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1. These Review Notes serve as a supplemental resource and are **not intended** to substitute for the comprehensive training materials referenced above.
2. They are designed to offer a review of the study guide material.

Should you identify any inaccuracies within the content of these Review Notes, we kindly request that you inform us via the Contact page on our website.

In the event of content updates or revisions to this study guide, the following will occur:

- Notification of such changes—including the rationale behind them—will be published on the Downloads page of RadiationProtectionTech.com.
- The updated document will be uploaded to our website, where it will be accessible to all interested parties. Concurrently, the revision number will be updated to reflect the most current version.

FUN 1 Review Notes

Enabling Object 1.1

Atomic Structure

- Atom consists of proton, neutron, and electron.
- Proton: Located in the nucleus, positive charge, mass = $1.6724 \times 10^{-24}\,\mathrm{g}$, symbol = p.
- Neutron: Located in the nucleus, no charge, mass = $1.6747 \times 10^{-24}\,\mathrm{g}$, symbol = n.
- Electron: Orbits the nucleus, negative charge, mass is $\frac{1}{1838}$ of a proton, symbol = e.
- Atom is electrically neutral; number of electrons = number of protons.

Nuclear Notation

- $Z = \text{Atomic Number (number of protons)}.$
- $A = \text{Atomic Mass Number (protons + neutrons)}.$
- Number of neutrons = $A - Z$.

Atomic Mass and Weight

- Atomic Mass Unit (AMU) = $\frac{1}{12}$ mass of Carbon-12.
- $1\,\mathrm{AMU} = 1.6605 \times 10^{-24}\,\mathrm{g}.$

Electron Structure

- Chemical properties depend on outermost shell electrons.
- Max electrons in shells: $K = 2, L = 8, M = 18, N = 32, O = 50.$
- Full valence shell = unreactive; 1 or 2 valence electrons = highly reactive.

Isotopes

- Atoms with the same Z but different A are isotopes.
- Defined by mass number (e.g., hydrogen-1, hydrogen-2).

Mass Defect

- $\Delta m = \text{mass defect in AMU}.$
- Calculated using the formula $(A - Z)mn + Zm_H - M$.

Mass-Energy Equivalence

- $E = mc^2.$
- Binding Energy = Energy equivalence of mass defect.
- $E\,(\text{in MeV}) = \Delta m\,(\text{in AMU}) \times 931.5.$

Binding Energy per Nucleon

- $\frac{BE}{A}$ provides stability of the nucleus.
- Calculated as total binding energy divided by the number of nucleons.

EO 1.2: Nuclear Interactions and Reactions

Main Idea

Atoms become radioactive when they undergo spontaneous transformations, emitting various types of radiation:

- Alpha particles (α)
- Beta particles - positrons or negatrons (β)
- Electromagnetic Radiation - gamma (γ), X-rays
- Neutron (η)

Radioactive Decay Law

The rate of decay can be expressed using the formula:

$$N_{\text{Final}} = N_{\text{Initial}} \times e^{-\lambda T}$$

- N_{Final}: Number of atoms present in the future
- N_{Initial}: Number of atoms present initially
- λ: Decay constant = $\frac{0.693}{t_{1/2}}$
- $t_{1/2}$: Half-life
- T: Elapsed time

Conservation Laws

- Conservation of energy: $\Delta E_1 + \Delta E_2 = \Delta E_3 + \Delta E_4$
- Conservation of linear momentum: $p_1 + p_2 = p_3 + p_4$
- Conservation of charge: $Z_1 + Z_2 = Z_3 + Z_4$
- Conservation of mass: $A_1 + A_2 = A_3 + A_4$

Types and Energies of Emissions

- Beta emissions: Up to about 5 MeV
- Alpha particles: Up to about 10 MeV
- Gamma photons: Up to about 3 MeV

Rate of Decay

Rate of decay is characteristic for each radionuclide and occurs at an exponential rate. The half-life ($t_{1/2}$) is used to quantify this rate.

Artificial vs Natural Radionuclides

Artificial radionuclides are produced through man-made reactions. Despite their origin, they decay in a manner similar to natural radionuclides.

EO 1.3: Fission Process and Neutron Leakage

Main Idea: Fission and Neutron Leakage

Fission is a nuclear process where a nucleus absorbs a free neutron and splits into smaller parts, releasing a large amount of energy and additional neutrons. Different elements have varying likelihoods of undergoing fission based on their respective energy thresholds.

Sub-points

1. **Neutron Absorption**

   A free neutron can collide with a nucleus, leading to the absorption of the neutron by the nucleus, thereby increasing the energy level of the atomic system.

2. **Energy Requirement**

   The energy added to the system by the neutron equals its binding energy. This added energy may lead to fission under specific conditions.

3. **Liquid Drop Model**

   This model likens a nucleus to a liquid drop to explain why fission is possible. The model argues that, like liquid drops, nuclei can be deformed and may not return to their original shape, thus causing them to split.

4. **Calculation of Critical Energy for Fission** (E_c)

   The minimum energy needed to trigger fission is known as E_c. This value can be calculated for various nuclei based on our understanding of nuclear forces.

5. **Example: Fission in** $^{235}\mathrm{U}$

   Fission in Uranium-235 is provided as an example. When a neutron is absorbed by $^{235}\mathrm{U}$, the resulting fission releases about 200 MeV of energy.

6. **Energy Comparison**

   For some elements like $^{238}\mathrm{U}$ and $^{232}\mathrm{Th}$, additional energy beyond the neutron's binding energy is required for fission to occur. For others like $^{235}\mathrm{U}$, $^{233}\mathrm{U}$, and $^{239}\mathrm{Pu}$, the neutron's binding energy alone is sufficient.

7. **Resulting Instabilities**

   The new elements formed by fission are unstable and will undergo various transformations to achieve stability. This can include releasing more neutrons and other forms of radiation.

8. **Chain Reactions**

   The neutrons released during fission can trigger more fissions, leading to a chain reaction. This is the basis for nuclear power generation.

EO: 1.4 Describe the basic characteristics of BWRs and PWRs, including fission product barriers

Main Idea: In both Boiling Water Reactors (BWRs) and Pressurized Water Reactors (PWRs), the process of electricity generation is facilitated by the heat generated in the reactor core. This heat is used to produce steam, which drives turbines to generate electricity. However, the methods used to achieve this differ between BWRs and PWRs.

Boiling Water Reactors (BWRs)

1. The core inside the reactor vessel creates heat.
2. A steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat.
3. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

Pressurized Water Reactors (PWRs)

1. The core inside the reactor vessel creates heat.
2. Pressurized water in the primary coolant loop carries the heat to the steam generator.
3. Inside the steam generator, heat from the primary coolant loop vaporizes the water in a secondary loop, producing steam.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

Fission Product Barriers

Both BWRs and PWRs have three primary barriers for containing fission products:

1. Fuel cladding
2. Reactor system piping
3. Containment structure

EO: 1.5 Describe the statistical nature of radioactive decay as it relates to uncertainties encountered when measuring radioactivity

Main Idea: Measuring radioactivity involves a certain level of uncertainty due to the random nature of radioactive decay. Various statistical models and distributions, such as the Poisson and Gaussian distributions, are employed to interpret and analyze this data.

Poisson Distribution

The Poisson distribution describes the random decay of radioactive atoms. It is particularly useful when the population (i.e., number of counts) is small.

Gaussian Distribution

The Gaussian distribution is used in cases where the mean number of successes is relatively large. It is used for counting system calibrations, operational checks, and normal samples containing activity.

Errors and Confidence Levels

Different levels of confidence are associated with different errors. For example, a 95% confidence level corresponds to 1.96 standard deviations.

Background Radiation

Background radiation is always present and must be accounted for when making radioactivity measurements. It is determined during system calibration and subtracted from total counts.

Detection Limits and Errors

Errors in radioactivity measurements can be random or systematic. Random errors can be reduced by increasing the number of measurements. Systematic errors, however, need to be identified and eliminated.

Summary

- The decay of radioactive elements is inherently random, requiring statistical models for accurate measurement.
- Different errors and levels of confidence are associated with the measurement.
- Background radiation is always present and needs to be accounted for.

EO: 1.6 Describe the Use of the Chart of Nuclides

Main Idea

The Chart of the Nuclides serves as a comprehensive graphical representation of the properties of various nuclides. It maps the number of neutrons against the number of protons for various elements, providing a useful reference for studying nuclear properties.

General Arrangement

- The number of neutrons (N) is plotted horizontally on the x-axis.
- The number of protons (atomic number, Z) is plotted vertically on the y-axis.
- The chart helps to reveal the relationship between lighter and heavier elements.

Specific Nuclide Representation

- Each nuclide is represented by a block.
- The block's color and labeling indicate specific properties of the nuclide.
- Stable nuclides are usually denoted by a grey block, such as Sodium-23.

Summary

- The Chart of Nuclides is an important tool for understanding the properties and relationships of various nuclides.
- It provides a visual representation that can simplify complex data.
- Both students and professionals use the chart for study and reference.

EO: 1.7 Identify the Types of Radioactive Decay

Main Idea

Radioactive decay occurs in various forms including alpha, beta, and gamma radiation. Each form has unique characteristics and applications.

Modes of Decay and Types of Emissions

- Alpha, beta, and gamma radiation were initially discovered by Rutherford.
- Alpha and beta are particulate radiations, while gamma is electromagnetic radiation.
- When a nuclide decays, a transmutation occurs, forming a new element and emitting radiation.

Summary

- Various forms of radioactive decay have been identified, each with its unique characteristics.
- Understanding the type of decay is crucial for safe handling and application of radioactive materials.

EO: 1.8 Describe Each Type of Decay Using Basic Equations

Main Idea

The different types of radioactive decay, such as alpha, beta, and gamma decay, can be described using basic equations that indicate the changes in the atomic and mass numbers of the decaying elements.

Alpha Decay

Equation: $A_Z X \rightarrow A_{Z-4} Y + {}^4_2\alpha$

Beta Decay

Equation: $A_Z X \rightarrow A_{Z+1} Y + \beta^- + \bar{\nu}$

Positron Decay

Equation: $A_Z X \rightarrow A_{Z-1} Y + \beta^+ + \nu$

Summary

- Different types of decay can be described using equations.
- These equations are essential for understanding the fundamental processes involved in radioactive decay.

EO: 1.9 Describe the processes and characteristics of gamma and x-ray interaction with matter

Main Idea

- **Photoelectric Effect**
  - The photon transfers all of its energy to an electron; ejecting the electron from the atom
  - The photon disappears
  - Almost always a "K" shell electron (inner shell - lowest energy level)
  - Generally low energy gamma (eV range)

- **Compton Scattering**
  - Photon transfers a part of its energy to an electron (binding energy + kinetic energy = beta particle + lesser energy photon)
  - The less energetic photon (Compton photon) has its direction of travel changed and may undergo further Compton scatter or photoelectric effect interactions in the absorber
  - Any electrons except "K" shell (outer shells – higher energy levels)
  - Generally occurs with middle energy gamma (low MeV range)

- **Pair Production**
  - In an interaction between the electromagnetic field of a high Z number nucleus and a photon - all of the energy of the photon is transformed into an electron and a positron (two charged particles) each having some kinetic energy.
  - Very high energy gamma required because a minimum energy is required (1.022 MeV to make the mass of the two particles) in fact, it may take energy levels greater than 2 or 3 MeV and then only a very small part of all interactions will cause pair production.

