Science and Technology of Radiation Detection

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Basic Radiation Terms

- Roentgen equivalent man (Rem)
- Radiation absorbed dose (Rad)
- Sievert (Sv)
- Gray (Gy)
- Curie (Ci)
- Disintegrations per minute (DPM)
- Counts per minute (CPM)
- Exposure
- Electronvolts
- ALARA
- Inverse Square Law
- Half-life

Basic Radiation Terms (cont.)

- **Roentgen equivalent man (Rem):** A unit of equivalent dose. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation.
- **Radiation absorbed dose (Rad):** A unit of measurement of radiation absorbed by material or tissue.
- **Sievert (Sv):** International System of Units (SI) of an equivalent dose (biological effects).
  - Sievert is comparable to Rem
  - 1 Sv= 100 Rem
- **Gray (Gy):** International System of Units (SI) of a absorbed dose.
  - Rad is comparable to Gray
  - 1Rad= 1 Centigray (cGy)
  - 1 Gy= 100 Rad

Basic Radiation Terms (cont.)

- **Curie (Ci):** A non-SI unit of radioactivity corresponding to 3.7×10^{10}
  - 1Ci= 37,000,000,000 Becquerel.
- **Becquerel (Bq):** The SI unit of radioactivity, corresponding to one disintegration per second.
  - 1 Bq = 1 Disintegration
- **Disintegrations per second (DPS):** The number of atoms of an isotope that decay per second.
- **Counts per second (CPS):** The measurements (in counts) that your meter detects.
- **Exposure (radiation):** A measure of ionization in air caused by x-rays or gamma rays only. The unit of exposure most often used is the roentgen.
- **Electronvolt (eV):** The energy of ionizing radiation; 1 eV is an extremely small amount so we use kiloelectronvolt (keV) and megaelectronvolt (Mev)

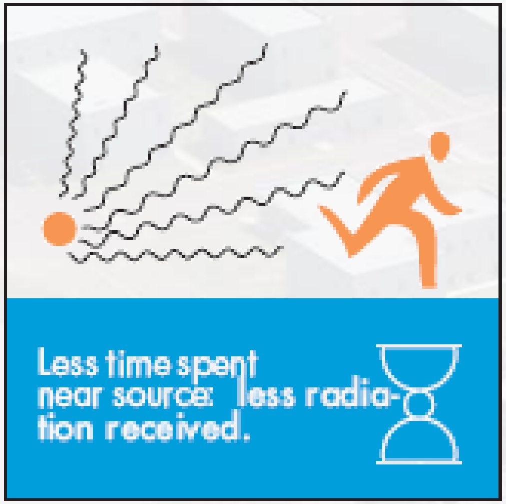
ALARA

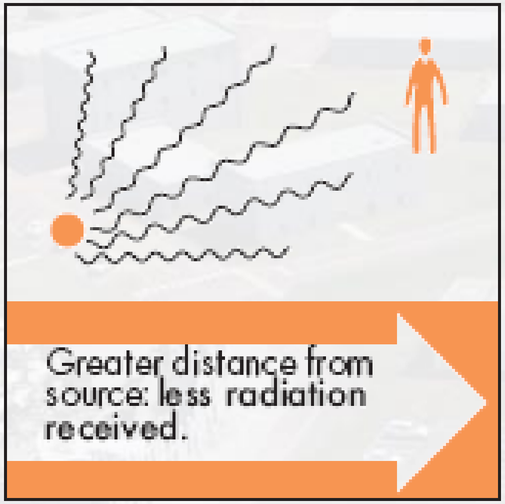
As **L**ow **A**s **R**easonably **A**chievable

