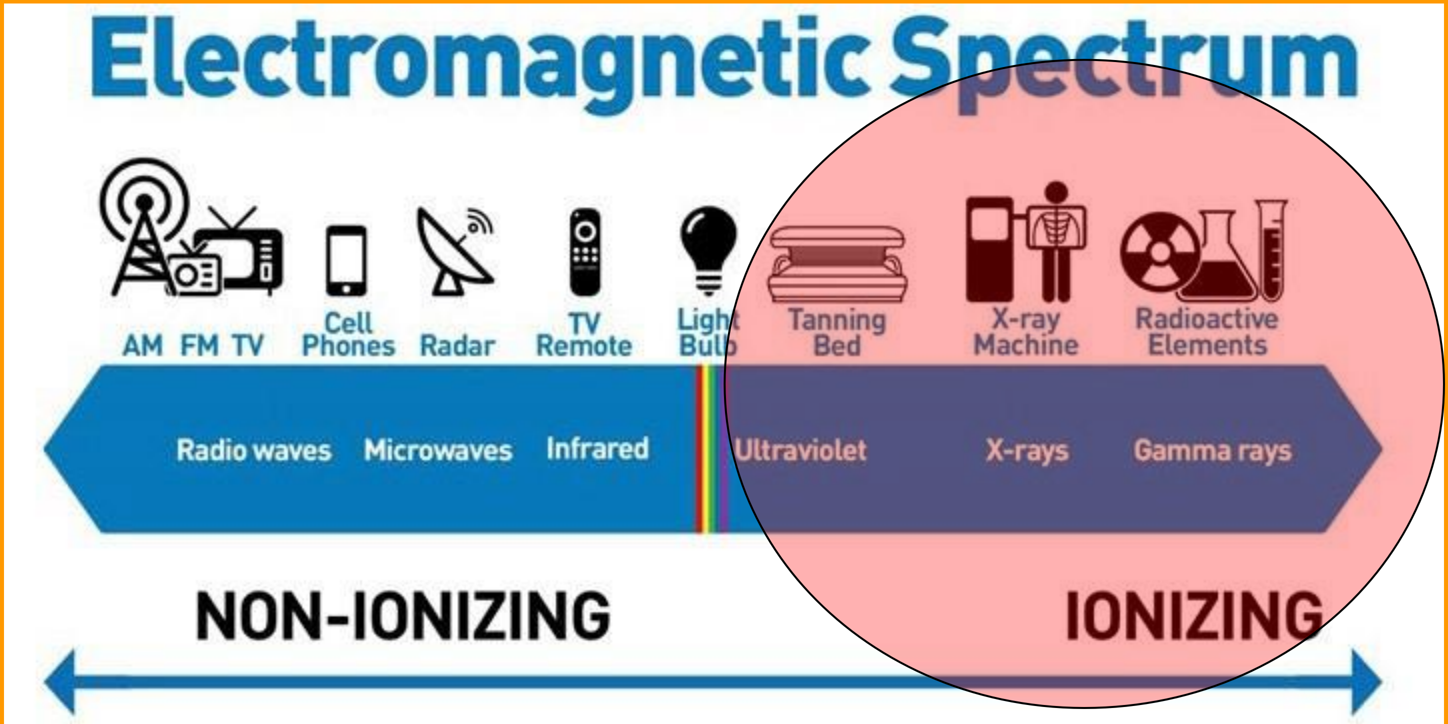






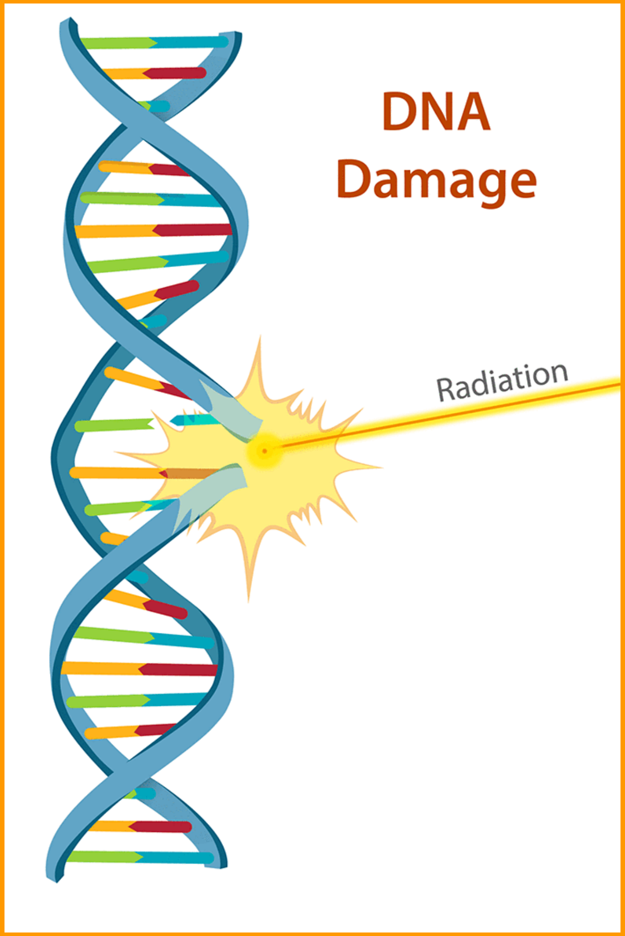
Ionizing Radiation

- Radiation like some Ultraviolet Light (UV), X-rays and Gamma rays that can produce charged particles (ions) in matter is called IONIZING RADIATION.



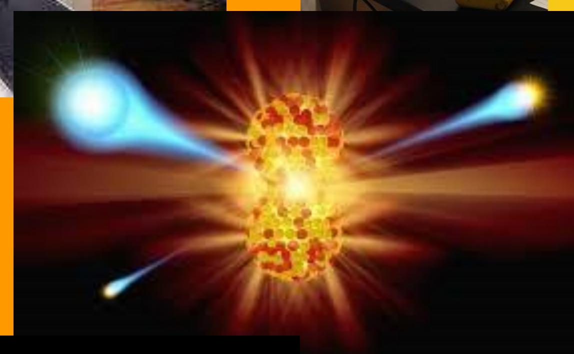
Ionizing Radiation

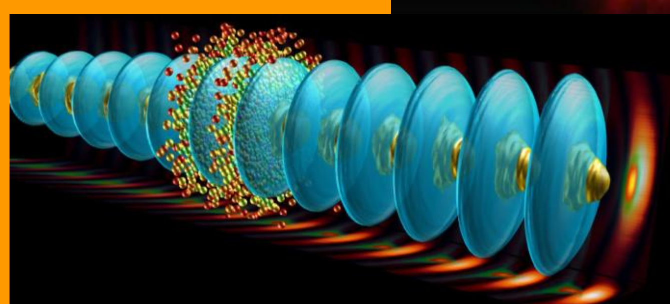
- **Ionizing Radiation is High energy radiation with the potential for direct cellular and DNA damage**



Ionizing Radiation

- **Sources of IONIZING radiation include X-ray machines, radioactive material, nuclear fission, nuclear fusion, and particle accelerators**





Ionizing Radiation

Less known sources of IONIZING radiation are

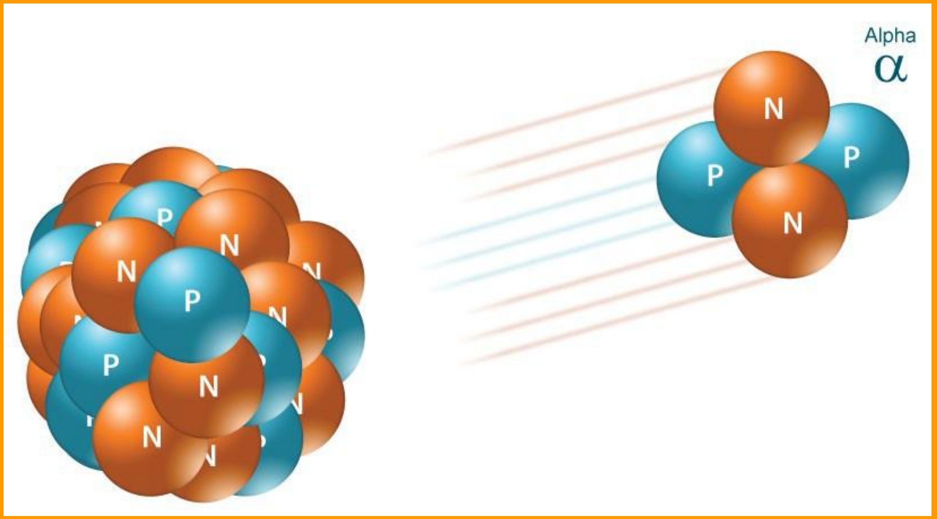
- **Airport Scanners**
- **Smoke Detectors**
- **Radium Wrist Watches**
- **Tritium Exit Signs**
- **Uranium Glaze Products**

Types of Ionizing Radiation

Alpha particles consist of 2 protons and 2 neutrons. Due to their charge and mass, **Alpha particles** interact strongly with matter, and only travel a few centimeters in air.

Alpha particles are unable to penetrate the outer layer of dead skin cells, but are capable, if an alpha emitting substance is ingested in food or air, of causing serious cell damage.

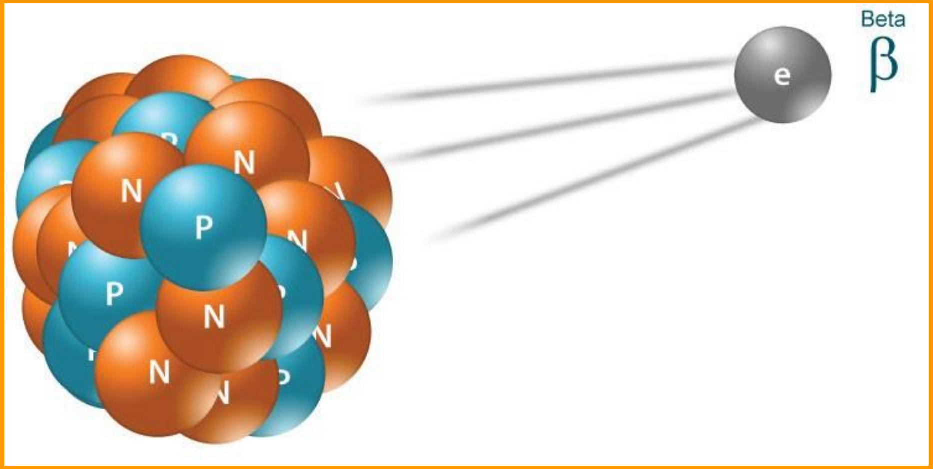
Alexander Litvinenko is a famous example. He was poisoned by polonium-210, an alpha emitter, in his tea.



Types of Ionizing Radiation

Beta radiation takes the form of either an electron or a positron (a particle with the size and mass of an electron, but with a positive charge) being emitted from an atom. Due to the smaller mass, it is able to travel further in air, up to a few meters, and can be stopped by a thick piece of plastic, or even a stack of paper.

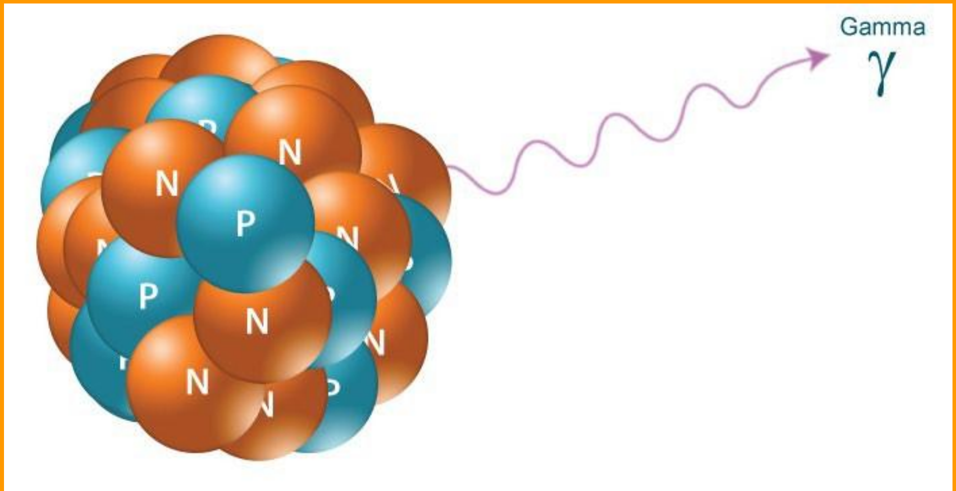
It can penetrate skin a few centimeters, posing somewhat of an external health risk. However, the main threat is still primarily from internal emission from ingested material.



Types of Ionizing Radiation

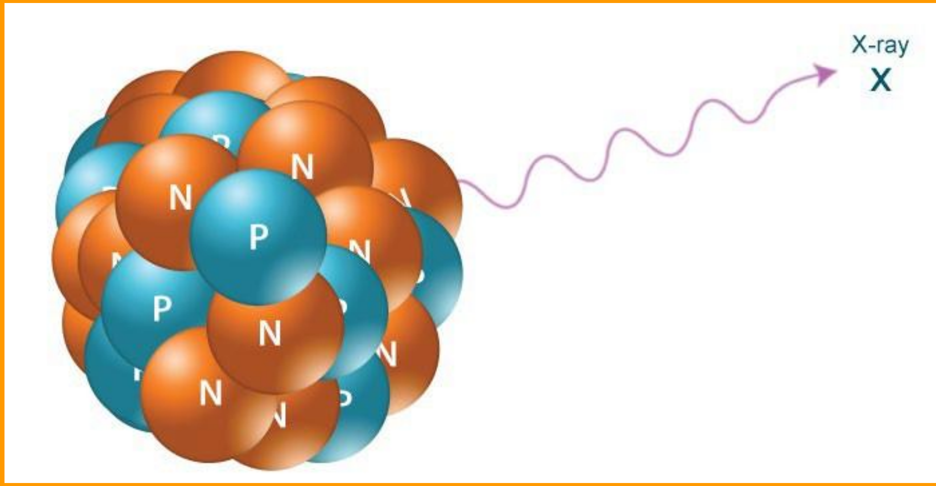
Gamma radiation, unlike alpha or beta, does not consist of any particles, instead consisting of a photon of energy being emitted from an unstable nucleus. Having no mass or charge, gamma radiation can travel much farther through air than alpha or beta, losing (on average) half its energy for every 500 feet.

Gamma waves can be stopped by a thick or dense enough layer material, with high atomic number materials such as lead or depleted uranium being the most effective form of shielding.



Types of Ionizing Radiation

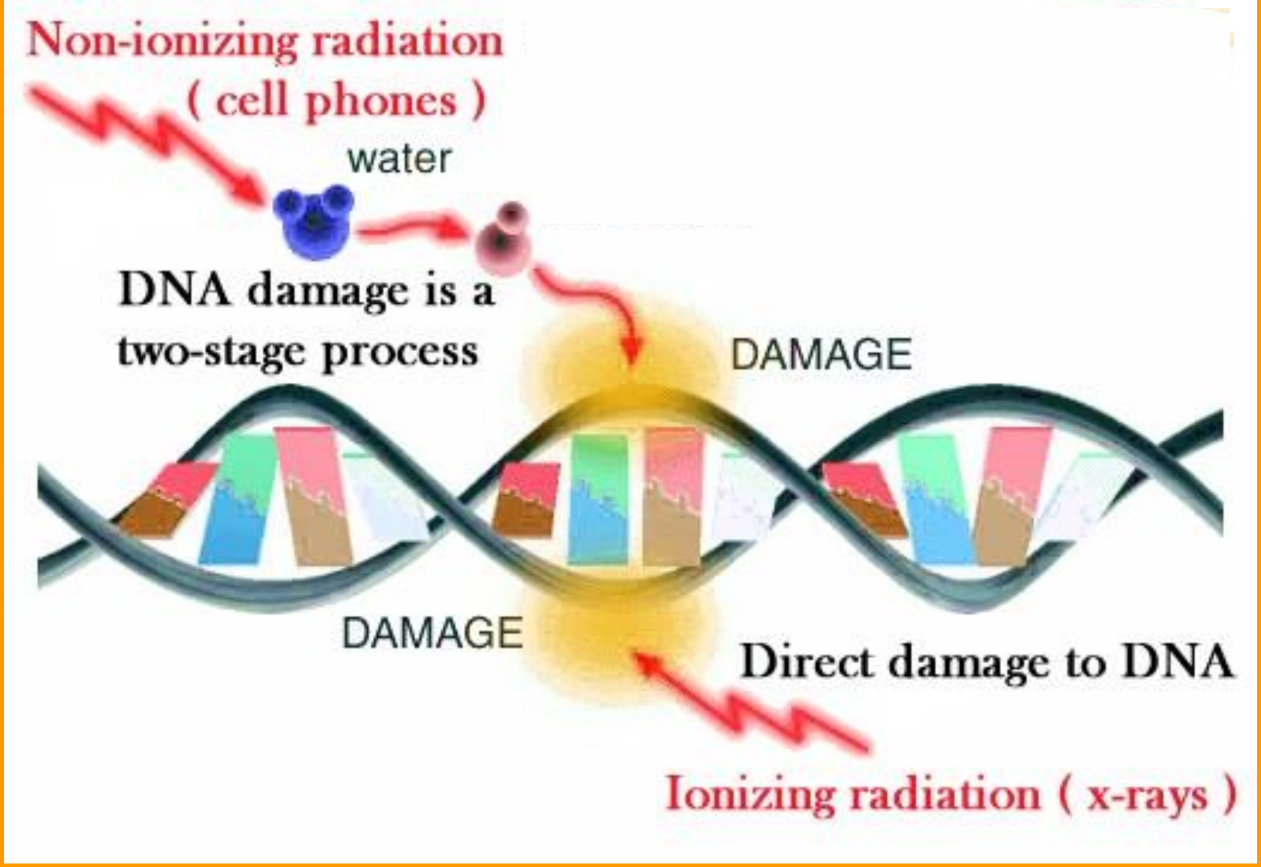
X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released.



