8 Preservation by Drying

Preservation of foods by drying has been practiced for centuries. Some foods, e.g., grains, are sufficiently dry as harvested or with a little drying remain unspoiled for long periods under proper storage conditions. Most foods, however, contain enough moisture to permit action by their own enzymes and by microorganisms, so that to preserve them by dryness the removal or binding (e.g., by solutes) of moisture is necessary. Table 8.1 compares the moisture contents of several foods before and after drying to the level of moisture which would make the product stable.

Table 8.1 *Moisture Content of Various Foods before and after Drying*

Food	*Moisture, before drying, %*	*Moisture, after drying, %*
Milk		
Whole	87	5.0
Nonfat	90	5.0
Egg		
Whole	74	2.9
White	88	7.3
Yolk	51	1.1
Beef, lean, roasted	60	1.5
Chicken, broiled	61	1.6
Beans, snap, cooked	92	11.5
Corn, sweet, cooked	76	3.2
Potatoes, boiled	80	4.0
Apple juice	86	6.2
Figs, raw	78	3.6
Parsley, raw	84	5.3

Source: Condensed from Van Arsdel et al. (1973).

Drying usually is accomplished by the removal of water, but any method that reduces the amount of available moisture, i.e., lowers the a_w, in a food is a form of drying. Thus, for example, dried fish may be heavily salted so that moisture is drawn from the flesh and bound by the solute and hence is unavailable to microorganisms. Sugar may be added, as in sweetened condensed milk, to reduce the amount of available moisture.

Moisture may be removed from foods by any of a number of methods, from the ancient practice of drying by the sun's rays to the modern artificial ones. Many of the terms used in connection with the drying of foods are rather inexact. A **sun-dried** food has had moisture removed by exposure to the sun's rays without any artificially produced heat and without controlled temperatures, relative humidities, or air velocities. A **dehydrated** or **desiccated** food has been dried by artificially produced heat under controlled conditions of temperature, relative humidity, and air flow. **Condensed** usually implies that moisture has been removed from a liquid food, and **evaporated** may have a similar meaning or may be used synonymously with the term dehydrated.

METHODS OF DRYING

Methods of drying will be mentioned only briefly: references on food technology should be consulted for details. The drying of individual foods will be discussed in the chapters on the preservation of these foods. Table 8.2 summarizes various forms of drying applied to several foods.

Table 8.2 *Types of Dryer used for Various Foods, Food by-products, and Wastes*

Product	*Type of dryer*
Vegetables, confectionery, fruits, pectin	Compartment and tunnel tray
Grass, grain, vegetables, fruit, nuts, breakfast cereals	Conveyor band
Grass, grain, apple pomace, lactose, poultry manure, peat, starch (vacuum)	Rotary
Coffee, milk, tea, fruit purees	Spray
Milk, starch, predigested infant foods, soups, brewery and distillery by-products	Film drum
Starch, fruit pulp, distillery waste products, crops	Pneumatic
Coffee, essences, meat extracts, malted and other confectioneries	Freeze dryers and vacuum dryers

Source: Williams-Gardner (1971).

❑ Solar Drying

Solar drying is limited to climates with a hot sun and a dry atmosphere and to certain fruits, such as raisins, prunes, figs, apricots, nectarines, pears, and peaches. The fruits are spread out on trays and may be turned during drying. Fish, rice, and other grains may also be sun-dried. Other special treatments will be discussed later.

❑ Drying by Mechanical Dryers

Most methods of artificial drying involve the passage of heated air with controlled relative humidity over the food to be dried or the passage of the food through such air. A number of devices are used for controlled air circulation and for the reuse of air in some processes. The simplest dryer is the **evaporator** or **kiln,** sometimes used in the farm home, where the natural draft from the rising of heated air brings about the drying of the food. Forced-draft drying systems employ currents of heated air that move across the food, usually in tunnels. An alternative method is to move the food on conveyor belts or on trays in carts through the heated air.