EO: 1.10 Calculate radioactive decay using exponential equations and appropriate graphs

Main Idea

- **The Radioactive Decay Law**
  - The activity of any sample of radioactive material decreases or decays at a fixed rate.
  - No known physical or chemical agents can influence this rate.
  - The rate can be characterized by observing the fraction of activity that remains after successive time intervals.
  - We choose a fraction that is easy to work with, one-half (½).
  - This time required for the activity to be reduced to one half is called the half-life.
  - Mathematically, this is expressed as: $n = \frac{t}{T_{1/2}}$
  - The activity at any time t after 0 is denoted as A_t.
  - Using a proportion, the relationship between the two activities is: $\frac{A_0}{A_t} = \frac{1}{(1/2)^n}$
  - By cross-multiplying, we get $A_t = A_0 \times (1/2)^n$
  - The decay constant $\lambda = \frac{\ln 2}{T_{1/2}}$
  - The equation for activity using the decay constant will be $A_t = A_0 \times e^{-\lambda t}$

- **Examples**
  - Example 1: $A_t = 52\mu Ci \times (1/2)^{4/10} = 39.4\mu Ci$
  - Example 2: $A_t = 10mCi \times e^{-(\ln 2/14.2)\times 60} = 0.534mCi$

EO: 1.11 Categorize alpha particles, beta particles, gamma rays and neutrons with respect to mass and energy

Main Idea

- **Alpha Particles**
    - Mass: ~4 AMU
    - Energy: Monochromatic at ~5 MeV

- **Beta Particles**
    - Mass: $<< 1$ AMU
    - Energy: Range from 15 keV to 15 MeV, average value is about one-third the maximum

- **Gamma Rays**
    - Mass: None
    - Energy: Discrete values typically between 0.1 - 2 MeV, but energies $>> 5$ MeV are possible

- **Neutrons**
    - Mass: ~1 AMU
    - Energy Classifications:
        - Thermal neutrons: ~0.025 eV
        - Epithermal neutrons: 0.5 eV to 10 keV
        - Fast neutrons: 10 keV to 20 MeV
        - Relativistic neutrons: > 20 MeV (not in our reactor)

EO: 1.12 Describe the process of neutron activation

Main Idea

- **Scattering**
    - Occurs when a nucleus, after being struck by a neutron, emits a single neutron
    - Categories: Elastic and Inelastic scattering

- **Elastic Scattering**
    - No energy transferred into nuclear excitation
    - Momentum and kinetic energy are conserved
    - Types: Resonance elastic scattering and potential elastic scattering

- **Inelastic Scattering**
    - Incident neutron is absorbed, forming a compound nucleus
    - Lower kinetic energy neutron is emitted, original nucleus in excited state
    - Excess energy is emitted as gamma rays

- **Absorption Reactions**
    - Result in loss of a neutron and production of a charged particle or gamma ray
    - Types: Radiative capture, particle ejection, and fission

- **Radiative Capture**
    - Incident neutron forms a compound nucleus, which decays to ground state by gamma emission

- **Particle Ejection**
    - Compound nucleus ejects a new particle while the incident neutron remains

EO: 1.13 List major sources of natural background radiation

Main Idea: Sources of Radiation

We live in a radioactive world and always have. The majority of us will be exposed to more ionizing radiation from natural background radiation than from our jobs.

Natural sources

There are several sources of radiation that occur naturally. The four major sources are:

- **Cosmic Radiation**: Originates from the sun and outer space. Average annual dose is about $28\,\mathrm{mrem/yr}$.
- **Terrestrial Radiation**: Comes from natural radioactive elements in the earth's crust like radium, uranium, and thorium. Average annual dose is about $28\,\mathrm{mrem/yr}$.
- **Internal Radiation**: Caused by ingesting food and water containing natural radioactive materials like $\mathrm{K}\text{-}40$. Average annual dose is about $40\,\mathrm{mrem/yr}$.
- **Radon**: A gas emitted from decaying uranium in soil. Mostly found in basements. Average annual dose is about $200\,\mathrm{mrem/yr}$.

Cosmic Radiation

1. Cosmic radiation comes from the sun and outer space. It consists of positively charged particles and gamma radiation.
2. At sea level, the average annual cosmic radiation dose is about 26 mrem.
3. At higher elevations, the amount of atmosphere shielding cosmic rays decreases; therefore, the dose increases.

Terrestrial Radiation

1. Some of the contributors to terrestrial sources are the natural radioactive elements radium, uranium, and thorium.
2. Many areas have elevated levels of terrestrial radiation due to increased concentrations of uranium or thorium in the soil.

Internal Radiation

1. The food we eat and the water we drink contain trace amounts of natural radioactive materials.
2. These naturally occurring radioactive materials deposit in our bodies and cause internal exposure to radiation.
3. Some naturally occurring radioactive isotopes include Sodium-24 (Na-24), Carbon-14 (C-14), Argon-41 (Ar-41), and Potassium-40 (K-40). Most of our internal exposure comes from K-40.

Radon

1. Radon comes from the radioactive decay of uranium, which is naturally present in the soil.
2. Radon is a gas. It can travel through the soil and enter through building foundation cracks.
3. Radon emits alpha radiation. It presents a hazard only when taken into the body (e.g., when inhaled).

Total Background Radiation

The average annual total effective dose to the general population (nonsmokers) from naturally occurring and manmade sources is about 620 mrem.

EO: 1.14 Identify specific isotopes of concern in power reactors during operation and following shutdown

Main Ideas

1. **Types of Radionuclides in Nuclear Reactors**: Generated due to neutron activation and fission product leakage.
   - **Common Radionuclides**: Include cobalt, iron, chromium, manganese, copper, zinc, nickel, zirconium, nitrogen, fluoride, oxygen, cesium, rubidium, strontium, iodine, krypton, and xenon.
   - **CRUD (Chalk River Unidentified Deposits)**: Deposits of activated corrosion material that accumulate in the reactor.

- **Fission Product Leakage**: Small defects in fuel rods can release fission products into the coolant system.

2. **Transuranic Nuclides**: Elements with atomic numbers greater than uranium, e.g., 239U, 239Np, 238Pu, 240Pu, 241Pu, 241Am, 242Cm, 243Cm, 244Cm.
   - Formed via neutron capture and sequential decays, often fissionable and/or alpha emitters.

EO: 1.15 Describe radon decay as related to daughters and physical properties

Main Ideas

1. **Radon Decay**: Radon is a radioactive gas that decays into a series of "daughters," which are also radioactive.
   - **Natural Decay Chains**: Radon decays through a chain of radioactive isotopes. For more information, see Berkeley Nuclear Forensics.
2. **Physical Properties**: Radon is colorless, odorless, and heavier than air. Its daughters may adhere to surfaces or dust particles, making them inhalable.

Example of a reactor-produced decay chain

Main Ideas

1. **Fission of U-235**: The fission of U-235 in reactors is initiated by absorbing a neutron.
   - $$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{A}_{Z}X + ^{235-A-2}_{92-Z}Y + 3^{1}_{0}n$$
   - Note: Number of nucleons is conserved.
2. **Example Reaction**: The thermal fission of U-235 can produce Mo-100 and Sn-133.
   - $$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{100}_{42}Mo + ^{133}_{50}Sn + 3^{1}_{0}n$$
   - Note: The total number of nucleons before and after the reaction remains the same (236 nucleons, with 92 of them being protons).

EO: 1.16 Identify and use radiological quantities and their units

Main Ideas

1. **Activity**: Measures the intensity of radioactivity in a sample.
   - **Curie (Ci)**: 2.2×10^{12} disintegrations per minute (dpm) or 3.7×10^{10} disintegrations per second (dps).
   - **Becquerel (Bq)**: 1 disintegration per second. $3.7 \times 10^{10} Bq = 1Ci$.
2. **Exposure**: Measures the ionization produced in air by gamma or x-rays.
   - **Roentgens (R)**: Amount needed to produce a charge of 0.000258 coulombs/kilogram of air.
3. **Dose**: Measures the amount of radiation absorbed.

- **Rad**: Absorbed dose where 1 gram absorbs 100 ergs of energy. 1 Gray (Gy) = 100 rad.
- **Gray (Gy)**: SI unit equivalent to 100 rad, measures energy absorbed as 1 Joule/kilogram.

4. **Dose Equivalent**: Combines the absorbed dose with the medical effects of the type of radiation.
   - **Rem**: Dose equivalent for beta and gamma is the same as the absorbed dose. 1 Sv = 100 rem.
   - **Sievert (Sv)**: SI unit for dose equivalent, $1Sv = 100rem$.

EO: 1.17 Identify and use significant dose terms

Main Ideas

1. **Deep Dose Equivalent (DDE)**: Whole-body dose at a tissue depth of $1cm$ $(1,000mg/cm^2)$.
2. **Eye Dose Equivalent**: Dose at a tissue depth of $300mg/cm^2$ $(0.3cm)$ for the lens of the eye.
3. **Shallow Dose Equivalent (SDE)**: External exposure dose at a tissue depth of $0.007cm$ $(7mg/cm^2)$.
4. **Effective Dose Equivalent (EDE)**: Sum of products of tissue or organ weighting factors and the dose to corresponding body tissues and organs from external radiation sources.
5. **Committed Dose Equivalent (CDE) (HT, 50)**: The dose to organs or tissues over a 50-year period after intake of radioactive material.
6. **Total Effective Dose Equivalent (TEDE)**: Sum of the DDE (external exposure) and the Committed Effective Dose Equivalent (internal exposure).
7. **Committed Effective Dose Equivalent (CEDE)**: Defined in 10 CFR 20.1003 as $HE, 50 = \Sigma WT \times HT, 50$ where WT are the weighting factors for each organ or tissue.
8. **Total Organ Dose Equivalent (TODE)**: Sum of the DDE and the CDE for the organ receiving the highest dose, consistent with 10 CFR 20.2106(a)(6).

EO: 1.18 Convert Radioactivity to Dose Rate

Main Ideas

To control exposure effectively, understanding the intensity of radiation fields is crucial. Various equations can be used to assess this intensity:

1. **"Curie/meter/rem" Rule** (for Co-60): $1 \text{ Ci @ } 1 \text{ meter } = 1 \text{ R/hr}$.
2. **Gamma Radiation Field Intensity for Point Source:**

$$I_{1ft} = 6 \times C \times E \times N$$

Where: I_{1ft} = Exposure rate in R/hr at 1 ft. C = Activity in Ci. E = Gamma energy in MeV. N = Number of gammas per disintegration.
- This equation is accurate to within $\pm 20\%$ for gamma energies between 0.05 MeV and 3 MeV.
- If N is not given, assume 100% photon yield (1.00 photons/disintegration).
- For multiple photon energies:

$$\sum_{n=1}^{k}(\gamma_n \times \%_n)$$

3. **For distances in meters:** $I_{1m} = 0.5 \times C \times E \times N$.

4. **For short distances greater than 1 foot:**

$$I = \frac{(6 \times C \times E \times N \times 12)}{d^2}$$

where d = distance in feet.

5. **For metric distances:**

$$I = \frac{(0.5 \times C \times E \times N \times 12)}{d^2}$$

where d = distance in meters.

