d. It should be emphasized that the relative risk from one rem equivalent dose from neutrons is the same as the risk from one rem equivalent dose from gamma or any other radiation.

e. Use of equivalent dose units for recording personnel radiation exposure permits us to add exposures from various types of radiation and get a total equivalent dose which is proportional to the risk.

f. Table 9 provides a summary of these dosimetry units and their associated values.

See Table 9 - "Dosimetry Terminology Summary"

III. SUMMARY

A. Review major topics

1. Neutron to proton ratio
2. Radioactivity and radioactive decay
3. Radiation characteristics
4. Decay modes
5. Natural/artificial radioactivity
6. Fission product stability
7. Chart of the nuclides
8. Units of activity
9. Activity calculation
10. Measurement terminology

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

Course Title: **Radiological Control Technician**
Module Title: **Interaction of Radiation with Matter**
Module Number: **1.07**

Objectives:

1.07.01 Identify the definitions of the following terms:
- a. ionization
- b. excitation
- c. bremsstrahlung

1.07.02 Identify the definitions of the following terms:
- a. specific ionization
- b. linear energy transfer (LET)
- c. stopping power
- d. range
- e. W-value

1.07.03 Identify the two major mechanisms of energy transfer for alpha particulate radiation.

1.07.04 Identify the three major mechanisms of energy transfer for beta particulate radiation.

1.07.05 Identify the three major mechanisms by which gamma photon radiation interacts with matter.

1.07.06 Identify the four main categories of neutrons as they are classified by kinetic energy for interaction in tissue.

1.07.07 Identify three possible results of neutron capture for slow neutrons.

1.07.08 Identify elastic and inelastic scattering interactions for fast neutrons.

1.07.09 Identify the characteristics of materials best suited to shield:
- a. alpha
- b. beta
- c. gamma
- d. neutron radiations

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
2. ANL-88-26 (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.
3. "Health Physics and Radiological Health Handbook"; Shleien; 1992.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

V. MODULE INTRODUCTION

E. Self-Introduction

5. Name

6. Phone number

7. Background

8. Emergency procedure review

F. Motivation

The understanding of how radiation interacts with matter is fundamental when providing radiological protection. You as an RCT should be particularly interested in how radiation is absorbed by the body for three reasons.

1. Absorption in body tissues may result in physiological injury

2. Absorption is the principle upon which detection is based.

3. The degree of absorption and type of interaction is a primary factor in determining shielding requirements

G. Overview of Lesson

1. Definitions of terminology used in the lesson

2. Mechanisms of Energy transfer for each type of ionizing radiation

3. Shielding characteristics

4. Interactions of radiation with our bodies

H. Introduce Objectives — O.H.: Objectives

VI. MODULE OUTLINE

Objective 1.07.01

i. Transfer of Energy Mechanisms (absorption) for radiations include:

1. Ionization

See Fig. 1 - "Ionization"

   a. Any process which results in the removal of an electron (with negative one charge) from an electrically neutral atom or molecule

   b. Whenever this happens it creates an ion pair made up of the negative electron and the positive atom or molecule. Some examples of the energy required to produce one ion pair:

   He = 42.7 eV
   Ar = 26.4 eV
   N_2 = 36.5 eV
   Air = 33.9 eV

2. Excitation

See Fig. 2 - "Excitation"

   a. Transfer of energy to (absorption by) the electrons or nucleus of an atom or molecule. This energy is less than that required for ionization. The process raises an electron from one energy level to a higher energy level within the atom and the atom remains electrically neutral.

   b. It is also important to remember that all of the particles or ray produced by primary interactions lose their energy the same way, ionization and excitation, in secondary interactions.

3. Bremsstrahlung

   a. Bremsstrahlung is the radiative energy loss of moving charged particles as they interact with the matter through which they are moving.

   b. Bremsstrahlung radiation results from the interaction of a high speed particle near a heavy (high Z) atom. The particle is deflected from its course by the electrostatic force of the positively charged nucleus. The kinetic energy the electron loses is emitted as X-ray radiation.

The photon emitted is an X-ray because it originated outside the nucleus.

ii. Direct Ionizing Radiation

1. Charged particles do not require contact to interact because the "Coulomb force" (force from the charge) will act over a distance to cause ionization and excitation in the absorber medium. This force is dependent on:

   Objective 1.07.02
   See Table 1 - "Summary of Energy Loss Terms and Units"

   a. energy (speed) of particle

   b. charge of particle

   c. density and number of absorber

2. Interaction concepts

   a. Specific Ionization (S.I.)

      1) Number of ion pairs formed by a charged particle per unit path length (ion pairs/cm). This is dependent on the material type of ionizing particle and the material being ionized.

   b. Linear Energy Transfer (LET)

      1) Average energy locally deposited in an absorber by a charged particle per unit distance of travel (keV/cm)

   c. Stopping Power (S)

      1) Average energy lost by a charged particle per unit distance of travel (keV/cm)

   d. Range (R)

      1) Average depth of penetration of a charged particle into an absorber before it loses all of its kinetic energy and stops (cm)

      2) Inversely related to stopping power

         high range = low stopping power
         low range = high stopping power

e. W-value (W)

1) Average amount of energy needed to produce an ion pair in a given medium

(W)(S.I.) = S or (eV/ion pair)(ion pairs/cm) = eV/cm

2) Allows one to relate Specific Ionization to Range or Stopping Power

See Fig. 3 - "Ionization by an Alpha Particle"

3. Alpha Absorption

Objective 1.07.03

a. Large charge +2

b. Large mass 4 AMU's

c. Interactions

1) Ionization

2) Excitation

d. Interaction concepts

1) Spec. ionization - very high

2) LET ------------ very high

3) Stopping power - very high

4) Range----------- very low

4. Beta particles

Objective 1.07.04

a. Charge –

b. Mass 5.49 E-04 AMU

c. Interactions

1) Ionization

2) Excitation

3) Bremsstrahlung

See Fig. 4 - "Bremsstrahlung Radiation"

d. Interaction concepts

1) Specific ionization - high

2) LET-------------------high

3) Stopping power----- high

4) Range------------- low

iii. Indirect Ionizing Radiation

1. Indirect ionizing radiations, having no charge, do not readily interact with matter.

2. When they do, they may produce direct ionizing radiation particles (charged particles) which will produce many secondary ions

3. Probability of interaction is dependent on

a. Density and Z number of the absorber

b. Energy of the radiation

4. Photon Interactions — Objective 1.07.05

a. Photoelectric Effect — See Fig. 5 - "Photoelectric Effect"

1) The photon transfers all of its energy to an electron; ejecting the electron from the atom

2) The photon disappears

3) Almost always a "K" shell electron (inner shell - lowest energy level)

4) Generally low energy gamma (eV range)

b. Compton Scattering — See Fig. 6 - "Compton Scattering"

1) Photon transfers a part of its energy to an electron (binding energy + kinetic energy = beta particle + lesser energy photon)

2) 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

3) Any electrons except "K" shell (outer shells - higher energy levels)

4) Generally occurs with middle energy gamma (low MeV range)

5) Optional Note:

The mechanism of Compton Scattering was first fully explained in 1923 by physicist A. H. Compton. He correctly suggested that the photons could be thought of as carrying a bundle of energy like a billiard ball, and that the resulting angles and energies of the electron and residual photon could be computed using the classical laws of physics i.e. conservation of energy and momentum. This explanation was initially rejected by others because it was felt that photons and other forms of electromagnetic energy were really waves which could not exhibit particle-like properties. Compton received the Nobel Prize in physics in 1927 for this discovery.

c. Pair Production

See Fig. 7 - "Pair Production and Annihilation"

1) 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.

2) 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

3) What happens to the two particles?

   a) Ionization, excitation, and bremsstrahlung occurs for both particles. When the positron loses almost all of its energy, it will then be attracted to an electron and will annihilate releasing two photons of equal energy (511 keV each).