X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well.

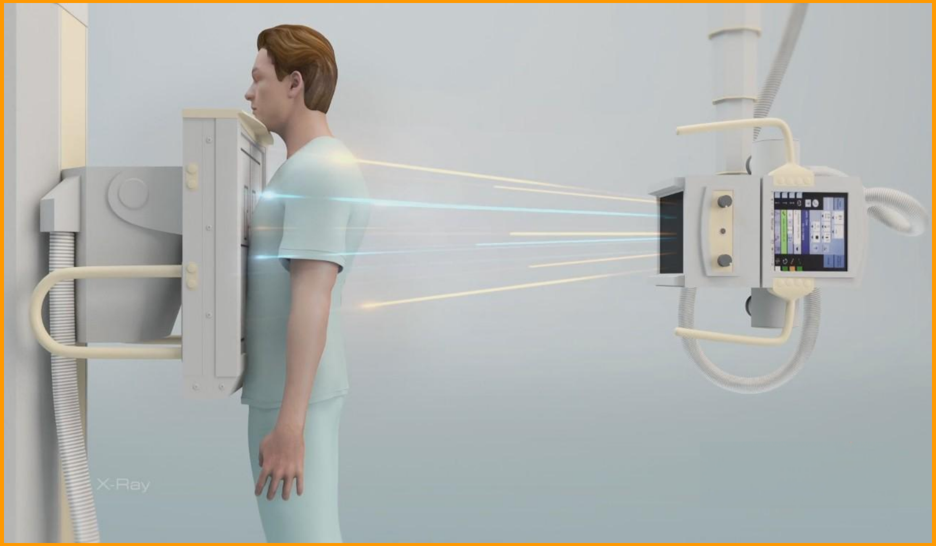
Ionizing v/s Non-Ionizing Radiation

Generally, when people hear the word radiation, they're thinking of ionizing radiation, like X-rays and gamma rays. Ionizing radiation carries enough energy to break chemical bonds, knock electrons out of atoms, and cause direct damage to cells in organic matter.



Ionizing v/s Non-Ionizing Radiation

In fact, ionizing radiation carries more than a billion times more energy than does non-ionizing radiation.



A little ionizing radiation can be used to produce x-ray images for diagnosis. A lot of ionizing radiation is needed to kill cancer cells in radiation therapy.

Ionizing v/s Non-Ionizing Radiation

By contrast, non-ionizing radiation does not have enough energy to break chemical bonds or strip electrons from atoms.

Scientific consensus shows that non-ionizing radiation is not a carcinogen and, at or below the radio frequency exposure limits set by the FCC, non-ionizing radiation has not been shown to cause any harm to people.

Background Radiation

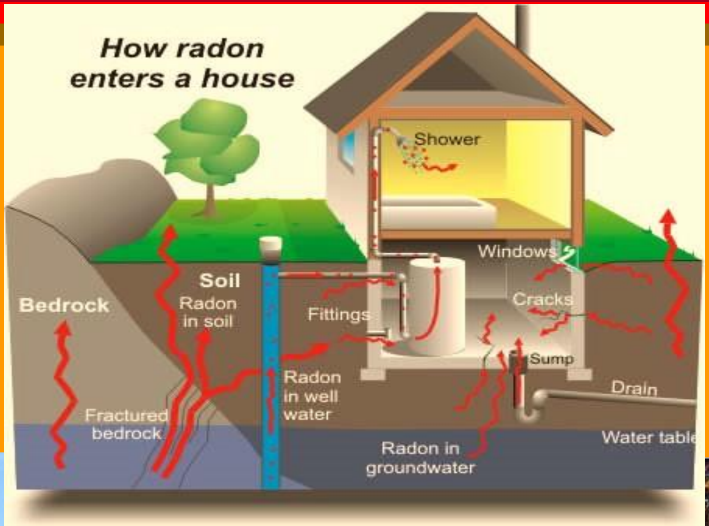
- Background radiation is a measure of the level of ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.

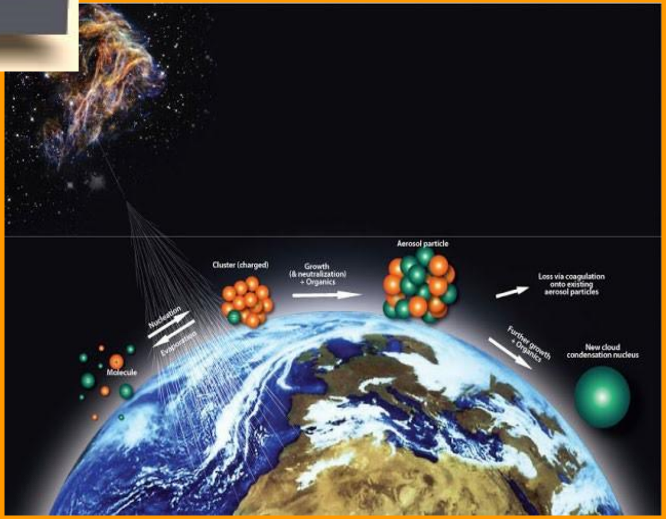
Background Radiation

- Background Radiation is present all around us in our everyday lives …
- We are exposed to Background Radiation daily irrespective of whether we work around radiation.

Background Radiation

- **Most of it is Naturally Occurring …**





Background Radiation

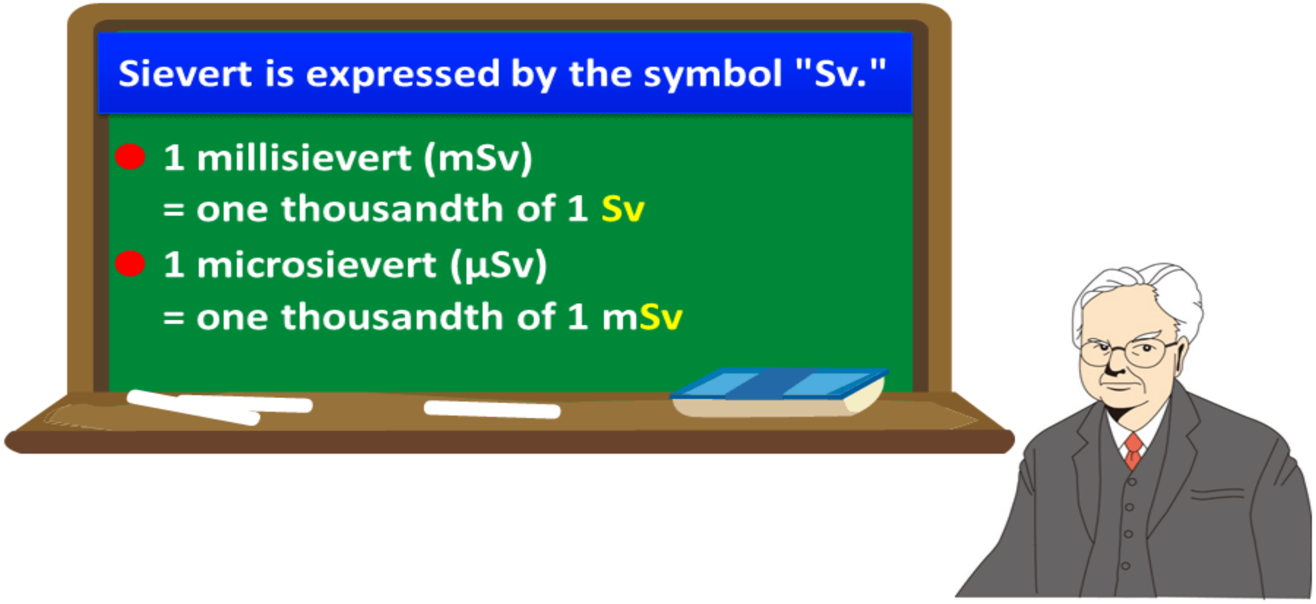
- Some of it is
  Man-Made ...

Background Radiation

- In addition to Naturally-Occurring radiation Occupationally Exposed Personnel also receive Man-Made **Medical radiation** …

Background Radiation

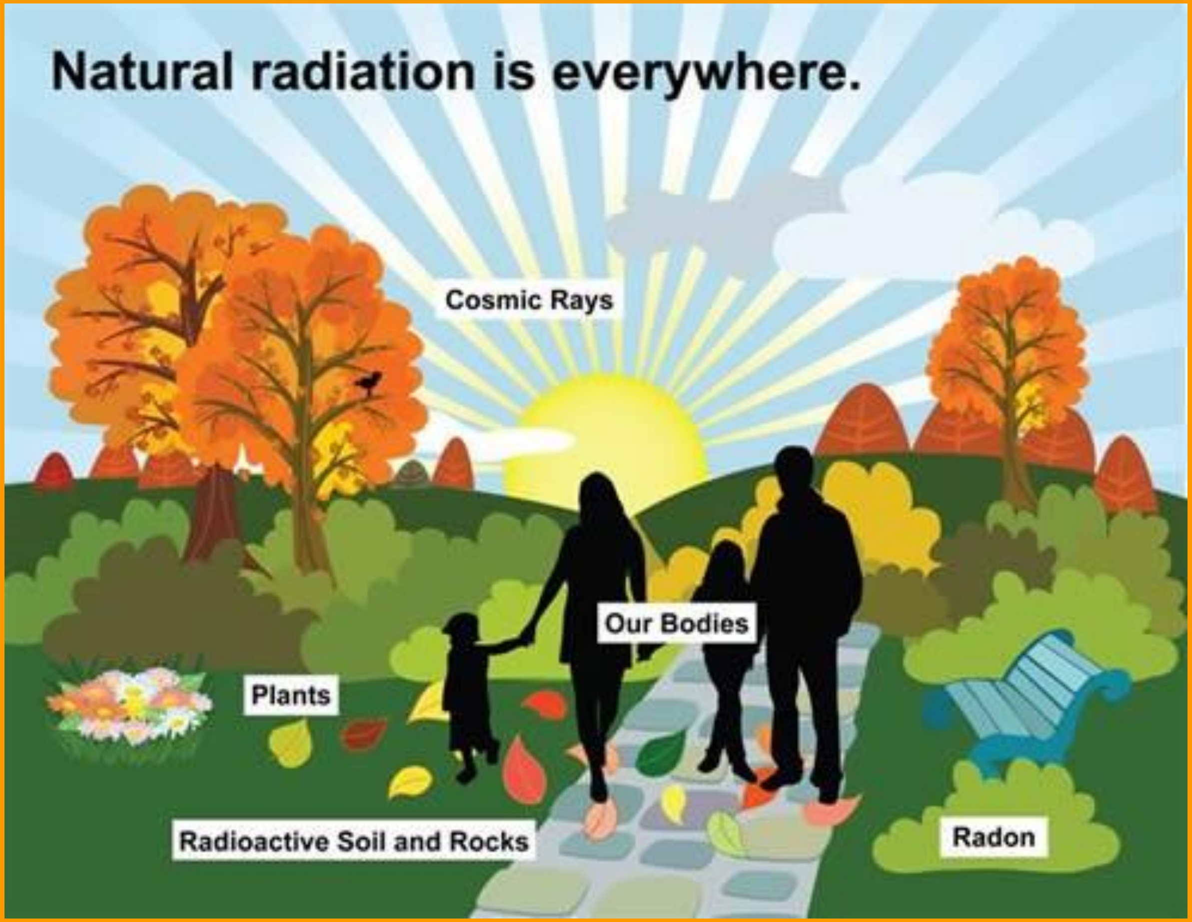
- **Exposure to background radiation is measured in units of millisieverts or mSv**



Rolf Sievert (1896-1966)
Founder of the physics laboratory at Sweden's Radiumhemmet
Participated in the foundation of the International Commission on Radiological Protection

- **The millisievert is a radioprotection unit measuring the radiation dose received either from a radioactive source or from other sources like X-rays in medicine.**

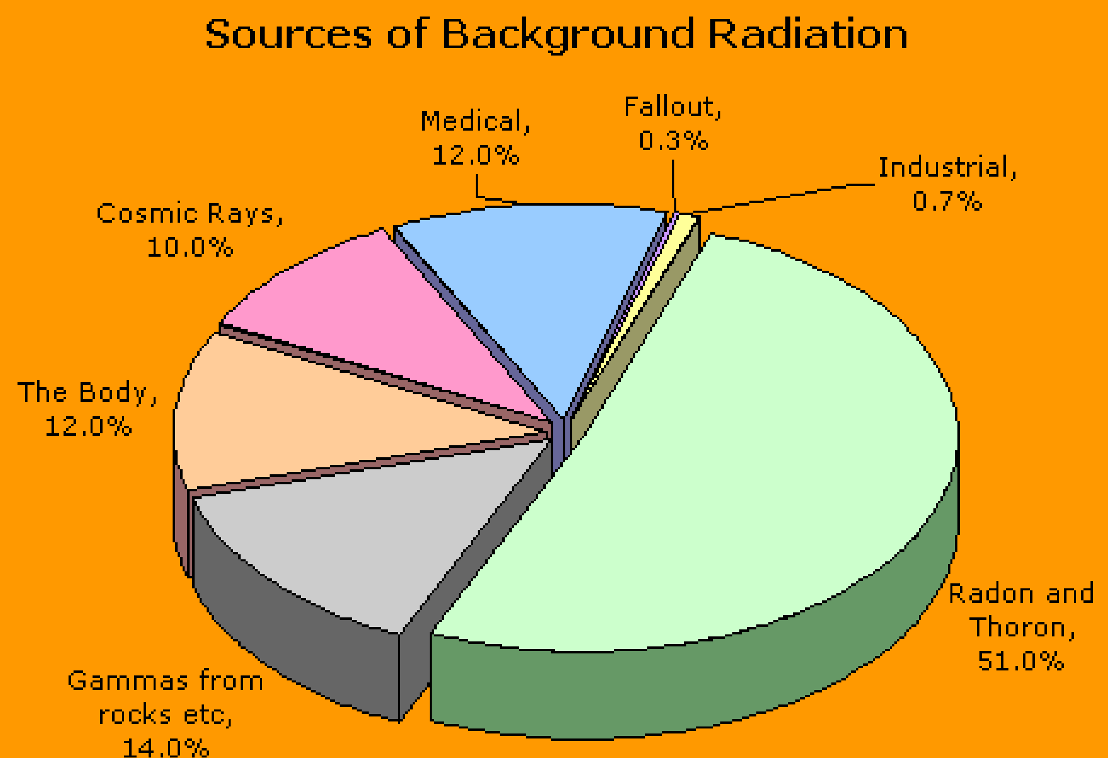
Background Radiation



- **On an average, an individual in the United States receives about 360 mSv in one year.**

