Radiographic Testing

Radiographic Testing

Topics

- History of RT
- Science of Radiation
- Radiation Terminology
- Radiation Safety

Radiographic Testing

Radiographic Testing (RT)

Definition: An NDT method that utilizes x-rays or gamma radiation to detect discontinuities in materials, and to present their images on recording medium.

History – X-Rays

- X-rays discovered in 1895 by Wilhelm Roentgen
- 1896 – used by physicians to locate bullets in soldiers
- 1913 – development of high vacuum x-ray tubes enabled voltages of 100,000 V. Increased penetrating power of x-rays led to industrial applications
- 1931 – GE developed 1,000,000 V x-ray generator
  - ASME approved use of x-ray to test fusion-welded pressure vessels
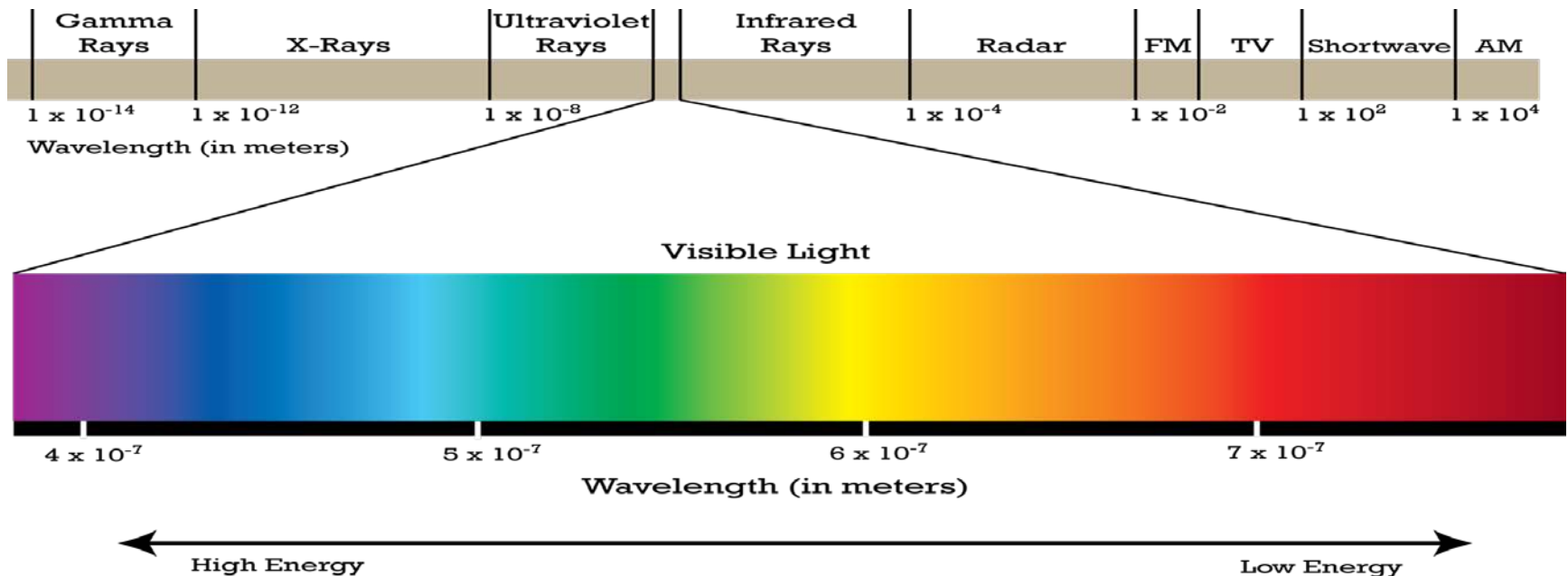
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History – Natural Radiation