EO: 1.19 Neutron Interactions with Matter

Main Ideas

Understanding the processes and characteristics of neutron interaction with matter is critical for radiation protection. These interactions are:

1. **Classified by:**
   - Kinetic energy of the neutron
     - Thermal: $< 0.5\,\mathrm{eV}$
     - Intermediate: $0.5\,\mathrm{eV} - 100\,\mathrm{keV}$
     - Fast: $100\,\mathrm{keV} - 20\,\mathrm{MeV}$
     - Relativistic: $> 20\,\mathrm{MeV}$
   - Z number of the target
     - Lower Z numbers absorb more energy per each interaction or collision.
   - Absorption cross-section of the target
     - Some elements, such as cadmium, boron, and hafnium, absorb neutrons more readily than others.

2. **Slow Neutron Interactions (Capture):**
   - Radiative Capture: Neutron is absorbed into the nucleus and a gamma-ray is emitted. This is also known as gamma emission or neutron activation.
   - Charged Particle Emission: Neutron is absorbed into the nucleus and a charged particle is emitted.
   - Fission: Neutron is absorbed into the nucleus, causing the nucleus to split into fission fragments.

3. **Fast Neutron Interactions (Scatter):**
   - Elastic Scattering: Kinetic energy is the only form of energy involved.
   - Inelastic Scattering: Some kinetic energy is converted to excitation energy of the nucleus, which then emits a photon (gamma ray) to remove this excitation energy.

4. **Additional Points:**
    - Neutrons are not charged particles, but their interactions do produce charged particles and photons, resulting in significant secondary ionization and excitation.

EO: 1.20 Select the Types of Materials for Shielding Each Type of Radiation

1. **Main Idea:**
    - Importance of type of radiation (gamma, neutron, alpha, beta) in shielding design.
    - Role of location, intensity, and energy distribution of radiation sources.
    - Permissible radiation levels as a design factor.

2. **Neutron Radiation:**
    - Low energies ($< 0.1\,\mathrm{MeV}$)
        - Effective materials: Hydrogenous materials, water
    - High energies ($> 10\,\mathrm{MeV}$)
        - Effective materials: Iron, steel
    - Composite shields
        - Iron and water layers in PWRs
        - Specialized concretes (e.g., barytes, iron concrete)
        - Boron additives in concrete and other materials

3. **Gamma Radiation:**
    - Challenges due to high penetration
        - Effective materials: Lead, iron
    - Efficiency comparisons
        - Lead generally more effective than iron

4. **Alpha and Beta Radiation:**
    - General ease of shielding
        - Alpha: Stopped by thin sheets
        - Beta: Stopped by materials like aluminum
    - Concern during outages and maintenance

EO: 1.21 Define Buildup Factor

1. **Main Idea:**
    - The buildup factor is defined as the ratio of the total value of a specified radiation quantity at any point to the contribution to that value from radiation reaching the point without having undergone a collision.
    - Alternatively, it is the ratio of the total photons at a point to the number arriving there without being scattered.
    - In thick shielding, it is essential to account for the buildup factor, which is due to the scattering of radiation in the absorber.

EO: 1.22 Recall values of Half or Tenth Value Layer (HVL/TVL) for Cobalt-60 gamma rays for lead, steel, concrete, and water

1. **Main Idea:**

- The character of α and β rays were identified through magnetic and electrostatic deflection experiments. α rays are essentially helium ions, and β rays are high-speed electrons.
- Gamma radiation was later recognized as electromagnetic waves.

2. **Shielding Calculations:**
   - HVL is defined as $\mathrm{HVL} = \ln 2/\mu = 0.693/\mu$.
   - TVL is defined as $\mathrm{TVL} = \ln(10)/\mu = 2.3026/\mu$.
   - The number of HVL or TVL needed can be calculated with $I = I_0(1/2)^n$ for HVL and $I = I_0(1/10)^n$ for TVL, where I is the final dose rate, I_0 is the initial dose rate, and n is the number of HVL or TVL.

3. **Rule of Thumb HVL and TVL for Co-60:**
   - Lead: $\mathrm{HVL} = 0.49''$, $\mathrm{TVL} = 1.57''$
   - Steel: $\mathrm{HVL} = 0.85''$, $\mathrm{TVL} = 2.71''$
   - Concrete: $\mathrm{HVL} = 2.38''$, $\mathrm{TVL} = 8''$
   - Water: $\mathrm{HVL} = 4''$, $\mathrm{TVL} = 24''$

EO: 1.23 Describe the phenomenon of "sky shine"

1. **Main Idea**
   - Gamma ray shielding design needs to account for sky shine. "Sky Shine" is radiation reflected back to Earth by the atmosphere.
   - The air provides a medium to scatter gamma rays. Sky shine appears to come from the sky but is generated when large gamma sources are not properly shielded above the source.
   - The name reflects the fact that gamma rays appear to shine down from the sky if adequate shielding is not placed above the source.

2. **Examples**
   - A classic example is the movement and storage of highly radioactive resins. Sky shine can occur and generate radiation areas at long distances from the source.
   - Typically during storage, these items have shielding above the resin to prevent sky shine.

EO: 1.24 Apply quality factors for converting dose to dose equivalent

1. **Main Idea**
   - Units of Radiation Dose definition of Quality Factor according to 10CFR20.104.
   - The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor.

2. **Table 1004(b).1 Quality Factors and Absorbed Dose Equivalencies**
   - $\text{Type of radiation - Quality Factor - Absorbed dose equal to a unit dose equivalent (Q)}$
   - X-, gamma, or beta radiation - 1 - 1
   - Alpha particles, multiple-charged particles, fission fragments and heavy particles of unknown charge - 20 - 0.05
   - Neutrons of unknown energy - 10 - 0.1
   - High Energy protons - 10 - 0.1

3. **Notes**
   - Absorbed dose in rad equal to 1 rem or the absorbed dose in gray equal to 1 sievert.

EO: 1.25 Describe the mechanisms of radiation interactions with cells

1. **Main Idea: Effects of Radiation on Cells**
    - Human body consists of organ systems, which are made of tissues, which are in turn made of specialized cells.
    - Ionizing radiation can potentially affect the normal function of cells.

2. **Biological effects begin with the ionization of atoms**
    - Ionization or excitation damages cells. The atoms constitute the tissues of the body.
    - Cells have two main parts: the body and the nucleus. The nucleus is like the cell's brain.
    - Ionizing radiation may hit vital (e.g., nucleus) or less vital parts (e.g., cytoplasm) of the cell.

3. **Radiation Damage to Cell Constituents**
    1. Cell Membrane
        - It takes about $3,000 - 5,000 \text{ rad } (30 - 50 \text{ gray})$ to rupture.
        - Results in leakage and potential harm.
        - At lower doses, some leakage occurs.
    2. Cytoplasm
        - Negligible effect.
    3. Mitochondria
        - A "few thousand" rad disrupts function.
        - Interrupts ATP storage.
        - If reserves are good, cell can repair.
    4. Lysosome
        - Ruptures between 500 and $1,000 \text{ rad } (5 - 10 \text{ gray})$.
        - Enzymes are released that digest the cell.
    5. Nucleus
        - Most radiosensitive part of the cell.
        - Affects DNA and RNA, inhibiting cell division.

4. **Primary and Secondary Effects of Radiation**
    1. Primary Effect
        - Ionization & Excitation of atoms making up the cell.
        - Produced when the primary interaction of radiation is with the target atoms in the cell such as those in the DNA.
    2. Secondary Effects
        - Formation of free radicals that can chemically attack molecules like DNA.
        - Occurs due to the dissociation of water, which makes up 70-80% of the cell.
        - Three possible reactions:
            - $H + H = H_2$
            - $OH + H = H_2O$
            - $H_2 + OH = H_2O_2$
        - Formation of H_2O_2 (hydrogen peroxide) can lead to cell death. H_2O_2 is a harmful oxidizer which poisons the cell.

EO: 1.26 Identify cell characteristics that affect radiosensitivity

1. **Main Idea**
    - Some cells are more sensitive than others to environmental factors such as viruses, toxins, and ionizing radiation.

2. **Cell Sensitivity**
    - Actively dividing and non-specialized cells
        - Cells that are actively dividing are more sensitive to ionizing radiation.
        - Rapidly dividing cells include blood-forming cells, cells that line the intestinal tract, hair follicles, and cells that form sperm.
    - Less actively dividing and more specialized cells
        - Cells that divide at a slower rate or are more specialized are not as sensitive to damage by ionizing radiation.

3. **Possible Effects of Radiation on Cells**
    - There is no damage

- Cells are damaged but are able to repair the damage and operate normally
  - The body of most cells is made up primarily of water. When ionizing radiation hits a cell, it interacts with the water in the cell, producing hydrogen peroxide, which can damage cell atomic structures.
  - Damage to chromosomes and other cell structures can be repaired.
- Cells are damaged and operate abnormally
  - Cell damage may not be repaired or may be incompletely repaired, leading to abnormal function.
  - If a chromosome in the cell nucleus is damaged but not correctly repaired and the cell continues to reproduce, this could result in a mutation and may lead to cancer.
- Cells die as a result of the damage

EO: 1.27 Define stochastic and non-stochastic effects

1. **Main Idea**

   - **Stochastic effects**: Effects that occur by chance and generally occur without a threshold level of dose. The probability is proportional to the dose, but severity is independent of the dose. Examples include cancer and genetic effects.

   - **Non-stochastic effect (Deterministic effect)**: Health effects whose severity varies with the dose and for which a threshold is believed to exist. For example, radiation-induced cataract formation.

2. **Stochastic and Deterministic Effects**
   1. Stochastic Effects
      - Probability of effect occurring increases with dose.
      - No established threshold; even low exposures have some risk.
      - Examples include cancer and genetic mutations.
   2. Deterministic (Non-Stochastic) Effects
      - Severity of effect increases as the dose increases.
      - Generally, a threshold exists below which no effects occur.
      - Effects result from collective injury to many cells.
      - Examples include cataracts, skin burns, lowering of blood cell counts, etc.

EO: 1.28 Compare and Contrast between Acute and Chronic Radiation Exposure

1. **Main Idea**
   - Effects of chronic exposures differ from the effects of acute exposures in terms of duration, disease risk, and nature of the effects.

2. **Effects of Chronic Exposures to Ionizing Radiation**
   1. Chronic exposure
      - Smaller exposures over a long time period
      - No unique disease, but statistical increase in risk
      - Evidence includes radium dial painters, early radiologists, atomic bomb survivors
   2. Cancer (Somatic)
      - Justification for protection standards
      - Possibility of inducing tumors
      - Can be used to treat or cause cancer
   3. Cataracts
      - Opacity of the lens of the eye
      - 600 rad (6 gray) may produce a cataract for high LET radiation
      - Symptoms may not appear for years
      - Effects may be cumulative
      - Primary hazards are neutrons and gamma
      - Younger age increases susceptibility
   4. Life Span (Shortening or Lengthening)
      - Uncertain data

        - Associated with aging

3. **Effects of Acute Radiation Exposures**
    1. Stages
        - Prodromal
        - Latent
        - Illness
        - Recovery/death
    2. Three syndromes
        1. Hematopoietic Syndrome
            - Also known as Therapeutic Range
            - Dose level between 200 to 1,000 rads (2 - 10 gray)
            - Critical organs: blood-forming organs
            - Decreased ability to fight infection and causes hemorrhaging
            - Symptoms include nausea, vomiting, epilation
            - Treatment: antibiotics, bone marrow transplants
            - Death due to infection and hemorrhaging
        2. Gastrointestinal Syndrome
            - Dose level between 1,000 to 5,000 rads (10 - 50 gray)
            - Affects GI tract
            - Stops production of new epithelial cells
            - Symptoms: nausea, vomiting, dehydration, electrolyte imbalance
            - Death: circulatory collapse from loss of fluids
        3. Central Nervous System (CNS) Syndrome
            - Dose level: >5,000 rad (>50 gray)
            - Critical Organ: Central Nervous System
            - Symptoms: convulsions, tremors, ataxia, lethargy
            - Death: Respiratory failure and/or brain edema

EO: 1.29 Describe the Purpose and Basic Content of 10 CFR 20, "Standards for Protection Against Radiation"

1. **Main Idea**
    - The regulations in 10 CFR 20 establish protection standards against ionizing radiation for activities under licenses issued by the Nuclear Regulatory Commission.