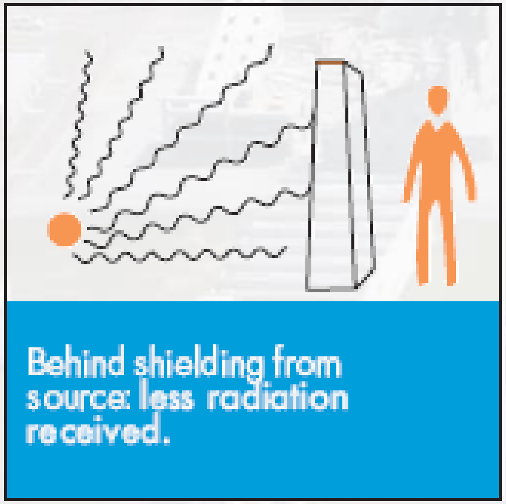
Time-Stay Time

Distance-Inverse Square Law

Shielding-Material Density Values

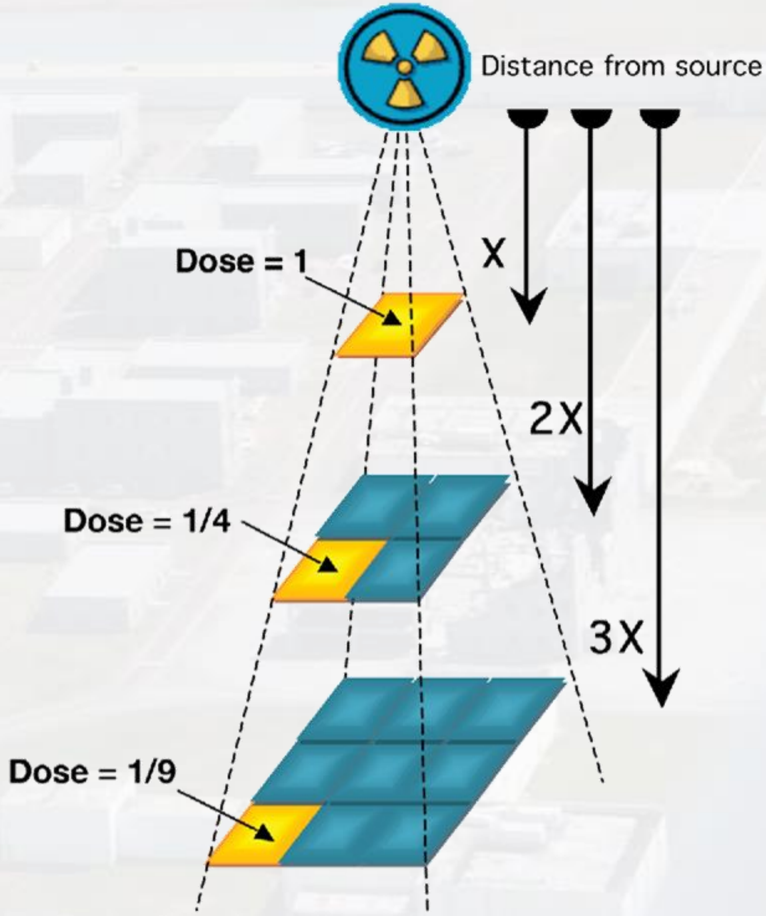






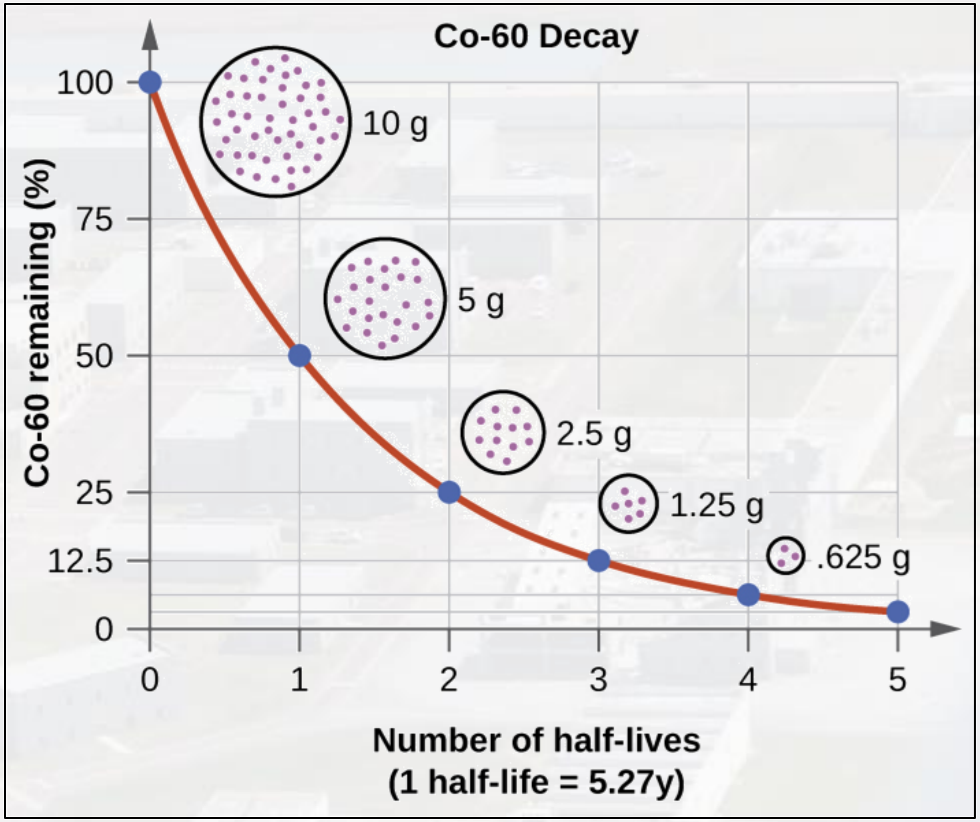
Basic Radiation Terms (cont.)

- **Inverse Square Law:**
  - Doubling distance from a point source, decreases dose by factor of four.
  - Tripling it decreases dose nine-fold
  - Inverse Square Law can only be used with point source
    - Spreads its influence equally in all directions without a limit to its range



Basic Radiation Terms (cont.)

- **Half-Life:**
- The time for the radiological source to lose half of it's strength (activity)
- If an isotope with a half life of 6 hours is reading 10 mR/hour at 1200, it will read 5 mR/h at 1800 (6 hour half life)



Radiation Dose Understanding

- Rem
  - 1 Rem
    - Equals 1,000 mRem (millirem)
    - Equals 1,000,000 uRem (microrem)
      - Background in most areas can range from 3-30 uRem
        - 30 uRem equals .03 mRem or .00003 Rem

- CPM to mRem
  - Co60: 1080 CPM is equal to 1 mRem/h
  - Cs137: 1200 CPM is equal to 1 mRem/h

  - ***<u>Note: Background radiation can fluctuate depending on your location and the buildings around you</u>***

Radiation Dose Limits

Occupational Dose

- 5 rem/yr - Whole Body
- 15 rem/yr - lens of the eye
- 50 rem/yr - skin & extremities

Pregnancy Dose

- 500 mRem/gestation
- 50 mRem/month

Public Dose

- 100 mRem/yr
- 2 mRem in any one hour

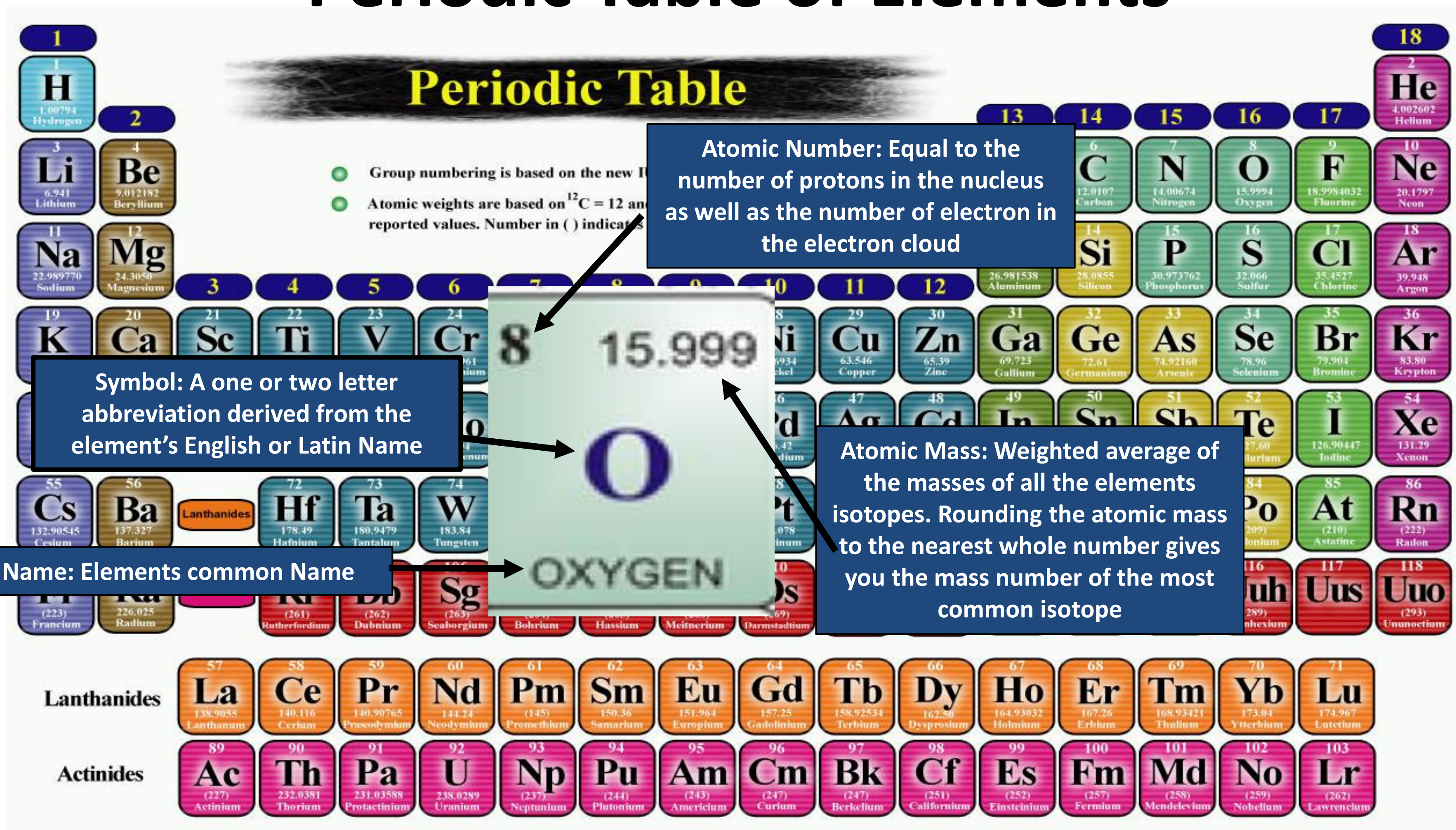
Emergency Dose Limits (guidance)