- 1896 – Henri Becquerel discovers and identified uranium as radioactive material
- 1898 – Pierre and Marie Curie discovered polonium, followed by radium ("shining" element)
  - Radium capable of filming through 10-12" thick steel castings
  - Used extensively during WWII as part of U.S. Navy shipbuilding program
- 1946 – cobalt and iridium became available
  - Both stronger and cheaper than radium
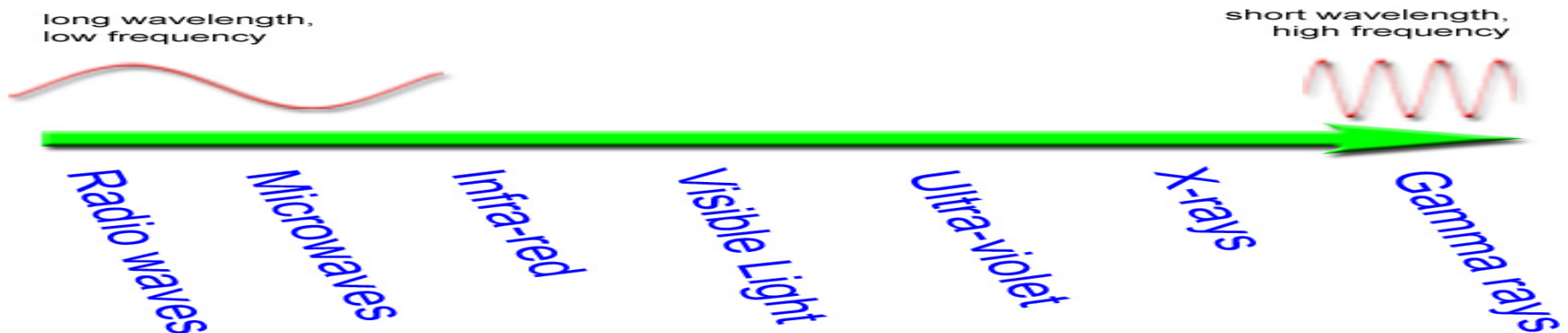
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What is radiation?

In the simplest sense, radiation is the emission of energy as electromagnetic waves. Below is a graphic of the various forms of radiation present in our environment.(Also known as the Electromagnetic Spectrum)

Gamma Rays	X-Rays	Ultraviolet Rays	Infrared Rays	Radar	FM	TV	Shortwave	AM

1×10^{-14} 1×10^{-12} 1×10^{-8} 1×10^{-4} 1×10^{-2} 1×10^{2} 1×10^{4}

Wavelength (in meters)

Visible Light

4×10^{-7} 5×10^{-7} 6×10^{-7} 7×10^{-7}

Wavelength (in meters)

High Energy   Low Energy

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What is radiation?

As seen in the previous graphic the wavelength and frequency of the radiation describes what form it takes. Radiation is in the form of radio Waves to visible light to gamma rays. The higher the frequency the more energetic and penetrating the radiation. This high energy radiation is generally classified as a X-ray or gamma ray and is characterized by its ability to ionize atoms that are exposed to it, thus called ionizing radiation.

long wavelength,
low frequency

short wavelength,
high frequency

Radio waves   Microwaves   Infra-red   Visible Light   Ultra-violet   X-rays   Gamma rays

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What is radiation?

In the simplest sense, radiation is the emission of energy as electromagnetic waves.

- X-rays and gamma rays are types of electromagnetic radiation of shorter wavelengths than visible light:

    $\lambda_{visible}$ = 600 Angstroms, $\quad \lambda_{x-rays}$ = 1.0 A,
    $\lambda_{gamma\ rays}$ = 0.0001 A

    – shorter wavelengths permit penetration through materials
    – high energy levels break chemical bonds
        *Leads to destruction of living tissue

- X-rays and gamma rays differ only in source of origin. X-rays come from the electron shell and gamma rays come from the Nucleus of a Atom.
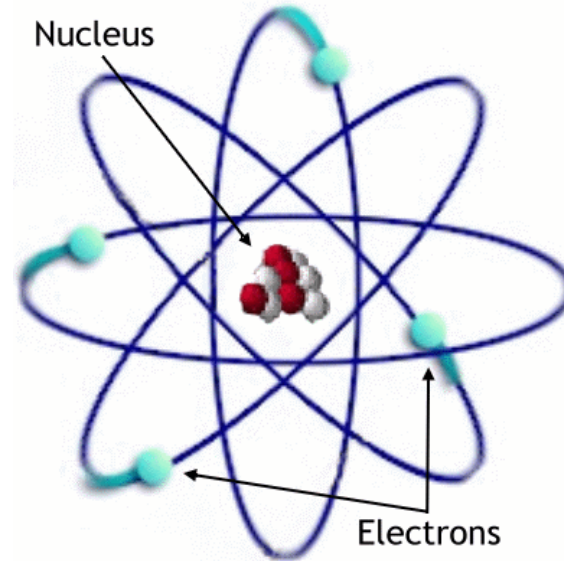
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X-ray or Gamma Ray radiation Properties
- Undetectable by human senses
  - Cannot be seen, felt, heard, or smelled
- Possesses no charge or mass
  - Referred to as photons (packets of energy)
- Generally travels in straight lines at the speed of light (can bend at material interfaces)
- Characterized by frequency, wavelength, and velocity
- Part of electromagnetic spectrum but not influenced by electrical or magnetic fields
- They have enough energy to ionize matter