4) This process demonstrates Einstein's mass-energy relationship $E = mc^2$ works in both directions

d. Photon interaction review

1) photoelectric effect: low energy = eV range

2) compton scattering: med energy = Low MeV

3) pair production: very high energy = High MeV

4. Neutron Interactions

a. Classified by:

1) Kinetic energy of the neutron

Objective 1.07.06
See Table 2 - "Neutron Energy Categories"

   a) Thermal: (< 0.5 eV)

   b) Intermediate: (0.5 eV - 100 keV)

   c) Fast: (100 keV - 20 MeV)

   d) Relativistic: (> 20 MeV)

2) Z number of target

   a) Lower Z numbers absorb more energy per each interaction or collision

3) Absorption cross section of target

   a) Some elements absorb neutrons more readily than others i.e. cadmium, boron, and hafnium

b. Slow Neutron Interactions (Capture) — Objective 1.07.07

1) Radiative Capture: neutron is absorbed into nucleus and a gamma is emitted. This is also called gamma emission or neutron activation.

2) Charged Particle Emission: neutron is absorbed into nucleus and a charged particle is emitted

3) Fission: neutron is absorbed into nucleus then the nucleus splits into fission fragments.

c. Fast Neutron Interactions (Scatter)

1) Elastic Scattering: kinetic energy is the only form of energy involved. — Objective 1.07.08

See Fig. 8 - "Elastic Scattering"

2) Inelastic Scattering: some kinetic energy is changed to excitation energy of the nucleus which then emits a photon (gamma ray) to remove this excitation energy.

See Fig. 9 - "Inelastic Scattering"

d. Remember neutrons are not charged particles but neutron interactions do produce charged particles and photons, which will cause large amounts of secondary ionization and excitation

iv. Shielding

1. Equations

a. $I = I_o e^{-ux}$

b. $I = I_o (½^n$ = thickness divided by the Half Value Layer (HVL)

2. Cautions

a. In thick shielding you have to account for buildup factor which is due to the scattering of radiation in the absorber

b. "Sky Shine" is radiation reflected back to earth by the atmosphere.

c. Scattering can cause radiation to go around corners or edges of shielding

d. High beta dose rate shielded with high Z absorber may increase dose rate due to bremsstrahlung production

3. Typical shielding materials

   a. alpha paper

   b. beta low Z (rubber, aluminum, plastic)

   c. gamma lead, steel

   d. neutron low Z (Hydrogenous Materials)

      1) The use of materials with a high Hydrogen concentration will moderate (slow down) the neutron intensity.

      2) Lower energy neutrons are easily captured by materials with a high cross section for absorption. (Boron, Cadmium)

      3) When shielding for neutron radiation consideration must be given for gamma production from activation of shielding material and bremsstrahlung X rays.

III. SUMMARY

A. Review major topics

   1. Definitions of terminology used in the lesson.

   2. Mechanisms of Energy transfer for each type of ionizing radiation.

   3. Shielding characteristics

   4. Interactions of radiation with our bodies.

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

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Course Title: **Radiological Control Technician**
Module Title: **Biological Effects of Radiation**
Module Number: **1.08**

Objectives:

1.08.01 Identify the function of the following cell structures:
  a. Cell membrane
  b. Cytoplasm
  c. Mitochondria
  d. Lysosome
  e. Nucleus
  f. DNA
  g. Chromosomes

1.08.02 Identify effects of radiation on cell structures.

1.08.03 Define the law of Bergonie and Tribondeau.

1.08.04 Identify factors which affect the radiosensitivity of cells.

1.08.05 Given a list of types of cells, identify which are most or least radiosensitive.

1.08.06 Identify primary and secondary reactions on cells produced by ionizing radiation.

1.08.07 Identify the following definitions and give examples of each:
  a. Stochastic effect
  b. Deterministic effect

1.08.08 Identify the LD 50/30 value for humans.

1.08.09 Identify the possible somatic effects of chronic exposure to radiation.

1.08.10 Distinguish between the three types of the acute radiation syndrome, and identify the exposure levels and the symptoms associated with each.

1.08.11 Identify risks of radiation exposure to the developing embryo and fetus.

1.08.12 Distinguish between the terms "somatic" and "heritable" as they apply to biological effects.

References:

1. "Radiation Biology"; Casarett, Alison; Prentice-Hall, Inc.; 1968.
2. "A Catalog of Risks"; Cohen, Bernard; Health Physics, Volume 36, pg. 707-722; 1979.
3. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
4. "The Effects on Population of Exposure to Low Levels of Ionizing Radiation"; National Academy of Sciences; 1972.
5. "Ionizing Radiation Levels and Effects"; United Nations, Volume II - Effects; New York; 1972.
6. "Health Effects of Exposure to Low Levels of Ionizing Radiation"; Biological Effects of Ionizing Radiation (BEIR) Report V; National Research Council; 1990.
7. Health Impacts from Acute Radiation Exposure, Pacific Northwest National Laboratory, PNNL-14424, Dan Strom, September 2003.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned.

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

B. Motivation

The biological effects radiation has on the human body has led to current radiation control programs. An RCT must have some basic understanding of the methods in which radiation may cause biological damage to protect themselves and the workers from unnecessary exposure to ionizing radiation.

C. Overview of Lesson

1. Cellular structure and damage
2. Radiosensitivity
3. Stochastic/deterministic effects
4. Chronic effects
5. Acute effects
6. Embryological effects
7. Heritable effects

D. Introduce Objectives

O.H.: Objectives

II. MODULE OUTLINE

A. Cell Structure

See Fig. 1 – "Basic Cell Structure"

1. Basic unit of life

a. Made up of protoplasm

1) Carbohydrates

Objective 1.08.01

2) Lipids

3) Inorganic salts

4) Proteins

5) Nucleic acids

6) Gases

b. Consists of 70-80% water

c. Primary constituents:

1) Membrane

2) Cytoplasm

3) Nucleus

2. Cell Membrane

a. Encloses the cell

b. 100 angstroms thick

c. Regulates the concentration of water, salts, and organic matter

d. Capable of "active transport"

e. All waste products or secretions pass through the membrane

3. Cytoplasm

a. Jelly-like substance in which the nucleus is suspended

b. Aqueous solution of proteins and salts

4. Mitochondria

a. Power plant of the cell

b. Contains a special energy storing molecule called Adenosine Tri-Phosphate (ATP)

c. Supplies the energy for all cell activities.

5. Lysosome
   a. Contains digestive enzymes which break down large molecules
6. Cell Nucleus
   a. Directs all cell activity
   b. Contains all the genetic material

See Fig. 2 - "Double Helix"

7. DNA/Chromosomes
   a. DNA (deoxyribonucleic acid) - master blueprint
   b. When the cell divides chromatic coils form chromosomes
   c. The number of chromosomes is fixed for a given species (Humans - 46)
   d. Chromosomes contain several hundred genes which are responsible for traits

See Fig. 3 - "DNA Base Pairs"

B. Radiation Damage to Cell Constituents

Objective 1.08.0

1. Cell Membrane
   a. It takes about 3,000 - 5,000 rad (30 - 50 gray) to rupture
   b. Results in leakage of beneficial material and introduction of potentially harmful fluids
   c. At lower doses, radiation increases the permeability and some leakage occurs
2. Cytoplasm
   a. Negligible effect
3. Mitochondria
   a. A "few thousand" rad will disrupt the function
   b. Interrupts the storage of energy via Adenosine Tri-Phosphate (ATP).

c. If the cell has a large reserve of stored food, it can repair itself

d. The greater the dose, the greater the damage, the longer the repair time

e. If the repair time is too long and the food reserve fails, the cell dies from starvation

4. Lysosome

a. Ruptures between 500 and 1,000 rad (5 - 10 gray)

b. Digestive enzymes are released and begin to digest the rest of the cell

5. Nucleus

a. Difficult to affix a dose because the nucleus is the most radiosensitive part of the cell

b. Inhibits the ability of the cell to divide by affecting the DNA and RNA

c. Without normal DNA the cell cannot produce a duplicate set of chromosomes

d. The longer division is delayed the greater chance it will die; as the dose increases, the delay time lengthens