Liquid foods, such as milk, juices, and soups, may be **evaporated** by the use of comparatively low temperatures and a vacuum in a vacuum pan or similar device; **drum-dried** by passage over a heated drum, with or without vacuum; or **spray-dried** by spraying the liquid into a current of dry, heated air.

❑ Freeze Drying

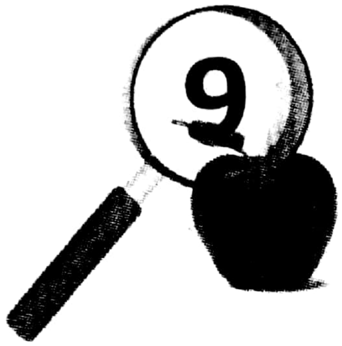
Freeze drying, or the sublimation of water from a frozen food by means of a vacuum plus heat applied at the drying shelf, is being used for a number of foods, including meats, poultry, seafood, fruits, and vegetables. Frozen thin layers of foods of low sugar content may be dried without vacuum by sublimation of moisture during passage of dry carrier gas.

❑ Drying During Smoking

As indicated in Chapter 9, most of the preservative effect of the smoking of foods is due to the drying of the food during the process. Indeed, some workers maintain that drying is the main preservative factor, especially drying at the surface of the food.

❑ Other Methods

Electronic heating has been suggested for the removal of still more moisture from a food already fairly well dried. Foam-mat drying, in which liquid food is whipped to a foam, dried with warm air, and crushed to a powder, is receiving attention, as is pressure-gun puffing of partially dried foods to give a porous structure that facilitates further drying. Tower drying in dehumidified air at 30 C or lower has been successful with tomato concentrate, milk, and potatoes.



Preservation by Food Additives

"A food additive is a substance or mixture of substances, other than the basic food stuff, which is present in food as a result of any aspect of production, processing, storage or packaging. The term does not include chance contamination" (WHO, 1965). This definition emphasizes one interpretation of a food additive; i.e., it is an intentional additive. Those food additives which are specifically added to prevent the deterioration or decomposition of a food have been referred to as **chemical preservatives.** These deteriorations may be caused by microorganisms, by food enzymes, or by purely chemical reactions. The inhibition of the growth and activity of microorganisms is one of the main purposes of the use of chemical preservatives. Preservatives may inhibit microorganisms by interfering with their cell membranes, their enzyme activity, or their genetic mechanisms. Other preservatives may be used as antioxidants to hinder the oxidation of unsaturated fats, as neutralizers of acidity, as stabilizers to prevent physical changes, as firming agents, and as coatings or wrappers to keep out microorganisms, prevent loss of water, or hinder undesirable microbial, enzymatic, and chemical reactions.

In addition to the chemicals intentionally added to foods or put on them or around them to help preserve them, there are many chemicals that get on or into foods during production, processing, or packaging. Residues of pesticides, herbicides, and fungicides on fruits and vegetables; residues of detergents used in washing foods; and residues of detergents and sanitizers used on utensils and equipment are likely to carry over into foods.

Factors that influence the effectiveness of chemical preservatives in killing microorganisms or inhibiting their growth and activity are similar to those considered in Chapter 6 in regard to the effectiveness of heating: (1) concentration of the chemical, (2) kind, number, age, and previous history of the organism, (3) temperature, (4) time, and (5) the chemical and physical characteristics of the substrate in which the organism is found (moisture content, pH, kinds and amounts of solutes, surface tension, and colloids and other protective substances). A chemical agent may be bactericidal at a certain concentration, only inhibitory at a lower level, and ineffective at still greater dilutions.

Table 9.4 *Maximum Levels of Antimicrobials Permitted in Foods*

Preservative	*Concentration allowed*
Benzoic acid	0.1%, covered by good manufacturing practices (GMPs)
Methylparaben	0.1%, covered by GMPs
Propylparaben	0.1%, covered by GMPs
Ethylparaben	Not authorized for use
Sodium nitrate	500 ppm
Sodium nitrite	200 ppm
Sorbates	Covered by GMPs
Acetates (acetic acid)	Covered by GMPs with concentrations from 0.25 to 9.0%
Propylene oxide	300 ppm cocoa, gums, starch, spices, processed nutmeats (except peanuts)
Ethylene oxide	Residues not to exceed 50 ppm
Sulfites	Covered by GMPs
Natamycin	200 to 300 ppm as a dip, spray, or solution

Source: From Code of Federal Regulations, Title 21, various subtitles, compiled January 1986.

