A small metal cylinder, baited with an extract prepared from the last two abdominal segments of female gypsy moths, is highly attractive to male gypsy moths. The cylinder has a rim at each end to which is attached a screen cone in which there is a hole for the moths to enter. A sticky paper lining prevents their escape. The use of the extract from two tips per trap will catch male gypsy moths, but the extract from 15 tips is necessary to attract the maximum number. The extract is dispensed on a corrugated paper roll suspended by a wire inside the cylinder. The traps are not practical for control, but were used in surveys of approximately 7 million acres for the presence of the gypsy moth in New England, New York, New Jersey, and Pennsylvania in 1950 and again in 1951.

THE INTEREST in traps remains at a high level and efforts to improve their effectiveness and extend their range of usefulness continue. The day may come when traps will be devised that are greatly superior to those we now have; the effort to develop them will be worth while.

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Radiant Energy and Insects

Alfred H. Yeomans

Radiant energy can be applied in uncounted ways to kill insects. To prevent damage in storage and the transportation of pests into quarantined zones, it has been tested on fruits, potatoes, grains, wood, textiles, and perhaps other commodities. It has been used to kill larvae of mosquitoes in water. The aim is to kill the insect without harming the material on which it lives and to do it economically.

Radiant energy includes electrical energy of various wavelengths—such as radio, infrared, visible and ultraviolet light, X-rays, and gamma rays. It includes sound waves of various wavelengths, such as audible and ultrasonic. It includes also the energy from various atomic particles such as neutrons, alpha, and electrons.

Its action depends on the structure of matter. All matter, including insects, is made up of combinations of some of the 92 basic elements. Each basic element comprises a particular type of electric solar system called an atom. The systems themselves are composed of elementary particles, some of which have no electric charge or mass. Two of the particles, the protons (which have a positive electric charge) and the neutrons (which have no electric charge) comprise the basic mass of the atomic nucleus. The number of protons determines the type of atom formed. The nucleus is surrounded at a relatively great distance by negatively charged electrons having a definite pattern. Normally the number of electrons equals the number of protons in the nucleus. Atoms can be combined chemically into various patterns of electrical solar systems, or molecules, that form the various materials as we know them.

Living organisms comprise such complicated patterns of these molecules that we do not know everything about their make-up. Nothing is known of the substance that gives life to the combination of molecules forming living organisms.

The energy contained in one atom is tremendous for its size. Some types of atoms can be broken apart and their energy released, such as the explosion of the atomic bomb. The electric solar system of the atom may also be changed less drastically. Radiant energy in various forms and intensities is the means employed to do so. Radiant energy may be used to increase the natural vibrations of the atoms and molecules. The result is increased temperatures of the material. It may be used to cause chemical combinations of atoms that are reluctant to combine. Molecules also may be struck with enough energy to break off electrons and leave fragments called ions.

The molecular structure of an insect is so complex that when radiant energy is applied it is difficult to determine which factors or combinations of factors cause its death. Each type of radiant energy results in a predominant action on the molecule, however. When the energy is intense enough, the insect is killed because it is torn apart physically.

THE USE OF HIGH-FREQUENCY or ultrasonic sound waves, other than the audible ones, is a relatively new science. The first work on it was done in about 1900. Until the First World War it remained a laboratory study, in which small tuning forks, sparks, and special whistles were used to produce the waves. During the war, a narrow beam of high-frequency sound was used to detect submarines. Since then it has been used for underwater signaling, testing for flaws in materials, and removing smoke. It has been used experimentally in television, medicine, biology, and metallurgy. It helps in the agitation of solutions and in making some chemical reactions.

The discovery that ultrasonic signals sent through water killed fish and destroyed other marine life led to research on the effect of ultrasonics on biological organisms. Many types of organisms have been exposed to various frequencies and intensities. Fish and frogs were easily killed, and some insects and bacteria were destroyed. Some of the effects of ultrasonics on biological organisms have been clearly explained. Others have been explained only partly. The biological effects may be due to heat generated by the sound waves or, when the energy is intense, to the shattering or tearing apart of the organism. Less apparent effects are probably due to chemical changes.