- 5 rem
- 10 rem – protect valuable property
- 25 rem – life saving or protection of large populations
- >25 rem – ***fully aware volunteer***

Radiation Dose examples

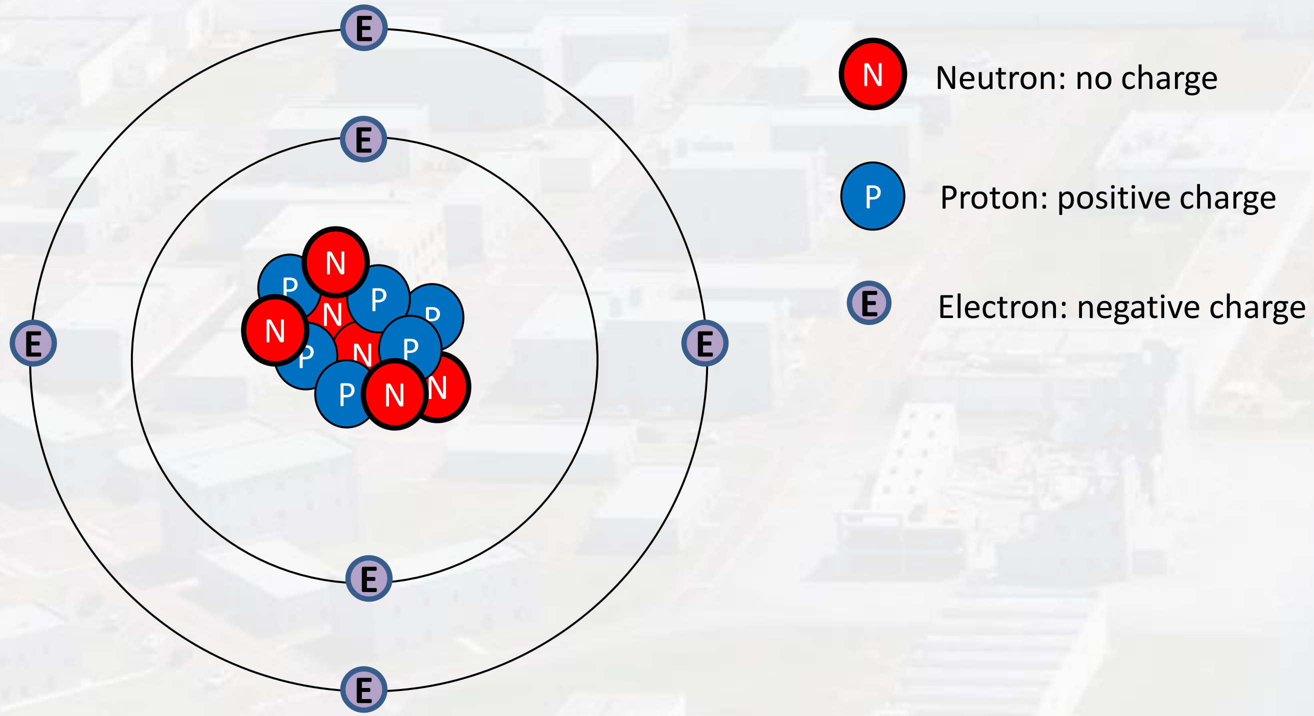
- 5 Rem: Annual safety limit (Occupational dose)
- 50 Rem: Total radiation exposure over time associated with high risk leukemia, bladder, breast, colon, liver, lung, stomach, and ovarian cancers
- 70 Rem: Instant radiation exposure causes vomiting
- 350-500 Rem: Levels at which the human being has a 50 percent chance of dying within 30 days of exposure (LD 50/30)
- 1,000 Rem: Internal bleeding, destruction of intestinal lining, and death within two weeks.
- 80 to 1,600 Rem: Exposure of plant workers and firemen at the Chernobyl disaster in 1986.