C. Radiosensitivity — Objective 1.08.03

1. The relative susceptibility of cells, tissues and organisms to the injurious action of radiation

2. Law of Bergonie and Tribondeau (1906):

a. "The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation"

3. Factors which affect a cells sensitivity to radiation — Objective 1.08.04

a. Cells are more sensitive if they have a high division rate.

b. The higher the metabolic rate in a cell, the lower its resistance to radiation

c. Cells tend to be more sensitive if they are non-specialized

d. Well nourished cells, or cells with a high level of oxygenation are more sensitive

4. Radiosensitive Tissues:

Note: They do not follow the four general rules

a. Germinal (reproductive) cells of the ovary and testis e.g., spermatogonia

b. Hematopoietic (bloodforming) tissues: red bone marrow, spleen, lymph nodes, thymus

c. Basal cells of the skin

d. Epithelium of the gastrointestinal tract (interstitial crypt cells)

5. Radioresistant Tissues:

A whole body exposure of 600-700 R will kill most animals; however, even higher doses have been delivered to the brain for cancer treatment.

a. Bone

b. Liver

c. Kidney

d. Cartilage

e. Muscle

f. Nervous tissue

6. Radiosensitivity not only differs from one cell or tissue to another but also between individuals and genders

D. Primary and Secondary Effects of Radiation

Objective 1.08.06

1. Primary Effect
   a. Ionization & Excitation of atoms making up the cell
   b. Produced when the primary (initial) interaction of radiation is with the target atoms in the cell such as those in the DNA
2. Secondary Effects
   a. Formation of free radicals which are very reactive and can chemically attack target molecules, such as DNA
   b. Occurs with the disassociation of water

      Water makes up 70 - 80% of the cell

      Three possible reactions:

      1) H interacting with H = H_2

      2) OH combining with H = H_20

      3) H_2 + OH = H_2O_2
   c. Formation of H_2O_2 (hydrogen peroxide) can lead to cell death. H_2O_2 is a harmful oxidizer which poisons the cell

E. Stochastic and Deterministic Effects

Objective 1.08.07

1. Stochastic Effects
   a. An effect in which the probability of the effect occurring increases with the dose.
   b. The effects have no established threshold, they can occur from the irradiation of only one cell; any exposure, however low, has some chance of causing the effect.
   c. Two examples of stochastic effects: cancer and genetic mutations.

2. Deterministic (Non-Stochastic) Effects
    a. Effects in which the severity of the effect increases as the dose increases
    b. It is generally assumed that a threshold exists; and if doses received are below the threshold dose, no effects will occur
    c. Effects typically result from the collective injury of many cells
    d. Effects include: cataracts, skin burns, lowering of blood cell counts, etc.

F. LD-50/30

Objective 1.08.08

1. Implies that 50% of a population will die within 30 days with NO medical treatment
2. LD-50/30 for humans is 300 - 500 rads (3 - 5 gray) in a short period of time, and is typically stated as 450 rad (4.5 gray)

Objective 1.08.09

G. Effects of Chronic Exposures to Ionizing Radiation

1. Chronic exposure
    a. Typically refers to smaller exposures over a long time period
    b. No unique disease associated with radiation exposure, but there is a statistical increase in the risk of developing disease
    c. Radium dial painters, early radiologists, atomic bomb survivors provide evidence of induced effects in humans

2. Cancer
    a. Radiation induced cancers are justification for today's protection standards
    b. Possibility of inducing tumors
    c. Radiation may cause cancer but also be used to treat cancer

Analogy: a knife can be use to heal (by a surgeon) or to inflict injury.

3. Cataracts

   a. A cataract is opacity of the lens of the eye

   b. A chronic exposure of 600 rad (6 gray) may produce a cataract for high LET radiation

   c. Generally symptoms will not appear for years after the exposure

   d. Effects may be cumulative

   e. Neutrons and gamma are primary hazards

   f. Exposures at younger ages increase susceptibility

4. Life Span (Shortening or Lengthening)

   a. Data is uncertain and firm conclusions are difficult to estimate.

   b. Aging is the progressive deterioration of tissues along with declining functional capacities

   c. Irradiated animals under lab conditions showed some cellular changes that can be associated with aging

   d. Low doses of 0.1 R/day or 100-400 R over a lifetime has indicated an increase in rat lifetime, and also a lower incidence of disease. This effect is known as Radiation Hormesis. No firm conclusions of this have been universally accepted.

H. Effects of Acute Radiation Exposures — Objective 1.08.10

Acute exposures are those exposures which involve relatively large doses of radiation received over a relatively short period of time.

1. Stages

   a. Prodromal

   b. Latent

   c. Illness

d. Recovery/death

2. Three syndromes

a. Hematopoietic Syndrome

1) Also called "Therapeutic Range" because treatment can play a large role

2) Dose level - Between 200 to 1,000 rads (2 -10 gray) - (Some blood changes can be seen at lower doses)

3) Critical organs are the blood forming organs

4) Affects the production of white blood cells - Leukopenia- decreased ability to fight infection

5) Lowered platelet count causes hemorrhaging and slowing of the healing process

6) Symptoms:

Nausea and vomiting

Epilation

7) Treatment - antibiotics to fight infection–bone marrow transplants to replace damaged cells, (uncertain if this works)

8) If death does occur it will be due to infection and hemorrhaging

b. Gastrointestinal Syndrome

1) Dose level - Between 1,000 - 5,000 rads (10 -50 gray)

2) Affects the GI tract

3) Stops the production of new epithelial cells which line the wall of the intestines and are responsible for absorption of nutrients and control body fluid metabolism.

4) Symptoms:

a) appear in a few hours

b) nausea and vomiting

c) dehydration from diarrhea and low nutrient absorption

d) electrolyte imbalance

5) Cause of death: circulatory collapse from loss of fluids

c. Central Nervous System (CNS) Syndrome

1) Dose level:

>5,000 rad (>50 gray)

2) Critical Organ:

Central Nervous System

3) Symptoms:

Convulsions

tremors

ataxia

lethargy

4) Cause of death:

Respiratory failure and/or brain edema

See Table 1 in the Student Guide for a summary of effects from extreme to low doses. Remind students that the dose ranges for effects might vary by reference.

3. In the event an individual survives an acute exposure of high dose, they run an increase risk of latent effects

I. Effects on the Embryo/Fetus

Objective 1.08.11

1. According to the law of Bergonie and Tribondeau, children are more radiosensitive than adults, fetuses more than children, and embryos are the most radiosensitive.

2. Radiation doses may cause death or abnormalities.

3. Most critical period 2 to 6 weeks gestation – most organs formed

4. Doses as low as 25 rad (0.25 gray) may cause defects.

5. Reported effects include blindness, cataracts, mental deficiency, coordination defects, deformed arms legs, and general mental/physical subnormality

6. An exposure of 400 - 600 rad (4 - 6 gray) during the first trimester (excluding the first week) of pregnancy is sufficient to cause fetal death and spontaneous abortion

J. Heritable Effects

Objective 1.08.12

1. Differences in the genetic structure of somatic and germ cells

2. Mutations can be produced in genes by radiation

3. Dominant genes will generally determine characteristics when the 23 chromosome pairs are matched

4. In order for a recessive gene to determine a characteristic it must be paired with another recessive gene

5. This indicates mutations may not appear for several generations

6. Doubling Dose - double natural mutation rate –estimated to be greater than 100 rem (1 Sv)

Reference: BEIR V

7. Radiation damage in humans can result in both somatic and heritable effects

   1) Somatic effects - Effects which occur in the exposed individual.

   2) Heritable effects - effects which occur in the future generations of the exposed individual.