2. **Legislative Framework**
    - Issued under the Atomic Energy Act of 1954, as amended
    - Also issued under the Energy Reorganization Act of 1974, as amended

3. **Purpose of the Regulations**
    - To control the receipt, possession, use, transfer, and disposal of licensed material.
    - To ensure the total dose to an individual does not exceed prescribed standards.
    - Inclusive of doses from both licensed and unlicensed radioactive material, and from radiation sources other than background radiation.
    - Does not limit actions necessary to protect health and safety.

EO: 1.30 For Acute Exposures, Describe the Dose-Response Relationship, Acute Radiation Syndrome, LD-50/30, and LD-50/60

1. **Main Idea**
    - High whole body dose rates, such as ~20 Rem, may result in initial signs of blood changes, like Chromosomal Aberration.
    - Acute Radiation Syndrome (ARS) occurs under certain conditions.

2. **Hematopoietic Syndrome**
    - Occurs between 200-1000 rad

- Affects blood-forming tissues
- Symptoms include nausea and vomiting, and epilation
- Treatment involves antibiotics and bone marrow transplants
- If death occurs, it is due to infection and hemorrhaging

3. **Gastrointestinal Syndrome**
   - Occurs between 1000-5000 rad
   - Affects the GI tract
   - Symptoms include nausea and vomiting, dehydration, and electrolyte imbalance
   - If death occurs, it is due to circulatory collapse

4. **Central Nervous System (CNS) Syndrome**
   - Occurs at doses greater than 500 rad
   - Affects the CNS
   - Symptoms include convulsions, tremors, ataxia, and lethargy
   - If death occurs, it is due to respiratory failure and/or brain edema

5. **Required Conditions for ARS**
   - Radiation dose must be greater than $0.7\,\mathrm{Gy}$ or 70 rads.
   - Dose must be external
   - Radiation must be penetrating
   - Entire body or significant portion must have received the dose
   - Dose must have been delivered in a short time

6. **LD-50/30**
   - Refers to the dose where 50% of the population is expected to die within 30 days without medical care.
   - The dose range is 400-500 rad

7. **LD-50/60**
   - Refers to the dose where 50% of the population is expected to die within 60 days without medical care.
   - The dose range is 200-300 rad

EO: 1.31 Explain the Concepts and Objectives of an ALARA TEDE Evaluation

1. **Main Idea**
   - The site-specific radiological control manual should define trigger levels for formal radiological reviews of non-routine or complex work activities.
   - These trigger levels should be based on existing or expected radiological conditions prior to the implementation of job-specific engineering and administrative controls.

2. **Appropriate Trigger Levels Should Include**
   - Estimated individual or collective dose exceeding pre-established values, e.g., any individual likely to receive a dose exceeding 50% of the local administrative control level or a collective dose likely to exceed $1\,\text{man-rem}$.
   - Predicted airborne radioactivity concentrations exceeding pre-established values.
   - Removable contamination on accessible surfaces greater than pre-established values.
   - Entry into areas where dose rates exceed $1\,\mathrm{rem/hour}$.
   - Potential releases of radioactive material to the environment.

EO: 1.32 Explain the Basis for and Implications of the Linear Zero-Threshold Dose-Response Curve

1. **Main Idea**
   - Reference: Radiation Risk In Perspective, Health Physics Society, PS010-2
   - Reference: Occupational Radiation Safety Standards and Regulations are Sound, Health Physics Society, PS013-01
   - The underlying theory for radiation protection standards is the Linear Non-Threshold (LNT) model.

2. **Importance of the LNT Model**
   - The LNT model is used partly because it is difficult to determine the health effects at low radiation doses based on the observable effects at high doses.
   - It is assumed that the health effects are directly proportional to the dose received. For example, doubling the radiation dose would result in a doubling of the effect.
   - This leads to a linear, no-threshold model for estimating health effects at various radiation dose levels, although this model may be an oversimplification.

3. **Scientific Observations**
   - Most reliable studies on low-level radiation exposure to occupational workers have not detected adverse health effects for lifetime exposures smaller than approximately $0.1\,\mathrm{Sv}$ ($0.1\,\mathrm{Sv} = 10,000\,\mathrm{mrem}$).

4. **Linear No-Threshold Theory**
   - The linear no-threshold theory uses observed effects at very high doses and extrapolates the risk through the zero point on the graph.
   - The most studied group of individuals with high radiation exposure are the atomic bomb survivors, who have been extensively researched since 1945.

EO: 1.33 Explain Why Radiation Exposures to Both Individuals and Groups of Workers Should be Kept ALARA

1. **Main Idea**
   - ALARA stands for "As Low As Reasonably Achievable"
   - In the context of occupational radiation exposure, ALARA does not imply reducing exposures to the minimum, but rather optimizing them.

2. **Optimization of Exposure**
   - Exposure optimization takes into account the benefits arising from the activity, the detriments arising from resultant radiation exposure, and the controls that need to be implemented.

3. **Effective ALARA Process**
   - An effective ALARA process involves planning, consideration, and implementation of both physical design features and administrative controls.
   - Engineering controls and administrative measures are balanced against the benefits and risks of authorized activities.

4. **Learning and Improvement**
   - Lessons learned are documented, institutionalized, and considered for planning and execution of subsequent activities.
   - This iterative learning process further strengthens the ALARA approach and optimizes employee protection.

EO: 1.34 Explain the Risk to a Pregnant Worker and Fetus

1. **Main Idea**
   - Effects on the Embryo/Fetus are of paramount importance.

2. **Law of Bergonie and Tribondeau**
   - Embryos are the most radiosensitive, followed by fetuses, then children, and lastly adults.

3. **Radiation Doses and Impact**
   - Doses may cause death or abnormalities.
   - Most critical period for organ formation is between 2 to 6 weeks of gestation.
   - Doses as low as 25 rad (0.25 gray) may result in defects.
   - Effects range from blindness and cataracts to mental and physical subnormality.
   - An exposure between 400 - 600 rad during the first trimester can lead to fetal death.

4. **Observations from Hiroshima and Nagasaki**

- Effects included smaller head size, lower birth weight, and mental retardation among children exposed in utero.

5. **Sensitivity of the Fetus**
    - Fetal cells are rapidly dividing and thus sensitive to environmental factors like ionizing radiation.
    - Most susceptible period for adverse effects is 8 - 15 weeks after conception.

6. **Other Factors Impacting Prenatal Exposure**
    - Many factors such as radiation, alcohol, lead, and heat can adversely affect a fetus, especially early in pregnancy.

EO: 1.35 Explain the Purpose of Radiation Protection Limits in Regard to Risk and Effect Minimization

1. **Main Idea**
    - Radiation Protection (RP) limits set by the NRC are meant to define an acceptable level of risk.
    - Limits aim to restrict both stochastic and non-stochastic effects.
    - Key limits include ALI, TODE, and VHRA, which can cause immediate radiation exposure effects.

2. **10 CFR 20, Paragraph 20.1(c)**
    - Emphasizes the ALARA (As Low As Reasonably Achievable) principle for maintaining doses and managing radioactive releases.
    - ALARA takes into account state of technology and economic considerations, among other factors.

3. **Regulatory Guide 8.8**
    - Highlights the importance of an ALARA program and outlines the following for effective implementation:
        1. Establishment of a program to maintain exposures ALARA.
        2. Consideration of exposure impacts in facility design and equipment selection.
        3. Development of a radiation control program with plans and procedures.
        4. Provision of supporting equipment and facilities.

4. **Key to ALARA is Reasonableness**
    - Discusses the cost-benefit analysis in terms of exposure savings.
    - Companies may base their cost calculations on insurance rates, which could be around $20,000 per collective rem depending on the station's INPO collective radiation exposure (CRE).
    - Cost-effectiveness is assessed through quantification. For example, a $60,000 shielding that saves 1 REM CRE is not justifiable, but if it saves 4 REM, it is.

EO: 1.36 Describe the Principles of Operation and Characteristics of the Types of Dosimetry Used at a Plant

1. **Main Idea**
    - The types of legal dosimeters typically found in nuclear power plants are Thermoluminescent Dosimeters (TLD) and Optically Stimulated Luminescent Dosimeters (OSLD).
    - Both types store energy from radiation in a crystalline material and emit visible light during processing.
    - The major difference between them is the method of luminescence: TLD requires heat, while OSLD uses visible light.

2. **OSL Principles of Operation**
    - Uses aluminum oxide crystal detectors or OSL material.
    - Traps electrons excited by ionizing radiation in imperfections within the crystal. They are released when stimulated by light.
    - Readout involves using green light to stimulate the detectors, and the emitted blue light is measured by a photomultiplier tube.
    - Light intensity released is directly proportional to incident radiation and is used for dose calculation.

3. **Advantages of OSLDs**
    - Faster and more accurate readings.
    - Allows for multiple readings, unlike TLDs that can only be read once.

- Less prone to "fading" compared to TLDs.

4. **Secondary Dosimeters**
    - Electronic personnel dosimeters are also used for secondary measurements.
    - Can read both dose and dose rates for various types of radiation.
    - Susceptible to electronic interference, such as during welding operations.

5. **Typical Ranges of Electronic Dosimeters**
    - Dose: $0 - 1000\,\mathrm{rem}$
    - Dose rate: $0 - 2000\,\mathrm{rem/hr}$

EO: 1.37 Describe the Dosimetry Used at a Plant to Determine Doses from Various Types of Radiation

1. **Main Idea: Types of Dosimetry**
    - Physical changes in some solid substances due to irradiation serve as energy storage and allow their use as dosimeters.
    - Studied features include:
        - Optical density changes in plastics and glass with dose ranges from 10^3 to 10^6 rads (10 to 10^4 gray) for glass and 10^6 to 10^9 rads (10^4 to 10^7 gray) for plastics.
        - Thermoluminescence (TL), further categorized into fluorescence and phosphorescence.

2. **TLD Operation**
    - Utilizes phosphorescence for radiation detection.
    - Explains the physics of electron energy states and their roles in luminescence.
    - Electron trapping and energy storage mechanisms.

3. **TLD Reader**
    - Basic principles and components such as the heater, photomultiplier tube, and meter/recorder.
    - Glow curve characteristics and interpretation.

4. **Advantages and Disadvantages of TLDs**
    - Advantages include wider dose range, on-site readout, quicker turnaround, and reusability.
    - Disadvantages include single readout and zeroing during the readout process.

5. **Pocket and Electronic Dosimeters**
    - Provide real-time dose indications and guidelines for their issuance and usage.
    - Worn location, readout thresholds, and actions to take when dose or dose rate exceeds expected levels.

6. **Site Self-Reading Dosimeters**
    - Self-Reading Pocket Dosimeters (SRPD) and their operation principles.
    - Components include a direct reading ion chamber, fiber electrometer, and metal frame.
    - The movement of the fiber is proportional to the dose received.