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Atoms

- Atom - the smallest particle of any element that retains the characteristics of that element

- Subatomic particles – protons, electrons, neutrons

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Atoms (continued)

- Nucleus of atom – contains the positively-charged protons and neutrally-charged neutrons
- Electrons – negatively-charged particles that travel at high speed around the nucleus
- Atomic number – based on an element's number of protons
  - Ex. Carbon (C) has atomic number 6, Potassium (K) has atomic number 19
- Isotopes – atoms of the same element with different number of neutrons
- Atomic mass – approximately equal to sum of protons and neutrons
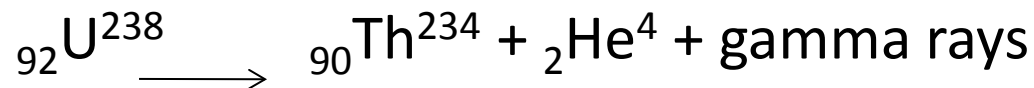
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Radioactivity

- Defined as the release of energy and matter that results from changes in the nucleus of an atom
- An atom that contains additional neutrons is unstable
- In order to move to a more stable state, the nucleus seeks to remove the extra neutrons, thereby emitting radiation
- Atoms with atomic numbers > 83 referred to as radioisotopes – they have unstable nuclei and are radioactive

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Radioactive Decay
- Defined as the spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter from the nucleus
- Occurs by:
  - Alpha decay (emits 2 protons and 2 neutrons from the nucleus)
  - Beta decay (a neutron split into a proton and an electron)
  - Gamma decay (energy in the form of gamma radiation emitted from the nucleus)
- Alpha and beta decay involve particles
- Example nuclear reaction:

$$_{92}U^{238} \longrightarrow \ _{90}Th^{234} + \ _2He^4 + \text{gamma rays}$$

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Radioactive Decay (continued)

- When an atom undergoes radiographic decay, it emits one or more forms of radiation with sufficient energy to ionize the atoms with which it interacts

- Ionizing radiation – high speed subatomic particles ejected from the nucleus, or gamma rays emitted by the either the nucleus or orbital electrons

- Ionization – complete removal of an electron from an atom following the transfer of energy from a passing charged particle

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Radioactive Decay (continued)

- Activity – quantity which expresses the degree of radioactivity or the radiation-producing potential of a given amount of radioactive material

  - Given in units of Curie (English system) or Becquerel (SI)
  - One Curie is quantity of radioactive material in which $2.22 * 10^{12}$ disintegrations per minute or $3.7 * 10^{10}$ atoms disintegrate per second (move to a more stable state)
  - 1 Becquerel = quantity of radioactive material in which 1 atom disintegrates per second
  - 1 Curie = $3.7 * 10^{10}$ Becquerel

- Specific activity – activity per unit mass or volume

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Half-Life
- Defined as the time required for the activity of a particular radioisotope to decrease to half of its original value
  - Varies for different radioisotopes
  - Ranges from microseconds to billions of years (uranium)
- Half-life of Cobalt-60 = 5.3 years
- Half-life Iridium-192 = 74 days
- Carbon-14 dating
  - used to approximate the age of fossils
  - Decays with a half-life of 5730 years

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Half-Life Example

Example: You originally have a 30-Curie source of Cobalt-60.

1. How many Curies will you have in 5.3 years?
    Answer: The source will have decayed by one half-life in 5.3 years, therefore half of the original source will remain, or 15 Curies.

2. How long will it take for the source to decay to 3.75 Curies?
    Answer: Every 5.3 years the source will be reduced by half. In 1 half-life, the source will be reduced to 15 Curies. In 2 half-lives, the source will be down to 7.5 Curies. Finally, in 3 half-lives, the source will be 3.75 Curies. Therefore, it will take a total of 3 half-lives (or 15.9 years) for the source to decay to 3.75 Curies.