III. SUMMARY

A. Review major topics

Cellular structure and damage

Radiosensitivity

Stochastic/Deterministic effects

Chronic effects

Acute effects

Embryological effects

Heritable effects

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

Course Title: Radiological Control Technician

Module Title: Radiological Protection Standards

Module Number: 1.09

Objectives:

1.09.01 Identify the role of advisory agencies in the development of recommendations for radiological control.

1.09.02 Identify the role of regulatory agencies in the development of standards and regulations for radiological control.

1.09.03 Identify the scope of the 10 CFR Part 835.

References:

1. ANL-88-26 (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.
2. U.S. Department of Energy, DOE-STD-1098-2008, "Radiological Control Standard".
3. 10 CFR Part 835 (2007) "Occupational Radiation Protection".

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned.

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone Number
3. Background
4. Emergency procedure review

B. Motivation

To understand why there are limits to exposure the RCT must understand the history of the development of the limits. The RCT has to be aware of the current CFRs and DOE Orders that may effect them at the work place.

C. Overview of Lesson

1. History of standards
2. Advisory agencies
3. Federal policy on radiation matters
4. Regulating agencies
5. Radiological Control Standard
6. 10 CFR Part 835

D. Introduce Objectives

O.H.: Objectives

II. MODULE OUTLINE

A. History of Standards

1. Setting exposure limits is vital and difficult.
   a. Vital: Workers must be protected from the harmful effects.
   b. Difficult: many factors enter into the effects which radiation produces.

2. Concept of an "acceptable risk"
   a. The benefits are weighed against the potential damage.
   b. Then limits are set at some level at which the most benefit to mankind.
3. Limits are revised as new knowledge is gained.
4. Early use of radiation led to large exposures.
5. As early as 1897, cases of skin damage began to appear.
6. Erythema Dose
   a. Early efforts at control were hampered by a lack of quantitative methods.
   b. There were no units by which one could assess the amount of radiation.
   c. As a result of the use of radiation by doctors in treating patients, a unit called the erythema dose came into use.
   d. Highly qualitative unit; defined in terms of the amount of radiation which would produce a well-defined reddening of the skin.
   e. Not a satisfactory unit.
   f. It varied not only with the type of radiation and the dose rate, but also with the response of different parts of the body.

B. ICRU, ICRP, AND NCRP

Objective 1.09.01

1. 1925, International Commission on Radiological Units and Measurements (ICRU).
   a. 1928, adopted the Roentgen.
   b. ICRU has been the main force in defining and adopting units for use on an international basis.

2. 1928, International Commission on Radiological Protection (ICRP).
    a. This group discusses and reviews basic protection principles.
    b. Recommendations serve as a guide from which regulations can be drawn up by each country.
    c. 1934, recommended a tolerance level of exposure: 0.2 R/day. This limit remained in force until 1950.
3. 1929, National Committee on Radiation Protection and Measurements (NCRP).
    a. Coordinated by the National Bureau of Standards.
    b. Recommendations of the Committee appeared in the National Bureau of Standards Handbooks.
    c. 1946 reorganized
    d. 1964 replaced by a non-profit corporation chartered by Congress National Council on Radiation Protection and Measurements.
    e. The Council is made up of the members and the participants who serve on a number of committees.
    f. These committees develop proposed recommendations on various aspects of radiation protection and radiation measurements, which when approved by the Council, are published as NCRP Reports. The initial report issued by the Council was NCRP Report No. 32.
4. Radiation exposure concerns
    a. Initially, concerns resulted from patients and medical personnel exposure to external radiation from the use of x-rays for diagnosis and therapy.

b. World War II produced a shift in emphasis due to the increase in the number, type and uses of radioactive materials. This introduced considerations about internal exposure and the dose to the general public.

c. Potential genetic effects of radiation and the impact of long-term exposure at low dose rates emerged.

d. Data from biological studies seemed to indicate that one could not assume that all effects had a threshold dose. Also, in the case of gene damage, effects could be expected at very low doses.

e. Efforts have been directed toward quantifying the risk associated with a certain level of exposure.

f. Non-threshold relationship, any dose carries some risk of producing damage therefore all exposure should be kept at the lowest practical levels. Several factors need to be considered.

    1) Information available for the quantification of risks is imperfect.

    2) The assumptions of a risk by an individual, in general, presumes a willingness to chance the risk in exchange for some resultant benefit.

    3) The resultant benefit which accrues justifies the risk.

    4) The balancing of risk versus benefit in order to obtain a net benefit is not easily accomplished.

    5) The prudent approach, adopted by both the ICRP and the NCRP is to keep exposures as low as reasonably achievable (ALARA).

g. In addition to the work of the ICRP, NCRP, and ICRU, the National Academy of Sciences National Research Council has undertaken the study of biological effects.

1) This group consists of a large number of scientists throughout the country.

2) The group functions as an advisory body.

3) Purpose is to supply technical information as a basis from which regulations can be developed

h. The results of continuing reviews of biological data have revealed two types of radiation effects.

1) Those for which a practical threshold dose for occurrence can be demonstrated, deterministic (nonstochastic) effects.

2) Those for which there is apparently no threshold, stochastic effects.

3) Deterministic effects can be prevented by limiting the dose to the individual to a value below the threshold dose for occurrence of the effects.

4) Since stochastic effects presume that there is no threshold level, and that the probability of the effect occurring increases with dose, any dose represents some probability of producing that effect.

5) Stochastic effects, limit the probability of occurrence to some level (deemed acceptable) by limiting the radiation exposure.

C. ICRP Basic Recommendations

1. In its current reports, the ICRP recommends a basic system of dose limitation which includes these three interrelated aspects:

a. No practice shall be adopted unless its introduction produces a positive net benefit.

b. All exposures shall be kept ALARA, economic and social factors being taken into account.

c. The equivalent dose to individuals shall not exceed the recommended limits.

D. Federal Policy on Radiation Matters

1. 1959, Federal Radiation Council (FRC) was formed (Public Law 86-373).

    a. Advised the President concerning radiation matters

    b. Provided guidance for all Federal agencies in setting standards and in working with the States.

    c. The recommendations of the FRC were approved in 1960 and formed the basis of the Federal radiation protection guidance.

    d. The FRC was abolished by Reorganization Plan No. 3 in 1970.

2. Environmental Protection Agency (EPA) took over. The Office of Radiation Programs (ORP) of the EPA took over the activities of the FRC.

    a. 1981, the EPA drafted proposed revised recommendations in the Federal Register regarding occupational exposure, and solicited comments.

    b. The EPA believes that it is appropriate to adopt the general features of the ICRP approach in radiation protection guidance for use by Federal agencies for occupational exposure.

    c. The revised EPA guidance was approved and issued in January 1987.

3. The Bureau of Radiological Health of the U.S. Department of Health and Human Services has developed a set of recommendations for protection from diagnostic x-rays.

E. Regulating Agencies

Objective 1.09.02

1. 1954, Atomic Energy Act, the United States Atomic Energy commission (AEC) was given the responsibility of regulating the atomic energy industry.
   a. The Act authorized the AEC to set up a licensing program to be augmented by whatever rules or regulations are deemed appropriate.
   b. The bases for these rules are: to protect the public health and safety, and provide for national defense and security.
2. 1974, Energy Reorganization Act, abolished the AEC and established two agencies to perform the functions of the AEC, Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA).
3. NRC
   a. The regulations of the NRC are set forth in the Code of Federal Regulations (CFR), Title 10.
   b. Part 20, Standards for Protection Against Radiation, deals specifically with the regulations for control of radiation hazards by the licensee.
   c. Other parts of Title 10 deal with licensing and regulatory requirements associated with the use of source, special nuclear material and by-product material.
   d. The NRC is charged with the task of seeing that these measures prevail. This aspect requires inspection and review in order to assure this.
      1) This function is carried out by NRC personnel (inspectors) at regular intervals.
      2) Their job is to make the inspections and report their findings. In the event that a failure to comply is noted, the licensee is required to correct this.

e. States have taken up the task of setting up their own safety standards. The NRC has been directed to assist the states to assure that the state and Commission programs are compatible. These states are referred to as Agreement States.