Background Radiation

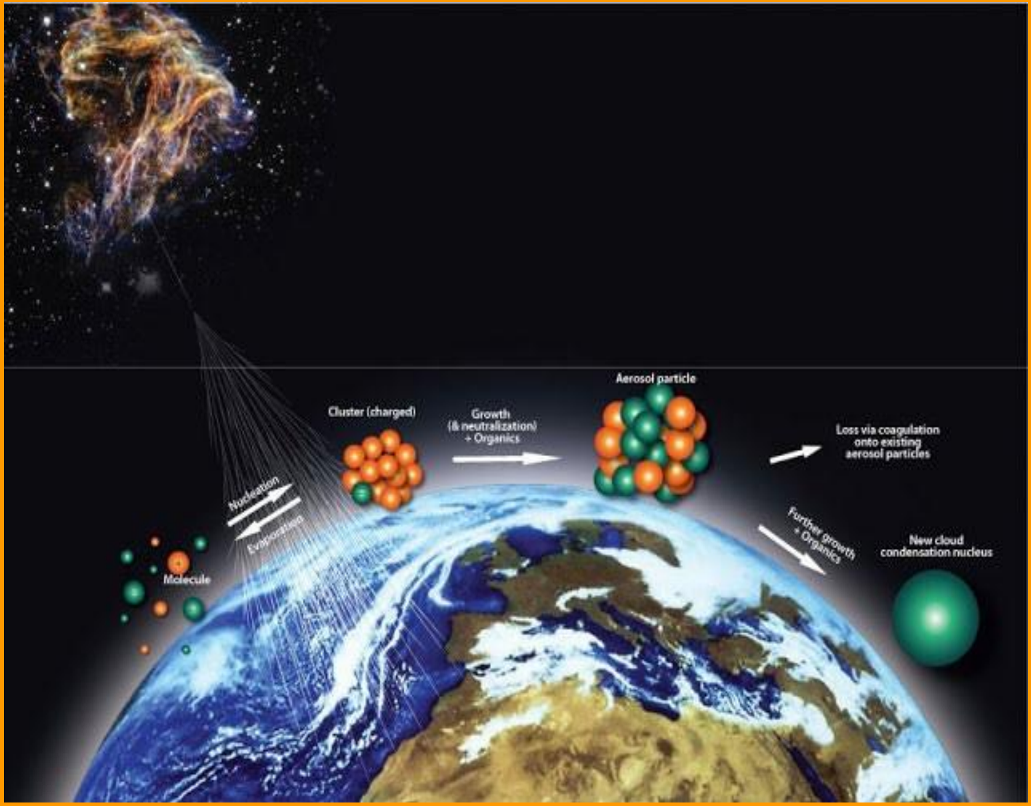
- **Lets look at a Break Down of the different contributors of Background Radiation to the Average American:**



Background Radiation

Average American:

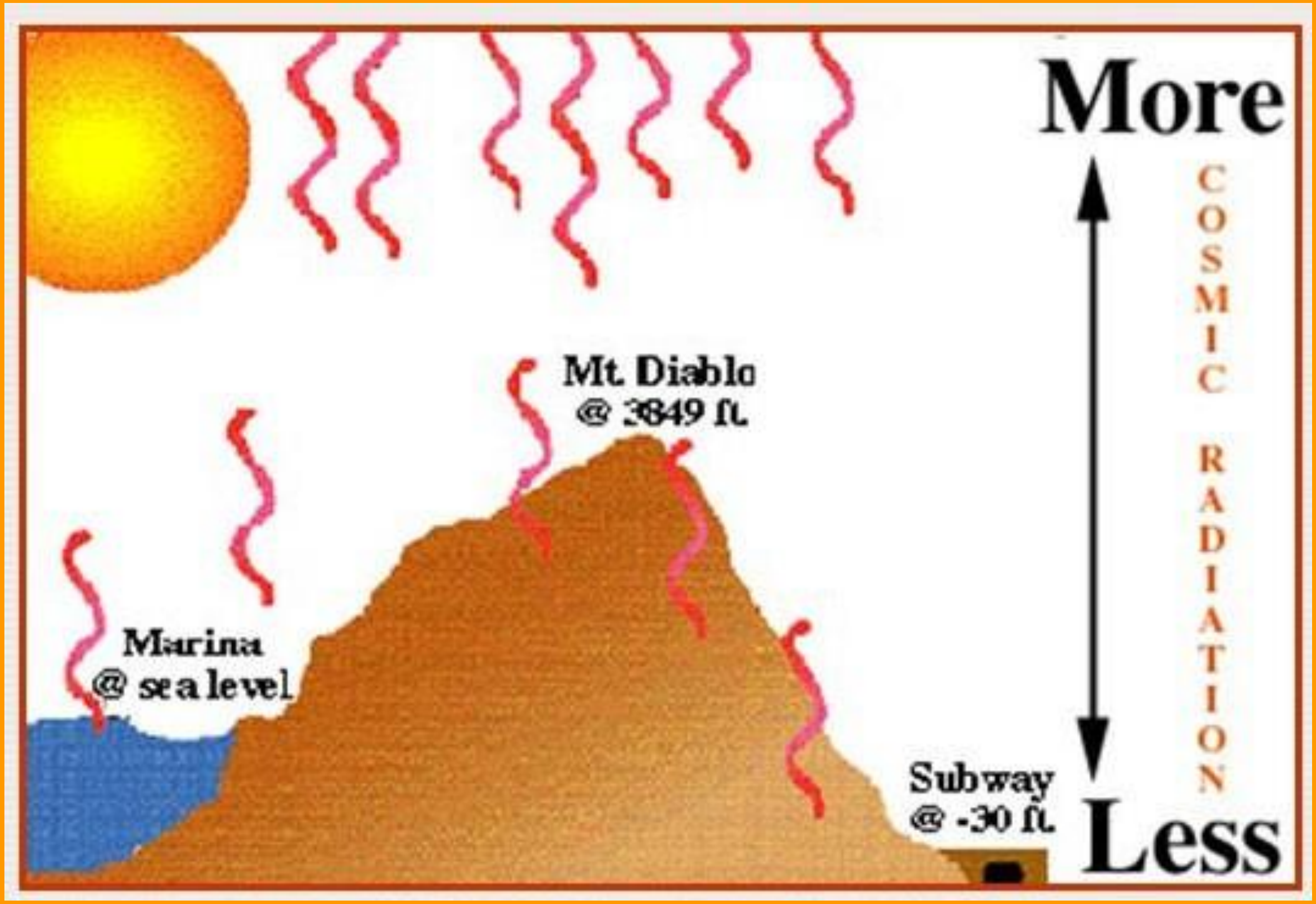
- Cosmic: 30 mrem



This is radiation in the form of heavy particles from Outer Space. The Earths Atmosphere provides a natural barrier absorbing most of it before it reaches us on the earths surface.

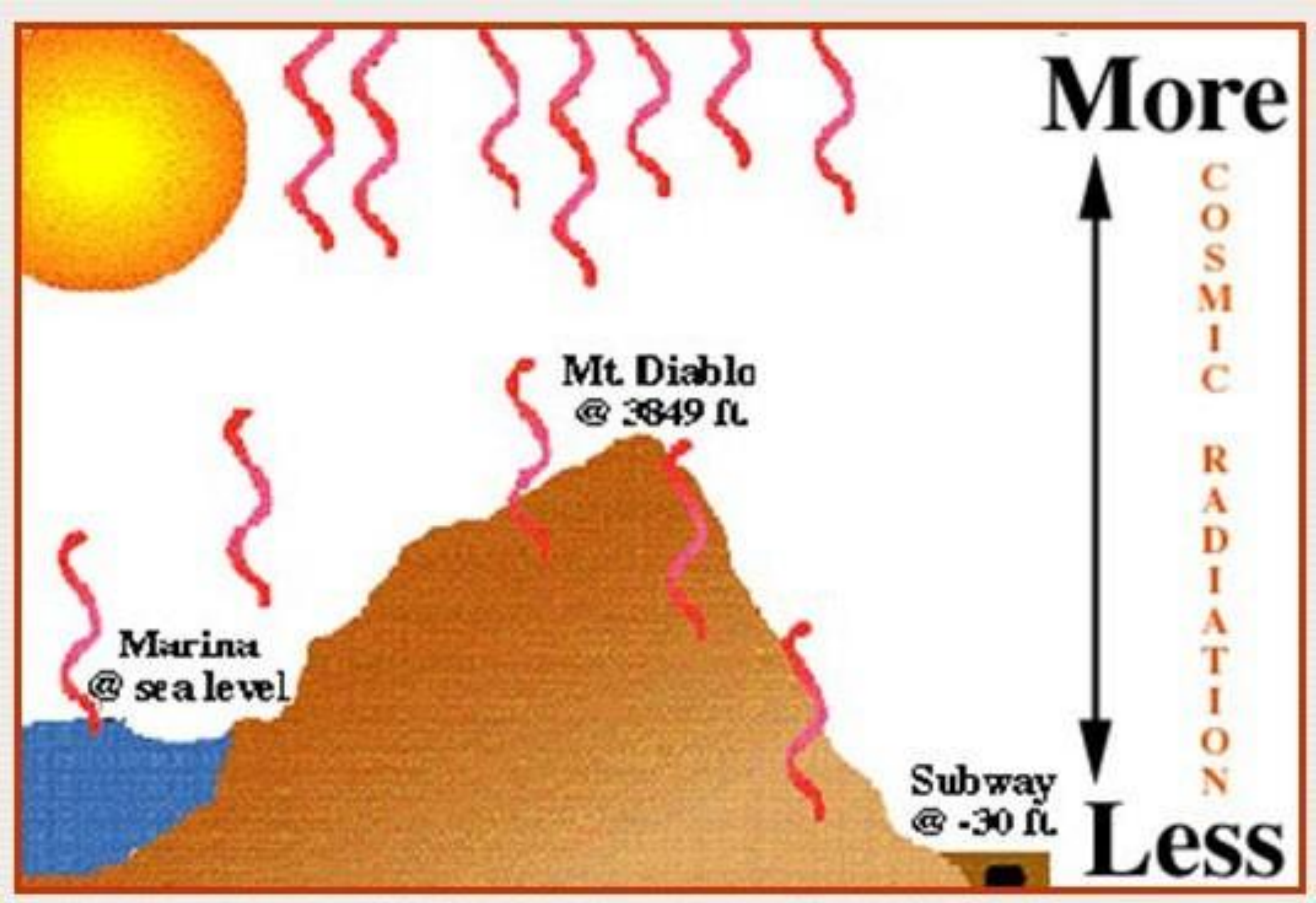
Background Radiation

- This level of background radiation is greater at Higher Altitudes and lower at Sea Level.



Background Radiation

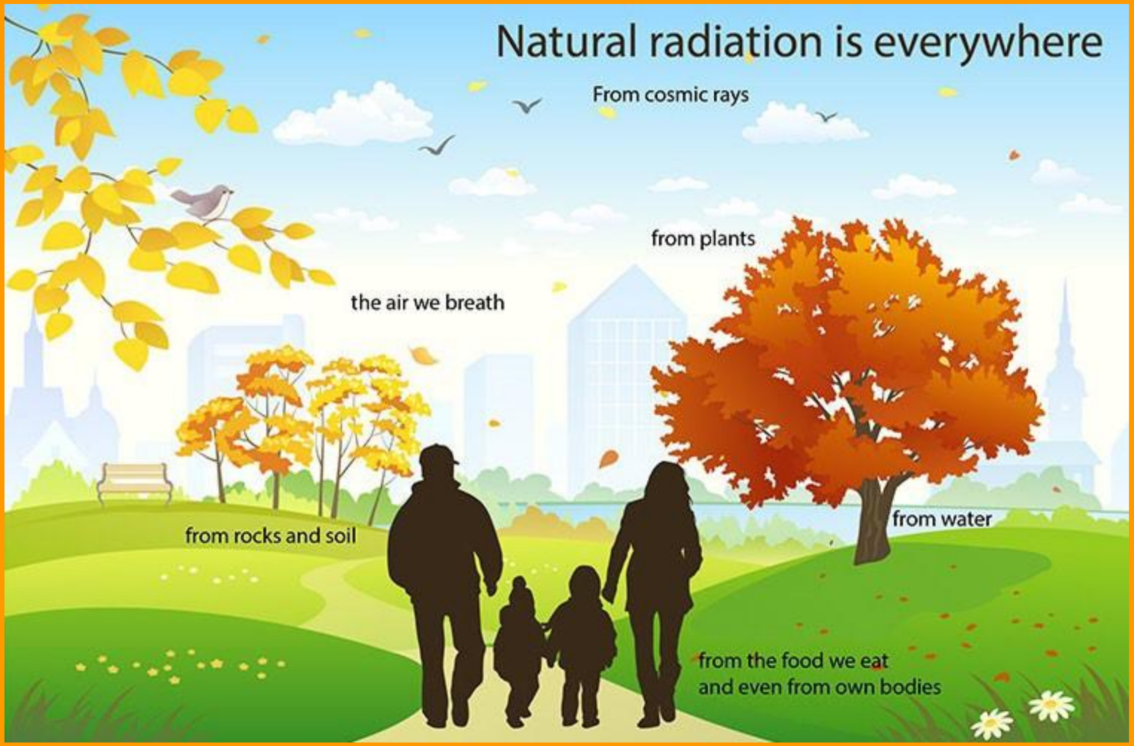
- The longer you are on a flight, the more radiation you receive.
- The higher you are in altitude, the higher the dose of radiation. This is a result of less shielding of cosmic radiation by the atmosphere at higher altitudes



Background Radiation

Average American:

- **Earth: 35 mrem**



This is radiation form natural earth elements like water, soil, plants, food sources, etc.

Background Radiation

- The Dose from Terrestrial Radiation also varies in different parts of the world.
- Locations with higher concentrations of Uranium and Thorium in theor soil have higher dose levels.
- Kerala (INDIA) has the world's highest level of natural radioactivity in a densely populated area, according to the researchers

Background Radiation

Naturally-occurring radionuclides such as potassium, carbon, radium and their decay products are found in some foods. Because the amount of radiation is very small, these foods do not pose a radiation risk.

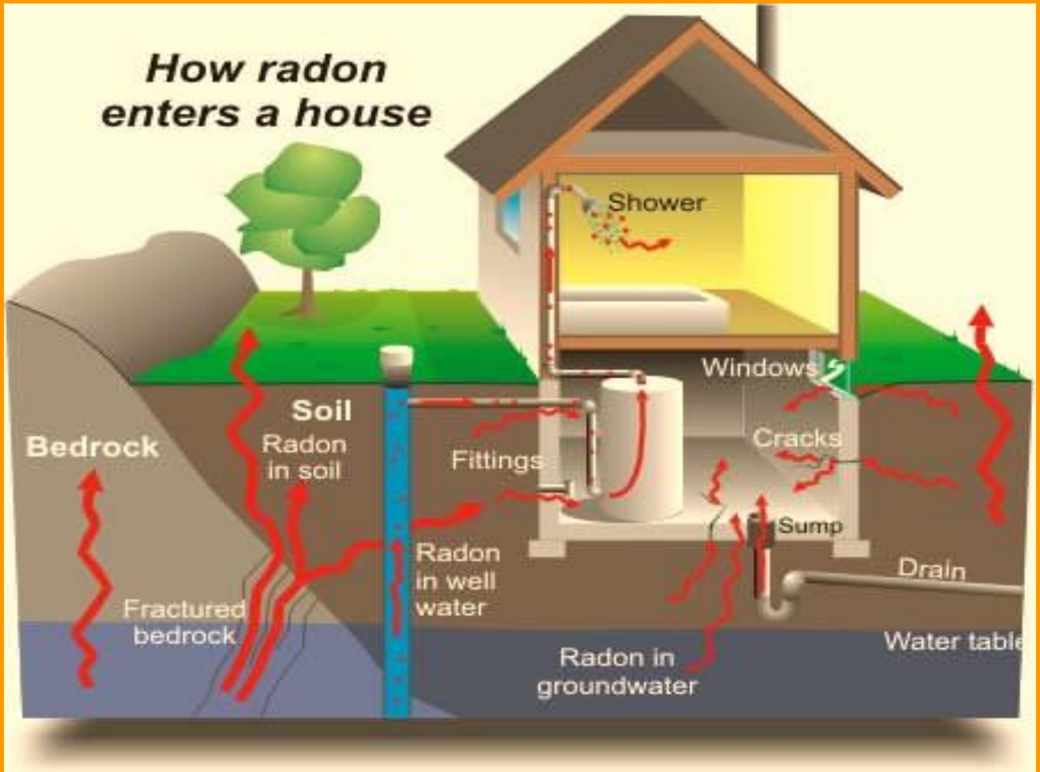
Food can gain this radioactivity in a few ways:

- **Uptake: roots of plants take in radionuclides from the soil.**
- **Deposition: radioactive particles in the air settle onto crops.**
- **Bioaccumulation: radionuclides accumulate in animals that ingest plants, feed, or water containing radioactive material.**

Background Radiation

Average American:

- **Internal:**
  - **Radon: 200 mrem**
  - **Other: 40 mrem**

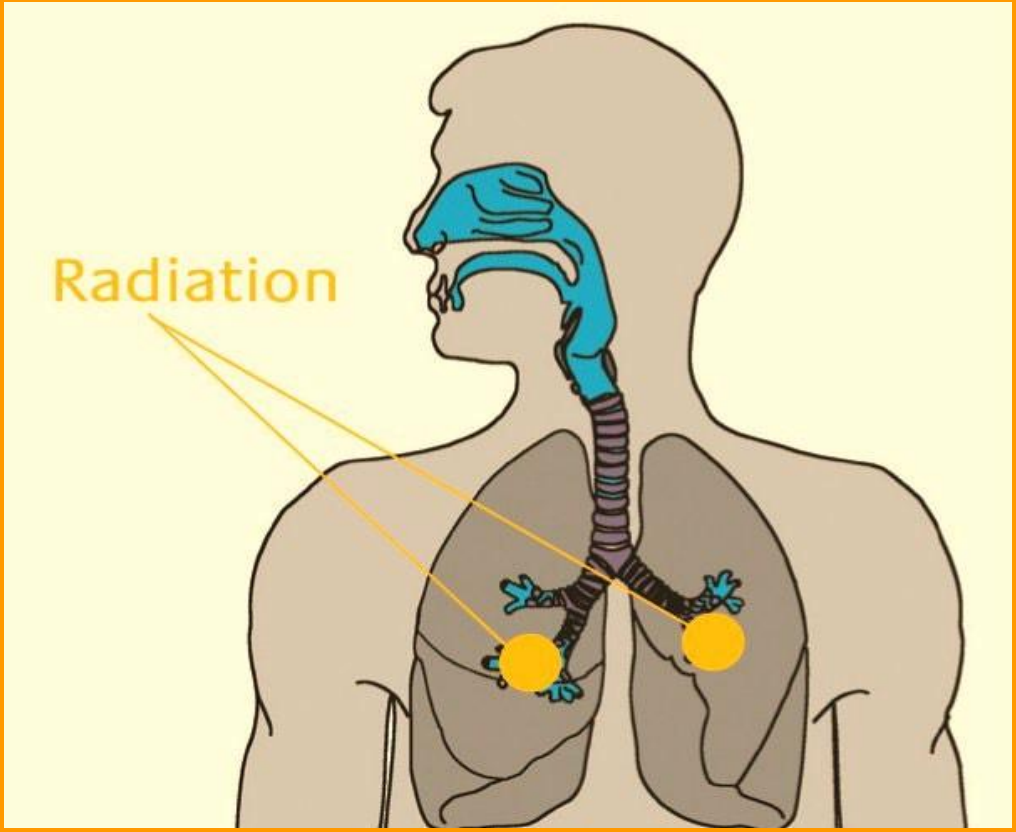


Radon is naturally occurring and enters our homes through various methods. If the home is not properly ventilated the Radon builds up and gets ingested through our lungs.