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Penetrating Power of Radiation

- Only x-rays and gamma rays can penetrate solid materials to a significant extent (alpha and beta particles can penetrate skin only up to 8 mm)
- Transmission of radiation depends on:
  - ➢ Material thickness
  - ➢ Material density
  - ➢ Energy of the photons
- Photons that are not transmitted are attenuated (absorbed or scattered)

THE PENETRATING POWER OF RADIATION.

1 meter of concrete

Alpha
Beta
Gamma

alpha   beta   gamma
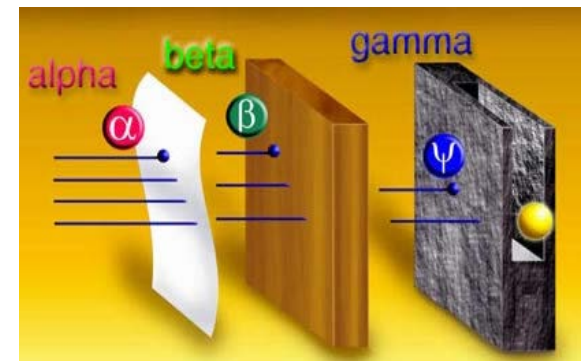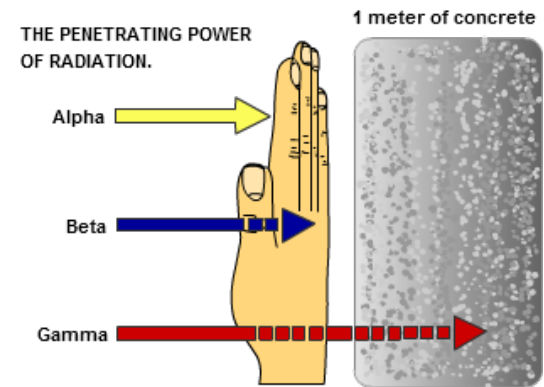
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Radiation Safety

- Science of radiation protection (also called health physics) developed to address acceptable radiation levels to reduce risk of injury to humans
- Primary health concern (for chronic, not acute exposure) is increased risk for cancer
- Depends on amount of radiation dose, duration of dose, and specific body parts exposed
- Possession and use of radioactive materials strictly regulated by the Nuclear Regulatory Commission (NRC) as specified in Title 10 of the Code of Federal Regulations (CFR) 20

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Radiation Safety (continued)

- By 1900 it was understood that use of x-rays and gamma radiation required safety precautions to protect one's health

- 1920's – routine use of film badges for personnel monitoring begun, genetic effects of radiation recognized

- Origin of radiation
  - Natural (sun, radon gas)
  - Man-made (x-rays, gamma rays)

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Radiation Energy

- Different radioactive materials and x-ray generators produce radiation at different energies
- Energy of radiation – responsible for the ability to penetrate matter
  - Measured in electronvolts (eV) or kiloelectronvolts (keV)
  - An electronvolt is the energy gained by an electron passing through a potential difference of 1 volt
  - Energy adjustable on an x-ray generator
  - Energy an unchangeable characteristic of a radioisotope

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Radiation Intensity
- Amount of energy passing through a given area (perpendicular to the direction of radiation travel) in a given unit of time
- Survey meter – used to measure intensity or radiation dose rate
  - Units in mRem/hr. or Rem/hr.
  - Frequently referred to as the most important tool a radiographer has to determine the presence and intensity of radiation
- Per the inverse square law, the intensity varies inversely with the square of the distance

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Dose

- Exposure – measure of the strength of a radiation field
    - Units of Roentgen or R
- Dose (also called absorbed dose) – amount of ionizing energy absorbed by an object
    - Units of Rad ("radiation absorbed dose")
- Dose equivalent relates absorbed dose to biological effect of dose – equals absorbed dose times a quality factor (quality factor = 1 for x-ray and gamma radiation in humans)
    - Units of Rem ("Roentgen equivalent in man")
- For humans, 1 R = 1 Rad = 1 Rem

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Dose vs. Dose Rate

- Dose rate – measure of how fast a radiation dose is being received
  - **dose rate = dose / time**
  - Units of R/hr, mR/hr, Rem/hr, mRem/hr (same units as intensity)
- To calculate a person's dose, multiply the dose rate (measured with a survey meter) by the duration of exposure
  - **dose = dose rate * time**
- Example: If the radiation intensity in a particular area is 5 mRem/hr, and the person remains in that area for 30 minutes, what is the person's radiation dose?