4. ERDA

a. In 1977, the U.S. Department of Energy (DOE) replaced ERDA.

5. DOE

a. The DOE activities relate to energy research and development.

b. The DOE has issued occupational radiation protection standards which pertain to its own activities as well as to those of its contractors.

Insert site-specific information addressing DOE orders/standards applicable to radiological control at the site, based on contracts.

Objective 1.09.03

1) These standards appear in 10 CFR Part 835.

2) These standards are based upon the recommendations of the ICRP, NCRP and the guidance of the EPA.

3) Rule 10 CFR 835: The scope of 10 CFR 835 establishes radiation protection standards, limits and program requirements for protecting individuals from radiation resulting from the conduct of DOE activities.

a) Implemented by the Price-Anderson Amendments Act

b) Civil penalties may be assessed

c) Requires DOE activities be conducted with a written radiation protection program.

d) Some sites may still contractually be obligated to adhere to provisions of the DOE RCS.

c. Similar to the NRC, the DOE is charged with the inspection of its contractors to see that they are in compliance with DOE requirements.

6. Department of Transportation (DOT)

   a. Safety in the shipment of radioactive substances

   b. Title 49 Transportation, of the CFRs, deals with hazardous shipments including radioactive materials.

7. Other Agencies

   a. Interstate Commerce Commission,

   b. Coast Guard,

   c. Federal Aviation Agency,

   d. Postal Service,

   e. International Atomic Energy Agency.

F. DOE Radiological Control Standard (RCS)

1. Radiological Control Policy

   a. The fundamental principle underlying the RCS is:

      1) "There should not be any occupational exposure of workers to ionizing radiation without the expectation of an overall benefit from the activity causing the exposure."

   b. Applies to those DOE activities that manage radiation and radioactive materials and that may potentially result in radiation exposure to workers, the public, or the environment.

   c. ALARA

      1) Personal radiation exposure shall be maintained ALARA.

      2) Exposure shall be controlled below regulatory limits and there is no exposure without commensurate benefit.

d. Ownership

1) Each person involved in radiological work is expected to demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity.

e. Excellence

1) Evident when radiation exposures are maintained well below regulatory limits, contamination is minimal, radioactivity is well controlled and radiological spills or uncontrolled releases are prevented.

2) Continuing improvement is essential to excellence in radiological control.

2. Standard Applicability and Control

a. Recommends practices for the conduct of radiological control activities.

b. Best courses of action currently available and should be viewed by contractors as an acceptable technique.

c. Not a substitute for regulations.

d. Following the course of action will achieve and surpass requirements, but RCS is not sufficient to ensure compliance with all of 10 CFR 835.

e. Revision

1) The RCS is a living document.

2) Revision will be made to incorporate lessons learning and suggestions.

3) The Chief, Health, Safety and Security Officer is responsible for this task.

4) Recommendations are requested.

f. Use of the RCS is recommended to conduct DOE-funded radiological activities at DOE and non-DOE sites.

g. In those cases at non-DOE sites or facilities where a specific activity is being conducted pursuant to an NRC or Agreement State license, the provisions of the RCS are not binding to that activity.

h. The RCS should be kept current and should be entered into the contractor document control system.

i. The RCS does not apply to the Naval Nuclear Propulsion Program.

3. Compliance

The RCS is a guidance document and compliance is not mandatory, unless the contractor is contractually obligated to follow provisions of the RCS.

4. Site-Specific Manual

a. A Site-Specific RCM should be issued and endorsed by the contractor senior site executive.

b. DOE-HSS approval is not required.

c. Management policies, requirements, expectations and objectives for the site Radiological Control Program should be clearly and unambiguously stated..

d. The Site-Specific Manual should be kept current and entered into the contractor document control system.

e. Subcontractors should comply with the Site-Specific RCM.

5. Application of Requirements

a. It is not the intent of the RCS to unnecessarily create new or separate organizations if those functions can be incorporated into existing ones.

b. Existing charters may need to be revised to address RCS recommendations.

c. The degree of program formality and extent of the associated administrative process are expected to be commensurate with the radioactive material contamination and dose potential.

III. SUMMARY

A. Review major topics

1. History of standards
2. Advisory agencies
3. Federal policy on radiation matters
4. Regulating agencies
5. Radiological Control Standard

B. Review of learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

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Course Title: Radiological Control Technician

Module Title: ALARA

Module Number: 1.10

Objectives:

1.10.01 Describe the assumptions on which the current ALARA philosophy is based.

1.10.02 Identify the ALARA philosophy for collective personnel exposure and individual exposure.

1.10.03 Identify the scope of an effective radiological ALARA program.

1.10.04 Identify the purposes for conducting pre-job and/or post-job ALARA reviews.

1.10.05 Identify RCT responsibilities for ALARA implementation.

References:

1. NCRP Report No. 91 (1987) "Recommendations on Limits for Exposure to Ionizing Radiation".
2. U.S. Department of Energy, DOE-STD-1098-2008, "Radiological Control Standard".
3. 10 CFR Part 835 (2007), "Occupational Radiation Protection".
4. ICRP Publication 37 "Cost-Benefit Analysis in the Optimization of Radiation Protection".

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone Number
3. Background
4. Emergency procedure review

B. Motivation

All personnel at a facility must be committed to ALARA. The RCT can play a major role in establishing and maintaining that commitment.

C. Overview of Lesson

1. ALARA Philosophy
2. Objectives of ALARA Programs
3. ALARA Concerns
4. Collective Dose Philosophy
5. Scope of ALARA Program
6. ALARA Reviews
7. RCT Responsibilities

D. Introduce Objectives — O.H.: Objectives

II. MODULE OUTLINE

A. ALARA Philosophy — Objective 1.10.01

1. The cautious assumption that a proportional relationship exists between dose and effect for all doses (non-threshold concept) is the basis for ALARA. There may be some risk associated with any dose.
2. The effects of low-level doses over extended periods of time are not definitively characterized and the risk is difficult to quantify.

3. Studies of atomic bomb survivors and individuals involved in Nuclear incidents show the relationship between dose and effects is well known only at high doses.

4. The benefit of completing a task must be compared to the risk of the exposure received.

B. Objectives of ALARA Programs

1. There should not be any occupational exposure of workers to ionizing radiation without the expectation of an overall benefit from the activity causing the exposure.

2. Personal radiation exposure shall be maintained As-Low-As- Reasonably Achievable (ALARA).

3. Radiation exposure of the work force and public shall be controlled such that radiation exposures are well below regulatory limits and that there is no radiation exposure without commensurate benefit.

C. ALARA Concerns

1. Implementation of ALARA concepts should be carried out through all phases of a facilities lifetime.

2. ALARA Program concerns include:

a. Engineering features

1) Discharge of radioactive liquid to the environment

2) Control of contamination

3) Efficiency of maintenance, decontamination and operations should be maximized

4) Components should be selected to minimize the buildup of radioactivity

5) Support facilities should be provided for donning and removal of protective clothing and for personnel monitoring

6) Shielding requirements

7) Ergonomics consideration

8) Access control designed for hazard level.

9) Surfaces that can be decontaminated or removed

10) Equipment that can be decontaminated

b. Area arrangement

1) Traffic patterns to allow access yet prevent unnecessary exposure

2) Equipment separation

3) Valve locations

4) Component laydown/storage areas

c. Operations

1) Inspection tour - access, mirrors, visibility

2) Inservice Inspections - use of remote control equipment, TV, Snap on insulation, platforms, etc.