The use of sound waves for most insect-control purposes is impractical because of the inefficiency of low-frequency waves and the difficulty in transmitting high-frequency waves through air. The high-frequency equipment available in 1952 could be used only in laboratory tests. Even when a specimen can be exposed in liquid, the high reflecting and absorbing qualities of materials shielding the insect make this method of controlling all but exposed insects impractical.

Sound is a mechanical force produced by rapid vibration in some medium, such as air or water. It travels in the form of waves. Sound waves have three major dimensions, frequency, velocity, and intensity.

The frequency is expressed in cycles or vibrations per second. One kilocycle (kc.) is 1,000 cycles per second. Frequency and pitch are identical in most respects; the notes of the musical scale are defined in terms of frequency. The human ear registers sound from about 16 to 20,000 vibrations per second. Beyond that is ultrasonic sound. The highest frequency so far attained is 500 million cycles.

The velocity of sound waves is determined by the medium in which they travel. Sound travels about 1,000 feet per second in air and about 4,800 feet per second in water, depending mainly on the temperature.

The wavelength can be determined by dividing the velocity by the frequency. In air, at a frequency of 1,126 cycles per second, the wavelength is about 1 foot. At 1,000 kilocycles, the wavelength in air is about 0.0344 inch and in water about 0.145 inch. The cathode-ray oscilloscope is used for making sound waves visible so that they can be studied.

The intensity is the amount of energy in the sound wave. A piano key struck violently or softly produces the same number of vibrations per second but with different intensities. Since it is the energy that does the work, the most effective sound machine is the one that can put the most power into the vibrations it emits. Intensities at low frequencies are measured in decibels and otherwise in watts per square centimeter. There are several instruments for measuring the energy in a sound wave, but it is difficult to obtain a high degree of accuracy in the measurements.

The greatest damage to insects is caused by sound waves having a frequency that produces the maximum absorption in the insect but the minimum in the surrounding materials. The amount of absorption has been found to increase with the square of the frequency of the sound wave, and with the viscosity and heat conduction of the material. The absorption of energy in air is quite high compared to that in water.

L. Bergmann, the German physicist, gives the following values for the distance in air and water in which the sound intensity is reduced to one-half.

	10 kc.	*100 kc.*	*1,000 kc.*
Air.....	220 m.	220 cm.	2.2 cm.
Water....	400 km.	4 km.	40 m.

The absorption in solids depends on the grain or fiber structure of the material. Such fibrous materials as cotton or glass wool have high absorption values.

The generation of heat at the boundary surface of two substances traversed by ultrasonics is especially strong.

When sound waves travel from one type of medium into another, part of the energy is reflected back into the first medium. The amount reflected depends on the density of each material and the velocity of sound. In an air-solid boundary, practically 100 percent of the energy is reflected.

When a sound wave meets an obstacle, the amount of reflection depends on the size and shape of the object. If the object is small compared to the wavelength, some of the wave tends to bend around the object. When sound waves strike an object at an angle, a certain amount of the wave is refracted and the rest is reflected. In liquids and solids, when the angle of incidence is greater than about 15 degrees, all of the wave is reflected.

Thin plates may or may not conduct sound waves, depending on their dimensions and physical properties.

The hard shell of some insects, such as adult roaches, has high reflecting qualities that are difficult to overcome.

When the sound energy is intense enough to cause shattering of the cells of the insect, the maximum bursting action perhaps is obtained by wavelengths shorter than the cell but long enough to produce natural resonance. That would cause the maximum in pressure on different parts of the cell at the same time. Gas bubbles may form which burst with tremendous pressure and disrupt the organism.

