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Radiation Primer - Part 1: Physical Terms and Concepts

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RADIATION PRIMER

PART I

PHYSICAL TERMS and CONCEPTS

Introduction

Radiation is a form of physical energy, and a dose of radiation results when energy is absorbed by an irradiated object as the radiation passes into it or through it. The fundamental way by which radiation transfers its energy in tissues, and produces its biological effect, is by causing ionization within the cells of our bodies, which means that it produces small electrical charges as it transfers its energy. These electrical charges may then affect one or another of the vital chemical processes within the cells.

When discussing radiation, the quantity of radiation is an important starting point of the discussion. But thereafter, it is equally important to think in terms of: the source, kind, and quality of radiation; under what conditions we may be exposed to it; what parts of our bodies and which body processes are likely to be affected by such quantity, and to what degree. These are all basic facts which must be incorporated into our thinking. Unfortunately, large gaps remain in our precise knowledge about many of these things. And the evaluation of the eventual biological effect of radiation is complicated because living organisms and their environment are extremely complex.

Before beginning any discussion of the biological effects of radiation, it will be helpful to have for reference the following basic dictionary of physical terms and concepts:

Basic Physical Terms

Atom: The smallest part of any element, or the characteristic building block of any element. Within the atom is a nucleus, or center, which consists of a clumping of even more elementary tiny particles, such as protons and neutrons. This atomic nucleus is surrounded by orbiting electrons (another type of elementary or subatomic particle). According to the classical Bohr - Rutherford concept, a typical atom is pictured as a miniature solar system, with its nucleus much like the sun, in the center, surrounded by electrons orbiting at varying distances much like the planets.

A lightweight atom like that of hydrogen is constructed of a nucleus containing one proton around which is a single orbiting electron. The atom of helium is somewhat heavier and more complex, with a nucleus made up of 2 protons plus 2 neutrons, and 2 electrons travel about this nucleus in a single orbital shell. Moving further along the periodic table of elements, consider a heavier atom such as that of oxygen, which is conceived as having a nucleus with 8 protons plus 8 neutrons, and two different orbital shells with 8 electrons. Further along in the table, uranium is a relatively heavy element. Its nucleus has 92 protons plus 146 neutrons, and there are 92 electrons orbiting in its 7 orbital shells.

Element: A substance all of whose atoms have the same atomic number. This gives an element a characteristic identity as a pure, elemental substance from the chemist's point of view. Examples of elements: hydrogen, carbon, oxygen, etc..

Compound: A substance made up of a combination of atoms from different elements, held together so that they assume a new physical and chemical identity. Example: water is a compound made up of hydrogen and oxygen.

Molecule: The smallest bit of any element or compound substance which still displays the characteristic physical or chemical properties of that substance.

Elementary (subatomic) Particles: Neutrons, protons, electrons, etc.. They are the bits of matter which group together to make up atoms, bound together within the atom by forces which can be thought of as electrical.

Radiation: A form of physical energy arising from, or mediated through, the actions of certain rays or beams, which in turn may be composed either of various elementary subatomic particles, or of electromagnetic waves of energy. Radio waves are radiation, as are x-rays, neutron beams, gamma rays, beta rays, etc. (see below). Even light rays and heat waves are forms of radiation. But further along in this text, the definitions of various types of radiation are limited to "ionizing radiation".

Ionizing Radiation: Radiation which produces electrical charges in the substance through which it is passing (see first paragraph in Introduction).

Fission: The division of a heavy atomic nucleus into two approximately equal parts. In the case of plutonium, when fission is accomplished there is a considerable output of energy in the form of light, heat and some gamma rays, x-rays, neutrons. This was the principle of the first "atomic bomb" or "nuclear bomb".

Fusion: The forcing together of relatively lightweight atomic nuclei to form new atoms with heavier nuclei. In this process of fusion, there is a relatively enormous output of heat. This is the basic principle of the "hydrogen bomb".

Radioisotope: A physically unstable form of an atom. Instability results from a variation in the number of elementary particles (neutrons, protons) contained within the nucleus of the atom. While the unstable isotope may act chemically like the stable form of the substance in question, its nucleus is in a constant physical state of unrest. Physical energy in the form of various types of radiation results as the radioisotope ejects or absorbs subatomic particles, or rearranges such particles to reach a state of relative stability.

During this nuclear transformation, the isotope may actually change its name and become a different atom and different element, eventually appearing in a different physical state and with new chemical properties.

Radium happens to be a naturally occurring radioactive element and it is undergoing radioactive decay constantly. In recent years it has become possible for man to produce artificially an extensive variety of radioactive elements and atoms which previously were unknown to him because of their scarcity in nature or their exceedingly rapid decay rates, or because conditions in nature do not lead to their spontaneous production. Manufacture is accomplished during nuclear bomb explosions, or in controlled nuclear piles, or in controlled machines such as cyclotrons, betatrons, synchrotons, etc..

The new substances are produced under these conditions by bombarding known substances with showers of subatomic particles. This artificially forces a change in the nucleus of the known atom by introducing new subatomic particles or by ejecting old ones. The result is a new atom or element, perhaps with a different name and different chemical and physical properties. Such transformed atoms may prove to be unstable radioisotopic analogs of the original atom, or radionuclides of a different atom entirely, or even a different stable atom.

Half-life: The time which it takes for any radioactive substance to decay to one half its original quantity. For example, the half-life of iodine-131 is approximately 8 days; at the end of each 8 day period there will be remaining one half of the quantity of iodine-131 which was present at its start. Each radioactive substance found naturally or manufactured artificially has its own characteristic half-life, and these vary enormously. The half-life of some substances is a matter of only minutes; in the case of strontium-90 it is approximately 28 years; for radium it is approximately 1600 years. However, all radioactive substances decay at a very regular rate.