  dose = 5 mRem/hr * 0.5 hr = 2.5 mRem

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Biological Effects of Radiation
- Absorbed dose depends on: Intensity of radiation source, Distance from source, Time of exposure
- Ionization of living tissue causes molecules in cells to be broken apart
- Biological effects vary with:
  – Type of radiation (penetrating ability)
  – Size of dose received
  – Dose rate
  – Body part exposed (extremities can handle more exposure than blood-forming organs)
  – Age of individual (cell divisions slow with age – older people less sensitive to ionizing radiation)

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Stochastic and Nonstochastic Effects
- Stochastic effects are delayed and difficult to specifically correlate to radiation exposure (cancer)
- Nonstochastic effects are acute effects
  - Directly proportional to size of dose
  - Symptoms
    - Skin reddening
    - Skin and tissue burns
    - Cataract formation
    - Sterility
    - Radiation sickness (nausea, vomiting, diarrhea, headache, fever, dizziness, weakness, hair loss)
    - Death

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Important NRC Codes

- 10CFR19 – Notices, Instructions, and Reports to Workers: Inspection and Investigations

- 10CFR20 – Standards for Protection Against Radiation

- 10CFR34 – Licenses for Industrial Radiography and Radiation Safety Requirements for Industrial Radiographic Operations

- Guidelines established to both prevent acute exposure and limit chronic exposure to "acceptable" levels

- Desire to maintain all exposure "as low as reasonably achievable" – referred to as **ALARA**

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Exposure Limits

- Effect of exposure (dose received in a 24-hour period):
  - 0-25 Rem – no evident injury (blood changes detectable at 5 Rem)
  - 400-500 Rem – results in death in 50% of cases
  - 1000+ Rem – results in death in ALL cases
- Annual Occupational Limits
  - Total effective dose – 5 Rem
  - For Declared pregnant women - 0.5 Rem during gestation period
  - For people younger than age 18 – 0.5 Rem

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Exposure Limits Continued

- Annual Non-Occupational Limits (for general public exposure to industrial ionizing radiation)
  - 0.1 Rem (2% of occupational limit)
  - Doesn't include natural background radiation (0.3 Rem) or radiation from man-made sources, such as medical x-rays (0.05 Rem)

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Controlling Radiation Exposure

- Remember: **TIME, DISTANCE, and SHIELDING**

- Recall that dose = dose rate * time

- Collimator – device used to direct radiation onto a part and shield the radiation in other directions

- In general, the denser the material the greater the shielding
  - Most effective shielding by depleted uranium – used to shield the source in gamma ray cameras
  - Lead and concrete commonly used for shielding

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Controlling Radiation Exposure

- Recall **inverse square law** – "the radiation intensity varies inversely with the square of the distance"

$$I_{1*}D_1{}^2 = I_{2*}D_2{}^2$$

- Example: If the intensity at 1' from the source is 500 Rem/hr, at what distance is the intensity 2 mRem/hr?
  Solution: Let I_1 = 500 Rem/hr; D_1 = 1 foot; I_2 = 2 mRem/hr
  Solve for D2.

$$\mathbf{D_2 = Square\ root\ (I_{1*}D_1{}^2 / I_2) = 500\ feet}$$

- Signs must be posted at intensity boundaries (usually 2 mRem/hr and 100 mRem/hr) to warn individuals that radiographic testing is in progress

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Half-Value Layer

- Defined as the thickness of a material needed to reduce the radiation intensity to ½ of its original value
  - To provide shielding
  - Depends on radioisotope used for gamma radiation (or voltage if radiation source is an x-ray)
  - Depends on voltage if radiation source if an x-ray

Source	Half-Value Layer, mm (inch)				
	Concrete	Steel	Lead	Tungsten	Uranium
Iridium-192	44.5 (1.75)	12.7 (0.5)	4.8 (0.19)	3.3 (0.13)	2.8 (0.11)
Cobalt-60	60.5 (2.38)	21.6 (0.85)	12.5 (0.49)	7.9 (0.31)	6.9 (0.27)

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Radiation Safety Officer

- Radiation Safety Officer (RSO) - individual authorized by company to ensure radiation activities performed safely and per approved procedures and regulations

