There are two main units of measure for ionizing radiation. Exposure is a quantity of radiation that can be measured directly by collecting electrical charge in air (Roentgen). Absorbed Dose is the amount of energy absorbed by an object per unit mass (Gray or rad). The units "Sievert" and "rem" are frequently used and are simply absorbed dose modified to account for different types of radiation (e.g., protons, neutrons) that are more ionizing.

### Radiation Units

- **Exposure**
  - Can be measured directly by appropriate meters
  - Roentgen (R) – ionization in air

- **Absorbed Dose**
  - Radiation dose to organs or body parts
  - Gray (rad) – energy absorbed per unit mass

- **Dose Equivalent**
  - Takes into account different types of radiations
  - Sievert (rem) – same as Gray (rad) for x-rays
These various units become simple when dealing with diagnostic x-rays because they are all essentially equivalent!
The conversions between Grays and rads and between Sieverts and rems is also simple, only requiring the ability to multiply or divide by 100!

**Radiation Units**

- In diagnostic radiology, all three basic units are numerically essentially equal:
  \[ 1 \text{ R} \approx 1 \text{ rad} \approx 1 \text{ rem} \]
- Converting between systems:
  - \[ 1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg} \]
  - \[ 100 \text{ rad} = 1 \text{ Gy} \]
  - \[ 100 \text{ rem} = 1 \text{ Sv} \]
X-rays are just a more energetic part of the electromagnetic spectrum. They are a natural part of our environment.

What Are X-Rays?

- X-rays a part of the electromagnetic spectrum, as shown below
- Only x-rays and gamma rays are ionizing
We live in a sea of radiation, with many natural sources constantly bombarding us in our everyday lives. Background radiation comes from three main sources and can vary widely depending on such factors as locale, elevation, what kind of building we live in and even our diet.

**Natural Background Radiation**

- Three main sources
  - Terrestrial
    - Radioactive elements in the soil
  - Cosmic
    - "Solar wind" - x-rays, gamma rays and other particles from stellar events
  - Internal
    - Radioactive elements are incorporated by plants, which eventually end up in the food we eat
Many areas of the USA and the world have higher terrestrial radiation due to naturally occurring radioactive materials in the soil and rocks.

Terrestrial Radiation

- Variable by location
- 60 mrem/year in NE, E, W and Central States
- 45 mrem/year in Atlantic and Gulf Coastal states
- 90 mrem/year in Colorado Plateau
This map demonstrates the wide range of terrestrial radiation exposures across the USA.
We are constantly bombarded with cosmic radiation, radiation literally hitting earth that emanates from space. Most of this radiation is absorbed by earth’s atmosphere. Higher elevations have less protective atmosphere and thereby experience higher levels of cosmic background radiation. Denver, for example, has roughly twice the cosmic background radiation levels than areas at sea level.

**Cosmic Radiation**

- **Composition**
  - About 90% are protons
  - About 10% are alpha particles
  - Less than 1% are heavier particles, electrons and gamma rays
- Most originate from the Sun (it’s closest), but all stellar objects emanate them
- Most are absorbed in the atmosphere
- Higher altitude → less atmosphere → more radiation
Naturally occurring radioactivity can be found in almost everything we eat and drink.

**Internal Radiation**

<table>
<thead>
<tr>
<th>Food</th>
<th>$^{40}$K pCi/kg</th>
<th>$^{226}$Ra pCi/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>3,520</td>
<td>1</td>
</tr>
<tr>
<td>Brazil Nuts</td>
<td>5,600</td>
<td>1,000-7,000</td>
</tr>
<tr>
<td>Carrot</td>
<td>3,400</td>
<td>0.6-2</td>
</tr>
<tr>
<td>White Potatoes</td>
<td>3,400</td>
<td>1-2.5</td>
</tr>
<tr>
<td>Beer</td>
<td>390</td>
<td>—</td>
</tr>
<tr>
<td>Red Meat</td>
<td>3,000</td>
<td>0.5</td>
</tr>
<tr>
<td>Lima Bean raw</td>
<td>4,640</td>
<td>2-5</td>
</tr>
<tr>
<td>Drinking water</td>
<td>—</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Radon

- The majority of the radon dose is not from radon itself, but from short-lived alpha-emitting radon daughters, most notably $^{216}$Po (T$_{1/2}$ 3 min) and $^{214}$Po (T$_{1/2}$ 0.164 msec) along with beta particles from $^{214}$Bi (T$_{1/2}$ 19.7 min)
- No compelling evidence for increased cancer risks has yet been demonstrated from "acceptable" levels (<4–8 pCi/liter)
- Varies region to region, and house to house
This map illustrated how variable radon levels are across the USA. Many parts of Colorado are in the highest radon concentration areas.
X-rays are created in x-ray tubes by slamming high energy electrons into a dense target material. The electrons interact with atomic nuclei in the target and give up energy in the form of x-radiation. The German word “bremsstrahlung” that describes this interaction means literally “braking radiation.”

Electrons passing near an atomic nucleus are deflected and braked, causing them to give off energy in the form of x-rays.
X-Ray Production

- In an x-ray tube, the electrons are supplied by the cathode, and the tungsten anode provides the nuclei to brake the electrons, resulting in x-ray production.
- The electric potential (kV) across the tube determines the energy of the x-rays produced.
- The quantity of electrons (mA) hitting the anode determines the amount of x-rays produced.
Image formation and contrast depends on two main interactions between x-rays and tissue, as described here.

**X-Ray Interactions**

In diagnostic imaging, most interactions are either:

* **Photoelectric absorption**
  
  All energy is absorbed and an electron is released

* **Compton scattering**
  
  The photon “bounces” off the atom, giving off some energy and continuing in another direction
X-Ray Interactions

Images are formed by looking at the difference in absorption between adjacent areas of tissue

- Only photons that penetrate the patient form the image
- Absorbed photons contribute to patient dose

Scattered photons degrade the image and contribute to both patient and staff dose.
The energy of the electrons as they hit the x-ray tube target determines the maximum energy of the resultant x-ray beam. This is called the kilovoltage or kVp of the beam. Higher energy x-rays are more likely to penetrate the patient and reach the detector, thereby reducing dose to the patient. However, imaging with higher kVp beams can also reduce image contrast.

**Tube Potential (kVp)**

- The higher the potential across the x-ray tube, the higher the energy of the x-rays
- Higher energy photons are more likely to penetrate the patient
- Lower contrast (less difference in absorption between adjacent areas)
- Lower patient dose
A significant difference in image contrast is demonstrated between these two images. The image on the right was formed using a much higher energy (kVp) x-ray beam as was used for the image on the left.
Another effect of increasing kVp is that more x-rays are produced.

**Tube Potential (kVp)**

- Increasing the tube potential increases both the energy of the x-ray photons (penetration) and the number produced ($\propto kVp^2$)
One can also increase the quantity of x-rays produced by increasing the number of electrons hitting the target. This is called milliamperage or mA.

**Tube Current (mA)**

- Operators can also increase current across the x-ray tube
- More electrons hitting the target mean more x-rays are produced
- The energy of the x-rays does not change
In summary, naturally occurring radiation is all around us. Many factors can change each individual's dose from background sources of radiation. Natural sources are no different than x-rays produced by medical x-ray tubes. Operator controlled factors such as kVp and mA can affect image quality and thereby must be used properly to optimize imaging.