Background Radiation

Average American:

- **Internal:**
  - **Radon: 200 mrem**
  - **Other: 40 mrem**

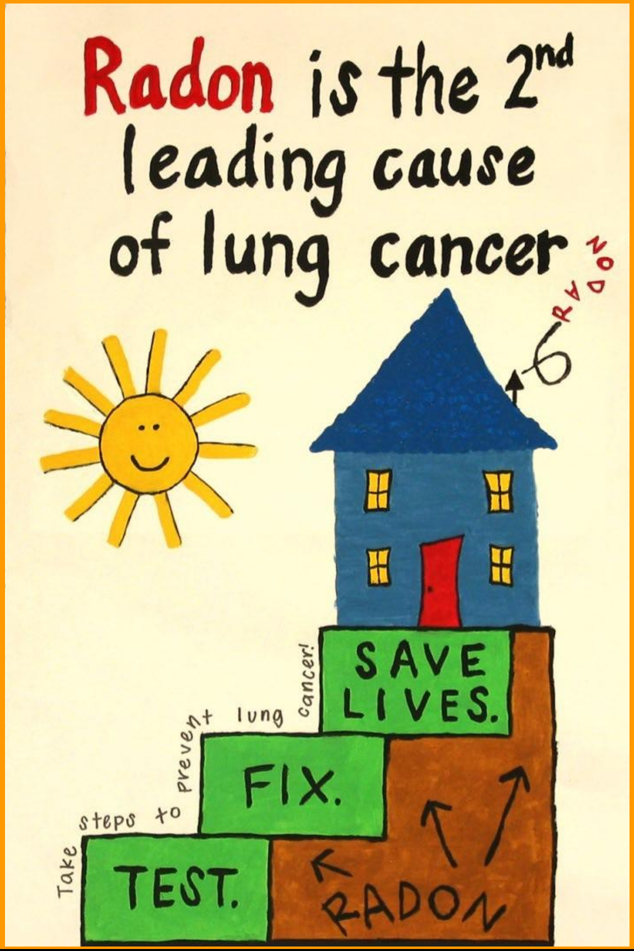


Radon continues to emit highly damaging Alpha Particles for a long time after it is trapped in the lungs.

Background Radiation

Average American:

- Internal:
  - Radon: 200 mrem
  - Other: 40 mrem



It is highly recommended to get homes (especially older ones) tested for levels or Radon

Background Radiation

Average American:

- Medical: 55 mrem

About 1/6th of the Annual Background Radiation is received from Medical Procedures utilizing radiation like CT, X-Rays, Mammograms, etc.

Background Radiation

Average American:

- Medical: 55 mrem

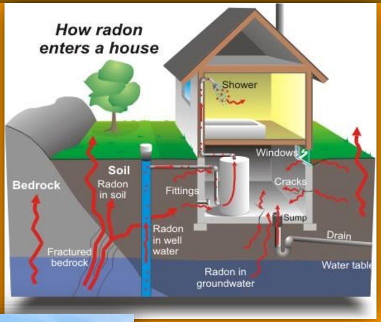
Patients exposed to medical radiation have NO significantly increased risk of cancer

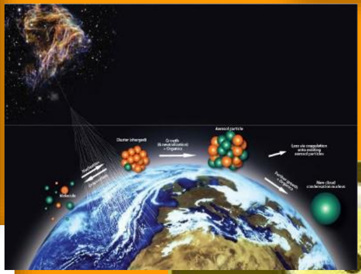
Background Radiation

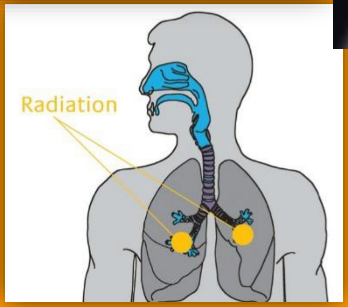
Average American:

- Cosmic: 30 mrem
- Earth: 35 mrem
- Internal:
  - Radon: 200 mrem
  - Other: 40 mrem
- Medical: 55 mrem

TOTAL: 360 mrem/year







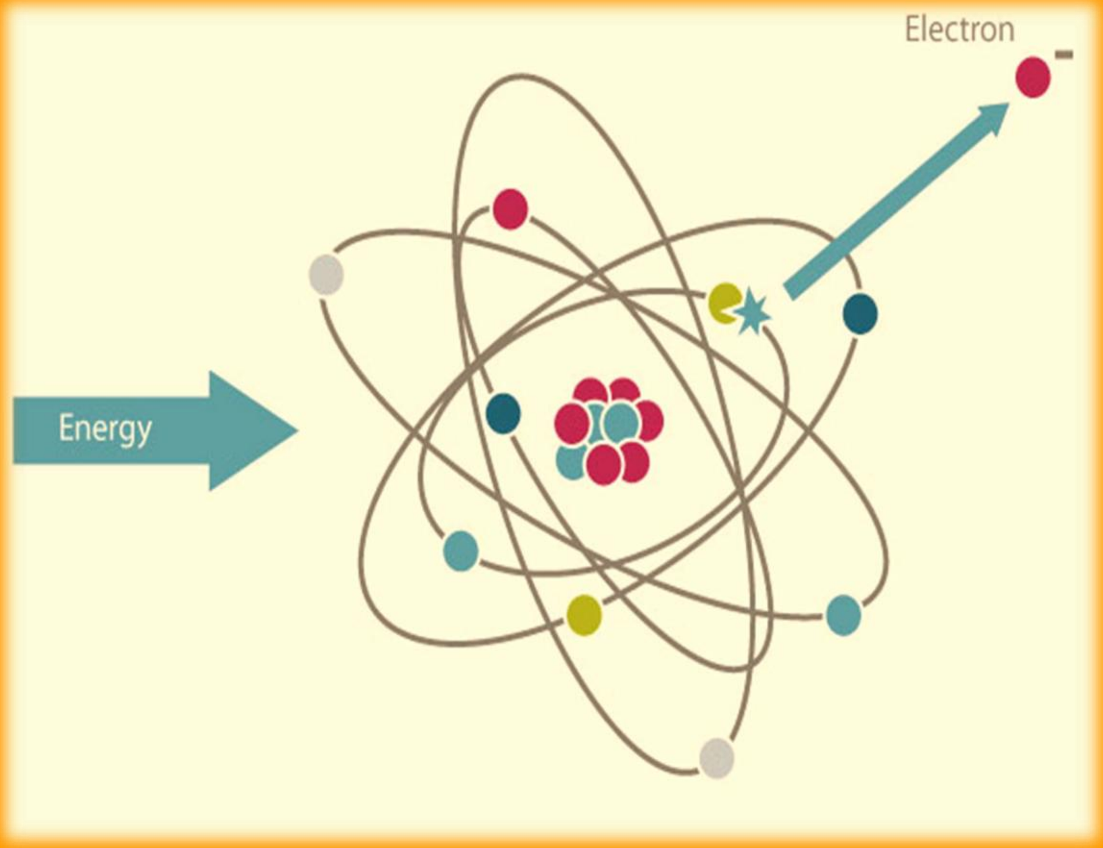
X-Ray Physics & Technology

X-Rays & Gamma rays have enough energy (electron volts) to cause ionization.

X-rays have the ability to "knock" electrons out of orbit in an atom.

This leads to creation of an Ion Pair.

Ionization is responsible for biological damage.

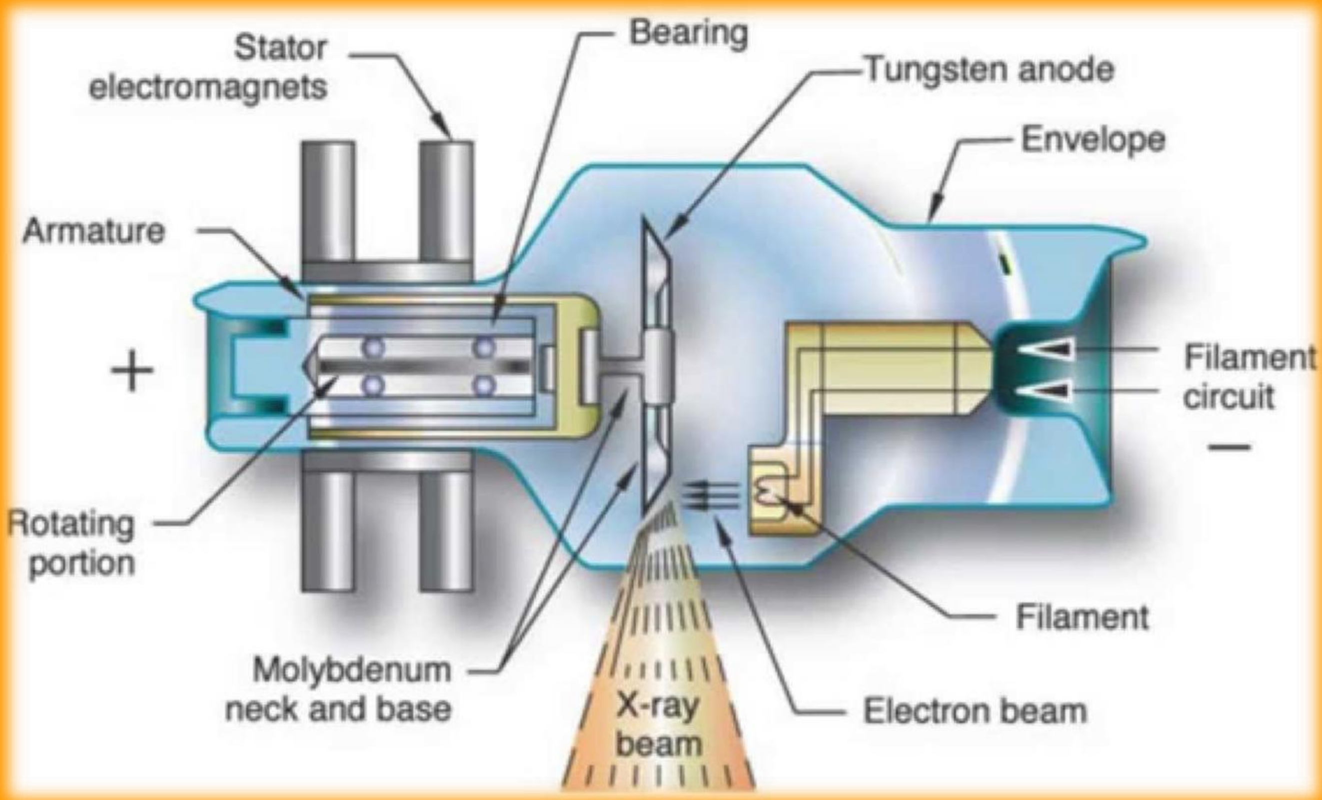


X-Ray Physics & Technology

X-rays are produced within the X-ray machine, also known as an X-ray tube. No external radioactive material is involved.

X-Ray Physics & Technology

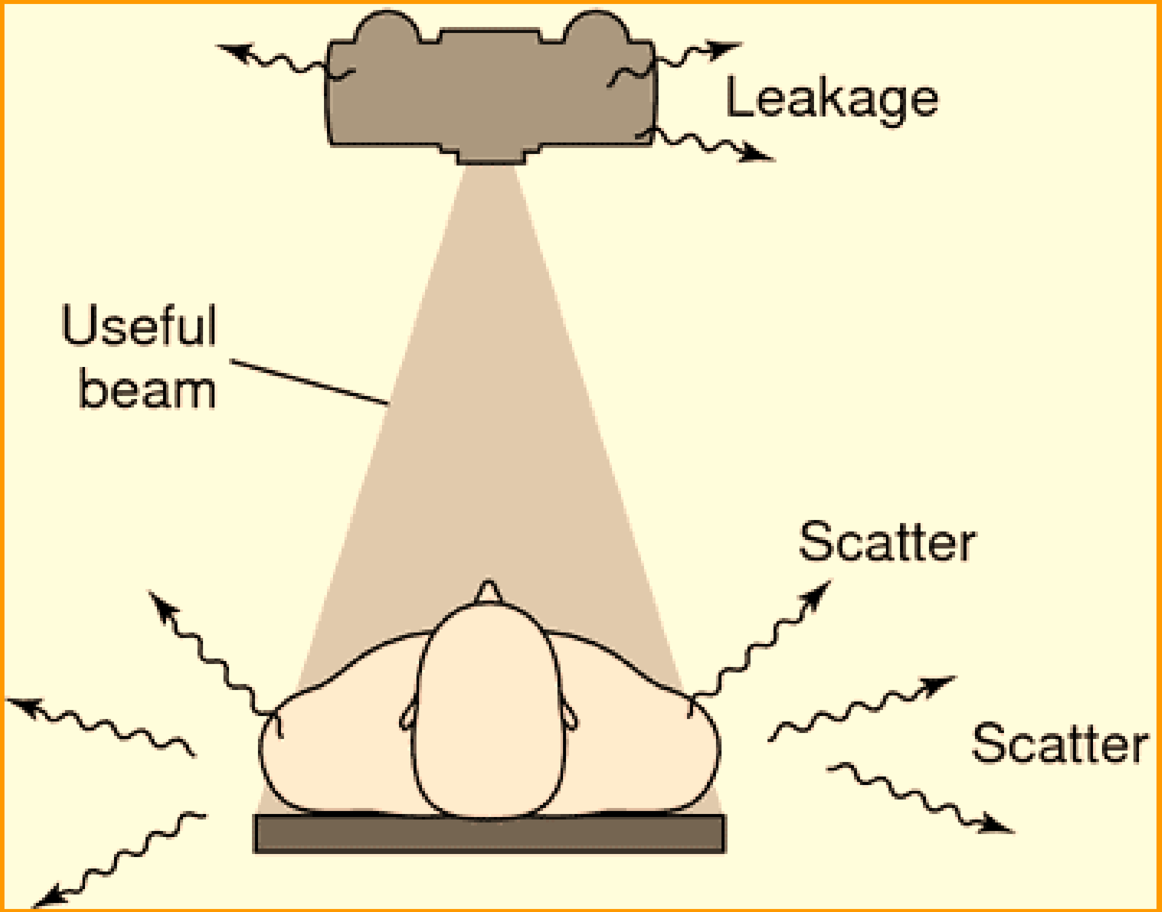
X-Rays are produced by accelerating electrons to high energies and causing them to strike a metal target from which the X-rays are emitted.



X-Ray Physics & Technology

The body parts of the patient being imaged is done by the PRIMARY useful beam

The Exposure to Personnel is due to SECONDARY Scattered Radiation from the patient and Leakage Radiation from the tube head.