Periodic Table of Elements



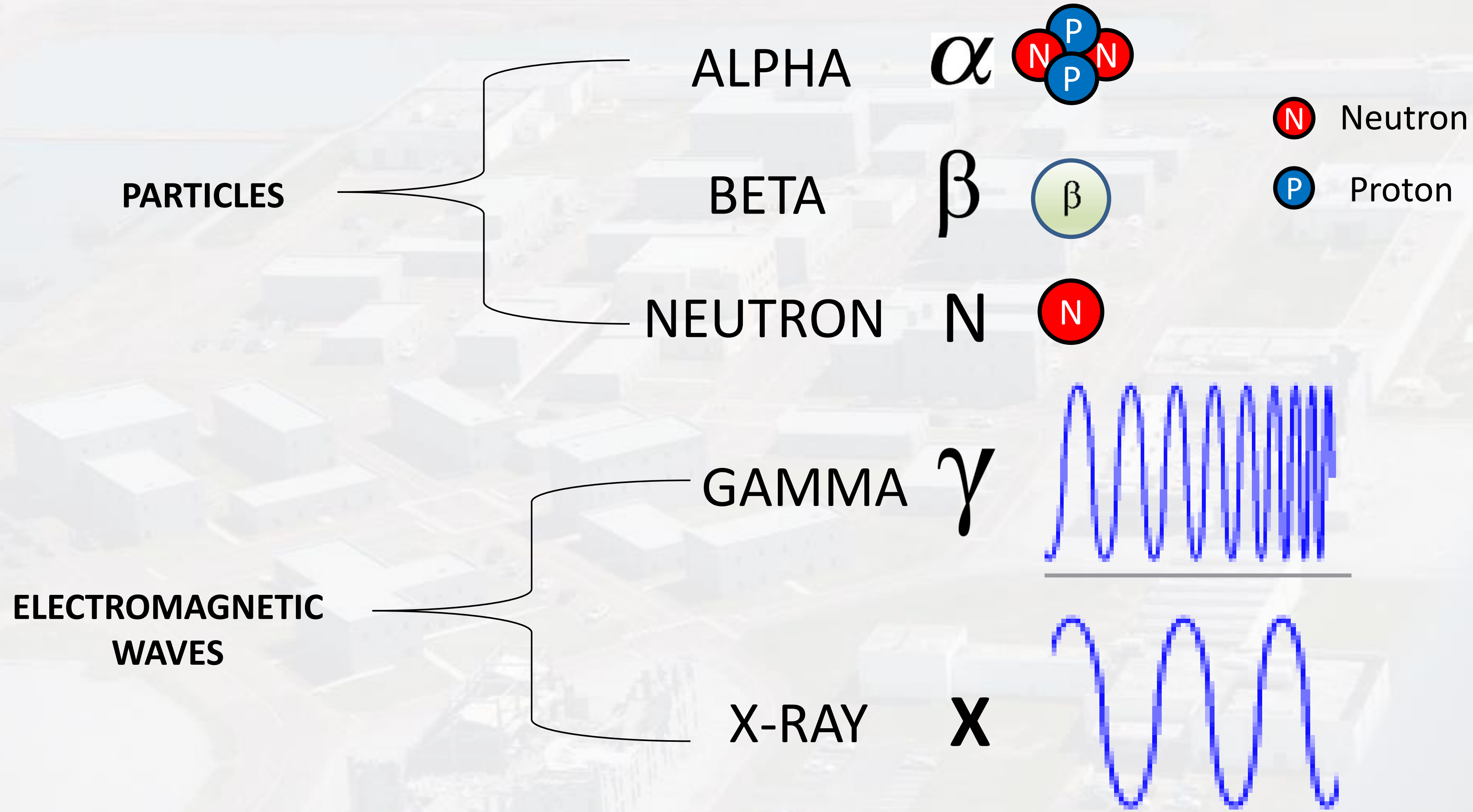
Neutron to Proton Ratio and Nuclear Stability

All matter is made up of atoms:



