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CHAPTER 7 - RADIATION

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RADIATION

7.1 PURPOSE

Provide information to develop a basic understanding of radiation terms, concepts, and applications that are related to the Department's Radiation Safety Program.

7.2 SCOPE

This chapter provides a limited overview of radiation principles. The main function is to familiarize users with terms and concepts used in nuclear science that are relevant to the safety of nuclear equipment users.

7.3 BASIC CONCEPTS OF NUCLEAR SCIENCE

7.3.1 About Atoms

All atoms are composed of protons, neutrons, and electrons. Protons, neutrons, and electrons are subatomic particles.

A proton has a positive charge (+1), an electron has a negative charge (-1), and a neutron has no charge.

Protons and neutrons are clustered together to form a nucleus, which is the center of an atom. The nucleus comprises only a tiny fraction of the total volume of an atom, yet nearly all the mass of an atom resides in the nucleus. Electrons orbit the nucleus and are nearly weightless.

(Refer to Appendix A-12 for atom diagram and atomic mass chart).

7.3.2 Elements

Each element is a type of atom, which has its own unique structure. A chemical element is identified by the number of protons in the nucleus (atomic number). The weight of an atom (atomic weight) is determined by adding the number of protons and neutrons present in the atom. Known elements are organized according to size and characteristics, which forms the Periodic Chart.

Refer to Appendix A-13, Periodic Table

7.3.3 Isotopes

Isotopes are defined as atoms of the same element that contain different numbers of neutrons in their nuclei. Isotopes of a given element contain the same numbers of protons and electrons because they are atoms of the same element.

7.3.4 Half-life

A half-life is the time required for half (50%) of a radioactive isotope to decay.

Refer to Appendix A –14, Decay curve for Cesium 137.

7.3.5 Radioactivity

The proton-to-neutron ratio within the nucleus of most elements is stable, meaning they do not have radioactive decay. However, those atoms whose nucleus has proton-to-neutron ratios that are outside of the stable region undergo spontaneous radioactive decay by emitting one or more particles and/or electromagnetic rays. Restated, radioactivity is the spontaneous breakdown of unstable nuclei with resulting emission of radiation.

7.4 TYPES OF RADIATION

7.4.1 Ionizing Radiation

Ionizing radiation means alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons and other particles capable of producing ions. Our discussions are limited to alpha particles, beta particles, gamma rays, and neutrons.

7.4.1.1 Ions – This is an atom, group of atoms, or molecule with an electrical charge. Emissions of radiation are a transfer of energy, and such emissions may cause the removal of an electron from an atom. This freed electron, with its negative charge, and the unbalanced atom, with its positive charge is called an ion pair. For our purposes “ionizing radiation” and “radiation” are equivalent terms.

7.4.1.2 Alpha Particles – An Alpha Particle is a helium nucleus, which consists of 2 protons and 2 neutrons. They have a +2 charge, and travel at high speeds. Alpha particles are stopped by a few millimeters of glass or paper, or the outer layer of skin.

7.4.1.3 Beta Particles – Beta particles are electrons emitted from the nucleus, traveling near the speed of light. Their penetrating power is about 100 times greater than an alpha particle. Beta Particles can penetrate several layers of skin and can damage the germinal layer (deepest or developing layer of skin).

7.4.1.4 Gamma Rays – Gamma Rays are high-energy electromagnetic radiation, which cannot produce ionization directly because they have no electrical charge and have no mass. Ionization is indirectly formed from gamma radiation by absorption through the Compton effect or the photoelectric effect.

7.4.1.4.1 Compton effect – A gamma ray collides with an electron of an atom and knocks it out of orbit, or away from the atom. The gamma ray loses energy, and the loose electron causes the photoelectric effect.

7.4.1.5 Neutrons – Neutrons or fast neutrons are ejected from the nucleus of an atom during certain types of nuclear reactions. It has no electrical charge, which allows neutrons to have great penetrating power.

7.4.2 Non-Ionizing Radiation

Non-ionizing radiation such as low energy electromagnetic rays, radio waves, microwaves, visible, infrared, or ultraviolet light are not discussed within the scope of this chapter.

7.5 MEASURES OF RADIATION

Activity is the rate of disintegration or decay of radioactive material. The units of activity are the Becquerel (Bq) and the Curie (Ci).

7.5.1 Becqerel (Bq)

The Standard International (SI) unit of radiation is the Becquerel. One Becquerel is equal to one disintegration (spontaneous breakdown of nuclei) per second.

7.5.2 Curie (Ci)

The standard unit of radiation is the Curie. One Curie is defined as 3.7 x 10^{10} disintegrations of nuclei per second.

7.5.2.1 One Curie is equal to 3.7 x 10^{10} Becquerels.

7.5.2.2 The units most applicable to the nuclear equipment used by the Department are Giga-Becquerels (GBq), 1 x 109 Becquerels in SI units, and milli-Curie, 1/1000 of a Curie in standard units.

7.6 RADIOLOGICAL DOSES

7.6.1 Categories

There are three categories of radiological doses: Exposure Dose, Absorbed Dose, and Biological Dose.