3) Remote readout instrumentation

4) Remote valve/equipment operators

5) Sampling stations, piping, valving, hoods, sinks

d. Maintenance needs

1) Adequate lighting, electric outlets, other utilities

2) Removal and storage areas for insulation/shrouding

3) Relocation of components to low dose areas

4) Workspace for maintenance personnel

5) Lifting equipment

6) Conditions that could cause or promote the spread of contamination, such as a leaking roof or piping need to be identified and corrected on a priority basis.

e. Radiological control needs

1) Access control
2) Shielding adequacy and access plugs
3) Temporary shielding and support structures
4) Adequate ventilation
5) Breathing air
6) Contamination control - drip pans, curbs, drains, and routing
7) Decontamination facilities
8) Radiation monitoring equipment
9) Communications

D. Collective Dose Philosophy

Objective 1.10.02

1. Control of the collective dose to the work force.
2. Collective dose is defined as the total individual doses in a group or a population.
3. Spreading dose among more workers versus higher individual exposures for fewer workers is an ALARA issue.

a. Spreading dose

1) The linear model states that the less exposure a worker receive the less chance they will receive harmful biological effects.
2) Lower collective dose is a good indicator of an effective ALARA Program

b. Higher Individual Exposure

1) Exposure to fewer individuals means that the risk to the rest of the work force has been minimized.
2) Merely controlling maximum dose to individuals is not sufficient, collective dose must be controlled as well.

4. Reducing radiological risks should not result in higher risks for other hazards.
5. Reduction in radiological risk should be reasonably achievable based on the current state of technology, economic factors, and social conditions

E. Scope of ALARA Program — Objective 1.10.03

1. Establish a program to maintain exposures ALARA.
2. Design and modify facilities and select equipment with ALARA concepts integrated into the processes.
3. Establish radiological control programs, plans and procedures.
4. Make available equipment, instrumentation and facilities necessary for ALARA program implementation.
5. Train facility workers and management as well as radiological control personnel in ALARA programs and reduction techniques.
6. Applies equally to the reduction of external and internal exposure.
7. The ALARA program must be incorporated in everyday, routine functions as well as non-routine, higher risk tasks.
8. The involvement and commitment of all facility personnel, not just radiological control personnel, is necessary to achieve the reduction of external and internal exposure.
9. To justify activities that could result in exposure to ionizing radiation, the following conditions should be satisfied:
   a. The risks associated with projected radiation exposures should be small when compared to the benefit derived.
   b. Further reduction in projected exposure is evaluated against the effort required to accomplish such reduction and is not reasonable
   c. The risks from occupational exposure or to the public should not exceed everyday or accepted risks.

10. Ownership - each individual involved in radiological work must demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity.

    a. Management responsibilities:

        1) Design and implement ALARA program
        2) Provide resources such as tools, equipment, adequate personnel
        3) Create and support ALARA Review Committee
        4) Approve ALARA goals
        5) Design and implement worker training

    b. Radiological Control Technician Responsibilities:

        1) Perform the functions of assisting and guiding workers in the radiological aspects of the job
        2) Knowledge of conditions at the work site
        3) Knowledge of work activities to be performed
        4) Identification of protective clothing and equipment requirements
        5) Identification of dose reduction techniques
        6) During work conduct, maintaining awareness of conditions
        7) Correction of worker mistakes
        8) Response to abnormal events

    c. ALARA "group" - including facility/RC supervision/management:

        1) Evaluate worker suggestions and provide feedback in a timely manner
        2) Participate in pre-and post-work meetings
        3) Keep abreast of ALARA techniques pertinent to operations on site.
        4) Track facility performance in comparison to stated goals

F. ALARA Reviews

1. Pre-job ALARA Reviews — Objective 1.10.04

   a. For every task involving radiological work, sufficient radiation protection controls should be specified in procedures and work plans to define and meet requirements.

   b. Applicable ALARA practices shall be factored into the plans and procedures for each task or type of task. The practices shall be communicated to the workers in ways that ensure that the employee is able to maintain their exposure ALARA.

   c. Proposed ALARA protective measures shall be evaluated to ensure the costs are justified.

2. Pre-Job Briefing

   a. Pre-job briefings are held with employees who will be involved in work activities involving unusual radiological conditions.

   b. Identify effective dose reduction measures.

   c. RC needs are communicated to workers. Worker needs are communicated to RC.

   d. Procedures are verified.

   e. Worker qualifications are verified.

   f. Emergency procedures are discussed.

   g. At the end of the meeting, everyone should know what is expected of them, how to do it, and the conditions under which it is to be done.

   h. ALARA pre-job briefing checklists

      1) Scope of work to be performed

      2) Radiological conditions of the workplace

      3) Procedural and RWP requirements.

      4) Special radiological control requirements

      5) Radiologically limiting conditions, such as contamination or radiation levels that may void the RWP

      6) Radiological Control Hold Points

      7) Communications and coordination with other groups

8) Provisions for housekeeping and final cleanup

9) Emergency response provisions

3. Post-Job ALARA Reviews

    a. Jobs determined to require a ALARA review shall undergo a post-job review to ensure the overall effectiveness of job planning and implementation.

    b. Unusual exposure events are investigated to determine the root cause. Recommendations are made and corrective actions are then taken to prevent future reoccurrences of these events.

4. Post-Job Debriefing

    a. The opportunity to critique the work performance.

    b. Although, they will not affect the dose already received for a particular job, they can be effective in reducing the doses received the next time that job is performed.

    c. Information discussed at post-work meetings include discussions of what went wrong and what could have been done differently to reduce the exposures received.

    d. Post-work meeting rely heavily on the input of each radiation worker for information on how best to reduce exposure the next time that job is performed.

    e. Typical questions asked could include:

        1) Were there any problems performing the job in accord with the procedure?

        2) Did you have the tools and equipment needed to perform the work? Could special tools ease the job?

        3) Were there any unexpected conditions noted during the work? Could these conditions have been anticipated?

        4) Were there any unexpected delays in the performance of the job? What was the cause of the delay?

        5) Was temporary shielding used? Could the use of temporary shielding reduce exposures received for this job?

G. Radiological Control Technicians

1. The responsibilities of the Radiological Control Technician: — Objective 1.10.05

   a. Pre-job ALARA reviews

   b. Pre-job briefings

   c. Radiation hold points identified

   d. Tool and equipment requirements/need for special tools

      1) Pre-fabrication of temporary shielding

      2) Removal of component to low dose areas

      3) Previous job evolutions, previous survey conditions

   e. Area Set-up

      1) Access to and from work area

      2) Service lines available - air, electric, ventilation, lighting

      3) Staging areas - low radiation areas, tool preparation and personnel waiting areas

      4) Communications - equipment, lines, TV monitoring.

      5) Radiological controls - anticipation of conditions during job with identification of controls required, surveys completed, high and low dose areas identified, contamination control requirements, airborne

   f. Worker preparation

      1) Experienced workers

      2) Specialized training - mock ups, photographs, rehearsals, etc.

      3) Briefings - conditions, needs of RC personnel, what to expect, abnormal conditions

      4) Pre-work check off packages

g. Conduct of the job

1) The technician is tasked with assisting other workers in maintaining their exposures ALARA.

2) The technician can not lose sight of his own exposure reduction needs.

3) The RCT is expected to observe the worker to ensure that the radiological control requirements pertinent to the hazards present are taken and followed properly.

4) If the technician notices the worker not following good radiological work practices, on the spot corrections should be made.

5) Stop work authority is granted to all employees and all radiological control personnel should exercise this authority when:

a) Inadequate radiological control

b) Radiological controls not being implemented

c) Radiological controls hold point not being satisfied.

III. SUMMARY

A. Review major topics

1. ALARA Philosophy
2. Objectives of ALARA Programs
3. ALARA Concerns
4. Collective Dose Philosophy
5. Scope of ALARA Program
6. ALARA Reviews
7. RCT Responsibilities

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

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Course Title: Radiological Control Technician
Module Title: External Exposure Control
Module Number: 1.11

Objectives:

1.11.01 Identify the four basic methods for minimizing personnel external exposure.

1.11.02 Using the Exposure Rate = 6CEN equation, calculate the gamma exposure rate for specific radionuclides.

1.11.03 Identify "source reduction" techniques for minimizing personnel external exposures.

1.11.04 Identify "time-saving" techniques for minimizing personnel external exposures.

1.11.05 Using the stay time equation, calculate an individual's remaining allowable dose equivalent or stay time.

1.11.06 Identify "distance to radiation sources" techniques for minimizing personnel external exposures.

1.11.07 Using the point source equation (inverse square law), calculate the exposure rate or distance for a point source of radiation.