One of the earliest practical ultrasonic generators was based on the discovery by Pierre and Jacques Curie in 1880 that a specially cut quartz crystal, when subjected to pressure and tension, will develop electric charges on its crystal faces. Later it was found that this is reversible and that the crystal will expand and contract, thus producing sound waves when an alternating voltage is applied to the surface. It is possible to amplify the vibrations greatly by cutting the crystals properly and backing it in such a way that resonance or natural vibrations amplify the waves. The crystal can also be cut concave to focus the waves. A con-

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cave crystal has been found to be more efficient than a flat one. At the focal point of converging sound waves, the energy is as much as 150 times greater than at other points. The crystal ultrasonic generator is called the piezoelectric type and is widely used to produce frequencies above 200 kilocycles. With special crystal rods they can also be made to produce lower frequencies. Because of the high frequency, this type of generator is not used to generate ultrasonics in air or other gases. The part of the generator that converts the electrical energy to sound waves, the transducer, is submerged in transformer oil, from which the sound waves are transferred to the testing medium.

Another method of producing ultrasonic waves is with the magnetostriction type of generator, which produces sound waves by the magnetization and demagnetization of a metal rod. When some metals are magnetized and subjected to tension and compression, a voltage is induced in a surrounding coil. The process is reversible; by magnetizing the rod by one coil and impressing an alternating voltage on another coil surrounding the rod, ultrasonic waves can be generated at the end of the rod. The waves generated depend on the frequency and magnitude of the applied voltage. Nickel or nickel alloy are usually used. To be efficient the rod must be designed properly to utilize resonance in amplifying the waves sent out. A circular plate is usually attached to the end of the rod to act as a radiator. The electrical circuit can be very simple. At low frequency it is possible to get large amounts of energy from this type of generator. At high frequency it cannot be tuned sharply and it is too sensitive to temperature. The magnetostriction generator usually is used for frequencies of 5,000 to 60,000 cycles. At that frequency it can be used to generate sound waves in gases and liquids. Magnetostriction and piezoelectric generators operate on a fixed frequency, with the intensity varying with the applied electrical energy. They are usually arranged so that the frequency can be changed by changing the transducer unit.

The siren type of sound generator is used to produce low-frequency sound waves in air. It is not so efficient as the magnetostriction or piezoelectric type, but it can handle a large amount of mechanical energy and the frequency can be changed by changing the speed of the rotor.

A number of exploratory tests of the use of ultrasonic waves on insects have been made at the Agricultural Research Center at Beltsville, Md. A piezoelectric type of generator, an Ultrasonerator, model SL 520, was used. It has four transducer assemblies, each designed to produce a fixed frequency. The frequencies available are 400, 700, 1,000, and 1,500 kc. We used the 400 kc. The maximum power input was 300 milliamperes (ma.) and 1,800 volts or 540 watts. Other tests were run at 200 milliamperes and 1,250 volts or about one-half power. Because of various losses, only about one-half the input power could be applied to the specimen. It is hard to expose test samples to the sound waves without shielding out a good part of the energy with the materials used to hold the samples.

Standing waves usually are set up in the enclosure in which the generator is operating. The position in which the sample is placed in relation to the standing waves is important. The crystal and other parts of the transducer are housed in a battery jar containing about 12 liters of transformer oil. The quartz radiates the ultrasonic waves upward through the transformer oil into a very thin copper cup, 3 inches in diameter and 3 inches deep, which contains circulating water. The test samples were suspended in the water-cooling cup. In the piezoelectric and magnetostriction generators operating in liquid, heat is produced in the liquid by the conversion of electrical to mechanical vibrations as well as by the absorption of the sound waves. Since the effect of temperature is fairly well known in entomology, the first tests were made to learn the other effects of ultrasonics. That was done by maintaining the circulating water at a constant temperature. However, temperature seems to modify other effects of ultrasonics and should be later explored.

We tested newly hatched codling moth larvae. We tried several means of holding them. Paper extraction thimbles or filter paper shielded them too much. Better results were had when the larvae were exposed in small glass vials containing water. In one series of the latter, when the temperature was maintained at about 17° C., and the power at 300 ma. and 1,800 volts with a 400-kc. frequency, the mortality varied from 100 percent at 40 seconds exposure to 25 percent at 10 seconds. When the temperature was increased to 20° C., the mortality varied from 70 percent at 5 seconds to 50 percent at 2 seconds. When the power was reduced to 160 ma. and 1,100 volts and a temperature of 20° C., the mortality was zero at 5 seconds exposure.