Organic Acids and Their Salts

Lactic, acetic, propionic, and citric acids or their salts may be added to or developed in foods. Their development in foods during fermentation will be discussed in a following section. Citric acid is used in sirups, drinks, jams, and jellies as a substitute for fruit flavors and for preservation. Lactic and acetic acids are added to brines of various kinds, green olives, etc.

Propionates Sodium or calcium propionate is used most extensively in the prevention of mold growth and rope development in baked goods and for mold inhibition in many cheese foods and spreads. Experimentally, or on a limited scale, they have been used in butter, jams, jellies, figs, apple slices, and malt extract.

They are effective against molds, with little or no inhibition of most yeast and bacteria. Their effectiveness decreases with an increase in pH, with an optimal upper limit of about pH 5 to 6, depending on the food item.

They appear to be ideal preservatives for bread and baked goods. Although the heat of baking destroys most molds, contamination of the loaves can occur during slicing and/or wrapping, hence the need for the propionates. Since they have little inhibitory effect on yeasts, they can be added to the dough of yeast-raised baked goods without interfering with leavening.

Propionic acid is a short-chain fatty acid (CH_3CH_2COOH) and, like some other fatty acids, perhaps affects the cell-membrane permeability, although its precise mode of fungistatic action is not known. Propionic acid is found naturally in Swiss cheese, as a developed preservative, at levels up to 1 percent.

Benzoates The sodium salt of benzoic acid has been used extensively as an antimicrobial agent in foods. It has been incorporated into jams, jellies, margarine, carbonated beverages, fruit salads, pickles, relishes, fruit juices, etc. Sodium benzoate is relatively ineffective at pH values near neutrality, and the effectiveness increases with increase in acidity, an indication that the undissociated acid is the effective agent. The pH at which sodium benzoate is most effective (2.5 to 4.0) is in itself enough to inhibit the growth of most bacteria, but some (not all) yeasts and molds are inhibited at pH levels that would otherwise permit their growth.

Two esters of *p*-hydroxybenzoic acid, methylparaben, and propylparaben, are also used extensively in foods, and to lesser extent the butyl and ethyl esters. These compounds are similar to benzoic acid in their effectiveness. Their distinct advantage is that they tend to be more effective at higher pH values than the other benzoates because the esterification of the carboxyl group means that the undissociated molecule is retained over a wider pH range; since it is the undissociated molecule that exerts inhibition, the esters are effective at higher pH values.

The mechanism of action of the benzoates is not clear; it is known, however, that the effectiveness of the benzoic acid esters increases with an increase in the chain length of the ester group.

Sorbates Sorbic acid, as the calcium, sodium, or potassium salt, is used as a direct antimicrobial additive in foods and as a spray, dip, or coating on packaging materials. It is widely used in cheeses, cheese product, baked goods, beverages, sirups, fruit juices, jellies, jams, fruit cocktails, dried fruits, pickles, and margarine.

Sorbic acid and its salts are known to inhibit yeast and molds but are less effective against bacteria. They are most effective at low pH values with a maximal level of use at about pH 6.5. These compounds are more effective than sodium benzoate at pH values above 4.0.

Acetates Derivatives of acetic acid, e.g., monochloroacetic acid, peracetic acid, dehydroacetic acid, and sodium diacetate, have been recommended as preservatives, but not all are approved by the Food and Drug Administration. Dehydroacetic acid has been used to impregnate wrappers for cheese to inhibit the growth of molds and as a temporary preservative for squash.

Acetic acid in the form of vinegar is used in mayonnaise, pickles, catsup, pickled sausages, and pigs' feet. Acetic acid is more effective against yeasts and bacteria than against molds, and its effectiveness increases with a decrease in pH, which would favor the presence of the undissociated acid.