This is the structure of a Carbon Atom – 6 Protons, 6 Neutrons, 6 Electrons

Types of Ionizing Radiation

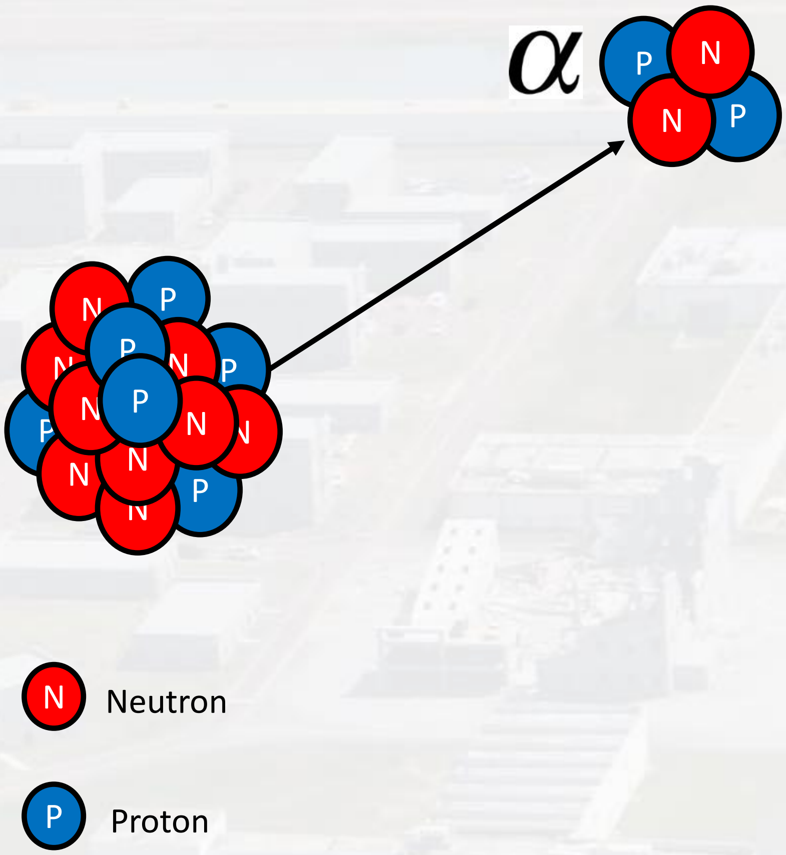


Alpha Particles

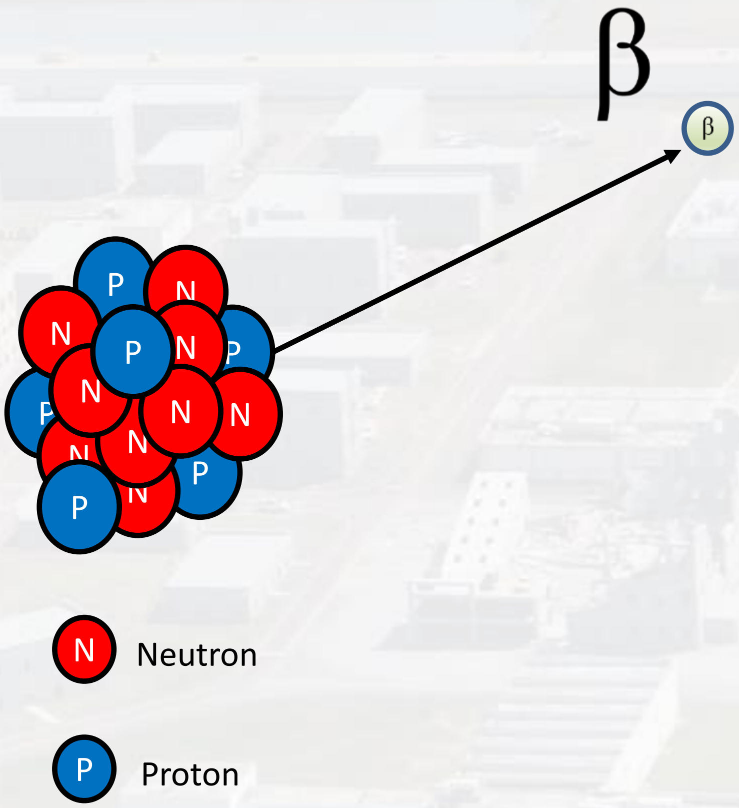
Alpha radiation occurs when an atom undergoes radioactive decay, giving off a particle (called an alpha particle) consisting of two protons and two neutrons.

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.



Beta Particles



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.

Beta Particles 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.

Beta-: a neutron is converted to a proton and the process creates an electron

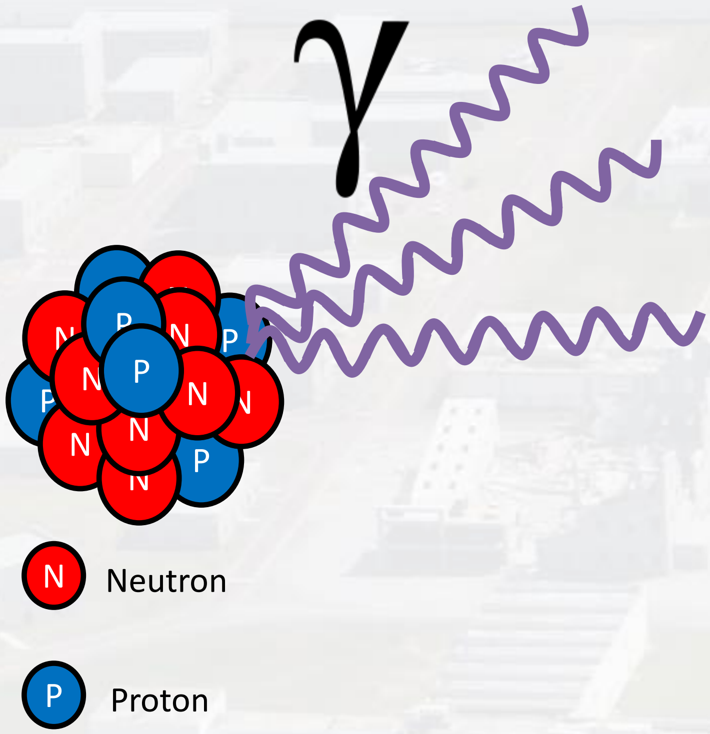
Beta+: A proton is converted to a neutron and the process creates a positron

Gamma 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 energy as it travels through space and medium.

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



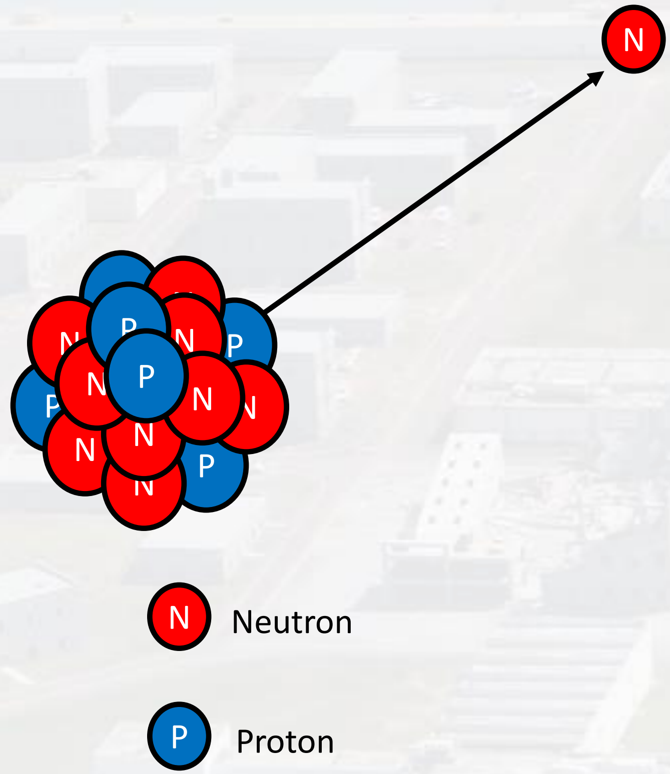
Neutron Particles

Neutron radiation consists of a free neutron, usually emitted as a result of spontaneous or induced nuclear fission.

Neutrons can travel hundreds or even thousands of meters in air, they are however able to be effectively stopped if blocked by a hydrogen-rich material, such as concrete or water.