7.6.1.1 Exposure Dose – The basic unit of exposure dose is the Roentgen. This describes the amount of X or gamma radiation that is present within a given space.

7.6.1.1.1 Roentgen – means the amount of X or gamma radiation which will produce one electrostatic unit of charge, either positive or negative, in one cubic centimeter of air at standard pressure and temperature.

7.6.1.2 Absorbed Dose – Absorbed Dose means the energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).

7.6.1.2.1 Rad – means the dose corresponding to the absorption of 100 ERGS per gram of tissue. (The ERG is a small unit measure of energy).

7.6.1.2.2 Gray – The SI unit of absorbed dose for radiation in living tissue is the Gray (Gy). (100 rad = 1 Gy)

7.6.1.3 Biological Dose – The Biological Dose is measured in Rems. A rem is a measure of the dose of any ionizing radiation to body tissue in terms of its biological effect relative to a dose of one roentgen of X-rays.

7.6.2 Quality Factor (QF)

Quality Factor means the modifying factor that is used to derive dose equivalent from absorbed dose. Different types of ionizing radiation will result in different levels of absorption.

7.6.3 Roentgen Equivalent Man (rem)

Once the QF is known for a type of radiation, we can calculate the roentgen equivalent man (rem). The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor. (REM=Rad x QF)

7.6.4 Sievert (Sv)

Sievert is the SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor. Sievert = 100 rems (Sv=Gy x QF)

Radiation Type	Quality Factor	Absorbed dose equal to a unit dose equivalent.
X, gamma, or beta particles	1	1
Alpha particles.	20	0.05
Neutrons	10	0.1

7.7 BIOLOGICAL EFFECTS AND RADIOLOGICAL HEALTH REQUIREMENTS

Concern for Radiation –

7.7.1 Short-term Dose

A short-term dose of gamma radiation is gamma exposure received over a period of about four days or less.

7.7.2 Long-Term Dose

A long-term dose of gamma radiation is gamma exposure received over a period of more than four days.

7.7.3 Effects of Radiation

Most information available as to the effects of radiation is based on short-term doses to the whole body. The effects of short-term exposure doses of gamma radiation are as follows:

(A) Doses of less than 50 rem will produce no visible effect.

(B) Doses of 50 to 200 rem will produce slight to no illness.

(C) Doses of 200 to 450 rem will cause sickness in more than half the people. The probability of death increases to 50% at 450 rem.

(D) Doses of 450 to 600 rem will cause sickness in most people. Less than one-half will survive.

(E) Few people exposed to more than 600 rem will survive.

NOTE: Only the effects of gamma radiation are shown in Section 7.7.3. Nuclear surface moisture-density gauge (density gauge) operators will be exposed to gamma radiation and a very small trace of beta radiation. Sufficient exposure to beta can cause burns; however, due to the shielding properties of the density gauges, the exposure to beta will be negligible.

7.7.4 External Radiation Hazards

Alpha Particles – Alpha particles do not have sufficient penetrating power to cause tissue damage. Alpha particles do not escape the source encapsulation in density gauges. The exposure to alpha particles while using the Department's nuclear equipment is negligible.

Beta Particles – Beta particles are not an external radiation hazard except at a high energy level. The exposure to beta particles while using the Department's nuclear equipment is negligible.

X-rays or Gamma Rays – X-rays or gamma rays are capable of deep penetration into the body and can cause tissue damage in sufficient quantities as stated in Section 7.3.

Neutrons – Neutrons have a high penetrating power and are considered external radiation hazards. Neutrons can cause tissue damage.

7.8 ABOUT THE GAUGE

7.8.1 Radioactivity

A typical density gauge has two types radioactive sources:

(A) Cesium-137 – Emits gamma rays at a rate of approximately 0.296 Giga-Becquerels (GBq) or 8.0 milli-Curies (mCi).

(B) Americium-241:Beryllium – The Americium-241 emits alpha particles at a rate of approximately 1.48 GBq or 40.0 mCi. These alpha particles bombard the nuclei of the Beryllium, yielding about 70,000 neutrons per second.

7.8.2 Isotope

An example of an isotope is Cesium-137.

Cesium-137 has 55 protons and 82 neutrons, has an unstable nucleus, and is considered a radioactive isotope of Cesium. Cesium-137 is used in a typical density gauge.

The most stable and abundant form of Cesium is Cesium- 132, which has 55 protons and 77 neutrons, and has a stable nucleus. Note the increase of 5 neutrons in the Cesium atom nucleus causes the atom to become radioactive.

7.8.3 Half-life

Examples of half-life in radioactive isotopes in typical density gauge sources:

(A) The Americium-241 in the Americium-241:Beryllium source has a half-life of 458 years.

(B) Cesium-137 source has a half-life of 30 years, it will decay about 2% a year in strength.

7.8.4 Radioactive Sources

The radioactive sources in density gauges must meet regulatory requirements of the United States and international authorities as “Special Form” or sealed source material. The radioactive elements are physically sealed in a steel capsule. Sealed sources are periodically leak tested to make sure they are not leaking any radioactive materials.