Sodium diacetate has been used in cheese spreads and malt sirups and as treatment for wrappers used on butter.

Nitrites and Nitrates Combinations of these various salts have been used in curing solutions and curing mixtures for meats. Nitrites decompose to nitric acid, which forms nitrosomyoglobin when it reacts with the heme pigments in meats and thereby forms a stable red color. Nitrates probably only act as a reservoir for nitrite, and their use is being restricted. Nitrites can react with secondary and tertiary amines to form nitrosamines, which are known to be carcinogenic. The assessment of the safety of nitrites in foods has been reviewed (Anonymous, 1981, 1982). The problem of possible carcinogenic nitrosamines may be greatest in bacon, and the extended

salted or smoked meat from pig.

future of nitrite use in foods will probably remain controversial. They are currently added in the form of sodium nitrite, potassium nitrite, sodium nitrate, and potassium nitrate.

Recent work has emphasized the inhibitory property of nitrites toward *Clostridium botulinum* in meat products, particularly in bacon and canned or processed hams. Nitrates have a limited effect on a limited number of organisms and would not be considered a good chemical preservative.

❑ Sulfur Dioxide and Sulfites

The Egyptians and Romans burned sulfur to form sulfur dioxide as a means of sanitizing their wine-making equipment and storage vessels. Today sulfur dioxide and sulfites are used in the wine industry to sanitize equipment and to reduce the normal flora of the grape must.

In aqueous solutions, sulfur dioxide and various sulfites, including sodium sulfite, potassium sulfite, sodium bisulfite, potassium bisulfite, sodium metabisulfite, and potassium metabisulfite, form sulfurous acid, the active antimicrobial compound. The effectiveness of sulfurous acid is enhanced at low pH values. Many mechanisms for the action of sulfurous acid on microbial cells have been suggested, including the reduction of disulfide linkages, formation of carbonyl compounds, reaction with ketone groups, and inhibition of respiratory mechanisms.

The fumes of burning sulfur are used to treat most light-colored dehydrated fruits, while dehydrated vegetables are exposed to a spray of neutral bisulfites and sulfites before drying. Sulfur dioxide has also been used in sirups and fruit juices and, of course, wine making. Some countries permit the use of sulfites on meats and fish.

In addition to the antimicrobial action of sulfites, they are also used to prevent enzymatic and nonenzymatic changes or discoloration in some foods.

❑ Ethylene and Propylene Oxide

Unlike the other chemical preservatives discussed, these two gases are sterilants. Ethylene oxide kills all microorganisms; propylene oxide, although it kills many microorganisms, is not as effective. They are thought to act as strong alkylating agents attacking labile hydrogens. The primary uses have been as sterilants for packaging materials, fumigation of warehouses, and "cold sterilization" of numerous plastics, chemicals, pharmaceuticals, syringes, and hospital supplies. They have also been used successfully in dried fruits, dried eggs, gelatin, cereals, dried yeast, and spices.

The FDA restricts the use of ethylene oxide to spices and other processed natural seasonings except mixtures containing added salt. Propylene oxide is permitted only as a package fumigant for dried prunes or glacé fruits and as a fumigant for cocoa, gums, spices, starch, and processed nutmeats (but not peanuts).

❑ Sugar and Salt

These compounds lower the a_w and thus have an adverse effect on microorganisms. Sodium chloride is used in brines and curing solutions or is applied directly to the food. Enough may be added to slow or prevent the growth of microorganisms or only enough to permit an acid fermentation to take place. Salt has been reported to have the following effects: (1) It causes high osmotic pressure and hence plasmolysis of cells, the percentage of salt necessary to inhibit growth or harm the cell varying with the microorganism, (2) it dehydrates foods by drawing out and tying up moisture as it dehydrates microbial cells, (3) it ionizes to yield the chlorine ion, which is harmful to organisms, (4) it reduces the solubility of oxygen in the moisture, (5) it sensitizes the cell against carbon dioxide, and (6) it interferes with the action of proteolytic enzymes. The effectiveness of NaCl varies directly with its concentration and the temperature.