Codling moth larvae in apple plugs sealed with wax in test tubes were exposed to 400-kc. ultrasonic waves at 200 ma. and 1,250 volts, and at 300 ma. and 1,800 volts, and there was no mortality when exposure was 15, 30, 60, or 120 seconds. When the wax was not used, there was still no mortality when exposed for 10 minutes at 17° C. or 1 hour at 20°. Codling moth eggs, on paper and 1 to 4 days old, were exposed in the water testing medium to ultrasonic waves at 400 kc., 300 ma., and 1,800 volts with exposure times up to 120 seconds. About 30 percent failed to hatch, as compared with 14 percent of unexposed eggs.

Cabbage aphids, with the usual waxy coating, were exposed on small sections of cabbage leaves. The wetting agent, sodium lauryl sulfate (1–10,000), we used did not entirely prevent the formation of air bubbles on the leaves. A frequency of 400 kc. and a power of 300 ma. and 1,750 volts were used. The mortality varied from 62 percent at 4 minutes exposure to 100 percent at 30 minutes. No wax was visible on the dead or dying aphids, but the surviving aphids had a normal waxy coating. Probably the latter were protected by air bubbles. There seems to be some direct correlation between the mortality and the apparent absence of wax on the aphids.

Bean aphids on bean leaves were similarly exposed. A direct correlation was found between the mortality and the protection of the aphid by air bubbles. All aphids that were thoroughly wet were killed, and many of them were bloated.

Two-spotted spider mites were also similarly exposed. They were more thoroughly wet than the aphids and more than 90 percent were killed at exposures of 4 to 30 minutes. Some of the dead mites were flattened out as a result of the ultrasonic waves.

Third-instar yellow-fever mosquito larvae were exposed to ultrasonic energy with a frequency of 400 kc. At a power of 300 ma. and 1,800 volts, the larvae were all killed at exposures of 7 seconds at 25° C. to 9 minutes at 42°. Many of the larvae were eviscerated after exposure of 3 minutes or more. With a power of 200 ma. and 1,250 volts the larvae had a mortality of 92 percent after 2.5 seconds exposure at 22.2° C. and 100 percent after 20 seconds exposure at 23.5°. When the power was further reduced to 100 ma. and 750 volts, varying the exposure from 2.5 to 20 seconds did not seem to affect the mortality, which was about 35 percent at 21.5° C.

In previous tests on adult yellow-fever mosquitoes, in which low-frequency sound waves in air produced by a siren-type generator were used, there was no apparent effect on the mosquitoes at frequencies of 100 to 21,000 vibrations per second with an energy of 2 watts nor any ill effect at 13,000 and 21,000 vibrations per second at 100 watts energy. The mosquitoes were exposed in 20-mesh copper-screen cylindrical cages 2 inches in diameter and 7 inches long.

Various investigators have studied

the sounds made by insects. Many of them can now be accurately reproduced. It has been suggested that the sounds could be used to attract insects so they can be destroyed.

RADIO WAVES have been used since about 1928 in a number of studies of insects. Most of the work has been with limited power and range of frequencies. The effect of the radio waves on the insect seems to be mainly due to heating. In experiments on bacteria, in which heat was removed as rapidly as it was generated and the temperature could be kept below the thermal death point, there was some evidence that high-intensity electric fields could kill without heat. Because heating would normally first kill the organisms from these high intensities, radio waves have been used only as a means of heating to the temperature required for the death of the insect. For practical purposes, heating with radio waves must be cheaper than the simpler heating methods, much faster, or less harmful to the commodity. In order to use and evaluate radio waves for insect control, some of their properties should be known.