- Radiographers required to wear personnel monitoring devices to aid in tracking and minimizing their radiation exposure
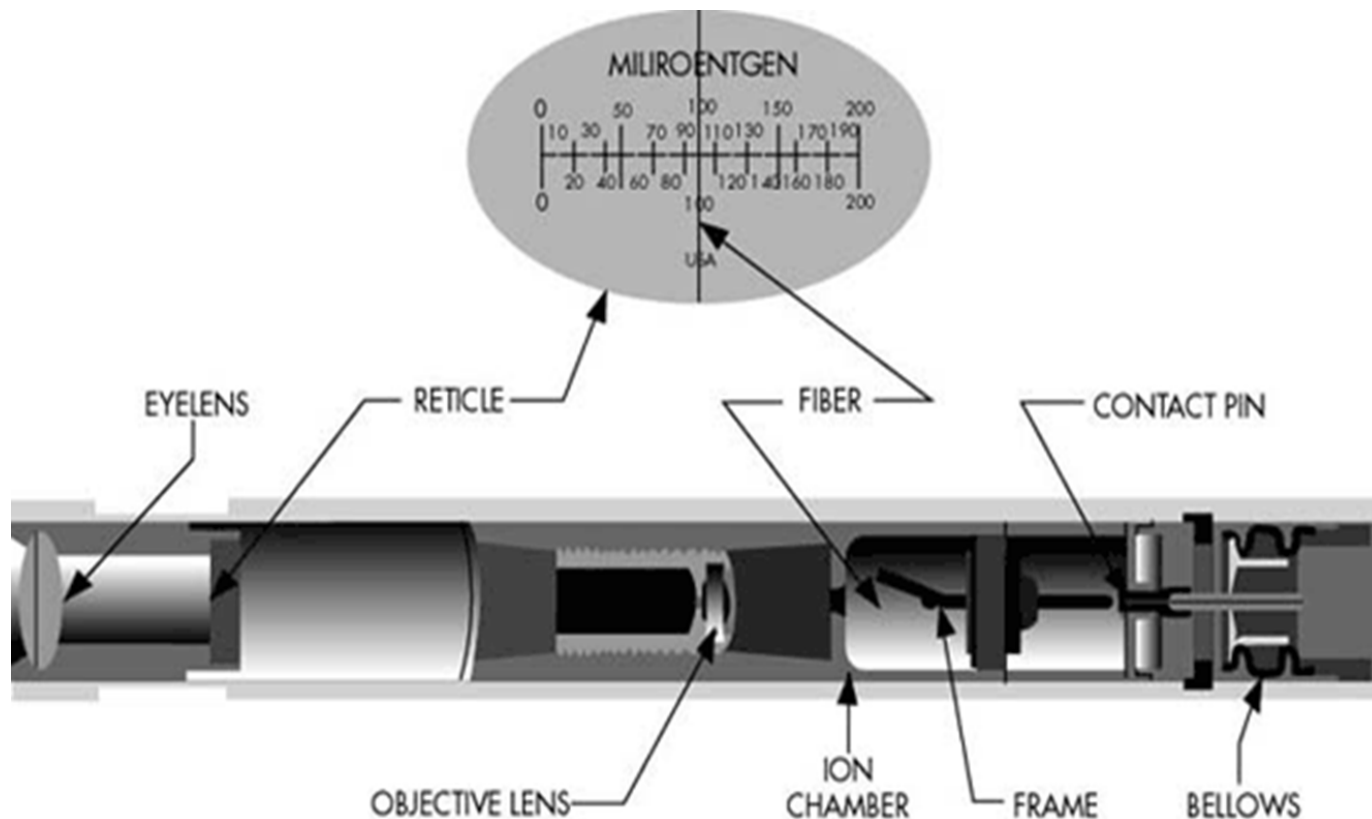
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Personnel Monitoring Devices
- Pocket dosimeter
  - Similar in appearance to small marker
  - Reads radiation dose (not dose rate)
  - Allows workers to track daily dose received (reset at the start of each shift)
- Audible alarm rate meter
  - Sounds an alarm at a preset dose rate (typically 500 mRem/hr)
  - NOT a replacement for a survey meter!

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Personnel Monitoring Devices

- Pocket dosimeter

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Personnel Monitoring Devices (continued)

- Film badge
  - Piece of radiation-sensitive film that provides a permanent record of radiation dose received
- TLD (thermoluminescent dosimeter)
  - Often used instead of a film badge (may be reused)
  - Both film badges and TLDs typically worn for 1-3 months before being processed to determine dose
- OSL (Optically Stimulated Luminescent) dosimeter
  - Often used instead of a TLD or film badge (may be reused)
  - Can be work for longer periods of time due to good fading.