EO: 1.38 Explain the use of effective dose equivalent monitoring, including weighting factors and limitations in the process

Main Idea

From Reg Guide 8.4, METHODS FOR MEASURING EFFECTIVE DOSE EQUIVALENT FROM EXTERNAL EXPOSURE:

1. For the purpose of implementing workplace controls, and because of the difference in dosimetry methods, 10 CFR Part 20 breaks the TEDE into two components:
    - Dose resulting from radioactive sources internal to the body
    - Dose resulting from radioactive sources external to the body
2. In 10 CFR Part 20, the NRC defines the EDE as $\mathrm{EDE} = \Sigma \mathrm{WTHT}$ where:
    - HT = dose equivalent to each organ or tissue

- WT = weighting factors applicable to each of the body organs or tissues that are irradiated

Uniform and Non-uniform Exposures

1. In most relatively uniform exposure situations, a single dosimeter provides a reasonable measurement of the EDEX.
2. If the body is not irradiated uniformly, a single-dose measurement cannot determine an accurate EDEX.
3. To ensure a conservative TEDE determination, 10 CFR 20.1201(c) requires the use of DDE measured at the highest exposed part of the body unless an NRC-approved dosimetry method is used.

Methods to Determine EDEX

Several methods have been developed to determine EDEX from dose measurements on the surface of the whole body. These methods generally involve:

- Measurement of the DDE at one or more locations on the whole body.
- The use of weighting factors for each dosimeter result.
- The application of algorithms to provide a less conservative EDEX determination.

Care must be exercised to ensure each method is used within its limitations.

Non-TEDE Dose Limits

Licensees may still need to measure doses at specific body locations to comply with non-TEDE dose limits. Therefore, using the methods described may not lead to a reduction in monitoring requirements but may provide a more accurate determination of EDEX.

Multiple Dosimetry with Compartment Factors

ANSI/HPS N13.41-1997 provides a method for estimating EDEX using multiple dosimetry. This method divides the body into compartments and uses the formula:

$$\mathrm{EDEX} = \Sigma \mathrm{WC}\,\mathrm{DDEC}$$

Table 1. Compartment Factors

AREA OF THE BODY/COMPARTMENT	COMPARTMENT FACTOR (WC)
Head and neck	0.10
Thorax, above the diaphragm	0.38
Abdomen, including the pelvis	0.50
Upper right arm	0.005
Upper left arm	0.005
Right thigh	0.005
Left thigh	0.005

EO: 1.39 Explain actions to take in the event of abnormal situations

Main Idea:

A. **Determine the cause of the alarm**
   - When the SRD alarmed, where were you and what activities were you involved in?
   - What were the expected dose rates in the area?
   - Were you leaning against anything at the time of the alarm?
   - What activities were going on around you when your SRD alarmed?
   - What kinds of equipment were you using or were nearby?
   - Did you drop your dosimeter?
   - Were there any co-workers with you in the work area?
   - Did you compress your SRD against a hard surface?

B. **Determine if the alarm was due to a radiation or non-radiation event**
   1. For radiologically induced alarms consider:
      - Changes in plant configuration
      - Unknown radiological conditions
      - Working in wrong location
      - Body position
      - Wrong RWP / Task
   2. Obtain dose rate survey
   3. CR required for SRD dose or dose rate alarms
   4. Estimate worker's exposure
   5. Restrict RCA access

C. **Lost, Damaged, Suspect Dosimetry**
   1. If the individual's DLR(s) is lost, damaged, or requires processing, restrict the workers RCA access.
   2. Obtain the SRD histogram
   3. Initiate a CR
   4. Estimate worker's exposure
   5. Restrict RCA access

D. **Dosimetry analysis**
   1. If required, the worker's DLR will be processed.

E. **Anticipated SRD Dose Rate Alarms**
   - If an anticipated SRD Dose Alarm is authorized by an RP Leader:
      - Perform a Pre-Job briefing and Two Minute Drill to discuss expected alarms.
      - Insure the worker has available dose.
      - Provide continuous or remote surveillance
      - RP Log entries required

Personnel Exposure incidents that require notification to the NRC

These fall into three time-reporting categories that have caused or threaten to cause an individual to receive:

1. Immediate Notification Reports
   - Total Effective Dose Equivalent (TEDE) ≥ 25 rem
   - Eye Dose Equivalent (LDE) ≥ 75 Rem
   - Shallow Dose Equivalent (SDE) To The Skin Or Extremities ≥ 250 Rad

2. Twenty-Four Hour Notification Reports
   - Total Effective Dose Equivalent (TEDE) > 5 rem
   - Eye Dose Equivalent (LDE) > 15 Rem
   - Shallow Dose Equivalent (SDE) To The Skin Or Extremities > 50 Rem

3. Thirty-Day Notification Reports
   - Doses in excess of the occupational dose limits for adults in 10CFR20.1201
   - Doses in excess of any of the occupational dose limits for a minor in 10CFR20.1207
   - Doses in excess of any of the limits for an embryo/fetus of a declared pregnant woman in 10CFR20.1208
   - Doses in excess of any of the limits for an individual member of the public in 10CFR20.1301
   - Doses in excess of any applicable limit in the license

EO: 1.40 Define annual limit on intake, derived air concentration, weighting factors, and solubility class

Main Idea

The annual limit on intake (ALI) and derived air concentration (DAC) are measures defined in Federal Regulations, specifically 10CFR20, for protecting workers from radiation exposure. These measures also consider factors like weighting factors and solubility class for specific radionuclides.

1. **Annual Limit on Intake (ALI)**

Defined as the smaller value of intake of a given radionuclide in a year that would result in either:

- A committed effective dose equivalent (CEDE) of $5\,\mathrm{rems}$ $(0.05\,\mathrm{Sv})$
- A committed dose equivalent (CDE) of $50\,\mathrm{rems}$ $(0.5\,\mathrm{Sv})$ to any individual organ or tissue.

2. **Derived Air Concentration (DAC)**

   Defined as the concentration of a radionuclide in air which, when inhaled for a working year of 2,000 hours, results in an intake of one ALI. The dose rate equivalent of one DAC can be calculated as:

$$1\,\text{DAC-hr} = \frac{5\,\mathrm{rems}}{2000} = 2.5\,\mathrm{mrem}$$

3. **Weighting Factors**

   These are the proportions of risk of stochastic effects for specific organs when irradiated. For calculating the effective dose equivalent, $\mathrm{CEDE} = \mathrm{CDE} \times Wt$, where Wt is the weighting factor for the organ.

   - Gonads: $Wt = 0.25$
   - Breast: $Wt = 0.15$
   - Red bone marrow: $Wt = 0.12$
   - Lung: $Wt = 0.12$
   - Thyroid: $Wt = 0.03$
   - Bone surfaces: $Wt = 0.03$

4. **Solubility Class**

   Depending on the chemical nature of the radionuclide, different limits on ALI are provided in federal regulations, reflecting rates of removal from the body in days (D), weeks (W), and years (Y).

EO: 1.41 Explain how annual limit on intake, committed dose equivalent, committed effective dose equivalent, and the target organ relate to the appropriate derived air concentration

Main Idea

As described in the ALI definition, the resultant dose from an intake of $1\ \mathrm{ALI}$ for a given radionuclide could result in one of two outcomes which reaches an annual exposure limit.

1. If the limiting dose is to a specific target organ (for example, Strontium 90, shown below) the ALI value provided in regulations will cite the target organ (e.g. bone surface). Thus, an intake of $20\,\mu\mathrm{Ci}$, would result in a CDE dose of $50\,\mathrm{rem}$ to the bone surface.
2. If the limiting dose is to the whole body, the resulting dose would be $5\,\mathrm{rem}$, CEDE.

When the ALI is based on the CEDE, only one value is provided for each nuclide, as in the table shown below for Cesium-137. Note that in this case, an inhalation of $1\ \mathrm{ALI}\ (20\,\mu\mathrm{Ci})$ would result in a dose of $5\,\mathrm{rem}\ \mathrm{CEDE}$.

Atomic No.	Radionuclide Class	Table 1 Occupational Values	Table 2 Effluent Concentrations	Table 3 Releases to Sewers
55	Cesium-137 D, all compounds	ALI (µCi): 1×10^2 DAC (µCi/ml): 2×10^2	Water (µCi/ml): 6×10^{-8}	Monthly Average Concentration (µCi/ml): 2×10^{-10}

Strontium-90

Atomic No.	Radionuclide Class	Table 1 Occupational Values	Table 2 Effluent Concentrations	Table 3 Releases to Sewers
38	Strontium-90 D, see 80Sr	ALI (µCi): 3×10^1 Bone Surf DAC (µCi/ml): 2×10^1 Bone Surf	Water (µCi/ml): 8×10^{-9}	-

In each case, regardless of whether a radionulcide's ALI limit is based on a CDE or CEDE limiting exposure, the DAC provided in the Table 1 represents the airborne concentration that would yield the ALI to a worker if breathed at this concentration for 2000 hours.

EO: 1.42 Given 10CFR20 Appendix B, Locate derived air concentration values and calculate derived air concentration hours for practical situations involving exposure of individuals to airborne radioactivity

Main Idea

Derived Air Concentration (DAC): For the radionuclides listed in Appendix B of 10 CFR 20, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of $2400m^3$). The values are based on the U.S. Environmental Protection Agency's Federal Guidance Report No. 11.

Explanation of DAC

Excerpt from 10CFR20 Appendix B Table 1 "Occupational Values":

> The DAC values are derived to control chronic occupational exposures. The relationship between the DAC and ALI is given by:

$$\mathrm{DAC} = \frac{\mathrm{ALI\ (in\ }\mu\mathrm{Ci)}}{(2000\ \text{hours per working year}\ \times 60\ \text{minutes/hour}\ \times 2 \times 10^4\ \text{ml per minute})} = \left[\frac{\mathrm{ALI}}{2.4 \times 10^9}\right] \mu\mathrm{Ci/ml}$$

1. **1.40.1 Locate DAC values in 10CFR20 Appendix B.**

   10CFR20 Appendix B can be located on the Nuclear Regulatory Commission (NRC) website at NRC Website.

2. **1.40.2 Calculate DAC hours for practical situations involving exposure of individuals to airborne radioactivity.**

   Explanation of "Determination of internal exposure" 10CFR20 § 20.1204

   - Measurements of concentrations of radioactive materials in air in work areas.
   - Quantities of radionuclides in the body.
   - Quantities of radionuclides excreted from the body.
   - Combinations of these measurements.

How to calculate DAC hours

For example, locate Cobalt-60 in Appendix B Table 1 at NRC Website.

Activity: Calculate DAC hours for practical situations involving exposure of individuals to airborne radioactivity.