Electromagnetic waves, which include radio waves, can be classified according to their wavelength. The audio waves useful in converting electrical to audible sound waves have a wavelength longer than 20,000 meters. The radio waves useful in transmitting energy over long distances have a wavelength of 20,000 meters to about 1 centimeter. Infrared rays have a wavelength from 1 centimeter to about 1 micron; visible light rays from 1 micron to 4,000 angstrom units, each color having its own wavelength band; ultraviolet from 4,000 to 300 angstrom units; X-rays from 300 to 1 angstrom units; and gamma and cosmic rays below 1 angstrom unit.

Electromagnetic waves are simply traveling fields in which the energy alternately varies between an electric and a magnetic field. These waves can be projected through a vacuum and, like other wave forms, have three major dimensions, frequency, velocity, and intensity.

The frequency is the cycles per second in which a field changes from an electric through a magnetic and back to an electric field. One kilocycle equals 1,000 cycles per second, and one megacycle equals 1 million cycles per second.

The velocity of electromagnetic waves in a vacuum is about 300 million meters per second, which is said to be the speed of light. The permeability and dielectric constant of the material through which the waves travel affect the velocity.

The wavelength is a function of frequency and velocity. In free space, the wavelength in meters can be computed by dividing 300 million by the frequency.

A field of high-frequency radio waves is more useful in heating poor conductors of electricity than in heating good conductors such as metals, which are affected mainly near the surface. If heating of good conductors by electricity is desired, it is more efficient to run alternating current directly through the conductor or to induce an alternating current in the conductor by surrounding it with an alternating current.

Heating nonconductors (dielectrics) in a field of high-frequency radio waves is usually done in an oven whose top and bottom are condenser plates. Oscillating tubes are used to activate one plate with a positive charge while the other is negatively charged and to reverse this charge with any frequency desired. With proper design, an efficient field can be established when specimens are inserted between the plates. To be efficient the frequency must be such that standing waves are not formed on the plates or in the specimen. Also, the plates must be shaped to prevent edge effects, and the specimens must establish a uniform dielectric constant between the plates.

The intensity of the field in radio waves is given in volts per centimeter. The permissible voltage across the electrodes in dielectric heating is limited by the dielectric strength of the material, which sometimes changes with frequency and temperature. When moisture is present steam may be generated. If the conductivity of the material is such that arcing occurs when high voltages are applied, the arcing will char the specimen.

The heat generated in a dielectric specimen placed in an electromagnetic field can be computed when certain electrical properties of the specimen are known. The properties can be measured but differ in various ways with the frequency of the electromagnetic waves and the temperature and moisture content of the specimen. Those factors cause each type of material to have an optimum frequency for efficient heating as well as an optimum frequency for producing a strong field without arcing. Heating has been found to vary directly with the square of the field intensity and with the first power of the electrical properties of the material.

The investigations of high-frequency radio waves of insects have shown that when the insects are imbedded in flour, grain, or similar material no noticeable selective action occurs on the insect. That is probably due to the conduction of heat either to or away from the insect as the temperature varies between the two. It is therefore likely that even though each insect might have an optimum frequency of its own, practical considerations would require the use of the optimum frequency for the material in which it is imbedded.

The electromagnetic waves can be reflected, refracted, and diffracted. The waves can be reflected from any sharply defined gap if its dimensions are at least comparable to the wavelength and of a different dielectric constant from that of the medium.

Infrared rays have been used for heating insects to the death point. If the insects are in grain or other such material, the material itself has to be heated to the required temperature. The infrared rays are readily absorbed by most materials so that the penetration is not so deep as with radio waves. The usual method of producing infrared rays is by means of the red incandescent bulbs that are widely used as heat lamps. In some commercial applications for heating grain to kill insects, the loose grain has been carried on belt conveyors between banks of infrared lamps both above and below the belt. In this way the grain is quickly brought to the required temperature to kill the insects infesting it.

Visible light rays have been used to attract insects so that they could be trapped and destroyed. No other effects have been found that could be used in insect control. They are produced by the common incandescent or fluorescent light bulbs giving a wide range of wavelengths of relatively low intensity. Light and ultraviolet rays, X-rays, and gamma rays are thought to be photons resulting from the collision of two atomic particles, the electron and the positron.