Sugars, such as glucose or sucrose, owe their effectiveness as preservatives to their ability to make water unavailable to organisms and to their osmotic effect. Examples of foods preserved by high sugar concentrations are sweetened condensed milk, fruits in sirups, jellies, and candies.

❑ Alcohol

Ethanol, a coagulant and denaturizer of cell proteins, is most germicidal in concentrations between 70 and 95 percent. Flavoring extracts, e.g., vanilla and lemon extracts, are preserved by their content of alcohol. The alcoholic content of beer, ale, and unfortified wine is not great enough to prevent their spoilage by microorganisms but limits the types able to grow. Liqueurs and distilled liquors usually contain enough alcohol to ensure freedom from microbial attack. Methanol is poisonous and should not be added to foods; the traces added to foods by smoking are not enough to be harmful. Glycerol is antiseptic in high concentrations because of its dehydrating effect but is unimportant in food preservation. Propylene glycol has been used as a mold inhibitor and as a spray to kill airborne microorganisms.

❑ Formaldehyde

The addition of formaldehyde to foods is not permitted, except as a minor constituent of woodsmoke, but this compound is effective against molds, bacteria, and viruses and can be used where its poisonous nature and irritating properties are not objectionable. Thus it is useful in the treatment of walls, shelves, floors, etc., to eliminate molds and their spores. Paraformaldehyde can be used to control bacterial and fungal growth in tapholes of maple trees. Formaldehyde probably combines with free amino groups of the proteins of cell protoplasm, injures nuclei, and coagulates proteins.

❑ Woodsmoke

The smoking of foods usually has two main purposes; adding desired flavors and preserving. Other desirable effects may result, however, e.g., improvement in the color of the inside of meat and in the finish, or "gloss," of the outside and a tenderizing action on meats. The smoking process helps preservation by impregnating the food near the surface with chemical preservatives from the smoke, by combined action of the heat and these preservatives during smoking, and by the drying effect, especially at the surface. Commonly, smoke is obtained from the burning wood, preferably a hardwood such as hickory, but it may be generated from burning corncobs or

... be used for steam that comes in contact with foods (Anonymous, 1960).

❑ Antibiotics

Most of the better-known antibiotics have been tested on raw foods, chiefly proteinaceous ones like meats, fish, and poultry, in an endeavor to lengthen the storage time at chilling temperatures. Aureomycin (chlortetracycline) has been found superior to other antibiotics tested because of its broad spectrum of activity. Terramycin (oxytetracycline) is almost as good for lengthening the time of preservation of foods. Some success also has been claimed with Chloromycetin (chloramphenicol). These three antibiotics inhibit protein synthesis in the cell. Streptomycin, neomycin, polymyxin, nisin, subtilin, bacitracin, and others are not as satisfactory, and penicillin is of little use. Nisin has been employed in Europe to suppress anaerobes in cheese and cheese products. Natamycin is effective against yeasts and molds; it is used, or tested, in orange juice, fresh fruits, sausage, and cheese.

Experimentally, antibiotics have been combined with heat in attempts to reduce the thermal treatment necessary for the preservation of low- and medium-acid canned foods. Most tests have been with the peptides, subtilin and nisin, and tylosin. It has been suggested that a botulinum cook, i.e., enough of a heat treatment to inactivate all spores of *Clostridium botulinum*, be given canned foods, combined with the addition of enough antibiotic to inhibit germination and outgrowth of surviving spores of the most heat-resistant thermophilic spoilage bacteria and putrefactive anaerobes. Subtilin supposedly has no effect on the heat resistance of bacterial spores but inhibits heat-damaged cells during outgrowth, whereas nisin apparently interferes with spore germination and with lysis of the spore coat. Tylosin may inhibit cell growth.