Types of Ionizing Radiation

Alpha Rays: Particles of radiation emitted by nuclei of some radioactive substances in the process of their disintegration or decay. These alpha particles appear physically to be the same as the nuclei of helium atoms. They have relatively heavy mass, relatively small velocity and contain an electric charge. They produce very dense ionization effect along their paths, but their range of penetration into matter is very small.

Beta Rays: High speed electrons ejected by the atoms of certain radioactive substances. They have relatively light mass and an electric charge. While their relatively high speed and low weight permit them to penetrate more deeply into matter than alpha rays, they cause less dense ionization effect.

Neutrons: These subatomic particles are normal constituents of atomic nuclei which are ejected during processes such as fission. They are not charged, have relatively heavy weight and travel at varying speeds. Because they do not carry an electric charge, they produce ionization indirectly. "Fast" neutrons transfer their energy by colliding with atoms in the substance being irradiated, producing recoil nuclei which then produce ionization as they in turn dissipate the energy transferred to them from the neutron. These recoil nuclei are heavy and do not move at high speeds, tending to create relatively dense ionization. "Slow" neutrons interact with matter by nuclear reactions, during which charged particles or electromagnetic radiation may be produced.

Gamma Rays: These are not particles, but electromagnetic radiation waves or quanta of energy emitted by some radioactive substances. They are not charged and therefore ionize matter indirectly by causing the ejection of high speed electrons from the material in which they are absorbed. The energy of these electrons is then transferred to the medium which is penetrated.

Gamma rays are in the same electromagnetic spectrum in which are found the energy waves of visible light, ultraviolet, infrared and radio waves. In this broad spectrum or band of radiations, the gamma rays are classified with those which have relatively short wave lengths and relatively high frequencies of vibration; radio frequency waves are relatively long with relatively low frequencies; the waves of visible light are somewhere in between these two.

X-rays: Electromagnetic radiations similar to gamma rays. In general the difference is that they are produced artificially such as during electrical stimulation of an x-ray tube, whereas the gamma rays come from spontaneously radioactive substances. In the x-ray machine, when the electrical current is turned off in the x-ray generator, there is no radiation coming from the x-ray tube.

Cosmic Rays: A highly penetrating mixed type of radiation which originates in heavy particles from outer space. The primary component is partially absorbed as the rays enter the earth's upper atmosphere, which may result in various secondary types of radiation also. These naturally occurring rays are a significant portion of the background radiation to which we have always been and always will be exposed on earth.

Terms Used in Measuring Radiation

Exposure: The amount of radiation directed against an object or body.

Dose: Estimation of the energy absorbed within the object being irradiated as the result of an exposure to a source of radiation.

Roentgen: Unit to express exposure to x-rays or gamma rays, defined and measured as the amount of ionization produced by these types of energy (exposure), not of absorbed energy (dose).

Rad: Unit of absorbed radiation energy or dose. One rad equals energy absorption equivalent to 100 ergs in each gram of irradiated material at the point of interest. It is applicable to any type of ionizing radiation as long as the energy deposited is measured within the particular irradiated material under discussion. (Biological effects are mainly expressed as tissue dose in rads.)

RBE (relative biological effectiveness): This unit attempts to compare the relative effect of one type of radiation upon a tissue as opposed to another type. It is associated primarily with the linear energy transfer along the path of the ionizing particle, and will vary depending upon the type of radiation, the particular biological process being studied and the rate and level of exposure. By international convention, x-rays and gamma rays of certain energies are used as reference radiation. If, for certain biological processes, the RBE of alpha rays is found to be 10, this implies that, for these processes, an alpha ray dose of one rad will produce the same degree of biological effect as an x-ray dose of 10 rads (i. e., the relative biological effect of the alpha ray would be 10 times the biological effect of the x-ray, even though the absorbed dose of alpha ray energy is only 1/10 as great as the comparable dose of x-rays).

Rem: (roentgen - equivalent - man): A unit of dose which is biologically equivalent to the rad, but also takes into account the RBE of the particular type of radiation being discussed. The rem is defined as follows: (Dose in rem) equals (Dose in rad) multiplied by (RBE).

NOTE: For practical purposes the reader may consider roentgens, rads and rems as similar though the technical differences are detailed above.

Measures of Radioactivity

The Curie: This is a unit of radioactivity. It is defined broadly as the amount of any substance which is undergoing radioactive decay at the rate of 37 billion of its atoms each second. The term "curie" expresses how much of a radioactive substance we are dealing with. From this, a scientist has to make calculations to determine how large a dose of radiation would result from exposure to any given quantity of such radioactive substance.

Millicurie (mc): One thousandth of one curie.

Microcurie (μc): One millionth of one curie.

Micromicrocurie (μμc): One millionth of one millionth of one curie.

Picocurie (pc): Same as micromicrocurie.

Metric System of Weights and Measures

Gram (gm): A small unit of weight (mass) in the metric system of weights and measures. It is established by measuring the mass of a tiny cube of water, under standard conditions of temperature and pressure, and is equivalent to approximately one twenty-eighth of one ounce. (1 gm equals about four hundredths of one oz.)

Milligram (mg): One thousandth of one gram. (0.001 gm)

Microgram (μg): One millionth of one gram. (0.000001 gm)

Micromicrogram (μμg): One millionth of one millionth of one gram. (0.000000000001 gm)

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