Ultraviolet rays, which have various effects on biological organisms, usually are produced by means of the mercury arc enclosed in quartz. This produces wavelengths from about 2,400 to 4,350 angstrom units. Most of the wavelengths shorter than 3,000 angstrom units can be shielded out by using ordinary glass. The intensity of this type of radiation is given in ergs per square centimeter. The equipment used for biological studies has produced relatively low intensity.

Ultraviolet rays cause excitation of the molecules but not ionization. This excitation sometimes causes chemical changes. The absorption of ultraviolet rays seems to depend on the molecular structure of the material and on its color. The wavelength of about 2,600 angstrom units is the maximum absorption length for one group of acids often found in biological life.

Ultraviolet rays do not penetrate very deeply because of high absorption and some reflection.

G. F. MacLeod, at Cornell University, found that bean weevil adults were not killed when exposed for 20 minutes at 30 cm. to a 5-ampere, 100-volt, 60-cycle Cooper Hewitt burner, but most of the eggs were killed when exposed for 15 minutes.

J. G. Carlson and A. Hollaender, at the Oak Ridge National Laboratory, found that the mitotic ratio of grasshopper neuroblast exposed to ultraviolet rays of 2,537-angstrom wavelength was reduced from 0.97 to 0.58 as the intensity was increased from 750 to 24,000 ergs per centimeter. They also found that the length of exposure time was not important as long as the material received the same total amount of radiation.

Several forms of radiant energy can be projected with enough intensity to cause ionization of molecules on which they impinge. X-rays, one of the widely used forms, are usually produced by impinging high-velocity electrons (cathode rays) against platinum in a vacuum tube. Gamma rays resemble X-rays, but have shorter wavelength and are usually produced by the disintegration of radium. Various atomic particles can be projected against materials with extremely high velocities and thus cause ionization. The particles include electrons, alpha particles, deutrons, (which are the nucleus of "heavy" hydrogen), and neutrons (which can be obtained from atomic piles). The atomic particles can be accelerated to high velocity by such machines as the Betatron and the Cyclotron. These machines use magnets to rotate the charged particles in spiral paths while they are being accelerated by high voltage. The X-rays, neutrons, and gamma rays cannot be bent by magnets. The different forms of radiant energy produce ionization by various methods. The electromagnetic (X- and gamma) rays produce ionization by Compton scattering or the photoelectric effect. They are much less efficient than electrons or alpha particles, which utilize an electric charge to produce ionization. The neutron with no charge produces ionization indirectly by giving high velocity to a nucleus by inelastic collision or by disrupting a nucleus. When ionization is severe, often other side effects, such as secondary X-rays, are produced. The Geiger-Müller counter is one of the methods for determining ionization.

The principal difference in the effects of the various types of ionizing radiation is in the density of the ion clusters and the depth of penetration. X-rays and gamma rays produce very low ion densities but penetrate deeply. The shorter wavelengths penetrate more deeply than the longer wavelengths. The atomic particles produce ion densities in relation to their mass or self-energy and their electric charge. The alpha particles produce much higher ion densities than the smaller electrons, but the penetration is greatest with the small particles. The penetration would depend on the intensity of electromagnetic radiation or the velocity and electric charge of the atomic particles and on the density of the material on which they impinge. The greater the penetration the less dense the ion clusters, but the density of the ionization would not necessarily be uniform along the path of the ionizing radiatron. In the case of the electrons, the maximum ionization occurs at about one-third the depth of penetration. When the velocity of the atomic particles increases sufficiently their mass also increases, which fact agrees with the Einstein theory that mass and energy are the same thing.

The energy unit used in nuclear physics is the electron volt. It is defined as equal to the kinetic energy that a particle carrying one electronic charge acquires in falling freely through a potential drop of one volt. It is often convenient to use the million-times greater unit: million electron volt (mev).

$$1 \text{ mev} = 3.83 \times 10^{-14} \text{ g. cal.} = 1.07 \times 10^{-3} \text{ mass units} = 1.60 \times 10^{-6} \text{ ergs} = 4.45 \times 10^{-20} \text{ kw.-hrs.}$$

Most of the machines used to accelerate particles or produce X-rays are classified according to their potential in volts.