Sample calculation:

$$\text{Answer: } \frac{4.5 \times 10^{-9} \text{ microcuries/cc}}{1 \times 10^{-8} \text{ microcuries/cc}} = 0.45 \text{ fDAC}$$

$$\text{Formula: DAC-hr} = \text{fDAC} \times \text{exposure time in hours}$$

$$\text{DAC-hr} = 0.45 \text{ fDAC} \times 1.5 \text{ hours} = 0.675 \text{ DAC-hrs}$$

$$1 \text{ DAC-hr} = 2.5 \text{ mrem}$$

$$\text{Therefore, } 0.675 \text{ DAC-hrs} \times 2.5 \text{ mrem} = 1.69 \text{ mrem exposure from inhaling Cobalt-60.}$$

Compliance Formulas

ALIs and DACs

- Stochastic:

$$1 \text{ ALI} = 5 \text{ rem/year (CEDE) } = 2000 \text{ DAC-hrs}$$

$$1 \text{ DAC-hr} = 2.5 \text{ mrem}$$

- Non-Stochastic:

$$1 \text{ ALI} = 50 \text{ rem/year (CDE) } = 2000 \text{ DAC-hrs}$$

$$1 \text{ DAC-hr} = 25 \text{ mrem}$$

EO: 1.43 Define biological half-life and effective half-life

Main Idea

Half-life (radiological) - The time required for half the atoms of a particular radioisotope to decay into another isotope. A specific half-life is a characteristic property of each radioisotope. Measured half-lives range from millionths of a second to billions of years, depending on the stability of the nucleus. Radiological half-life is related to, but different from, the biological half-life and the effective half-life.

Definitions

- **Radioactive half-life (T_R)** - the time it takes for one half of the radioactive material to decay.
- **Biological half-life (T_B)** - The time it takes for one half of the originally deposited radionuclide to be eliminated from the body due to the natural biological process.
- **Effective half-life (T_E)** - The time it takes for the activity of a radionuclide in the body to be one half of its original value as a result of the radioactive decay and the biological elimination.

Effective half-life formula

The formula for effective half-life is given by:

$$T_E = \frac{T_R \times T_B}{T_R + T_B}$$

NOTE

Uncertainties come from the complexities of human metabolic rates and the statistical anomalies.

EO: 1.44 Describe requirements for monitoring and reporting internal exposure

Main Idea

10CFR20 § 20.1502 Conditions requiring individual monitoring of…internal occupational dose.

Each licensee shall monitor exposures to radiation and radioactive material at levels sufficient to demonstrate compliance with the occupational dose limits of this part. As a minimum—

Monitoring Requirements

1. Each licensee shall monitor (see § 20.1204) the occupational intake of radioactive material by and assess the committed effective dose equivalent to—
   a. Adults likely to receive, in 1 year, an intake in excess of 10 percent of the applicable ALI(s) in table 1, Columns 1 and 2, of appendix B to §§ 20.1001-20.2402;
   b. Minors likely to receive, in 1 year, a committed effective dose equivalent in excess of 0.1 rem (1 mSv); and
   c. Declared pregnant women likely to receive, during the entire pregnancy, a committed effective dose equivalent in excess of 0.1 rem (1 mSv).

Additional Information

All of the occupational doses in § 20.1201 continue to be applicable to the declared pregnant worker as long as the embryo/fetus dose limit is not exceeded.

§ 20.2206 Reports of individual monitoring

This section applies to each person licensed by the Commission to--

1. Operate a nuclear reactor designed to produce electrical or heat energy pursuant to § 50.21(b) or § 50.22 of this chapter or a testing facility as defined in § 50.2 of this chapter; or
2. Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter; or
3. Possess or use at any one time, for purposes of fuel processing, fabricating, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium, or any combination thereof pursuant to part 70 of this chapter; or
4. Possess high-level radioactive waste at a geologic repository operations area pursuant to part 60 or 63 of this chapter; or
5. Possess spent fuel in an independent spent fuel storage installation (ISFSI) pursuant to part 72 of this chapter; or
6. Receive radioactive waste from other persons for disposal under part 61 of this chapter; or
7. Possess or use at any time, for processing or manufacturing for distribution pursuant to parts 30, 32, 33 or 35 of this chapter, byproduct material in quantities exceeding any one of the following quantities:

Radionuclide Quantities

- Cesium-137: 1 curie
- Cobalt-60: 1 curie
- Gold-198: 100 curies
- Iodine-131: 1 curie
- Iridium-192: 10 curies
- Krypton-85: 1,000 curies
- Promethium-147: 10 curies
- Technetium-99m: 1,000 curies

Additional Conditions and Reporting

(b) Each licensee in a category listed in paragraph (a) of this section shall submit an annual report of the results of individual monitoring carried out by the licensee for each individual for whom monitoring was required by § 20.1502 during that year.

(c) The licensee shall file the report required by § 20.2206(b), covering the preceding year, on or before April 30 of each year. The licensee shall submit the report to the REIRS Project Manager by an appropriate method listed in § 20.1007 or via the REIRS Web site at http://www.reirs.com.

EO: 1.45 State the purpose of having plant administrative limits for radiation exposure

Main Idea

Title 10, Part 20, of the Code of Federal Regulations, 10CFR20, "Standards for Protection Against Radiation," establishes the dose limits for radiation workers.

Federal Legal Limits

The dose limits established by 10CFR20 are the federal legal limits for exposure that a licensee can permit a worker to be exposed to. If federal limits are not maintained, several possible consequences can occur:

- Increased risk of adverse health effects
- NRC fines of the plant
- Disciplinary actions for willful violations
- Increased regulatory oversight by the NRC

Administrative Limits

Administrative limits for exposure to ionizing radiation are set by licensees to achieve specific objectives:

1. To minimize the risk of challenging the legal dose limits set in 10CFR20.
2. As a method to limit exposures to workers at licensee facilities.

Role of Workers, Supervisors, and Managers

All workers, supervisors, and managers working in commercial nuclear power must work to reduce and control radiation exposure. Administrative limits are a tool that facilitate exposure controls.

EO: 1.46 Explain the differences between general area dose rate and contact dose rate and how each is used in controlling exposures

Main Idea

A major task for RP technicians is to perform surveys to ensure that an area's radiological conditions are understood and comprehensively represented to brief workers (extracted from INPO 05-008, Rev 03). Both general area and contact dose rates are documented during the performance of these surveys.

General Area Dose Rates

General area dose rates are established by conducting a *'General Area Survey'*, which is defined as a dose rate survey performed in the general area at least 30 cm from the radiation source or from any surface that radiation penetrates (extracted from NISP-RP-013, rev 00).

- Important for establishing stay times for personnel entering the area.
- Used for deriving estimates of whole body exposures that will aid job planning and establishment of exposure controls.

Contact Dose Rates

Contact dose rates are dose rate measurements taken by placing the radiation detector housing on the surface being measured (extracted from NISP-RP-013, rev 00).

- Important for establishing expected rates of exposure to the extremities.
- When specific work requires having extremities in contact with components that have a measurable dose rate, contact dose rates inform the determination to use extremity dosimetry.
- Can require component decontamination as a result of documenting these rates.

EO: 1.47 Describe dose reduction techniques that can be used by technicians to reduce workers' radiation exposures.

Main Idea

“Dose reduction techniques such as effective engineering controls, including shielding, robots, long-handled tools and remote monitoring, and other techniques, are used to limit worker dose” (extracted from INPO 05-008, Rev 03).

Types of Dose Reduction Techniques

- **Temporary Shielding**
  - Uses radiation-attenuating materials like vinyl-encased lead or tungsten.
  - Installed temporarily for specific durations to support plant work activities.
  - Removed at the completion of the work activity.
  - Load capacities and calculations are considered to ensure equipment is not overloaded.
- **Long-handled Tools**
  - Simple hand tools or purpose-built devices.
  - Allows workers to handle components or complete tasks from a distance.
- **Robotics**
  - Used in areas of high dose rates for various tasks.
  - Must have a backup plan for potential failures.
- **Remote Monitoring**
  - Uses cameras, telemetry, and communications.
  - Allows technicians to guide workers to re-position themselves to reduce exposure.
- **Other Techniques**
  - Remove the source material.
  - Move the work to a lower dose area.
  - Flushing of piping/components.
  - Decontamination to remove source term.
  - Use of HEPA ventilation for airborne radioactivity control.
  - Transit planning to avoid elevated dose areas.

EO: 1.48 Describe the effects from stellite being present in reactor coolant.

Main Idea

Stellite is a trademarked name for a variety of chromium and cobalt alloys designed for wear resistance. In the nuclear power industry, its use has been a significant contributor to personnel radiation exposure due to the transformation of Cobalt-59 into Cobalt-60.

Characteristics of Stellite

- Trademarked name for alloys of chromium and cobalt.
- Formulated for wear resistance.
- Corrosion-resistant, non-magnetic, and can be designed to resist hardening or have extreme wear resistance.
- Used for components subject to repetitive metal-to-metal contact.

Applications in the Nuclear Power Industry

- Originally used for:
  - Valve seats
  - Pump seals
  - Roller bearings on control rods
  - Leading edges of turbine blades
- Contributes to personnel exposure due to Cobalt-59 in the alloy.

Activation Process

1. Cobalt-59 atoms in Stellite are subjected to neutron flux in the reactor core.
2. Cobalt-59 absorbs a neutron and becomes activated.
3. Transforms into Cobalt-60, a long-lived radioactive isotope.

Effects on Reactor Coolant

- Increased levels of Cobalt-60 in the coolant.
- Higher levels of loose contamination in the primary system.
- Increased nuclear worker exposures.

Industry Response

The industry has initiated a long-term process of replacing Stellite in reactor-related systems and cleaning up system piping and components to remove existing Cobalt-60.

EO: 1.49 Explain the difference between loose and fixed contamination

Main Idea

Contamination is defined as the presence of radioactive material in places where it is not wanted, such as work areas. The contamination can be categorized into fixed and loose types.

Types of Contamination

- **Fixed Contamination** - Radioactive contamination that is not easily transferred to other personnel or equipment through normal contact.

- **Loose Contamination** - Radioactive contamination that is easily transferred to other personnel or equipment through normal contact.

Measuring Removable Contamination

Removable contamination is assessed via a transfer test using suitable sampling materials. Common methods include:

- Standard paper disk smear
- Cloth smear

The standard technique involves wiping approximately $100\,\mathrm{cm}^2$ of the surface with moderate pressure. A 16 square-inch "S" shape is often used to ensure a $100\,\mathrm{cm}^2$ sample.

Qualitative, large area wipe surveys may also be done using Masslin cloth or Kimwipe when exact levels are not necessary.

Measuring Fixed Contamination

Fixed contamination is evaluated using a direct survey technique, commonly referred to as "frisking," which measures both fixed and removable contamination. To determine the level of fixed contamination, the removable level must be subtracted from the total.

EO: 1.50 Discuss the reason for having lower limits for alpha contamination

Main Idea

The presence of Alpha contamination represents a significant risk for internal exposure if proper monitoring and controls are not in place. This is largely because Alpha radiation has a higher Relative Biological Effectiveness (RBE) than other types of radiation, making it more biologically damaging.

Biological Effect of Internal Alpha Exposure

- **RBE (Relative Biological Effectiveness)** - Alpha radiation has a higher RBE than Beta or Gamma radiation, making it more biologically harmful. RBE is a measure that quantifies the ability of radiation to cause biological effects like cancer or cell death. The RBE for Alpha radiation is set at 20, compared to 10 for Neutron and 1 for Beta-Gamma.
- **High LET (Linear Energy Transfer)** - The high LET of Alpha radiation means that it deposits more energy into the tissues it interacts with, causing greater damage.

Impact of Alpha Contamination on Internal Organs

Once an Alpha particle enters the body, it is surrounded by living tissue and has a limited range of motion. This leads to high levels of ionization in the localized area, resulting in significant tissue damage. Factors affecting this include:

- **High Specific Ionization** - The Alpha particles can severely affect delicate internal organs, as they release all their energy in a localized area.
- **Density of Energy Deposition** - The denser the energy deposition in the organ tissue, the more damage it will sustain. This means that cells can be mutated or killed outright by Alpha particles.