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Personnel Monitoring Devices (continued)

Various monitoring devices.

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Radiography Equipment – X-Ray Generators
- X-rays are generated by directing a stream of high-speed electrons at a target material, such as tungsten, which has a high atomic number
- Interaction with the tungsten atoms slows or stops the electrons, and x-rays are produced
- Major components of an x-ray machine
  - Tube – contains a cathode (coiled wire) and an anode (target) – operates in a vacuum
  - High voltage generator
  - Control console (to adjust output)
  - Cooling system

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X-Ray Generators (continued)

- X-ray control console
  - Increasing current (or milliamperage) increases number of electrons that flow from the cathode to the anode – thus increases the x-ray intensity
  - Increasing the voltage increases the speed at which the electrons travel – thus increasing the energy or penetrating power of the x-ray

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Radiography Equipment – Gamma Sources
- Man-made radioactive sources produced by introducing an extra neutron to atoms of the source material by neutron bombardment
- As the atoms shed the neutron energy is released in the form of gamma ray
- Co-60 and Ir-192 common industrial gamma ray sources due to:
  - high energies
  - Portability (as opposed to x-ray machines)
- Disadvantage of gamma sources – cannot be turned off, therefore source must be isolated and shielded within an exposure device (camera)
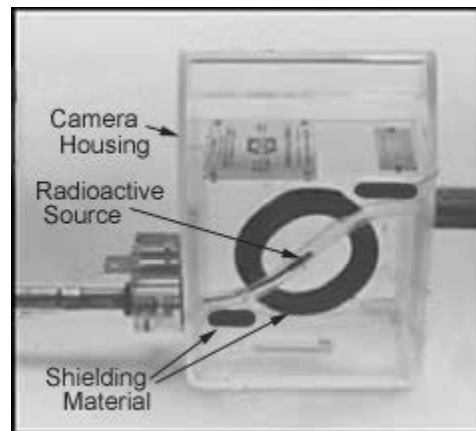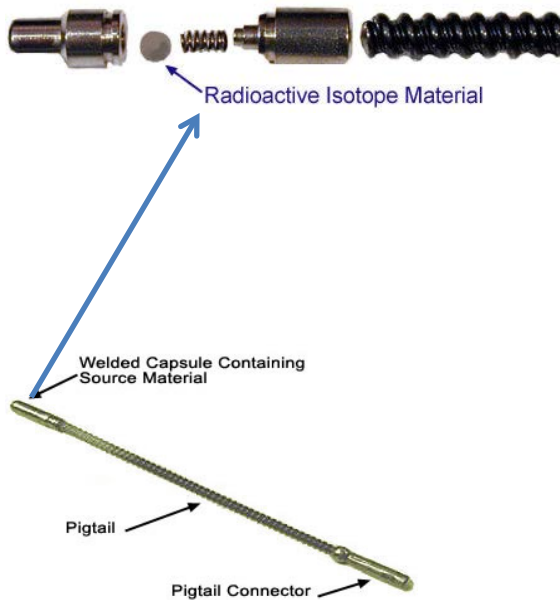
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Radiography Equipment – Gamma Sources
- Sources typically consist of multiple pellets loaded into a stainless steel capsule to obtain desired activity level (number of Curies)
- Capsule sealed by welding
- Attached to a short flexible cable called a pigtail
- Housed in a shielding device referred to as an exposure device or camera
- Activity of source governs amount of shielding required
  - Co-60 has a higher comparable energy (1.25 MeV) than Ir-192 (460 keV)
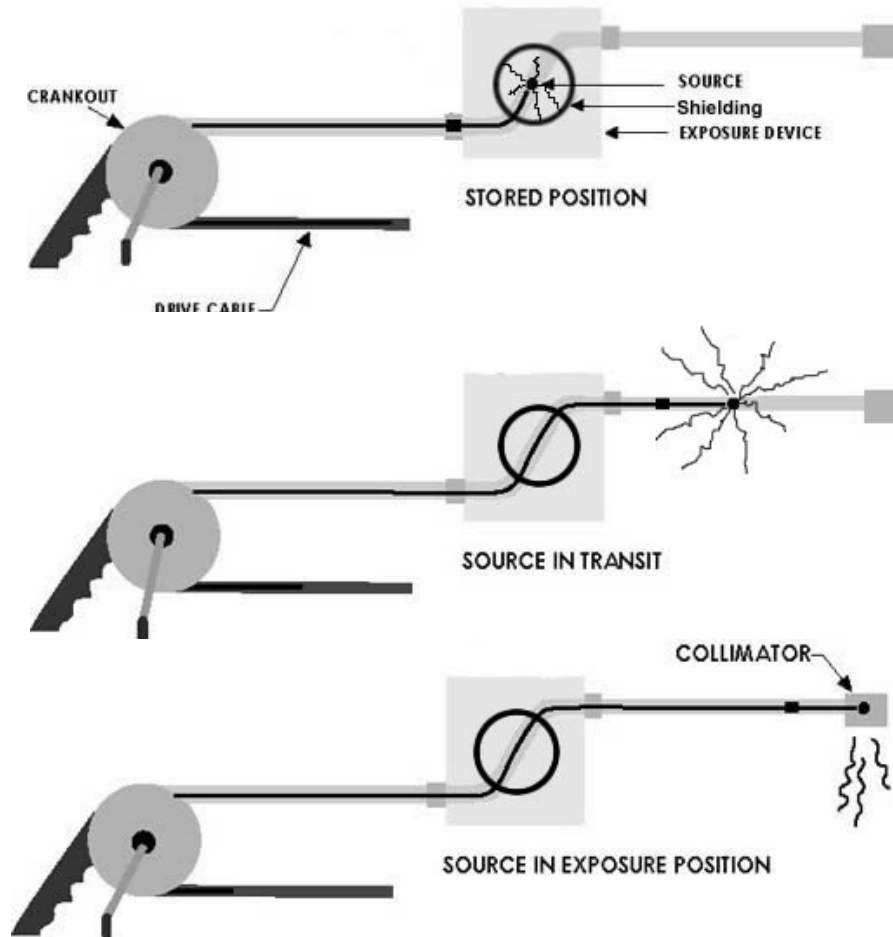 - Co-60 cameras typically weigh 500 lbs vs. ~45 lbs for Ir-192 cameras