The unit used to express the absorbed energy in ionizing radiation is rep (roentgen-equivalent physical). This replaces the roentgen unit (r) which has been widely used in X-ray work and which is primarily a unit for photon energy dissipated in an arbitrary material, air, where 1 r is about 83 ergs/g. The two are somewhat similar, but the roentgen unit would vary for tissue absorption to some extent with the type of tissue and the amount of radiated energy. One rep equals 83 to 100 ergs/g. tissue.

A dose of 100,000 rep corresponds to a temperature rise in water of 0.2° C. The temperature effects caused by ionizing radiation in the absorber are negligible.

Many experiments have been conducted on the chemical and biological effects of ionizing radiation since 1900, and yet the exact nature of what takes place has yet to be explained. These experiments indicate that doses of radiation required to produce measurable chemical changes *in vitro* often far exceeded those required for profound biological changes *in vivo*.

According to F. G. Spear, of the British Strangeways Research Laboratory, ionization and not excitation has become generally regarded as the link between energy absorption and biological response—there exists in the cell a specially sensitive volume within which ionizations are biologically effective; any ionization outside the sensitive volume is ineffective. It is known as the target or "Quantum hit" theory. Differences in sensitivity to radiation are explained by the chance distribution of ionization in the vital volume of the cell.

One of the methods of producing ionizing radiation has been investigated by the Bureau of Entomology and Plant Quarantine. The method uses cathode rays with ultrashort exposure time to treat food and commodities. The inventors say the ultrashort exposure time of using accelerated electrons destroys biological organisms with the minimum amount of harmful side effects to the material. The reason is that a time element is required for a chemical change but not for a biological change.

All kinds of ionizing radiation can be used under proper conditions for sterilization and preservation. The argument in favor of the electrons is that X-rays and gamma rays are not usable for practical purposes. The biological intensity of penetrating electrons is about 500,000 to 1,000,000 times greater than that obtainable with X-rays. The neutron particles that are easily obtained from the atomic pile cause a high amount of concentrated ionization that leads to greater amounts of side reactions than would be tolerable. The electrons accelerated by tensions up to 10 million volts would cause practically no radioactive byproducts in the irradiated products, but the contrary is true of neutrons.

According to R. D. Evans, a physicist at Massachusetts Institute of Technology, low-energy electrons, when traversing matter, result in elastic scattering by atomic electrons or nuclei. The intermediate-energy electrons result in ionization by inelastic collision with atomic electrons. The high-energy electrons (above 1.5 mev) cause inelastic collision with atomic nuclei and are deflected by the Coulomb field, so that X-radiation, together with ionization, is produced. The proportion of radiative and ionization losses depends on the type of material.

The cathode-ray machine investigated was of 3-million-volt capacity. The electrons were released from a specially designed tube through a window device about 15 cm. in diameter and of very thin aluminum. Each discharge of approximately one-millionth of a second was made by means of a spark gap and the discharges could be produced about once every second. The air scatters the rays slightly after they emerge from the window so that at a distance of 1 foot from the window the rays cover an area of about 1 square foot.

The penetrating range of electrons depends on the accelerating voltage and the density of the target. Electrons of 3 million mev attain a velocity of about 99 percent of light and penetrate into water as far as about 15 mm. with the maximum intensity of ionization at a depth of about 4 mm. and tapering off rapidly below that.

Some foods have been treated with this machine. The red color in meat often turned to dark purple when treated at room temperatures, whereas in such products as strawberries and carrots, a definite bleaching took place. These color changes were eliminated when the food was irradiated below $-40°$ C. Tests have indicated that undesirable side effects could also be eliminated by evacuating the air around the object. Vegetables irradiated with overdoses of electrons showed a partial destruction of the cell walls and oozing-out of the cell contents.

We exposed some wood samples containing powder-post beetle larvae 3 to 7 months old to 1 and 2 impulses at a distance of 10 inches from the window and obtained 100 percent kill. This dosage was computed to be 145,000 and 290,000 rep.