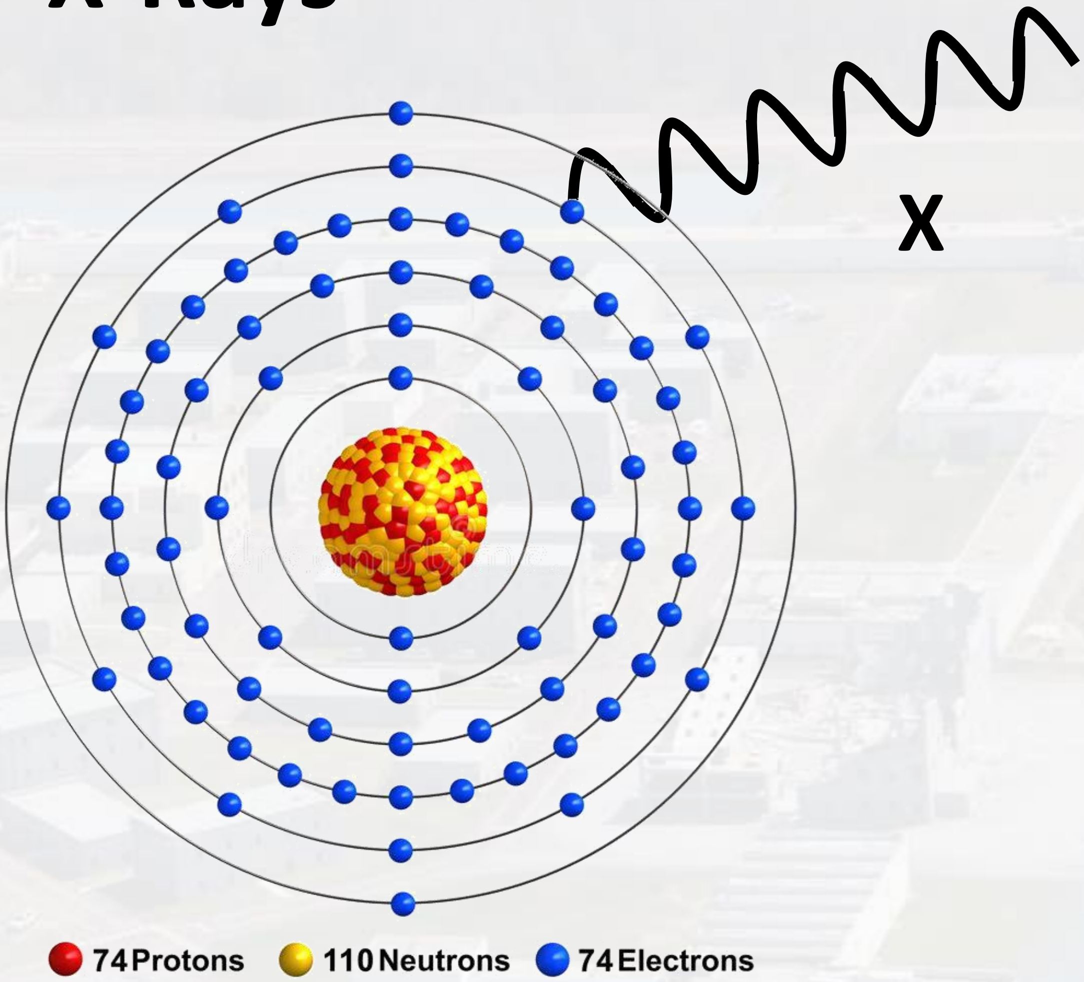
Neutrons have a neutral charge so they are not typically able to ionize an atom directly. Neutrons are indirectly ionizing, because they are absorbed into a stable atom, thus causing increased probability for that atom to become unstable and emit radiation.

Note: Neutrons are, in fact, the only type of radiation emission that is able to turn other materials radioactive.

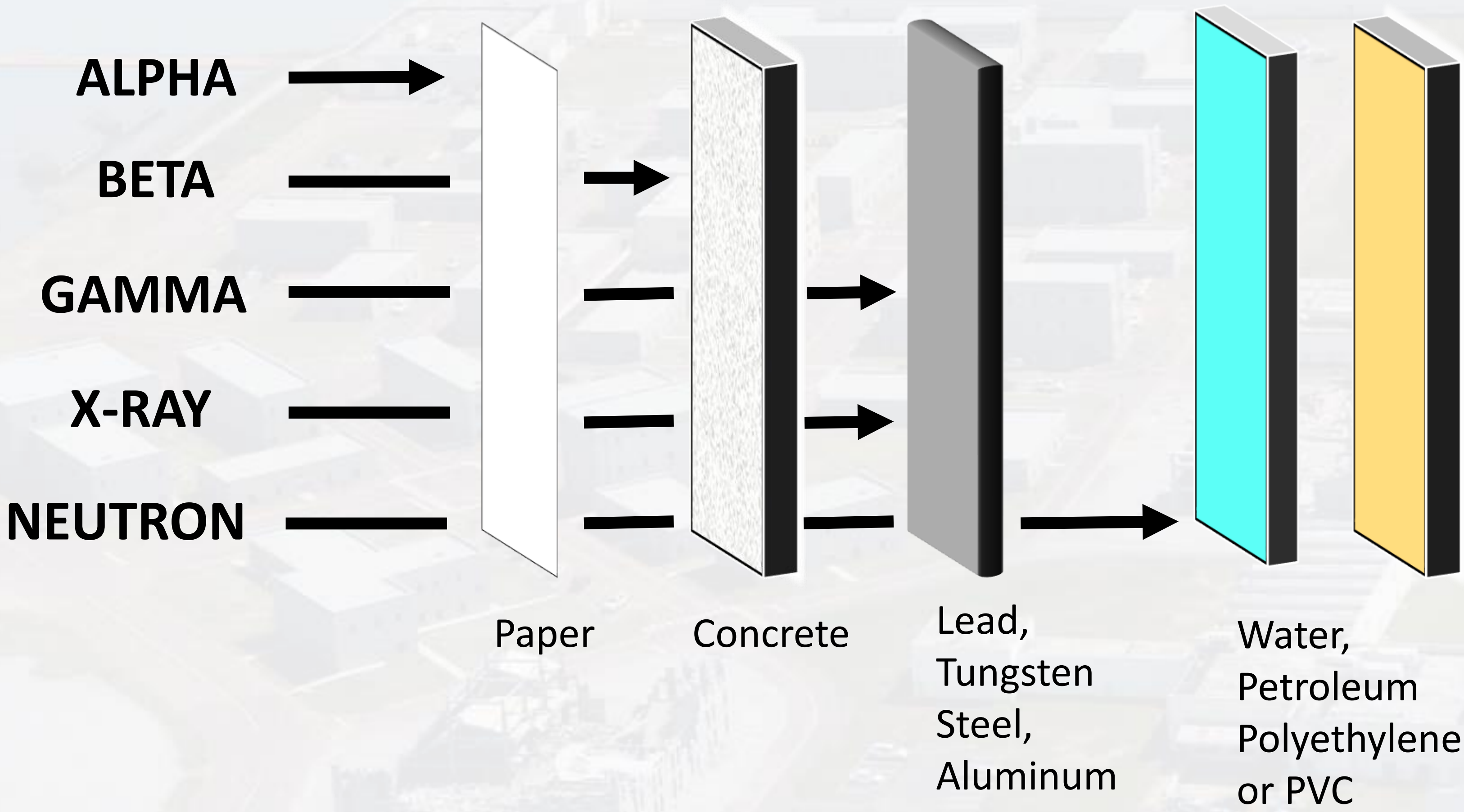


X-Rays

- 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.
- Tungsten is the most commonly used element to make X-rays.