X-Ray Physics & Technology

The X-Ray beam is controlled by the following three main parameters:

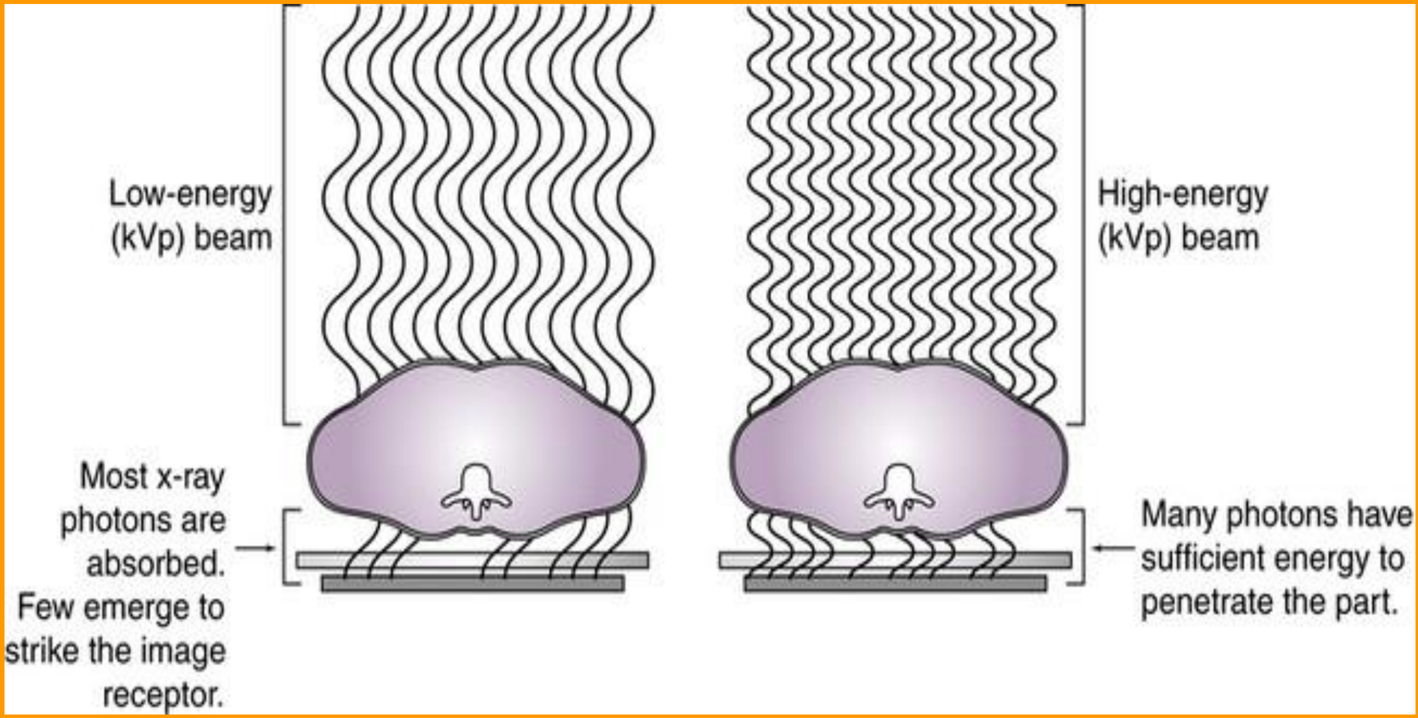
kVp	mA	ms
Tube Kilovoltage	Tube Current	Exposure TIme

X-Ray Physics & Technology

kVp

Varying the kVp changes the energy of the X-Rays and thereby its Penetration power.

The higher the kVp the greater the penetration.

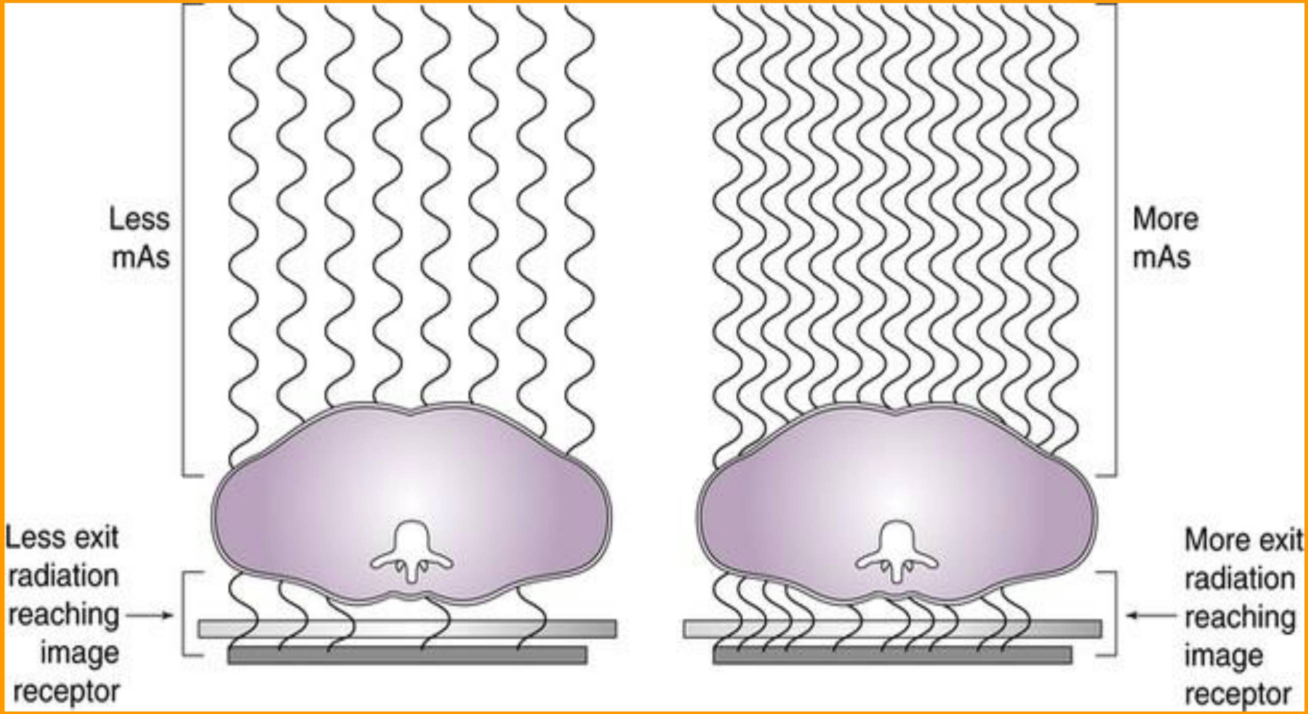


X-Ray Physics & Technology

mA

Varying the mA (current) changes the quantity of the X-Rays and thereby its Flux.

The higher the mA the greater the flux.

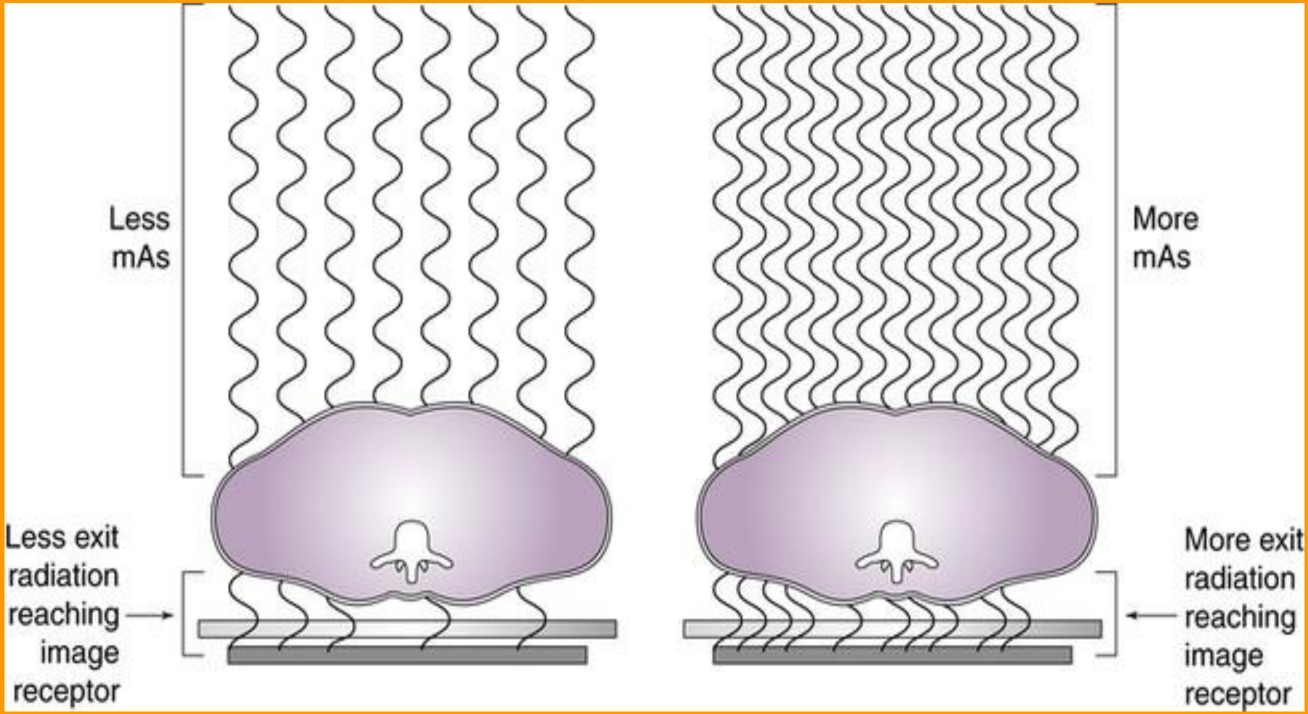


X-Ray Physics & Technology

ms

Varying the ms (total beam on time) changes the total number of X-Rays.

The higher the ms the greater the total exposure.



X-Ray Physics & Technology

X-Rays can be produced in:

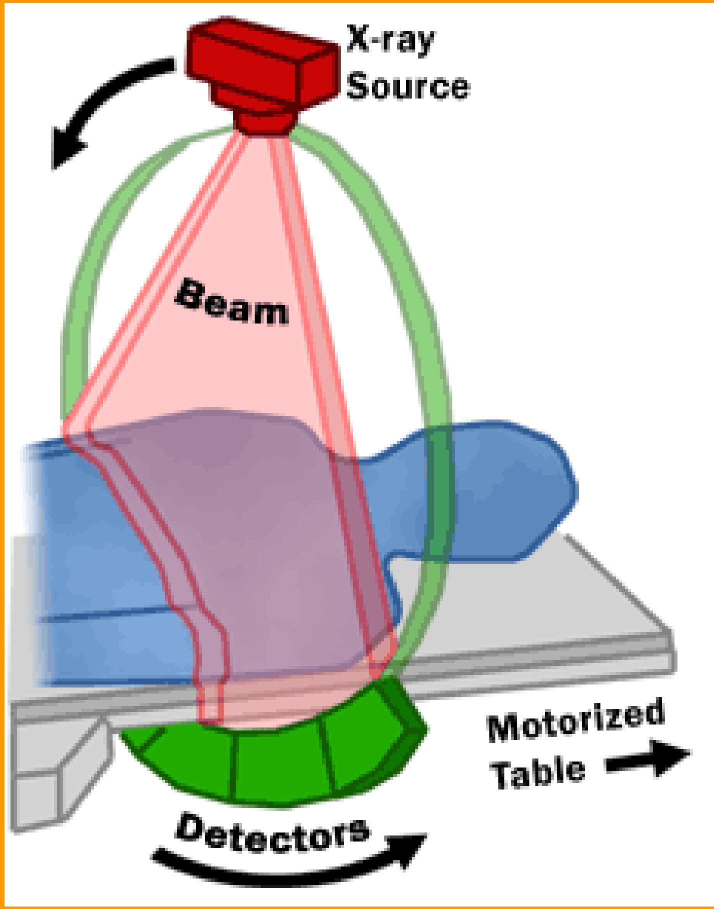
X-Ray Units

CT Units

Dental Units

X-Ray Physics & Technology

In the traditional CT scanner there is one X ray source but a large number of detectors.

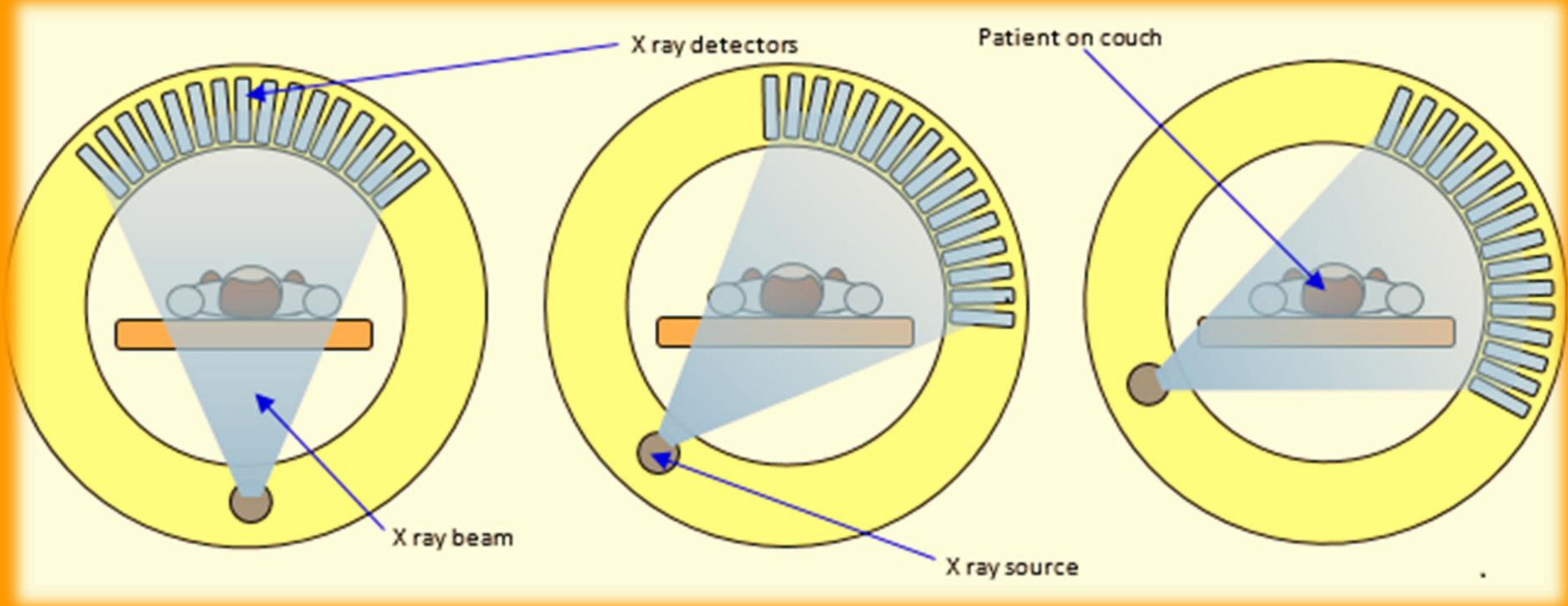


X-Ray Physics & Technology

The source and the detectors are mounted in a large doughnut shaped machine and the patient is placed inside this on a couch, or upright as in the case of CBCT Dental Units.

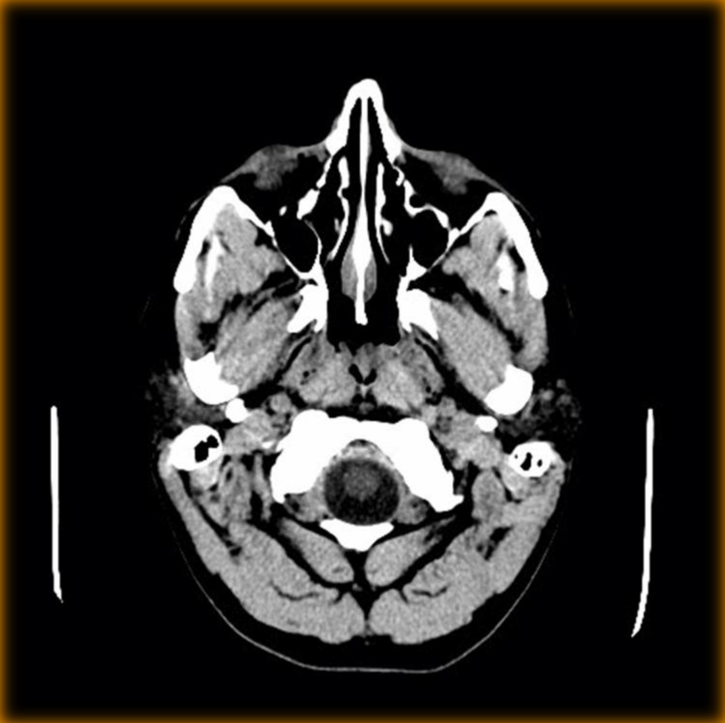
X-Ray Physics & Technology

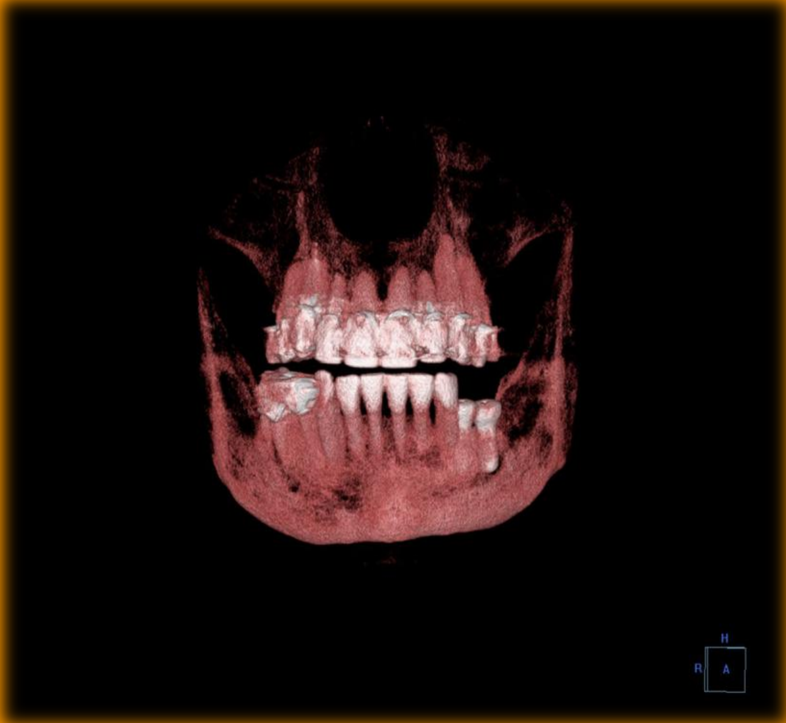
Each detector records an image, and the source and detectors are then rotated around the patient to give views from a variety of direction. The image is called a tomogram.