Due to these reasons, having lower limits for Alpha contamination is crucial for minimizing the biological damage that can occur from internal exposure.

EO: 1.51 Define cross-contamination, and describe how it can result in the uncontrolled spread of contamination

Main Idea

Cross-contamination is defined as the uncontrolled spreading of radioactive contamination among people, places, or things. The nature of the contamination—whether it's fixed or loose—depends on various factors, and its spread can have serious consequences.

Cross-Contamination Defined

The term refers to the uncontrolled spreading of radioactive contamination on or into people, places, or things.

Types of Contamination

Generally, contamination is categorized as either:

1. Fixed Contamination
2. Loose Contamination (also described as smearable, spreadable, movable, etc.)

Factors Determining the Type of Contamination

Several factors can influence whether contamination is fixed or loose:

1. Porosity of contaminated surface
2. Physical form of contaminant
3. Chemical bonding
4. Electrostatic forces
5. Ambient air conditions

Fixed Contamination

This is radioactive material that is either not removable from a surface or is absorbed into the surface. The degree to which a contaminant is fixed can vary, from being so strongly bonded that it requires surface abrasion for removal, to being easily transported by slight air currents.

Leaching

Leaching is an observed phenomenon where the level of contamination can increase hours or days after decontamination. This usually occurs due to the physical migration of the radioactive material from the pores of the item to its surface.

Loose Surface Contamination

This occurs when radioactive material is deposited in an undesirable location. Various processes can produce loose contamination, such as grinding, peeling of contaminated paint, scaling, or drying of contaminated components.

Cross Contamination Mechanisms

After the initial contamination, it may be transported or spread through several means:

- Contaminated dust becoming airborne and carried by ventilation systems
- Improper decontamination techniques or work habits
- Transfer to personnel clothing and skin
- Releasing of contaminated equipment to uncontaminated areas

EO: 1.52 Identify potential sources of radioactive contamination, including work operations that can generate contamination

Main Idea

Radioactive contamination can originate from a variety of sources including equipment failures, human errors, and maintenance operations. Each of these can lead to the release of airborne or liquid radioactivity into the surrounding environment.

Sources of Contamination

Contamination primarily stems from:

1. Equipment Failures
2. Human Errors
3. Maintenance Operations

Equipment Failures

Systems containing radioactive substances like liquids, solids, or gases can develop leaks, often found at:

- Pipe flanges
- Sealing surfaces (e.g., pump seals, manways, handholes)
- Valve packing

Additionally, sealed sources used for equipment calibrations can also develop leaks.

Human Errors

Errors can occur when personnel perform tasks either remotely or hands-on. Common human errors include:

- Improper system valve lineup
- Overfilling of tanks
- Over-pressurization of equipment/systems
- Improper use of equipment/tools
- Improper identification of systems/components to be opened (aka breached)
- Improper handling of radioactive materials

Maintenance Operations

Maintenance activities can produce contamination, particularly when opening systems and components that contain airborne or liquid radioactivity. Such activities may involve:

- Grinding
- Welding
- Cutting contaminated components

EO: 1.53 Explain the characteristic difference between particulate, iodine, tritium, and noble gases and how they affect the method of detecting and controlling airborne radioactivity

Main Idea

The different types of airborne radioactivity—Noble Gases, Particulates, Iodines, and Tritium—are sampled using various methods. Noble Gas sampling involves the use of a specific volume container, while the others use capture methods. A known volume of air is processed through different types of media to determine a concentration per unit volume.

Methods for Sampling Different Types of Airborne Radioactivity

1. **Noble Gas Sampling**: Evacuation of a known volume container

2. **Particulates**: Known volume of air pulled through filter media

3. **Iodines**: Known volume of air pulled through filter media

4. **Tritium**: Known volume of air aspirated through demineralized water for collection

EO: 1.54 Explain the purpose of radiation work permits (RWPs), the typical requirements for their use, the difference between general and job-specific RWPs and when each of them is used.

Main Idea

Radiological Work Permits (RWPs) are administrative controls used to identify radiological conditions, establish worker protection measures, and lay out specific approvals for radiological work. They serve to inform workers of radiological conditions and requirements, thus linking worker exposure to specific tasks.

Use of Radiological Work Permits

Facilities generally employ two types of RWPs: General and Job-specific.

1. **When RWPs should be used:**
    - Entry into radiological areas
    - Handling of materials with removable contamination exceeding industry limits
    - Work in localized benchtop areas, fume hoods, sample sinks, and containment devices with potential for contamination
    - Disturbing soil in contaminated areas
    - Digging in areas with underground radioactive material

2. **Radiological Surveys:** The adequacy of RWP requirements should be routinely reviewed, and RWPs should be updated if conditions change such that protective measures need modification.

3. **Accessibility:** RWPs should be posted at the access points to relevant radiological areas or otherwise be made available at the work location.

4. **Acknowledgement:** Workers should acknowledge, either by signature or through electronic means, that they have read, understood, and will comply with the RWP. This should be done before initial entry and after any RWP revisions.

5. **Dosimeter Readings:** Worker dosimeter readings should be recorded and linked to the applicable RWP.

An alternative formal mechanism, like written procedures or experiment authorizations, may replace an RWP as long as it meets industry standards.

Job-Specific RWP vs. General RWP

1. **Job-Specific RWPs:** These are for non-routine operations or areas with changing radiological conditions and are in effect only for the duration of the specific job.

2. **General RWPs:** These are for routine activities like tours and inspections, or minor work in stable radiological areas. They should not be approved for periods longer than one year.

EO: 1.55 Identify the information that should be included on RWPs

Main Idea

1. **Information to Include on the RWP:**
    - Description of work
    - Work area radiological conditions
    - Dosimetry requirements
    - Pre-job briefing requirements, as applicable
    - Training requirements for entry
    - Protective clothing and respiratory protection requirements
    - Radiological Control coverage requirements and stay time controls, as applicable
    - Limiting radiological conditions that may void the RWP
    - Special dose or contamination reduction considerations
    - Special personnel frisking considerations
    - Technical work document number, as applicable
    - Unique identifying number
    - Date of issue and expiration
    - Authorizing signatures

2. **Integration with Other Work Authorizations:** The RWP should be coordinated with other work authorizations that address safety and health concerns, such as those for industrial safety, hygiene, welding, or confined space entry.

3. **Accounting and Tracking:** If necessary, the RWP number should be used alongside the radiation dose accounting system to associate individual or collective radiation doses with specific activities.

EO: 1.56 Explain the purpose of having each worker read and log in on the RWP and the administrative process of logging in on an RWP

Main Idea

The Radiation Work Permit (RWP) serves as an acknowledgement by the worker that they have read, understand, and will comply with the radiological requirements for the task they are about to perform. The signing process for an RWP may either be electronic, using a computer system, or manual, on paper. By signing, the worker acknowledges that they understand the radiological conditions and will abide by the limitations set forth in the RWP.

- **Generation of Permits:** These permits are typically generated by the Radiation Protection department.

- **Role of Radiation Protection Technician:** Given that these permits are generated by the Radiation Protection department, the Radiation Protection Technician is often viewed as the expert and may be asked questions related to a worker's specific job.

EO: 1.57 Describe the purpose and use of single and multiple step-off pads in controlling the spread of contamination

Main Idea

Step-off Pad Purpose and Use: The use of step-off pads (SOP) is a proven method for controlling contamination. They serve as:

1. A boundary of the contaminated area.
2. The access point to the contaminated area.
3. A double SOP is used for Highly Contaminated Areas and Discrete Radioactive Particle Zones/Areas.

Location and Cleanliness

Step-off pads are located at access points adjacent to the contaminated area boundary and are considered radiologically clean. They are often found in low dose waiting areas. In high contamination areas, a double step-off pad may be used for additional safety.

Use During Refueling Outages

For example, during refueling outages, there might be a step-off pad for individuals leaving the cavity and another one just outside the upper cavity area, which is a lower contamination zone.

Safety Considerations

Step-off pads should not be situated in areas where they may create a safety hazard, such as in stairwells or elevators.

SOP Removal Process for using a Single Step-off Pad

1. **While in contaminated area:** Remove protective clothing except inner booties and cotton glove liners. Discard into appropriate containers.

2. **When stepping onto Step-off Pad:**
   a. With back towards the SOP, remove one bootie and place foot on step-off pad. Repeat for the other bootie.
   b. Discard shoe covers in appropriate container.

3. **While in Clean Area:**
   a. Pick up dosimetry/hard hat and proceed to the nearest frisking station.
   b. Monitor yourself, cotton liners, and dosimetry for contamination.
   c. Remove cotton glove liners and place them in the appropriate container.

SOP Removal Process for using a Double Step-off Pad

1. **In Highly Contaminated Area:** Remove all outer protective clothing except shoe covers. Discard clothing/trash in appropriate receptacle.

2. **Stepping onto first (inner) Step-off Pad:** Remove outer shoe cover using the same procedure as discussed for a single Step-off Pad. Discard in appropriate receptacle.

3. **In Lower Contaminated Area:** Remove protective clothing except inner shoe covers and inner gloves. Discard in appropriate receptacles.

4. **Stepping onto second (outer) Step-off Pad:** Follow steps as outlined for a single Step-off Pad.

Special Consideration for DRP Areas

In Discrete Radioactive Particle (DRP) Areas, a tacky step-off pad should be used at the exit.

EO: 1.59 Identify the isotopes of primary concern for airborne radioactivity at a plant

Main Idea

Information about specific isotopes of concern for airborne radioactivity can be found in the following sources:

- Information about AM-241
- Information about I-131
- General information about isotopes of concern for airborne radioactivity at nuclear power plants

Additional information on Radon can also be included in the lesson material, as obtained from the NRC website.

Origin of Radioactivity in Nuclear Power Plants

Nuclear power reactors are fueled with uranium that is slightly enriched in the isotope Uranium-235. This isotope is capable of sustaining a controlled nuclear chain reaction necessary for the production of electrical energy. This results in the production of neutrons that induce radioactivity in the fuel, cooling water, and structure components of the reactor.

Induction of Radioactivity

Radioactivity is induced primarily through processes involving the capture of neutrons by uranium atoms in the fuel. Fission occurs when the nucleus of a Uranium-235 atom (less common Uranium-238) captures a neutron, becomes unstable, and splits into two or three lighter nuclei. These are referred to as fission products.

Common Fission Products

The most common fission products are Strontium-90 and Cesium-137. Noble gases like Krypton-85 and Xenon-133 can also be produced from fission products. Halogens such as Iodine-131 and Tritium can also be created from ternary fission of uranium atoms.

Additional Context

The information below might be better included into the sources discussing isotopes of concern at nuclear power plants. This material shows where and how each isotope is produced and may be appropriate for the radioactivity portion of the lesson material.

EO: 1.60 Relate major isotopes expected to be present in the event of fuel damage and the types of surveys used to assess their radiological hazards

Main Idea

General Information and Rad Issues

- One hour after shutdown, the core inventory is 397.42 million Curies of noble gases.
- In the first two weeks after shutdown, short-lived noble gases inside the spent fuel are the significant nuclides.
- The skin dose from Kr85 is approximately 100 times the whole body.

Readings from sealed GM-tube Area Radiation Monitors (ARMs) will not accurately reflect the skin dose hazard posed by Kr85 released during a fuel-handling incident.