Larvae of the confused flour beetle in an 8-mm. thickness of flour were exposed to one impulse on each side and all were killed. The dosage was computed to be 310,000 rep.

Complete mortality of the following insects resulted from similar treatment: American cockroach egg capsules, with a dosage of 350,000 rep; yellow-fever mosquito eggs, with a dosage of 600,000 and 900,000 rep; black carpet beetle larvae in 6 mm. of dog food, with a dosage of 310,000 rep; and bean weevil adults and larvae in one layer of lima beans, with a dosage of 460,000 rep.

Codling moth larvae buried at various depths in apples were killed when at a depth of 6 mm. with a dosage of 70,000 rep, and when at a depth of 8 mm. with a dosage of 140,000 rep. Death of the codling moth larvae extended over 16 days at a minimum dosage, whereas with an adequate dosage the mortality occurred within several hours of treatment.

Potato tuberworm larvae at depths of as much as 1 cm. in whole potatoes were exposed to a dosage of 350,000 rep. This resulted in 100 percent kill of 5-day-old larvae, 95 percent kill of 3-day-old larvae, and 83 percent kill in 2-day-old larvae. The difference was thought to be due to differences in depth of the larvae in the potato. The 5-day larvae were found at a depth of 4 to 9 mm. where the maximum intensity of radiation would occur. The younger larvae were less than 4 mm. from the surface of the potato.

In experimental work it is often necessary to trace the insect or insecticide. This can be done by using some radioactive material such as triphenylphosphate, and taking readings with a Geiger-Müller counter. The counter can be used not only for tracing but also for determining the amount of insecticide in a particular area.

Radiant energy has been experimented with for detecting the presence of insects in material. When X-rays were projected through material containing insects, the insects could be detected under certain conditions on film.

Reports have indicated that material exposed to "black light," the shorter ultraviolet wavelengths, may cause fluorescence when the light is projected on insects, thus making it possible to detect their presence.

Male screw-worm flies have been sterilized by X-rays and then released with the hope that if this were done on a large scale the normal populations would be greatly reduced.

Many contraptions that supposedly

use radiant energy for insect control have been given wide publicity. Some of them were probably meant to give satisfactory results, but the inventor was not familiar with the possibilities of radiant energy. Others probably were meant to fool the public. Some of these schemes have been investigated. One dubious machine was supposed to project various insecticides by means of radio waves. Another machine was supposed to kill insects in fruit by short impulses of high-voltage electric current. Insufficient time was allowed for heating and the method did not work, and arcing of the electric charges sometimes damaged the fruit.

So, IN SUMMARY, the use of radiant energy for controlling insects is still in the experimental stage and will probably remain so for a long time.

Sound waves do not penetrate most materials that shield the insect. High-frequency waves are difficult to transmit through air, and low-frequency waves do not efficiently produce enough heat to kill the insect. High-intensity waves will shatter the insect and also injure most surrounding materials.

Radio waves kill insects by heat and also penetrate dielectric materials readily, but the cost of operation compared with other methods, such as vapor heat, makes them impractical to use at the present time.

Killing insects by heat produced by infrared waves is restricted not only by the cost of operation but by the poor penetrating qualities of this wavelength.

The chemically active ultraviolet rays have such poor penetrating qualities that their use for most insect problems is impractical.

The ionizing radiation used so far is either very inefficient, as with X-rays and gamma rays, or does not penetrate sufficiently without harming the commodity or material on which the insect lives. The most promising future application of ionizing radiation will be for producing more penetrating electrons or more efficient X-radiation. In any case the high initial cost of equipment must be considered.

THE SUCCESSFUL APPLICATION of radiant energy is so dependent on a knowledge of the fundamentals of life and matter that both must progress together. The work with insects has opened up possible methods of control, however, and with the correlated work on mutations has added to the knowledge of life itself. It is hoped that, with the accelerated development of radiant energy equipment in recent years, increased interest will be shown in applying this energy to a study of insect problems.

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