X-Ray Physics & Technology

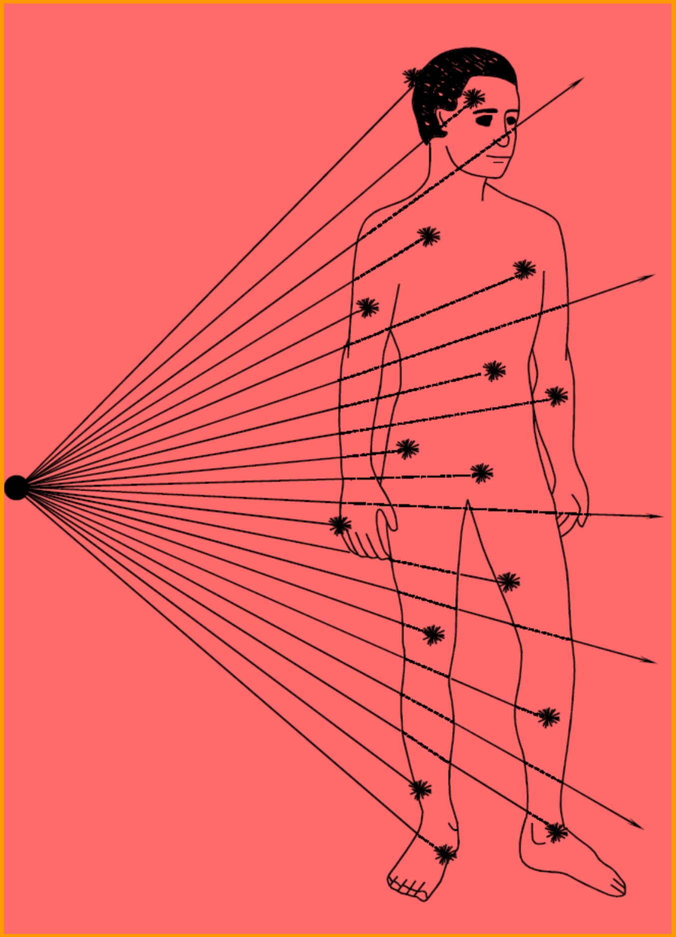
This large number of images (many hundreds) are then combined by a computer to give a composite detailed 3D image of the organs under investigation.





Biological effects of X-ray Exposure

Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some biological effects.



Biological effects of X-ray Exposure

Although we tend to think of biological effects in terms of the effect of radiation on living cells, in actuality, ionizing radiation, by definition, interacts only with atoms by a process called ionization.

Thus, all biological damage effects begin with the consequence of radiation interactions with the atoms forming the cells. As a result, radiation effects on humans proceed from the lowest to the highest levels

Radiation Causes Ionizations of:

ATOMS

which may affect

MOLECULES

which may affect

CELLS

which may affect

TISSUES

which may affect

ORGANS

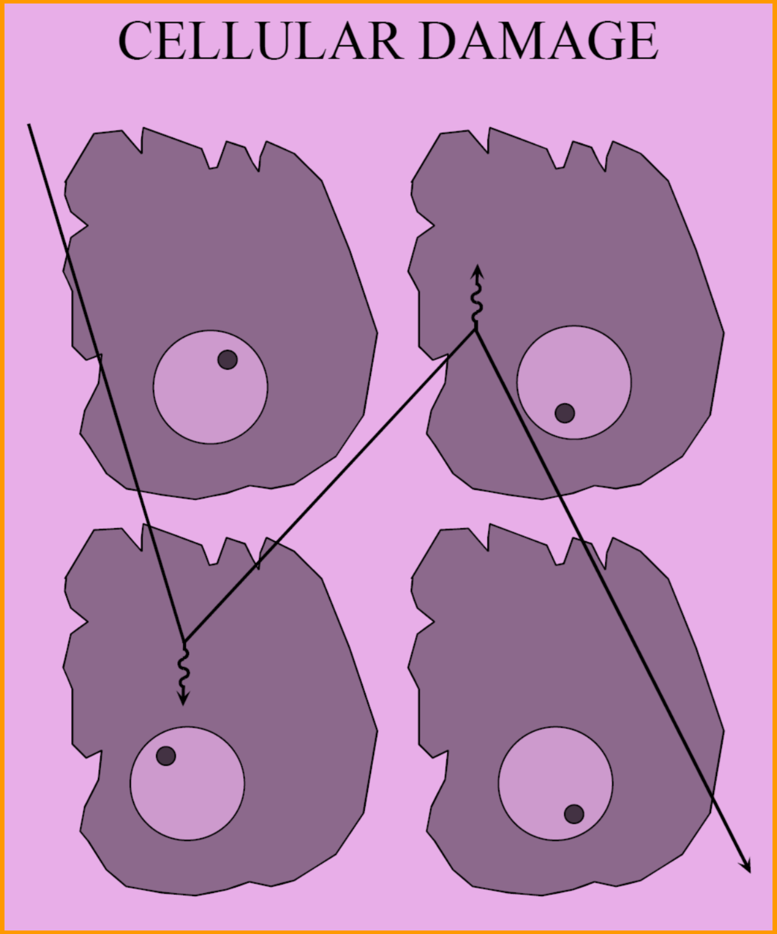
which may affect

THE WHOLE BODY

Biological effects of X-ray Exposure

Even though all subsequent biological effects can be traced back to the interaction of radiation with atoms, there are two mechanisms by which radiation ultimately affects cells.

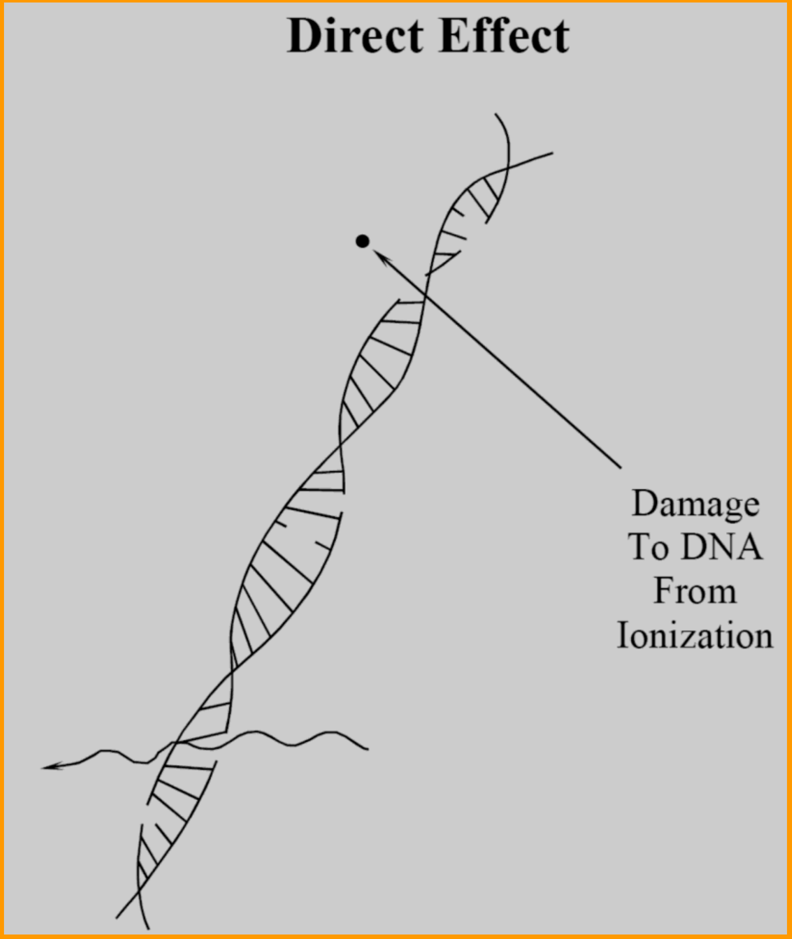
These two mechanisms are commonly called DIRECT and INDIRECT effects.



Biological effects of X-ray Exposure

If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as a direct effect. Such an interaction may affect the ability of the cell to reproduce and, thus, survive.

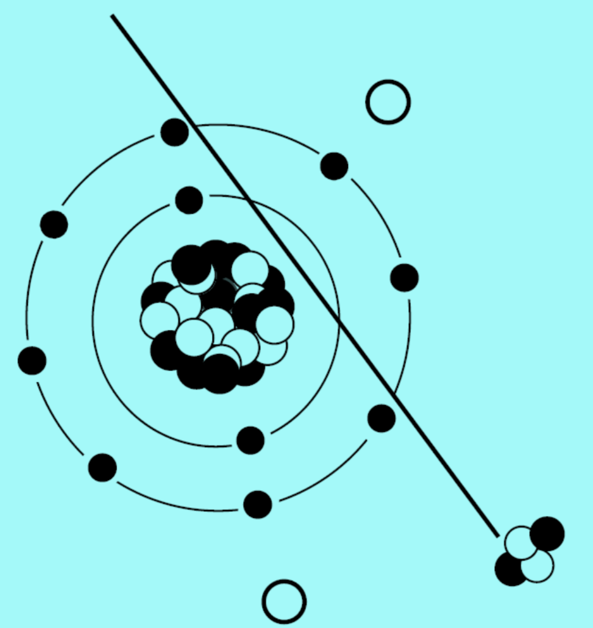
If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by "direct" interference with its life-sustaining system.



Biological effects of X-ray Exposure

If a cell is exposed to radiation, the probability of the radiation interacting with the DNA molecule is very small since these critical components make up such a small part of the cell. However, each cell, just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume.

Indirect Effect

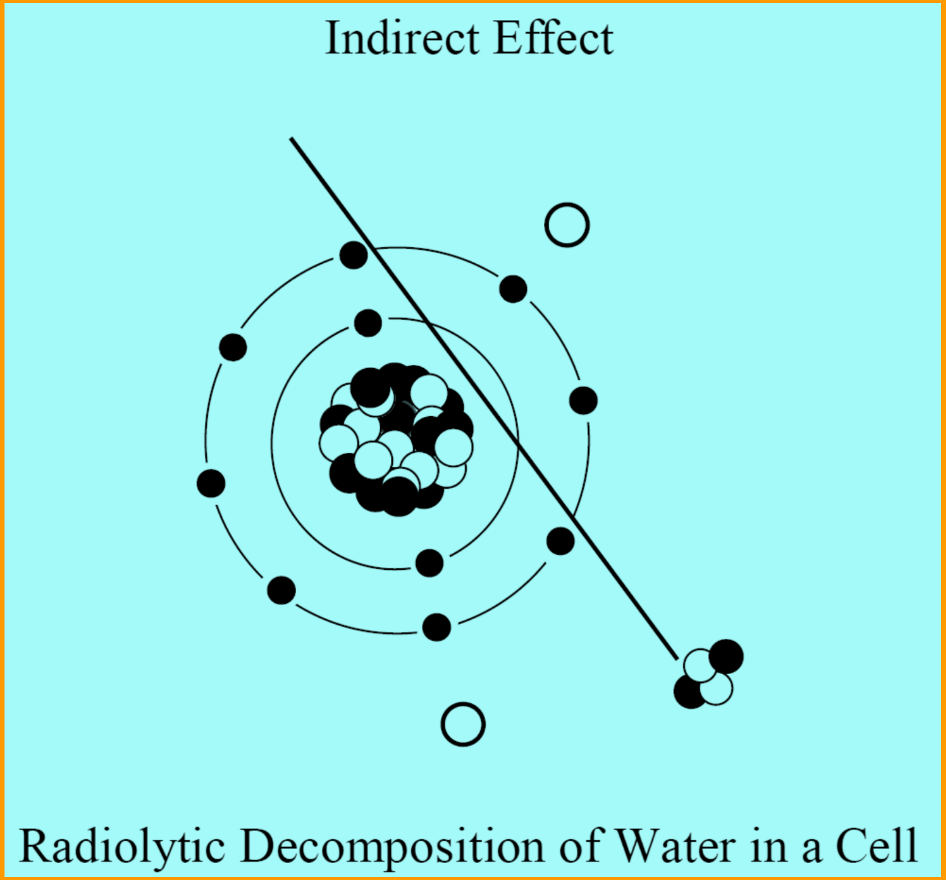


Radiolytic Decomposition of Water in a Cell

Biological effects of X-ray Exposure

When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell.

However, they could combine to form toxic substances, such as hydrogen peroxide (H2O2), which can contribute to the destruction of the cell.



Biological effects of X-ray Exposure

Not all living cells are equally sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not. This is because dividing cells require correct DNA information in order for the cell's offspring to survive. A direct interaction of radiation with an active cell could result in the death or mutation of the cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect.

Cellular Sensitivity to Radiation
(from most sensitive to least sensitive)

Lymphocytes and Blood Forming Cells

Reproductive and Gastrointestinal (GI) Cells

Nerve and Muscle Cells

Biological effects of X-ray Exposure

As a result, living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation. This means that different cell systems have different sensitivities. Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are, therefore, the most sensitive. Reproductive and gastrointestinal cells are not regenerating as quickly and are less sensitive. The nerve and muscle cells are the slowest to regenerate and are the least sensitive

Cellular Sensitivity to Radiation
(from most sensitive to least sensitive)

Lymphocytes and Blood Forming Cells

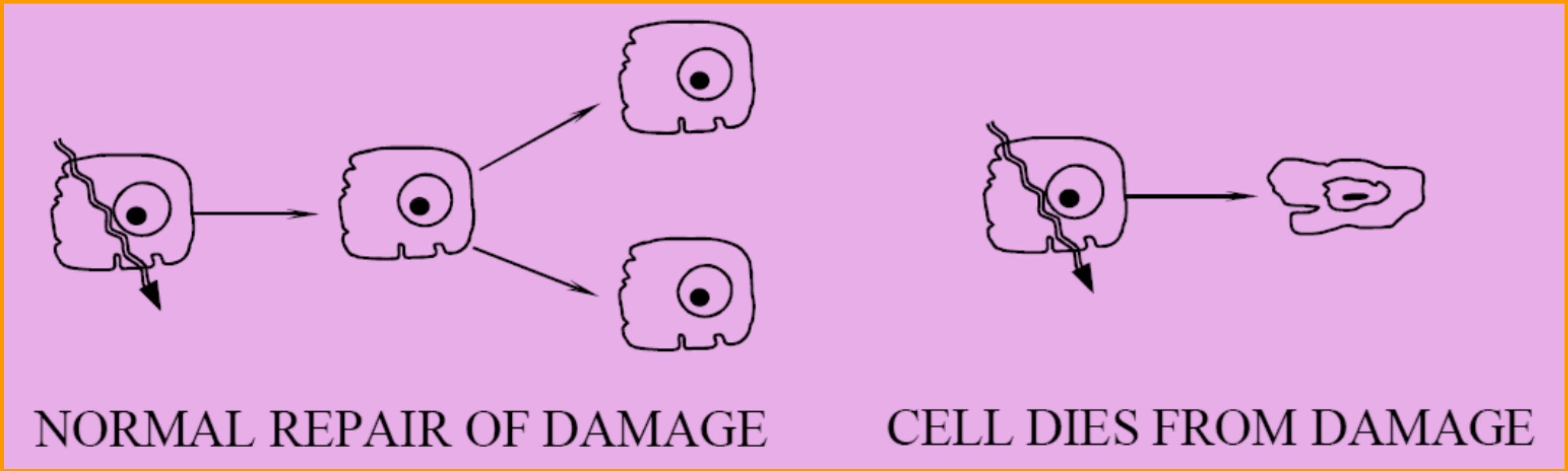
Reproductive and Gastrointestinal (GI) Cells

Nerve and Muscle Cells

Biological effects of X-ray Exposure

Cells, like the human body, have a tremendous ability to repair damage. As a result, not all radiation effects are irreversible. In many instances, the cells are able to completely repair any damage and function normally.