1.11.08 Using the line source equation, calculate the exposure rate or distance for a line source of radiation.

1.11.09 Identify how exposure rate varies depending on the distance from a surface (plane) source of radiation, and identify examples of plane sources.

1.11.10 Identify the definition and units of "mass attenuation coefficient" and "linear attenuation coefficient".

1.11.11 Identify the definition and units of "density thickness."

1.11.12 Identify the density-thickness values, in mg/cm^2 , for the skin, the lens of the eye and the whole body.

1.11.13 Calculate shielding thickness or exposure rates for gamma/x-ray radiation using the equations.

References:

1. ANL-88-26 (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.
2. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
3. "Health Physics and Radiological Health Handbook"; Shleien; 1992.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

B. Motivation

1. The goal of any radiation safety program is to reduce exposure, whether internal or external, to a minimum. The external exposure reduction and control measures available are of primary importance to the everyday tasks performed by the RCT.

C. Overview of Lesson

1. Minimizing Personal exposure
2. "Source reduction" techniques and calculations
3. "Time-saving" techniques and calculations
4. "Distance to radiation source" techniques and calculations
5. Skin density thickness
6. Shielding calculations

D. Introduce Objectives

O.H.: Objectives

II. MODULE OUTLINE

A. Basic Methods for Exposure Reduction

Objective 1.11.01

1. The goal of radiological control is embodied in the acronym "ALARA," which stands for As Low As Reasonably Achievable. The radiological control organization shall make whatever reasonable efforts it can to reduce exposure to the lowest levels, taking into account economic and practical considerations.

2. There are four basic methods available to reduce external exposure to personnel:
   a. Reduce the amount of source material (or reduce emission rate for electronically-generated radiation).
   b. Reduce the amount of time of exposure to the source of radiation.
   c. Increase the distance from the source of radiation.
   d. Reduce the radiation intensity by using shielding between the source and personnel.
3. In order to use the basic methods for controlling exposure, the worker must be able to determine the intensity of the radiation fields. The following equations are used to make this determination.

   Not very accurate, valid only for certain photon energies

   a. A "rule-of-thumb" method to determine the radiation field intensity for simple sources of radioactive material is the "curie/meter/rem" rule. (Co-60)

      1 Ci @ 1 meter = 1 R/hr

   b. To determine the gamma radiation field intensity for a radioactive point source

      Objective 1.11.02

      $I_{1ft} = 6CEN$

      where:

      I_{1ft} = Exposure rate in R/hr 1 ft.
      C = Activity of the source in Ci
      E = The gamma energy in MeV
      N = The number of gammas per disintegration

      1) This equation is accurate to within $\pm$20% for gamma energies between 0.05 MeV and 3 MeV.
      2) If N is not given, assume 100% photon yield (1.00 photons/disintegration).
      3) If more than one photon energy is given, take the sum of each photon multiplied by its percentage, i.e.:

         $[(\gamma_1)(\%_1) + (\gamma_2)(\%_2) + \cdots + (\gamma_n)(\%_n)]$

$I = [(.5)(1.8Ci)(2.505\ MeV)(1.00)] \div (2)^2$

$I = 0.564$ R/hr @ 2 meters

i. Example: Calculate the exposure rate at 1 ft., for a 400-mCi 192 Ir which emits the following gammas: 0.316 MeV (87%), 0.486 MeV (52%), 0.308 MeV (32%), 0.295 MeV (30%).

Sample Problem 1.11-3
Note: Ir-192 emits other gammas at lower percentages, but these are not included

$I_{1ft} =$

$6(0.4Ci)[(0.316)(.87) + (0.486)(.52) + (0.308)(.32) + (0.295)(.3)]$

$I_{1ft} = 6\ (0.4Ci)(0.7147)$

$I_{1ft} = 1.715$ R/hr

$I_{1ft} = 1{,}715$ mR/hr

Objective 1.11.03

B. Source Reduction

1. The first method that should be employed to reduce personnel external exposure is source reduction. If a source can be eliminated or if its hazard potential can be significantly reduced, then other engineering means may not be necessary.

2. Various techniques are employed to accomplish external exposure reduction using source reduction.

   a. Allow natural decay to reduce source strength

      1) If the radioisotopes involved are short-lived, then waiting to perform the task may significantly reduce the hazard.

Sample Problem 1.11-4

      2) For example, a contaminated system pump has been replaced with a rebuilt pump and the replaced pump must be rebuilt prior to the next replacement. Assume the 1 Ci mixture of radio-nuclides contained in the pump has an effective half-life of 40 days. In 80 days the activity in the pump will be reduced to one fourth of original activity:

      $A = A_o\ 2^{-n}$

b. By algebraic manipulation, the equation can be used to determine the distance from a point source for a given exposure rate or the exposure rate at a given distance.

Sample Problem 1.11-9

c. For example: a 1 Ci point source of Cs-137 has a gamma exposure rate of 3.38 R/hr at 1 ft. What would the exposure rate be at 3 ft?

$$I_2 = I_1 (\frac{d_1^2}{d_2^2})$$

$$I_2 = (3.38 R/hr)(\frac{(1)^2}{(3)^2})$$

$$I_2 = 0.376 R/hr = 376 mR/hr$$

Sample Problem 1.11-10

d. Example: A 1 Ci point source of ^{60}Co has an exposure rate of 15.03 R/hr at 1 ft. At what distance would the exposure rate be 100 mR/hr?

$$(d_2)^2 = \frac{I_1 d_1^2}{I_2}$$

$$(d_2)^2 = \frac{15.03 R/hr - (1 ft)^2}{0.1 R/hr}$$

$$d_2 = 12.26 ft.$$

e. The inverse square law holds true only for point sources; however, it gives a good approximation when the source dimensions are smaller than the distance from the source to the exposure point.

Objective 1.11.08

f. Some sources, such as a pipe or tank, can not be treated as a point source. These sources must be treated as line sources or large surface sources.

4. Line source calculations — Objective 1.11.08

   a. The actual calculations for a line source involve calculus; however, the mathematics can be simplified if the line source is treated as a series of point sources placed side by side along the length of the source.

   b. If the line source is treated in this manner, the relationship between distance and exposure rate can be written mathematically as:

      $I_1 d_1 = I_2 d_2$

      1) The exposure rate is inversely proportional to the distance from the source

      3) Assuming the source material is distributed evenly along the line

      4) Assuming the point at which the exposure rate is calculated is on a line perpendicular to the center of the line source

      5) Assuming the width or diameter of the line is small compared to the length

      6) Valid to a point that is one half the distance of the longest dimension of the line source (L/2), beyond which the point source formula should be used

   c. For example: A small diameter pipe containing radioactive resin has a length of 10 ft. The exposure rate at 1 foot is 5 R/hr. What is the exposure rate at 4 feet? — Sample Problem 1.11-11

      $I_1 d_1 = I_2 d_2$

      $$I_2 (5R/hr)(\frac{1\,ft}{4\,ft})$$

      $$I_2 = 1.25R/hr$$

   d. Example: What would the exposure rate be at 15 feet for the same small diameter pipe? — Sample Problem 1.11-12.1

$I_1 d_1 = I_2 d_2$

Determine rate at L/2.

$$I_2 = (5R/hr)(\frac{1\,ft}{5\,ft})$$

Determine rate at 15 ft.

$$I_2 = \frac{(1R/hr)(5\,ft^2)}{(15\,ft^2)}$$

$$I_2 = 111 mR/hr$$

5. Planar or surface sources

Objective 1.11.09

   a. Planar or surface sources of radiation can be the floor or wall of a room, a large cylindrical or rectangular tank or any other type of geometry where the width or diameter is not small compared to the length.

   b. Accurate calculations for these types of sources require the use of calculus; however, a relationship can be described for how exposure rate varies with distance from the source.

   c. When the distance to the plane source is small compared to the longest dimension, then the exposure rate falls off a little slower than

$$\frac{1}{d}$$

   (i.e. not as quickly as a line source).

   d. As the distance from the plane source increases, then the exposure rate drops off at a rate approaching:

$$\frac{1}{d^2}$$

6. The exposure rate versus distance calculations can be used to make an estimate of the radiation intensity at various distances.
7. These estimates are valuable tools to estimate and verify the readings obtained from exposure rate meters.