Shielding


ALPHA
BETA
GAMMA
X-RAY
NEUTRON
Paper
Concrete
Lead,
Tungsten
Steel,
Aluminum
Water,
Petroleum
Polyethylene
or PVC

Radioactive Elements

- Americium-241
- Cesium-137
- Cobolt-60
- Iodine-131
- Plutonium-238
- Polonium-210
- Stronium-90
- Uranium-235 & Uranium-238

Radioactive Elements of Concern

Americium-241 (Am-241)

Protons: 95

Neutrons: 146

Decay Energy: alpha: 5.486 MeV gamma: .0595 MeV

Half Life: 432.2 years

Production: Produced from plutonium and past nuclear weapons testing from the 1950's and 1960's.

Main Emitter: Alpha particles

Secondary Emitter: low gamma

Chemical Properties: Crystalline metal that is solid under normal conditions.

What it is used for: Industrial, medical, or commercial devices in metal or plastic discs. Am-241 sources present in smoke detectors are the size of a pencil eraser.

Why it's a concern: When swallowed or absorbed, Am-241 can stay in your body for decades concentrating in the bones, liver, and muscles, exposing these organs to alpha particles.

Radioactive Elements of Concern

<u>Cesium-137 (Cs-137)</u>

Protons: 55
Neutrons: 82
Energy: Beta-: .512 MeV gamma: .661 MeV
Half Life: 30.2 years
Production: By nuclear fission
Main Emitter: Gamma rays
Secondary Emitter: beta while decaying to Barium-137 (153 sec half life)
Chemical Properties: Metallic solid, gray-blue metal. It resembles iron or nickel.
What it is used for: Calibration of radiation detectors, radiation therapy devices for cancer
Concerns: Cs-137 reacts with water in the body and has a biological half-life of 70 days

- Prussian Blue can be taken to reduce the biological half life to 30 days.

Radioactive Elements of Concern

Cobalt-60 (Co-60)

Protons: 27

Neutrons: 33

Energy: Beta: .317 MeV, Gamma (2): 1.173 and 1.33 MeV

Half Life: 5.27 years

Production: Nonradioactive Cobalt occurs naturally in minerals and used as a blue coloring agent for ceramic and glass. Radioactive Co-60 is a biproduct of nuclear reactor operations, when rods are exposed to neutron radiation.

Main Emitter: Gamma rays

Secondary Emitter: low beta

Chemical Properties: Metallic solid that might appear as small metal disks or in a tube, enclosed at both ends, that holds small disks; can be a fine powder if the sources have been ground or damaged.

What it is used for: Medical use for radiation therapy, industrially in leveling gauges and to x-ray welding seams to detect flaws, and used for food irradiation as a sterilization process.

Concerns: External exposure to large sources of Co-60 can cause skin burns, acute radiation sickness, or death. Most is excreted in the feces; however small amounts are absorbed by the liver, kidneys, and bones causing cancer.

Radioactive Elements of Concern

Iodine-131 (I-131)

Protons: 53

Neutrons: 78

Energy: Beta: .606 MeV, Gamma: .364 MeV

Half Life: 8.06 days

Production: I-131 is produced commercially for medical and industrial uses through nuclear fission. It also is a byproduct of nuclear fission processes in nuclear reactors and weapons testing.

Main Emitter: Beta

Secondary Emitter: Gamma

Chemical Properties: I-131 is a non-metallic, purplish-black crystalline solid. It can change directly from a solid into a gas, skipping the liquid phase (sublimation). It dissolves easily in water or alcohol and readily combines with other elements.

What it is used for: I-131 is used in medicine to diagnose and treat cancers of the thyroid gland.

Concerns: I-131 can cause burns to the eyes and skin. Once in your body, I-131 will be absorbed by the thyroid gland exposing it to radiation; the thyroid cannot distinguish between radioactive and non-radioactive Iodine.

Radioactive Elements of Concern

Plutonium-238 (Pu-238)

Protons: 94

Neutrons: 144

Energy: Alpha: 5.6 MeV

Half Life: 87.7 years

Production: Pu-238 is created from uranium in nuclear reactors. It is a by-product of nuclear weapons production and nuclear power operations. It generates significant heat through its decay process.

Main Emitter: Alpha

Secondary Emitter: Very minimal gamma

Chemical Properties: Pu-238 is solid material under normal conditions.

What it is used for: Because of the heat Pu-238 generates, it is useful as a heat source for sensitive electrical components in satellites.

Concerns: Pu-238 is most dangerous when inhaled, causing scarring of the lungs, leading to further lung disease and cancer. It can also enter the bloodstream through the lungs, concentrating in the bones, liver, and spleen.

Radioactive Elements of Concern

Polonium-210 (Po-210)

Protons: 84

Neutrons: 126

Energy: Alpha: 5.4 MeV

Half Life: 138 days

Production: Po-210 is generated in the decay chain of Uranium-238 and radium-226.

Main Emitter: Alpha

Secondary Emitter: Very minimal gamma

Chemical Properties: Po-210 is a solid metal with a silver color; in high amounts, it can give of a blue glow due to ionizing the air around it.

What it is used for: Po-210 is used in industry to make devices that remove static as well as in the production of computer chips to keep them free of dust.

Concerns: Po-210 is one of the most lethal substances on earth. Toxicologists estimate that one gram of Po-210 is enough to kill 50 million people

Alexander Litvinenko

Alexander Litvinenko was a British Naturalized Russian defector and former officer for the Russian secret service who dealt with organized crime.

1 November 2006: Litvinenko became suddenly ill and was hospitalized where it was determined he was poisoned by radioactive Polonium-210.

23 November 2006: Litvinenko dies from radiation poisoning.

Radioactive Elements of Concern

<u>Stronium-90 (Sr-90)</u>

Protons: 38

Neutrons: 52

Energy: Beta: .546 MeV

Half Life: 28.8 years

Production: Sr-90 is produced commercially through nuclear fission for use in medicine and industry. It is also found in the environment for nuclear testing in the 1950's and 1960's

Main Emitter: Beta

Secondary Emitter: Very minimal gamma

Chemical Properties: Sr-90 is a soft, shiny silver metal that changes rapidly to yellow when exposed to air.

