RADIATIONS AND THEIR PROPERTIES

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The applications of high-energy radiation to agriculture fall into two main categories. In the first of these the radiation is used to cause changes in living material, such as in the prevention of sprouting in potatoes, the killing of pests in stored grain, and the production of mutations in seeds; in the second, the radiation from a radioactive substance is used to trace the movement of something, such as insects in the ground or fertilizer in a plant. What follows is a summary of the properties of high-energy radiations that are of interest in agricultural applications, and a brief mention of units and methods of measurement.

Properties of Radiations

The principal high-energy radiations and their properties are listed in the table. *a-particles* are doubly charged helium nuclei emitted by certain radioactive nuclei. They lose energy gradually by ionization and excitation of the atoms of the matter through which they pass. Particles of a definite initial energy have a definite *range* in matter, that is, they travel a definite distance before their energies are completely dissipated and the stop. Generally *a*-particles have ranges in tissue of less than a tenth of a millimeter.

Protons are hydrogen nuclei. Energetic protons do not occure naturally, but they can be accelerated to great energies in machines such as the cyclotron. They lose energy in the same way as *a*-particles, and while their ranges tend to be somewhat greater, they require very great energies (about 100 Mev) to penetrate as much as a few centimeters of tissue.

It is evident that *a*-particles and protons will not be of much use in most agricultural applications simply because they cannot penetrate beyond the outer layers of the sample.

Electrons are negatively charged and much less massive than protons. They can be accelerated to high energies in a number of kinds of machines, including Van de Graaff generators, betatrons, and linear accelerators. They are also emitted by many naturally occurring radioactive elements and artificially produced radioactive isotopes; in this caose they are referred to as *β*-particles. As well as losing energy by ionization, a fast electron in a close collision with a nucleus can lose a portion of its energy as electromagnetic radiation. (In fact, it is by this process that conventional x-rays are produced.) An electron of a particular energy loses energy much less quickly than a proton of the same energy, and consequently travels farther before stopping. The range of a 1-Mev electron in tissue is about 0.4 cm, that of a 30-Mev electron about 15 cm. The ranges of *β*-rays mostly lie between 0.2 and 1 cm.

When a beam of high-energy electrons strikes a solid or liquid medium, the absorption of energy is greatest near the surface and falls off steadily with increasing depth, reaching zero at a depth equal to the range. However, by choosing an appropriate electron energy, and irradiating the material from both sides, it is possible to achieve a reasonably uniform absorption of energy over a considerable thickness.

Radiation	Mass (Relative to H Nucleus)	Charge (Relative to H Nucleus)	Source	Mode of Energy Loss	Penetration of Tissue
a-particles	4	2	Radioactivity	Ionization	Fraction of mm.
protons	1	1	Accelerator	Ionization	.01 cm (2 Mev) to 10 cm (100 Mev)
electrons	1/1836	-1	Accelerator	Ionization and radiation	0.4 cm (1 Mev) to 15 cm (30 Mev)
β-rays	1/1836	-1	Radioactivity	Ionization and radiation	0.2 to 1 cm
x-rays	0	0	Accelerator	Transfer to secondary electrons	Exponential: reduced to ½ by 5-20 cm
g-rays	0	0	Radioactvity	Transfer to secondary electrons	
neutrons	1	0	Nuclear reactions	Transfer to recoil nuclei	Comparable to x-rays

X-rays are high-energy photons of electromagnetic radiation, produced when fast electrons are slowed down suddenly in matter. Radiations identical in nature but emitted by radioactive nuclei are called *g*-rays. Rather than losing energy gradually in small amounts, an x-ray loses all, or a large part, of its energy to an atomic electron in a single chance encounter. Since such encounters occur with a rather low probability, an x-ray travels on the average through several centimeters of tissue before being absorbed. A beam of x-rays falls off more or less exponentially in matter. In tissue such a beam loses half its energy in the first 5 to 15 cm, half of what is left in the next 5 to 15 cm, and so on. X-rays can therefore be used to irradiate substantial thicknesses of material, and again improved uniformity can be achieved by irradiating from more than one direction.

Neutrons are uncharged particles of about the same mass as protons. They do not occur free in nature but they can be produced in certain nuclear reactions. They leave energy in matter through occasional collisions with nuclei much as x-rays lose energy to electrons. Neutrons are penerating but difficult to detect.

For the irradiation of material in bulk, penetration is usually of prime importance, and x-rays or *g*-rays are

(Continued on page 20)