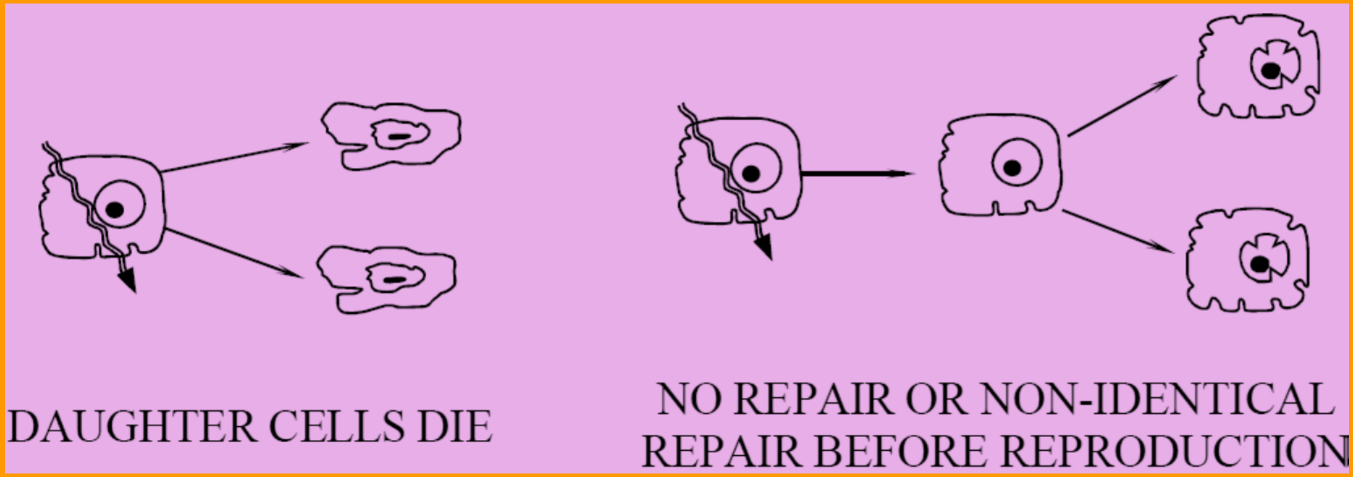
If the damage is severe enough, the affected cell dies.



Biological effects of X-ray Exposure

The daughter cells, however, may be lacking in some critical life-sustaining component, and they die.

The other possible result of radiation exposure is that the cell is affected in such a way that it does not die but is simply mutated. The mutated cell reproduces and thus perpetuates the mutation. This could be the beginning of a malignant tumor.



Biological effects of X-ray Exposure

The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed.

For example, since the blood forming cells were one of the most sensitive cells due to their rapid regeneration rate, the blood forming organs are one of the most sensitive organs to radiation.

Muscle and nerve cells were relatively insensitive to radiation, and therefore, so are the muscles and the brain.

Organ Sensitivity
(from most sensitive to least sensitive)

Blood Forming Organs

Reproductive and Gastrointestinal Tract Organs

Skin

Muscle and Brain

Estimating Risk

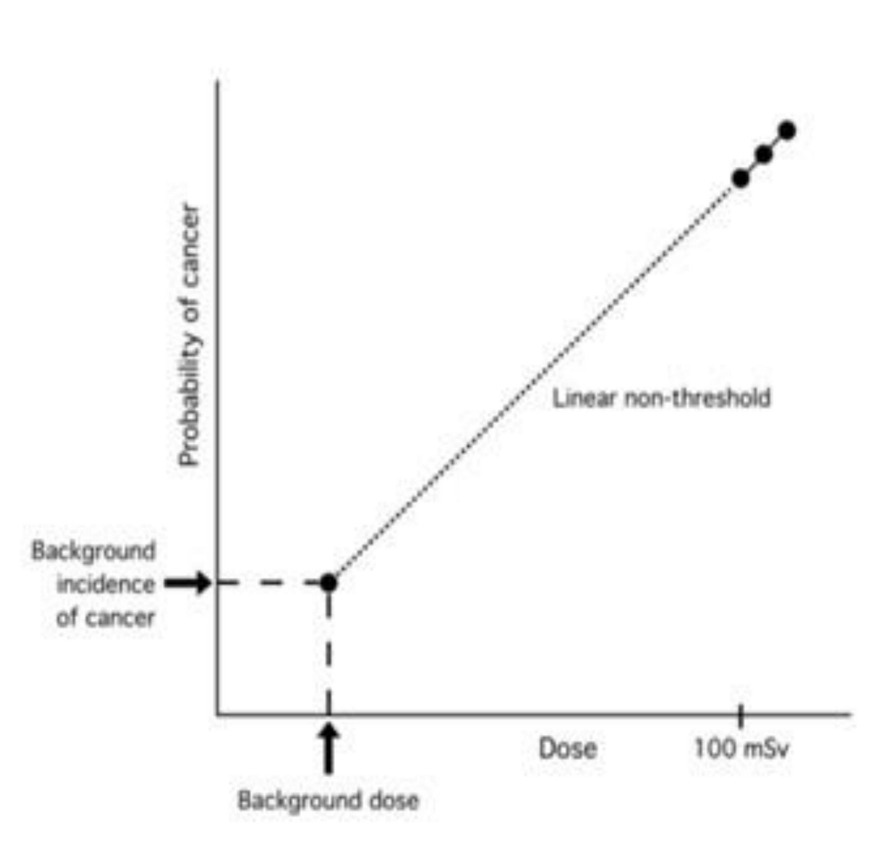
The primary risk from Radiation Exposure and the overwhelming concern of patients is the chance of developing radiation damage-induced cancer.

While the mechanism of action by which the risk of cancer formation is clear, very few studies have been conducted to assess a causal relationship from low-dose diagnostic procedures.

Estimating Radiation Risk

Risk from radiation at low-doses has been estimated with the development of the linear non-threshold (LNT) hypothesis which suggests that there is a linear relationship between radiation dose and the risk of spontaneous formation of a new cancer

As this is a linear relationship, this hypothesis suggests that there is no "safe dose" of radiation, below which there is no risk. Rather, it suggests that as exposure increases, so does the likelihood of developing cancer.



Radiation Risks

- All people react differently to risks.
- Statistics !
  - Experiments on laboratory animals
  - Results from reactor accidents
  - Results from atomic bomb victims
  - Analysis of radiation therapy patients

Estimate of Risks

	Estimate of Days of Life Lost
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	85
All accidents@combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (US average)	130
Home accidents	95
Drowning	41
Background radiation (300 mrem/yr)	8
Medical diagnostic x-rays (US average)	6
All catastrophes (earthquakes, etc.)	3.5
Occupational radiation dose, 1 rem	1
1 rem/yr for 30 years	30

Adopted from: B. Cohen and L Lee. Health Physics 36:707-722, 1979

Radiation Safety

Referrers for radiological investigations are required to provide sound clinical reasons to justify exposing patients to radiation.

Local rules of the X-ray department must be adhered to, as ignoring them may result in breaking the law.

Radiation Safety

All X-rays may cause alteration of cellular division and other intracellular processes and are therefore potentially harmful to the human body.

For this reason, all prescribed medical exposure to radiation should be justified in terms of risk to benefit ratio.

Radiation Safety

Some body parts are more susceptible to the random damaging effects of radiation. These are generally tissues with rapidly dividing cells, for example, radiation dose to the stomach is over 20 times more likely to result in a fatal cancer than the same dose to bone.

Radiation exposure to reproductive organs carries further potential risk to future generations. Children are more radiosensitive than adults and irradiation of a fetus should be avoided wherever possible.

Radiation Safety

Several principles should be adhered to in order to reduce risk to patients:

- **JUSTIFICATION - Potential benefit of radiation exposure should outweigh risk.**
- **OPTIMIZATION - Measures should be in place to reduce dose to patients and staff.**
- **LOCAL RULES - Measures to ensure wider regulations are enforced, for example that X-ray machines are correctly installed and used, and that referrals are justified.**

Radiation Safety

Staff are also at potential risk from radiation exposure.

The exposures that radiologists and radiographers are exposed to are generally small.

However, local rules are enforced to ensure that measures are taken in order to monitor and reduce staff radiation exposure.

A.L.A.R.A

In Order to minimize the Biological Effects and potential damage due to Ionizing Radiation we should always follow good Radiation Safety practices and strive to keep our exposure …

A L A R A

As Low As Reasonably Achievable

A.L.A.R.A

As Low As Reasonably Achievable

- This principle means that even if it is a small dose, if receiving that dose has no direct benefit, you should try to avoid it.

A.L.A.R.A

As Low As Reasonably Achievable

- The regulatory upper limit for occupational whole body exposure is 5000 mrem/year
- Good ALARA principles strive to keep personnel whole body exposure to below 10% of this Annual limit … which is 500 mrem
- By using ALARA practices, occupational radiation risk can be reduced to negligible levels:

A.L.A.R.A.

To Minimize Radiation Exposure:

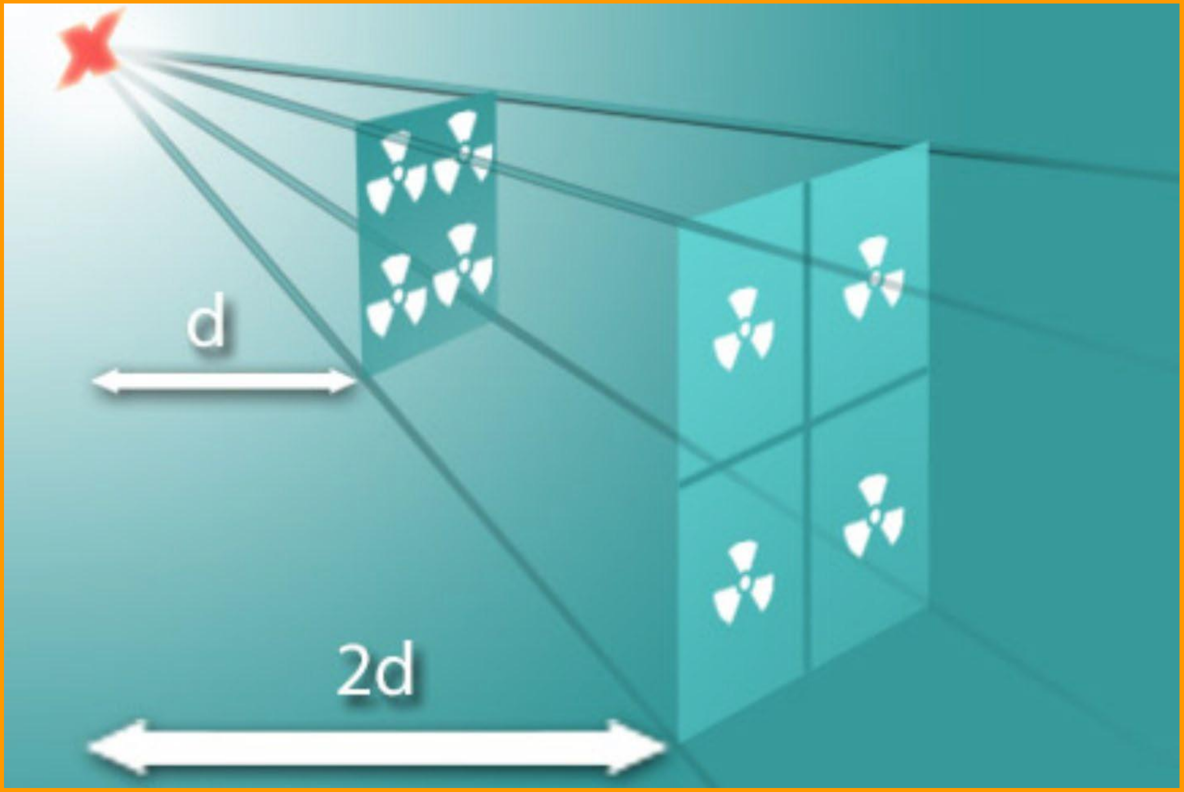
A.L.A.R.A.

- ## Limit Time
  - **If less time spent around a radiation source then less is the radiation exposure, and vice versa**

A.L.A.R.A.

Increase Distance

- Knowledge of the 'inverse square law' helps in reducing dose.
- This states that the dose to a given area is quadrupled be halving the distance from the radiation source. Simply put, standing back from a source of radiation reduces dose to staff.



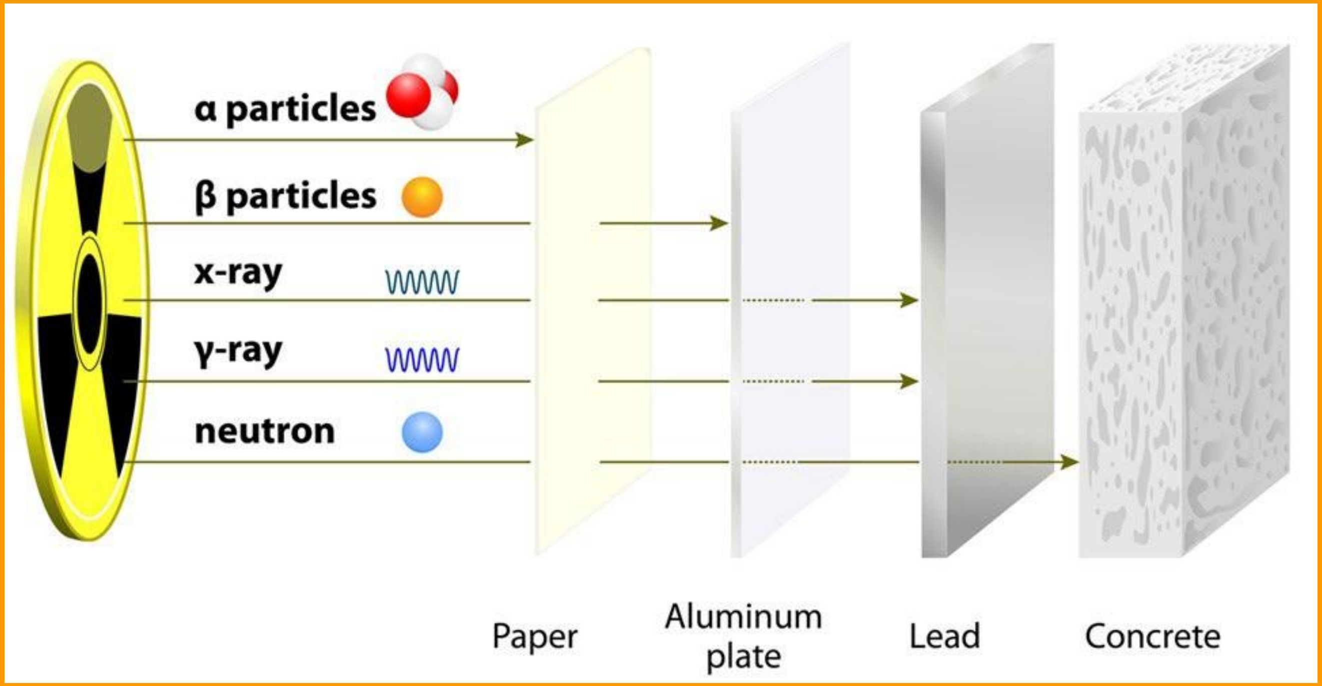
A.L.A.R.A.

Use Shielding

- Radiation shielding is based on the principle of attenuation, which is the gradual loss in intensity of any energy through a medium.

Lead acts as a barrier to reduce a ray's effect by blocking or bouncing through a barrier material.

When X-Ray photons interact with matter, the quantity is reduced from the original x-ray beam.



A.L.A.R.A.

- **Types of Shielding**
  - **Lead aprons**
  - **Lead glasses**
  - **Thyroid shields**
  - **Portable or mobile lead shields**





A.L.A.R.A.