What it is used for: Because it produces heat during decay, it is used as power sources for space vehicles, navigational beacons, and remote weather stations. It is also used in industrial gauges and to treat bone tumors.

Concerns: Sr-90 causes the greatest concern if ingested; Sr-90 acts like calcium and is readily incorporated into your teeth and bones.

Radioactive Elements of Concern

Uranium-235 (U-235)

Protons: 92

Neutrons: 143

Energy: Alpha: 4.679 MeV

Half Life: 703.8 million years

Production: U-235 occurs naturally in almost all water, rock, and soil. It can be concentrated ”enriched” allowing it to be used in nuclear reactors or weapons.

Main Emitter: Alpha

Secondary Emitter: Very minimal gamma

Chemical Properties: U-235 is an extremely dense silvery-white metal (65% denser than lead).

What it is used for: U-235 is used as fuel for nuclear power plants, reactors on naval ships and submarines, and nuclear weapons.

Concerns: U-235 can cause lung cancer if inhaled and high concentrations can cause bone or liver cancer. Chemically, it is more likely to cause liver damage sooner than its radioactive properties would cause cancer.

Radioactive Elements of Concern

Uranium-238 (U-238)

Protons: 92

Neutrons: 146

Energy: Alpha: 4.267 MeV

Half Life: 4.468 billion years

Production: U-238 is the most common and abundant isotope of uranium (99%). It occurs naturally in almost all water, rock, and soil. Unlike U-235, U-238 is non-fissile (cannot sustain a chain reaction in a reactor) but it is fissionable from high energy neutrons.

Main Emitter: Alpha

Secondary Emitter: Very minimal gamma

Chemical Properties: U-238 is an extremely dense silvery-white metal (65% denser than lead).

What it is used for: Depleted uranium (uranium containing mostly U-238) is used for radiation shielding or projectiles in armor-piercing weapons.

Concerns: U-238 has the same health effects as U-235.

Radiation Detectors and Dosimeters

Thermoluminescent Dosimeter (TLD)

- Measures ionizing radiation exposure
- Usually replaced each quarter to track dose records every 90 days
  - Some can be reused after deleting dose.
- History of lifetime dose is kept on file for up to 50 years after no longer requiring a TLD
- Worn by occupational workers with potential exposure to gamma, X-ray, beta and/or neutron radiation

Extremity Dosimeter

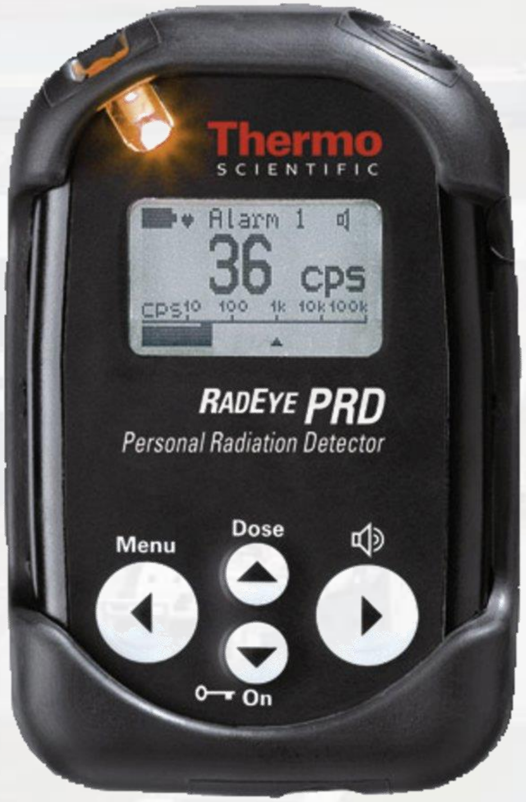
- Measures ionizing radiation exposure to the extremities
- Can be worn for a period of one week to six months
- History of lifetime dose is kept on file for up to 50 years after no longer requiring a extremity dosimeter
- Worn by workers who handle sources
- Reads low or high energy beta, X-Ray or gamma radiation

Electronic Personal Dosimeters (EPD)

- EPD’s are primarily designed to monitor individual responders dose in real time.
- EPD’s are not usually optimized for detection of radioactive materials.

Personal Radiation Detectors (PRD)

- **Ideal for law enforcement and first responders who require a wearable, hands free detector**
- Small, lightweight (about the size of a pager)
- Audio and visual alarm



Handheld Survey Meters

Handheld meters are used for dose rates, locate radiation, and tell us the type of radiation i.e. alpha, beta, gamma, etc.

- Interchangeable probes are used for Alpha, Beta, Gamma, etc.
- Handheld survey meters are the primary standard for measurement, quantification, and monitoring of radioactive materials.

Radiation Isotope Identification Devices (RIID) identiFINDER

- A RIID is a radiation detector with the ability to distinguish isotopes and identify them using their gamma spectrum.
- Able to detect neutron
- Comes with a set library of isotopes
  - Examples: Industrial, Special nuclear material, Medical
- Provides a confidence factor when identifying isotopes; 0-10

Neutron Detector (Rem Ball)

- Can measure dose equivalent rate
- Can measure slow and fast neutrons
- Uses gamma rejection for an accurate measurement of neutrons
- Many different types due to specialized application

Decontamination Principles and Techniques

Loose vs Fixed Contamination

- Loose contamination can be removed from the casualty
- Fixed contamination cannot be removed
  - To determine what type of contamination an individual has, swipe the contaminated area, then step back from the casualty to see if there is contamination on the rag; if no readings are present, the contamination is fixed.
  - While the casualty is irradiated, they pose no real threat to others and can be moved to the cold zone for follow-on care.
    - Humans shed and regrow the out layer of skin cells about every 27 days

Decontamination Principles and Techniques

Wet vs Dry Decontamination

- Wet and dry decon for the removal of radiation both have pro's and con's.
- Choosing which method is best will depend on many factors.
  - Quantity of casualties
  - Resources available to you
  - Air temperature

Special Considerations

- Wet Decontamination
  - With contamination and background readings increasing on the decontamination line, water must be pumped out of the pit into a bladder to reduce dose rate received by first responders.
    - Water may be able to be pumped back into the hot zone if a locations can be found that will not affect the public or first responders.
- Dry Decontamination
  - Location to store used towels and wipes that have been used by casualties.
- PPE Requirements
  - for long operations; some equipment and PPE have have seams where it is harder to remove contamination.
  - Plan for the worst and hope for the best.

Georgia Recovery of Orphan Sources

Can we see radiation?

Questions?

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