Although food bacteriologists realize the advantages of the preservation of raw foods by a nontoxic antibiotic or the use of one in combination with reduced amounts of heat in the processing of canned foods, they raise certain questions about the use of antibiotics as preservatives. They agree that antibiotics never should be substituted for good hygiene. The effect of an antibiotic on microorganisms is known to vary with the species or even with the strain of the organism; hence the antibiotic may be effective against some spoilage organisms but not others or against part of the population in a culture but not all organisms. Organisms are known to become adapted to increasing concentrations of an antibiotic so that new, resistant strains may develop. There also is the possibility that other organisms, not now significant in food spoilage but resistant to the antibiotic, may assume new importance in food spoilage. Then, too, there may be effects of the antibiotic on the consumer such as sensitization to it, changes in the intestinal flora, and the development of strains of pathogens in the body resistant to that antibiotic, although these effects probably would be minimized by the very low levels of antibiotics employed in foods compared with the amounts employed for therapy. It has been recommended that antibiotics selected for use in food preservation be other than those being used in the treatment of human diseases.

10 Preservation by Radiation

In their search for new, improved methods of food preservation, investigators have paid special attention to the possible utilization of radiations of various frequencies, ranging from low-frequency electrical current to high-frequency gamma rays (Figure 10.1). Much of this work has focused on the use of ultraviolet radiation, ionizing radiation, and microwave heating.

It is common to group the entire spectrum of radiation into two categories, one on each side of visible light. Low-frequency, long-wavelength, low-quantum-energy radiation ranges from radio waves to infrared. The effect of these radiations on microorganisms is related to their thermal agitation of the food. Conversely, the high-frequency, shorter-wavelength radiations have high quantum energies and actually excite or destroy organic compounds and microorganisms without heating the product. Microbial destruction without the generation of high temperatures suggested the term "cold sterilization".

When applied to the food industry, shorter-wavelength radiation can be further divided into two groups. Lower-frequency and lower-energy radiation, for example, the ultraviolet part of the spectrum, has sufficient energy only to excite molecules. This area of the spectrum is employed in the food industry and is covered in the section on ultraviolet irradiation. Radiations of higher frequencies have high energy contents and are capable of actually breaking individual molecules into ions, hence the term ionizing irradiation.

ULTRAVIOLET IRRADIATION

Of the various electromagnetic radiations, ultraviolet irradiation has been the most widely used in the food industry. Radiation with wavelengths near 260 nm is absorbed strongly by purines and pyrimidines and is therefore the most germicidal. Ultraviolet radiation around 200 nm is strongly absorbed by oxygen, may result in the production of ozone, and is ineffective against microorganisms.

❑ Germicidal Lamps

The usual source of ultraviolet radiation in the food industry is from quartz-mercury vapor lamps or low-pressure mercury lamps, which emit radiation at 254 nm. Radiation from these lamps includes rays in the visible range and those in the erythemic range, which have an irritating effect on skin and mucous membranes. The lamps are available in various sizes, shapes, and power. The newer types release only negligible amounts of ozone.

Factors Influencing Effectiveness

It should be emphasized that only direct rays are effective unless they come from special reflectors, and even then their effectiveness is reduced. The factors that influence the effectiveness of ultraviolet rays are as follows:

1. ***Time*** The longer the time of exposure to a given concentration, the more effective the treatment.
2. ***Intensity*** The intensity of the rays reaching an object will depend on the power of the lamp, the distance from the lamp to the object, and the kind and amount of interfering material in the path of the rays. Obviously, the intensity will increase with the power of the lamp. Intensity is usually measured as microwatts per square centimeter (μ W/cm^2). The quantity or dose of irradiation actually absorbed by an organism or a product thus is expressed by the product of the time and intensity. Within the short distances common in industrial uses, the intensities of the rays vary inversely with distance from the lamp. A lamp is about 100 times as effective in killing microorganisms at 5 in, than at 8 ft from the irradiated object. Most tests are reported from a distance of about 12 in. Dust in the air or on the lamp reduces the effectiveness, as does too much atmospheric humidity. Over 80 percent relative humidity definitely reduces the penetration through air, but humidities below 60 percent have little effect.
3. ***Penetration*** The nature of the object or material being irradiated has an important influence on the effectiveness of the process. Penetration is reduced even by clear water, which also exerts a protective effect on microorganisms. Dissolved mineral salts, especially of iron, and cloudiness greatly reduce the effectiveness of the rays. Even a thin layer of fatty or greasy material cuts off the rays. There is no penetration through opaque material. Therefore, the rays affect only the outer surface of most irradiated foods directly exposed to the lamp and do not penetrate to microorganisms inside the food. The lamps do serve, however, to reduce the number of viable organisms in the air surrounding the food.