E. Mass Attenuation Coefficient

Objective 1.11.10

1. The probability of a photon interaction per path length and therefore has units of $(\text{length})^{-1}$ (typically cm^{-1}).
2. Mathematically:

   $\mu_m = \mu_l/\rho$

   where:

   μ_m = mass attenuation coefficient

   μ_l = linear attenuation coefficient

   ρ = physical density

F. Density-Thickness

Objective 1.11.11

1. The value equal to the product of the density of the material times its thickness which then becomes the thickness of the material measured in $\text{mass}/(\text{length})^2$ (typically mg/cm^2)
2. Density Thickness values:

Objective 1.11.12
See Table 1 - "Density Thickness"

   a. Skin (shallow dose) - 7 mg/cm^2
   b. Lens of the eye - 300 mg/cm^2
   c. Whole body (deep dose) - 1000 mg/cm^2

G. Shielding Calculations

Objective 1.11.13

1. The simplest method for determining the effectiveness of the shielding material is using the concepts of half-value layers (HVL) and tenth-value layers (TVL).

2. One half-value layer is defined as the amount of shielding material required to reduce the radiation intensity to one-half of the unshielded value.

$$HVL = \frac{\ln 2}{\mu} - \frac{0.693}{\mu}$$

3. One tenth-value layer is defined as the amount of shielding material required to reduce the radiation intensity to one-tenth of the unshielded value.

$$TVL = \frac{\ln(10)}{\mu} = \frac{2.3026}{\mu}$$

4. Both of these concepts are dependent on the energy of the photon radiation and a chart can be constructed to show the HVL and TVL values for photon energies.

$$HVL = \frac{0.693}{\mu_{mass}{}^{xP}}$$

5. The basic calculational approach to photon shielding is to determine the existing exposure rate, decide on the desired exposure rate after shielding and then calculate how many HVL or TVL will be needed.

Density & μ_{mass} values from RH handbook See Table 2 - "HVL"

6. The basic equation for using the HVL concept is:

   $$I = I_o(\frac{1}{2})^n$$

   Where :

   $$I = shielded\ exposure\ rate$$

   $$I_o = unshielded\ exposure\ rate$$

   $$n = HVL = \frac{shield\ thickness\,(cm)}{HVL(cm)}$$

7. The basic equation for using the TVL concept is:

   $$I = I_0(\frac{1}{10})^n$$

$I = I_0$ *shielded exposure rate*

I_0 = *unshielded exposure rate*

$$n = \#\,TVL = \frac{shield\ thickness\,(cm)}{TVL\ thickness\,(cm)}$$

8. For example calculate the shielded exposure rate from a 500 mR/hr Cs-137 source with 5 cm of lead shielding. The HVL for Cs-137 and lead is 0.65 cm.

Sample Problem 1.11-13

$$n = \#\,HVL = \frac{5cm}{0.65} = 7.7\,HVL$$

$$I = (\frac{500mR}{hr})(\frac{1}{2})^{7.7}$$

$$I = 2.4mR/hr$$

9. For example, calculate the shielded exposure rate from a 7.4 R/hr Cs-137 source with 4 cm of lead shielding. The HVL for Cs-137 and lead is 0.65 cm.

Sample Problem 1.11-14

$$n = \#\,HVL = \frac{4cm}{0.65} = 6.15\,HVL$$

$$I = (\frac{7.4R}{hr})(\frac{1}{2})^{6.15}$$

$$I = 0.104R/hr = 104mR/hr$$

10. For example, calculate the #TVL and the thickness of lead required to reduce the exposure rate from a 7.5R/hr Co-60 source to less than 100 mR/hr. One TVL for Co-60 and lead is 4.0 cm.

Sample Problem 1.11-15

$$\frac{100mR}{hr} = (\frac{7.5R}{hr})(\frac{1}{10})^n$$

$$\log(\frac{100}{7500}) = \log(\frac{1}{10})^n$$

$$n = \#\,TVL = 1.88$$

$$1.88 = \frac{shield\ thickness\ in\ cm}{4.0cm}$$

$$shield\ thickness = (1.88)(4.0\ cm)$$

$$shield\ thickness = 7.5\ cm$$

Sample Problem 1.11-16

11. For example, calculate the #TVL and the thickness of lead required to reduce the exposure rate from a 450 mR/hr Co-60 source to less than 5 mR/hr. One TVL for Co-60 and lead is 4.0 cm.

$$\frac{5mR}{hr} = (\frac{450mR}{hr})(\frac{1}{10})^n$$

$$\log(\frac{4}{450}) = \log(\frac{1}{10})^n$$

$$n = \#TVL = 1.95$$

$$1.95 = \frac{shield\ thickness\ in\ cm}{4.0cm}$$

$$shield\ thickness = (1.95)(4.0cm)$$

$$shield\ thickness = 7.8cm$$

III. SUMMARY

A. Review major topics

  2. Minimizing Personal exposure
  3. "Source reduction" techniques and calculations
  4. "Time-saving" techniques and calculations
  5. "Distance to radiation source" techniques and calculations
  6. Skin density thickness
  7. Shielding calculations

B. Review learning objectives.

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the passing criteria for the examination.

Course Title: Radiological Control Technician

Module Title: Internal Exposure Control

Module Number: 1.12

Objectives:

1.12.01 Identify four ways in which radioactive materials can enter the body.

1.12.02 Given a pathway for radioactive materials into the body, identify one method to prevent or minimize entry by that pathway.

1.12.03 Identify the definition and distinguish between the terms "Annual Limit on Intake" (ALI) and "Derived Air Concentration" (DAC).

1.12.04 Identify the basis for determining Annual Limit on Intake (ALI).

1.12.05 Identify the definition of "reference man".

1.12.06 Identify a method of using DACs to minimize internal exposure potential.

1.12.07 Identify three factors that govern the behavior of radioactive materials in the body.

1.12.08 Identify the two natural mechanisms which reduce the quantity of a radionuclide in the body.

1.12.09 Identify the relationship between the physical, biological and effective half lives.

1.12.10 Given the physical and biological half lives, calculate the effective half life.

1.12.11 Given a method used by medical personnel to increase the elimination rate of radioactive materials from the body, identify how and why that method works.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; 5th ed.; Pacific Radiation Corporation; 2008.
2. DOE-STD-1098-2008, "Radiological Control Standard".
3. 10 CFR Part 835 (2007) "Occupational Radiation Protection".
4. "Health Physics and Radiological Health Handbook"; Shleien; 1992.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone Number
3. Background
4. Emergency procedure review

B. Motivation

The tasks that make up the responsibilities of the RCT include those actions used to minimize the potential exposure of workers from internal exposures.

This class is designed to familiarize the technician with those actions necessary as a result of the entry of radioactive materials into the body and the basis for those actions.

C. Overview of Lesson

1. Modes of entry into the body
2. Preventive measures, their use, and their basis
3. Metabolism of materials and elimination processes
4. Assessment methods
5. Definitions

D. Introduce Objectives

O.H.: Objectives

II. MODULE OUTLINE

A. Entry of Radioactive Materials into the Body

2. Knowledge of the ways in which radioactive materials enter the body is essential for two reasons.

    a. How radioactive material gets into the body must be known in order to design and implement measures to prevent entry.