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Radiography Equipment – Gamma Sources

Radioactive Isotope Material

Welded Capsule Containing Source Material

Pigtail

Pigtail Connector

DANGER

Camera Housing

Radioactive Source

Shielding Material

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Radiography Equipment – Gamma Sources

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Radiography Equipment – Exposure Vaults & Cabinets

- Exposure vaults and cabinets allow personnel to work safely in the area while exposures are taking place. Exposure vaults tend to be larger walk in rooms with shielding provided by high-density concrete block and lead.
- Exposure cabinets are often self-contained units with integrated x-ray equipment and are typically shielded with steel and lead to absorb x-ray radiation.
- They are equipped with protective interlocks that disable the system if anything interrupts the integrity of the enclosure.

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Performing Radiography
- Exposure device connected to source tube on one end and a crank-out mechanism on the other end
- Source tube is positioned as needed to obtain radiograph of component (with the source itself safely housed in the exposure device)
- From as far away as possible, the radiograph turns the crank to move the source from the camera to the tip of the source tube
- After the proper exposure time (calculated based on source strength, source to film distance, and thickness of the component), the radiographer cranks the source back into the camera
- The radiographer must use the survey meter to confirm the source fully retracted back into the camera

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Radiograph Image Properties

- Sensitivity – a measure of the quality of the image in terms of the smallest detail that may be detected
  - Image Quality Indicators (IQIs or penetrameters) – devices used to indicate the quality level or sensitivity of the radiograph (plaque type or wire type)
  - Depends on contrast and definition
- Contrast – degree of density difference between two areas on a radiograph
- Definition – degree of sharpness of the radiographic image
  - Codes require a minimum "unsharpness"

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Radiograph Image Properties

- Density – degree of film darkening
  - If 0.01% of transmitted light reaches far side of film the density is 4.0 (based on an exponential equation)
  - If 1.0% of transmitted light reaches far side of film the density is 2.0
  - Many governing codes require densities of 2-4% (don't want image too light or too dark)

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Radiograph Image Properties

- Densitometer – device used to measure film density
  - Density through the IQI must meet code (2-4%)
  - Also, the density in the area of interest (the weld perhaps), must satisfy plus/minus criteria
    - Darkest area must have a density of not more than 30% of the density under the IQI
    - Lightest area must have a density of not less than 15% of the density under the IQI