Effects on Humans and Animals

Gazing at ultraviolet lamps produces irritation of the eyes within a few seconds, and longer exposure of the skin results in erythema, or reddening. The effect on animals is usually not as marked, although the eyes, especially of chicks, may be irritated.

Action on Microorganisms

As has been stated, the intensity of the rays when they reach the organism, the time in which they act, and the location of the organism determine the germicidal effect. Each microorganism has a characteristic resistance to ultraviolet irradiation. This can vary with the phase of growth and the physiological state of the cell. It takes as much as five times the exposure to kill vegetative cells of some bacteria compared with others, but in general the killing exposure does not vary widely among different species. The amount of ultraviolet radiation needed to destroy several different microorganisms is summarized in Table 10.1. The location of the organism during the tests has a marked influence. For example, 97 to 99 percent of *Escherichia coli* in air were killed in

10 sec at 24 in with a 15-watt lamp, but 20 sec at 11 in was necessary for bacteria on the surface of an agar plate. Capsulation or clumping of bacteria increases their resistance. Bacterial spores usually take from two to five times as much exposure as the corresponding vegetative cells. Some types of pigmentation also have a protective effect. Generally, yeasts are from two to five times as resistant as bacteria, although some are easily killed. The resistance of molds is reported to be from ten to fifty times that of bacteria. Pigmented molds are more resistant than nonpigmented molds, and spores are more resistant than mycelium. The killing effect of ultraviolet rays is usually explained by the "target theory," which is described in the discussion of ionizing radiation.

❑ Applications in the Food Industry

The use of ultraviolet irradiation in the food industry will be discussed in connection with the preservation of specific foods. Examples of the successful use of these rays include treatment of water used for beverages; aging of meats; treatment of knives for slicing bread; treatment of bread and cakes; packaging of sliced bacon; sanitizing of eating utensils; prevention of growth of film yeast on pickle, vinegar, and sauerkraut vats; killing of spores on sugar crystals and in sirups; storage and packaging of cheese; prevention of mold growth on walls and shelves; and treatment of air used for, or in, storage and processing rooms.

IONIZING RADIATIONS

Kinds of Ionizing Radiations

Radiation classified as ionizing includes x-rays or gamma rays, cathode or beta rays, protons, neutrons, and alpha particles. Neutrons result in residual radioactivity in foods, and protons and alpha particles have little penetration. Therefore, these rays are not practical for use in food preservation and will not be discussed.

X-rays are penetrating electromagnetic waves which are produced by bombardment of a heavy-metal target with cathode rays within an evacuated tube. They are not currently considered economical for use in the food industry.

Gamma rays are like x-rays but are emitted from by-products of atomic fission or from imitations of such by-products. Cobalt 60 and cesium 137 have been used as sources of these rays in most experimental work thus far, with cobalt 60 being the most promising for commercial applications.

Beta rays are streams of electrons (beta particles) emitted from radioactive material. **Electrons** are small, negatively charged particles of uniform mass that form part of the atom. They are deflected by magnetic and electric fields. Their penetration depends on the speed with which they hit the target. The higher the charge of the electron, the deeper its penetration.

Cathode rays are streams of electrons (beta particles) from the cathode of an evacuated tube. In practice, these electrons are accelerated by artificial means.