- **Use Shielding**

  - **The Operator should always stand behind the Leaded barrier when making an exposure**

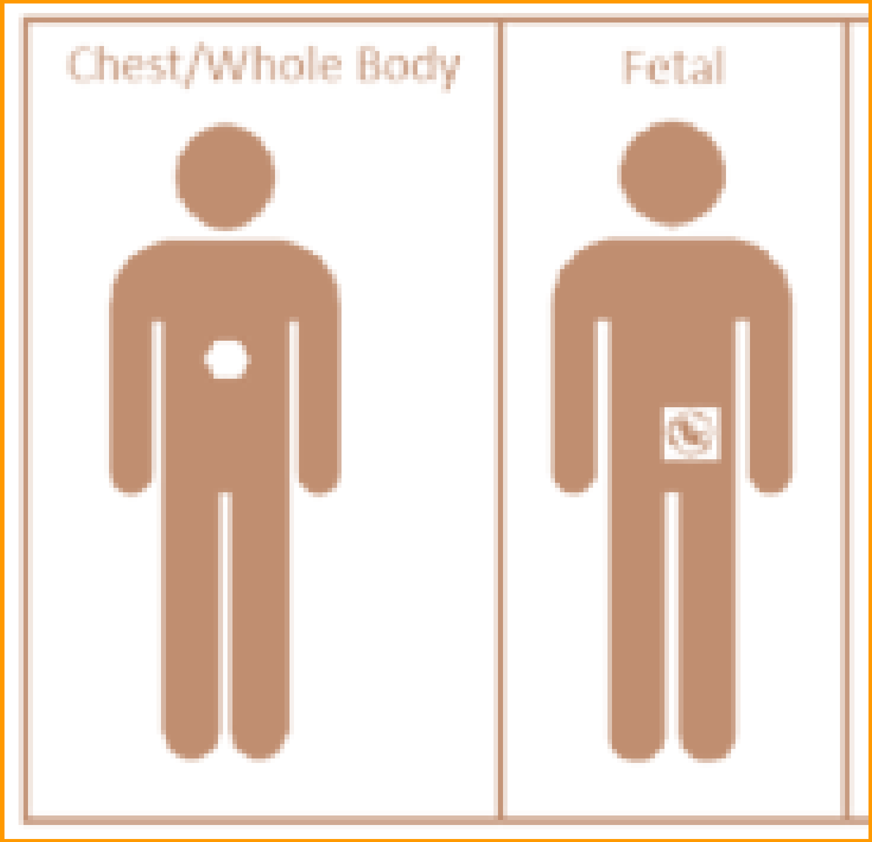
A.L.A.R.A.
PERSONNEL MONITORING

- The film badge dosimeter or film badge is a personal dosimeter used for monitoring cumulative radiation dose due to ionizing radiation.

- After use by the wearer, the film is removed, developed, and examined to measure exposure.

A.L.A.R.A.
PERSONNEL MONITORING

- **The badge is typically worn on the outside of clothing, around the chest or torso to represent dose to the "whole body". This location monitors exposure of most vital organs and represents the bulk of body mass.**
- **Additional dosimeters can be worn to assess dose to extremities or in radiation fields that vary considerably depending on orientation of the body to the source**
- **Fetal badges must be worn under the Lead Apron at the waist level**



A.L.A.R.A.
PERSONNEL MONITORING

- Exchange dosimeter on time
- Compared with control monitor (The control badge should be kept away from all sources of radiation)
- Utilize at primary employer
- Worn as a worker not as a patient
- Dosimeters will NOT protect the wearer from radiation exposure:

A.L.A.R.A.
Who Gets Badged ?

- **Diagnostic Imaging:**
  - **X-ray, Nuc Med techs;**
  - **Rad Therapy Techs;**
  - **Radiology Nurses;**
- **Optional Radiology:**
  - **US techs, transporters;**
- **X-Ray Angiogiography:**
  - **EKG, MD's, RN's**
- **O.R. Personnel:**
  - **"routine" fluoroscopy**

Pregnant Workers

- A "declaration of pregnancy" by a radiation worker to her supervisor is voluntary
- The "declaration of pregnancy" must be in writing, and have the date of conception
- The Employer will then provide the pregnant employee with a fetal badge that must be worn at the fetal (waist) level.

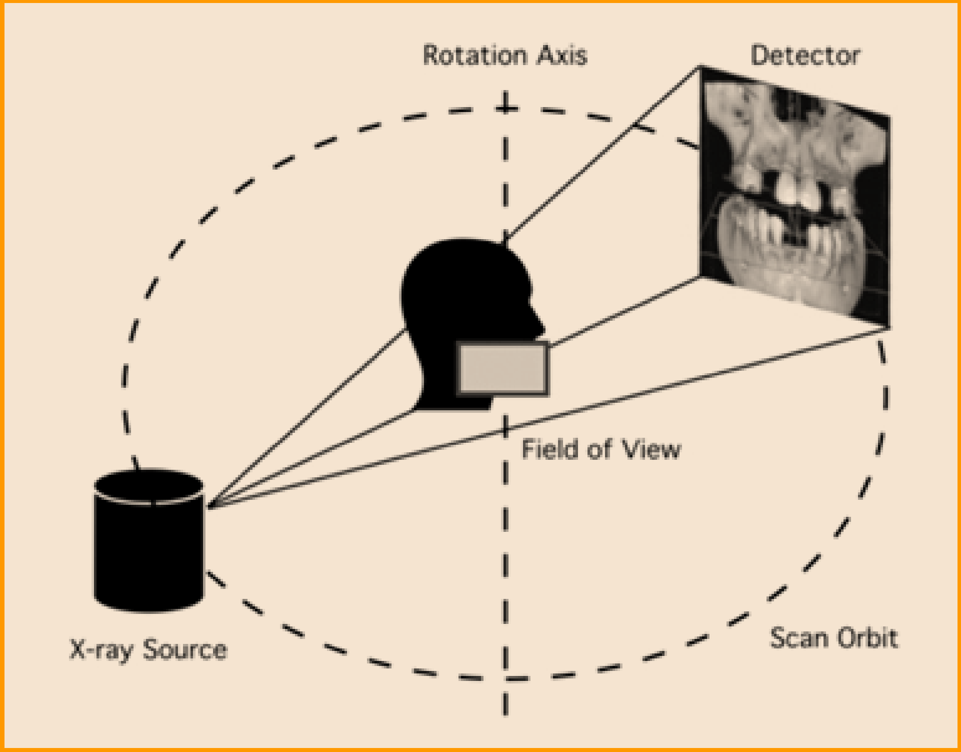
Reducing Dose

- There are a number of strategies to reduce the collective dose for patients undergoing a CBCT examination.
- Even though X-ray doses for CBCT can be considered low, its wide-scale application increases the collective dose received by patients;
- Furthermore, many patients undergoing this examination are children, who are more susceptible to the detrimental effects of radiation.
- It is crucial to optimize the relationship between diagnostic image quality (and equally important, diagnostic requirements) and radiation dose.

Reducing Dose

In general, there are a few strategies to lower patient dose:

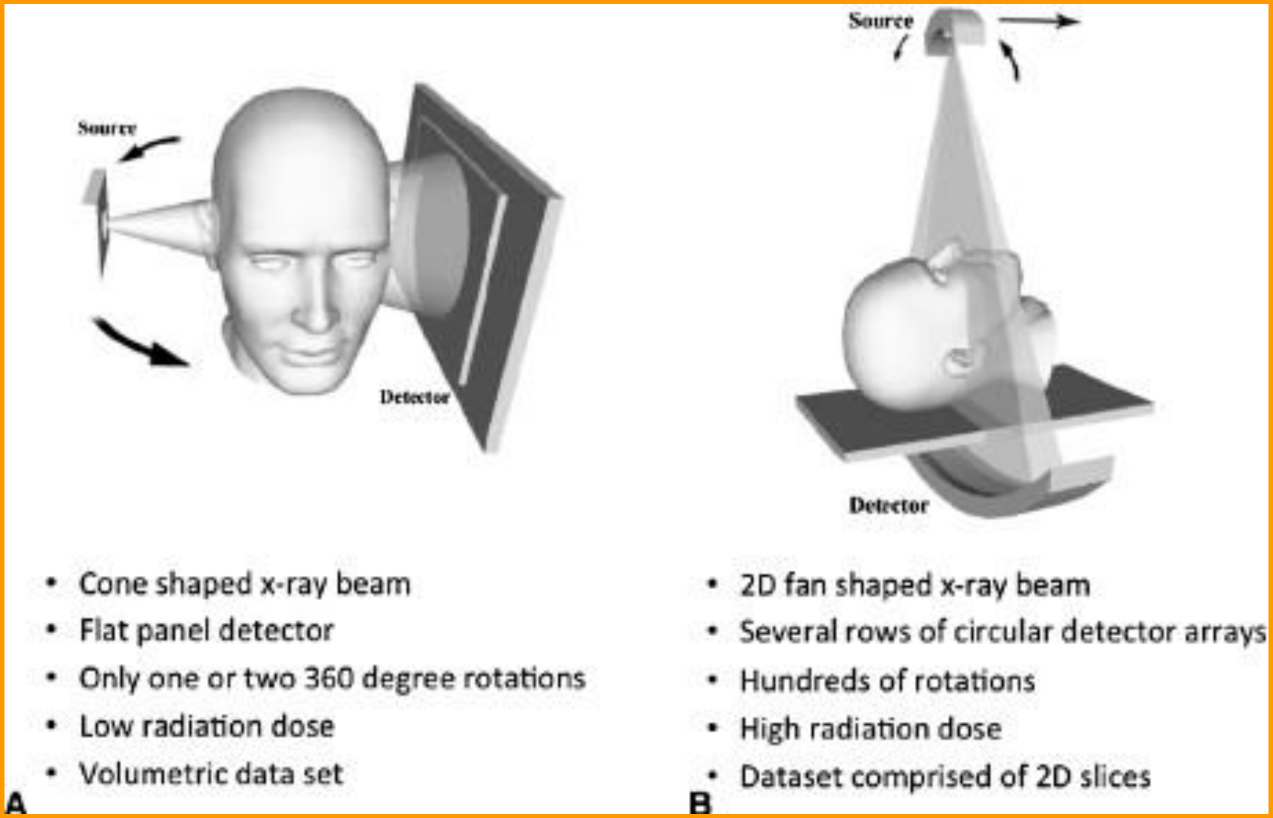
1. **Adjusting exposure factors such as the amount of X-rays (mAs), energy of X-rays (kV) and spectrum homogeneity (filtration).**
2. **Limiting the diameter & height of the field of view (FOV) to the region of interest (ROI), avoiding unnecessary exposure to radiosensitive organs and tissues which are outside the ROI.**
3. **Using dose reduction techniques such as thyroid shielding.**



It is never recommended to have a family member in the scan room

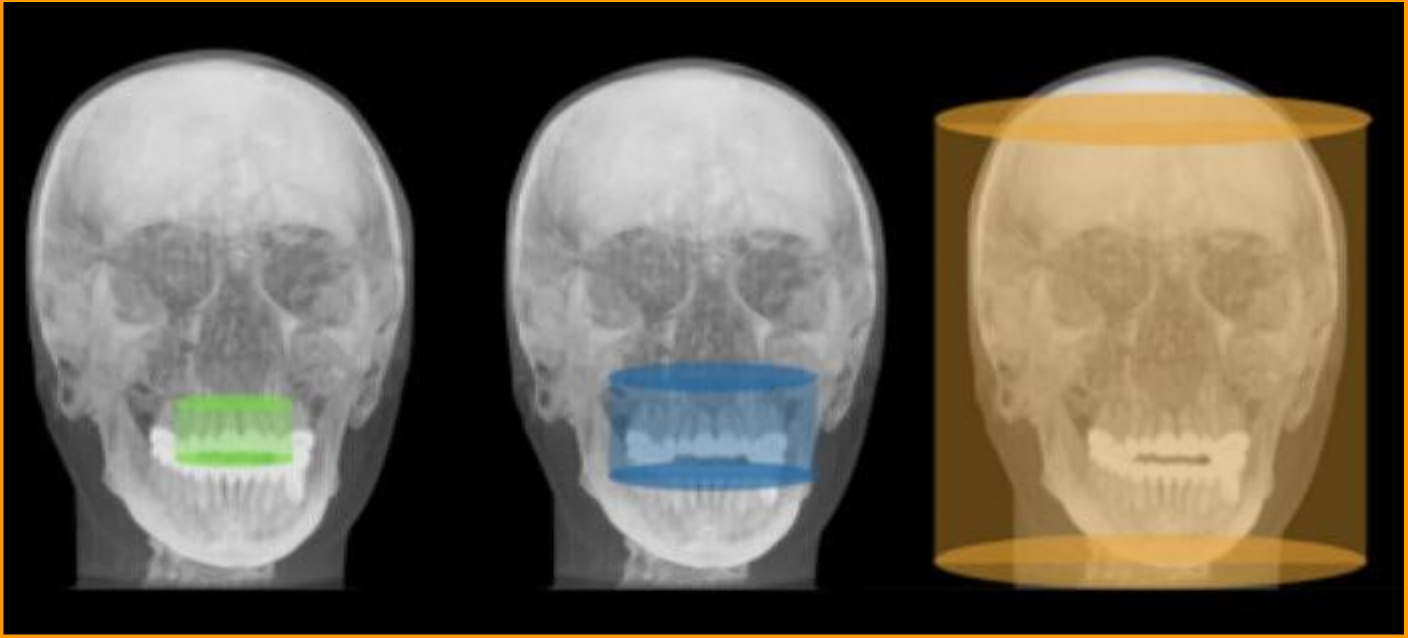
CBCT v/s Helical CT

The patient radiation dose is much lower for CBCT than for helical CT;



CBCT v/s Helical CT

The patient radiation dose is closely related to the FOV and exposure parameters used for a CBCT examination. Without alteration of any other exposure parameters, the larger the FOV used for scanning, the higher the radiation dose is;



CBCT v/s Helical CT

Compared with conventional dental radiography, the effective dose of CBCT is several to hundreds of times higher;

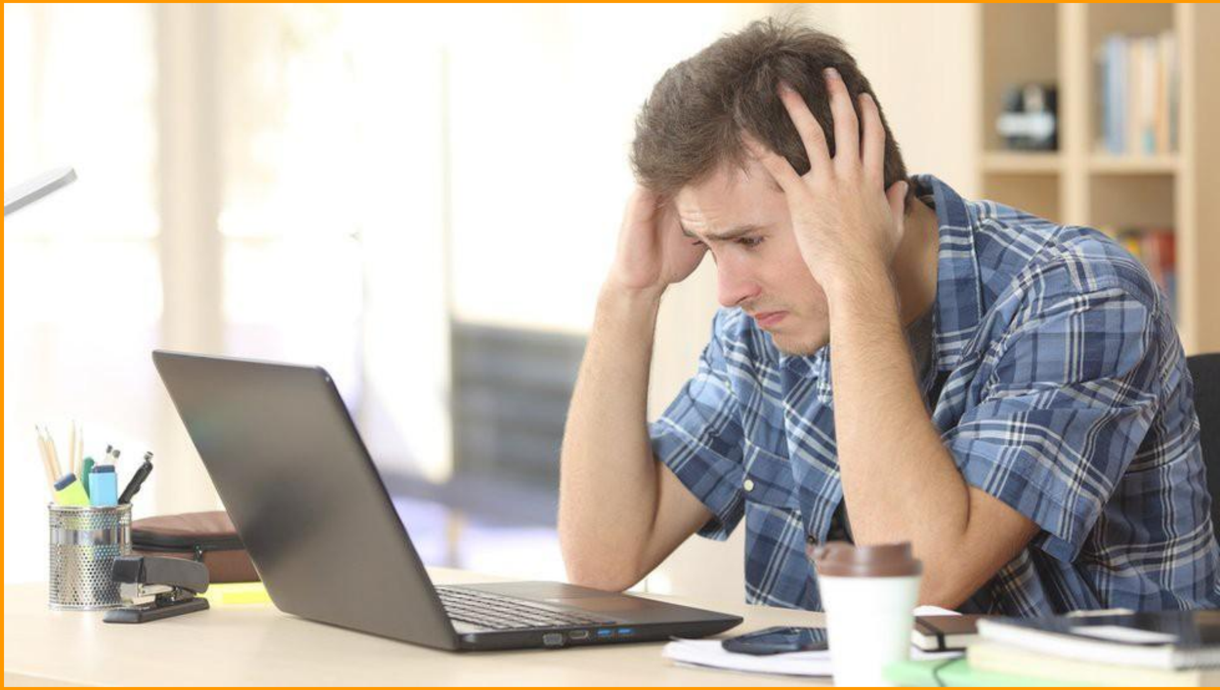
CBCT v/s Helical CT

A thyroid collar should be used for CBCT scanning; wearing leaded glasses is recommended when it does not detract from imaging quality.

Radiation Counseling

It is also imperative that health professionals stay up-to-date with recent media releases and publications on the topic of radiation imaging and radiation exposure.

Patients are exposed to a myriad of complex and ambiguous information sources every day. They rely on health professionals to provide them with a clear bottom line when it comes to risks to their health.



Radiation Counseling

Finally, do not dismiss patient concerns around radiation exposure and their perceived risk. Validate their concerns with empathy and understanding.

Education of your patients can go a very long way in shifting their perspective on the topic and their acceptance of your offer to do your best work to help them