Two Basic Scenarios for Fuel Handling Incident:

1. One or more bundles drop into the fuel pool or reactor cavity areas and breaks open.
    - This releases the gaseous contents within the fuel rods into the refuel water.

    - Affected ARMs may or may not alarm because of the high ratio of beta emitters to gamma emitters in the released gasses.
    - Personnel may be subsequently exposed to noble gas and iodine vapor activity.
    - This yields immersion dose from the noble gas and thyroid dose from the iodine.
2. A bundle is inadvertently removed from the water or is brought too near the surface of the water.
    - In either case ARMs will alarm.
    - Personnel may be exposed to very high levels of radiation emitted from the irradiated bundle.

In each case, the MCR will initiate procedures that will evacuate the affected area and direct initial response.

Relate Major Isotopes Expected to be Present in the Event of Fuel Damage and Types of Surveys Used to Assess their Radiological Hazards

Reactor accidents can release a variety of radioisotopes into the environment. An irradiated fuel rod that breaks out of the water will show radioactive gases of $\mathrm{Kr\text{-}85}$ and $\mathrm{Xe\text{-}133}$ along with $\mathrm{I\text{-}131}$.

- **Spill/Spread of contamination:** Primary isotopes are $\mathrm{Co58}$, $\mathrm{Co60}$, and $\mathrm{Cs137}$.
    - $\mathrm{Mn54}$ and $\mathrm{Fe59}$ may be present.

- **Steam leaks:**
    - Noble gases (Xenon, Krypton)
    - Iodines for internal exposure (predominately $\mathrm{I131}$)

EO: 1.61 Identify and explain the techniques for reducing the volume of radioactive solid waste generated

Main Idea

Radioactive Waste Minimization

One of the potential consequences of working with radioactive materials is the generation of radioactive waste. This radioactive waste needs to be properly disposed of.

Examples of radioactive waste include:

- Paper
- Gloves
- Glassware
- Rags
- Brooms, mops

The ALARA (As Low As Reasonably Achievable) concept also applies to minimizing radioactive waste. This will reduce personnel exposure associated with the handling, packaging, storing, and disposing of radioactive waste. It will also reduce the resultant costs. It is very important for each radiological worker to minimize the amount of radioactive waste generated.

Methods to Minimize Radioactive Waste

The following information identifies methods to minimize radioactive waste:

1. Minimize the materials used for radiological work.
    - Take only the tools and materials you need for the job into areas controlled for radiological purposes. This is especially important for contamination areas.
    - Unpack equipment and tools in a clean area. This will help to avoid bringing unnecessary material to the job site. This material can become radioactive waste if it is contaminated.
    - Use tools and equipment that are identified for radiological work when possible, such as a hot tool room.
2. Use only the materials required to clean the area. An excessive amount of bags, rags, and solvent adds to radioactive waste.
3. Sleeve, or otherwise protect with a covering such as plastic, clean materials brought into contaminated areas.
4. Separate radioactive waste from nonradioactive waste.
    - Place radioactive waste in the containers identified for radioactive waste. Do not place radioactive waste in nonradioactive waste containers.

    - Do not throw nonradioactive waste, or radioactive material that may be reused, into radioactive waste containers.
5. Separate compactable material from non-compactable material.
6. Minimize the amount of mixed waste generated. Mixed waste is waste that contains both radioactive and hazardous materials.
7. Use good housekeeping techniques.

EO: 1.62 Describe system components and configurations that can result in the accumulation of radioactivity

Main Idea

Valves are mechanical devices that control fluid flow and pressure within a system. They perform a range of functions and can have different designs. Understanding these valves is critical for the safe and effective operation of industrial systems, including those involving radioactivity.

Valve Components

1. Body (Shell)
    - Primary pressure boundary, resists fluid pressure.
    - Connects to inlet and outlet piping.
    - Shapes can be complex, accounting for ease of manufacture and assembly.
2. Bonnet
    - Secondary pressure boundary.
    - Functions can range from simple covers to supporting valve internals.
    - Potential source for leakage.
3. Trim
    - Internal elements like disk, seat, stem.
    - Affects the valve's performance and flow control.
4. Stem
    - Connects actuator and disk.
    - Positioning of the disk relies on the stem.
5. Actuator
    - Operates stem and disk assembly.
    - Can be manual or automatic (e.g., pneumatic, hydraulic).
6. Packing
    - Prevents leakage between stem and bonnet.
    - Proper compression needed to avoid leakage and stem damage.

Types of Valves

Various types of valves exist to meet the specific needs of different systems. Examples include globe valve, gate valve, ball valve, etc. Each type has its inherent advantages and disadvantages.

Flow Control Methods

There are generally four methods of controlling flow through a valve:

- Move a disc or plug into or against an orifice.
- Slide a flat, cylindrical, or spherical surface across an orifice.
- Rotate a disc or ellipse about a shaft extending across the diameter of an orifice.
- Move a flexible material into the flow passage.

Basic Parts of a Valve

- Packing: Material used to provide a tight seal
- Stem: Connects the actuator and disk
- Body: Outer casing of the valve
- Seat: Provides the sealing surface

Types of Valves

1. **Gate Valves**

   A gate valve is a linear motion valve used primarily to start or stop fluid flow. It is not suitable for regulating or throttling flow. When fully open, the disk is completely removed from the flow stream, resulting in virtually no flow resistance. When closed, the disk-to-seal ring contact surface exists for 360°, providing a good seal.

   - Flow rate changes unevenly with stem travel
   - Prone to vibration when partially open
   - More susceptible to seat and disk wear than globe valves
   - Repairs, such as lapping and grinding, are generally more difficult to accomplish

2. **Globe Valves**

   A globe valve is a linear motion valve used to start, stop, and regulate fluid flow. Its design allows for good throttling ability. When compared to gate valves, globe valves generally have much less seat leakage due to disk-to-seat ring contact at right angles.

   - High head loss from flow path obstructions
   - Heavy and large, requiring more operational power
   - Noisy in high-pressure applications

3. **Plug Valves**

   A plug valve is a rotational motion valve used to start or stop fluid flow. The disk is shaped like a plug and has a bored passage at a right angle to the longitudinal axis. When open, the passage aligns with the inlet and outlet ports; when closed, the solid part of the plug blocks flow.

   - Lubricated or non-lubricated designs available
   - Various styles of port openings and plug designs

Reducing Valves

Reducing valves automatically adjust supply pressure down to a preselected level. This is provided that the supply pressure is higher than or equal to this preselected level. Key components include:

- Main valve: an upward-seating valve with a piston on top of its valve stem
- Auxiliary (or controlling) valve: also an upward-seating valve
- Controlling diaphragm
- Adjusting spring and screw

Check Valves

Check valves are designed to prevent flow reversal in a piping system. They are activated by the material flowing through the pipeline.

- Opens under fluid pressure
- Closes under flow reversal
- Closure mechanisms: weight, back pressure, spring, or combinations

Types of Check Valves

1. **Swing Check Valves**

   Allows full, unobstructed flow and automatically closes as pressure decreases. Recommended for systems with gate valves due to low pressure drop.

   - Available in Y-pattern or straight body design
   - Seating is either metal-to-metal or metal-to-composition disk
   - Recommended for lines with low velocity flow
   - Not suitable for lines with pulsating flow

2. **Lift Check Valves**

   Commonly used in systems where globe valves are used for flow control. Suitable for horizontal or vertical lines with upward flow.

   - Available in horizontal, angle, and vertical body patterns
   - Flow must enter below the seat
   - Backflow and gravity force the disk or ball onto the seat

Relief and Safety Valves

Both valve types are designed to prevent over-pressurization of fluid systems, but they operate differently.

1. **Relief Valves**

   Gradually opens as the inlet pressure exceeds the setpoint. Used typically for incompressible fluids.

   - Opens only as much as necessary to relieve pressure

2. **Safety Valves**

   Rapidly pops open as soon as the pressure setting is reached and remains open until the pressure drops below a reset point. Typically used for compressible fluids.

   - Blowdown: The percentage difference between actuating and reset pressure
   - External lever for operational check

Pumps

Centrifugal pumps

Centrifugal pumps basically consist of a stationary pump casing and an impeller mounted on a rotating shaft. The pump casing provides a pressure boundary for the pump and contains channels to properly direct the suction and discharge flow.

- The pump casing has suction and discharge penetrations for the main flow path of the pump.
- Normally has small drain and vent fittings to remove gases trapped in the pump casing or to drain the pump casing for maintenance.

Types of Centrifugal Pumps

1. Single Volute Pumps
2. Double Volute Pumps: Also referred to as split volute pumps.

Diffuser

Some centrifugal pumps contain diffusers. A diffuser is a set of stationary vanes that surround the impeller. The purpose of the diffuser is to increase the efficiency of the centrifugal pump by allowing a more gradual expansion and less turbulent area for the liquid to reduce in velocity.

Centrifugal Pump Classification by Flow

1. Radial Flow Pumps: The liquid enters at the center of the impeller and is directed out along the impeller blades in a direction at right angles to the pump shaft.
2. Axial Flow Pumps: The impeller pushes the liquid in a direction parallel to the pump shaft.
3. Mixed Flow

Multi-Stage Centrifugal Pumps

A centrifugal pump with a single impeller that can develop a differential pressure of more than $150\ \mathrm{psid}$ between the suction and the discharge is difficult and costly to design and construct.

- A more economical approach is to include multiple impellers on a common shaft within the same pump casing.

- Internal channels in the pump casing route the discharge of one impeller to the suction of another impeller.

A pump stage is defined as that portion of a centrifugal pump consisting of one impeller and its associated components. Most centrifugal pumps are single-stage pumps, containing only one impeller. A pump containing seven impellers within a single casing would be referred to as a seven-stage pump or, generally, as a multi-stage pump.

Positive Displacement Pumps

A positive displacement pump is one in which a definite volume of liquid is delivered for each cycle of pump operation. This volume is constant regardless of the resistance to flow offered by the system the pump is in, as long as the power unit or component strength limits are not exceeded.

- Delivers liquid in separate volumes with no delivery in between.
- May have an overlapping delivery among individual chambers, which minimizes this effect.
- Differs from centrifugal pumps, which deliver a continuous flow.

Categories of Positive Displacement Pumps

1. Reciprocating Pumps
2. Rotary Pumps
3. Diaphragm Pumps

Principles of Operation

All positive displacement pumps operate on the same basic principle, most easily demonstrated by a reciprocating pump with a single piston in a cylinder, and a single suction and discharge port. Check valves in these ports allow flow in only one direction.

Reciprocating Pumps

Reciprocating pumps are generally categorized in four ways:

- Direct-Acting or Indirect-Acting
- Simplex or Duplex
- Single-Acting or Double-Acting
- Power Pumps

Direct-Acting and Indirect-Acting Pumps

Direct-acting pumps have a plunger directly driven by the pump rod. Indirect-acting pumps are driven via a beam or linkage connected to a separate reciprocating engine.

Simplex and Duplex Pumps

A simplex pump has a single liquid cylinder, while a duplex pump has two liquid cylinders placed side by side. The pistons of a duplex pump are arranged such that one is on its upstroke while the other is on its downstroke.

Single-Acting and Double-Acting Pumps

A single-acting pump fills the pump cylinder on the suction stroke and empties it on the discharge stroke. A double-acting pump fills one end of the cylinder while discharging from the other end, and vice versa.