❑ X-Rays

X-rays, gamma rays, and cathode rays are equally effective in sterilization for equal quantities of energy absorbed. X-rays and gamma rays have good penetration, while cathode rays have comparatively poor penetration. The greatest drawback at present to the use of x-rays in food preservation is the low efficiency and consequent high cost of their production, for only about 3 to 5 percent of the electron energy applied is used in the production of x-rays. For this reason, most recent research has concentrated on the application of gamma rays and cathode rays.

GAMMA RAYS AND CATHODE RAYS

Since these two types of rays are equally effective in sterilization for equal quantities of energy absorbed and apparently produce similar changes in the food being treated, they will be discussed together and compared where possible.

❑ Sources

Chief sources of gamma rays are (1) radioactive fission products of uranium and cobalt, (2) the coolant circulated in nuclear reactors, and (3) other fuel elements used to operate a nuclear reactor. Cathode rays usually are accelerated by special electrical devices. The greater this acceleration (i.e., the more meV), the deeper the penetration into the food.

❑ Penetration

Gamma rays have good penetration, but their effectiveness decreases exponentially with depth. They have been reported to be effective up to 20 cm in most foods, but this depth will depend on the time of exposure. Cathode rays, on the other hand, have poor penetration, being effective at only about 0.5 cm per meV when "cross firing". that is, irradiation from opposite sides, is employed. The absorption dose level in a material is not a uniformly decreasing fraction with depth but rather builds up to a maximum at a depth equal to about one-third of the total penetration and then decreases to zero.

❑ Efficiency

Because cathode rays are directional, they can be made to hit the food and therefore are used with greater efficiency than are gamma rays, which are constantly emitted in all directions from the radioactive sources. Various estimates of the maximal efficiency of utilization of cathode rays range between 40 and 80 percent, depending on the shape of the irradiated material, but only a maximum of 10 to 25 percent utilization efficiency is estimated for gamma rays. Radioactive sources of gamma rays decay steadily and hence weaken with time.

❑ Safety

The use of cathode rays presents fewer health problems than the use of gamma rays, since cathode rays are directional and less penetrating, can be turned off for repair or

Table 10.3 *Applications of Food Irradiation*

Type of food	*Radiation dose in kiloGrays*	*Effect of treatment*
Meat, poultry, fish, shellfish, some vegetables, baked goods, prepared foods	20–70	Sterilization. Treated product can be stored at room temperature without spoilage. Treated product is safe for hospital patients who require micro-biologically sterile diets
Spices and other seasonings	8–30	Reduces number of microorganisms and insects. Replaces chemicals used for this purpose
Meat, poultry, fish	1–10	Delays spoilage by reducing the number of microorganisms in the fresh, refrigerated product. Kills some types of food poisoning bacteria

Contd...

Contd...

Strawberries and some other fruits	1–4	Extends shelf life by delaying mold growth
Grain, fruit, vegetables, and other foods subject to insect infestation	0.1–1	Kills insects or prevents them from reproducing. Could partially replace fumigants used for this purpose
Bananas, avocados, mangos, papayas, guavas, and certain other noncitrus fruits	0.25–0.35	Delays ripening
Potatoes, onions, garlic	0.05–0.15	Inhibits sprouting
Pork	0.08–0.15	Inactivates trichinae
Grain, dehydrated vegetables, other foods	Various doses	Desirable physical and chemical changes

Source: ACSH (1985).

MICROWAVE PROCESSING

Microwave heating and processing of foods is becoming increasingly popular, particularly at the consumer level. Microwaves are electromagnetic waves between infrared and radio waves (Figure 10.1). Specific frequencies are usually at either 915 megacycles or 2,450 megacycles. The energy or heat produced by microwaves as they pass through a food is a result of the extremely rapid oscillation of the food molecules in an attempt to align themselves with the electromagnetic field being produced. This rapid oscillation, or intermolecule friction, generates heat. The preservative effect of microwaves or the bactericidal effect produced is really a function of the heat that is generated. In other words, the microwaves themselves do not result in any inactivation of foodborne microorganisms; rather, it is the heat produced by the excitation of food molecules that actually results in microbial destruction.