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RADIATION PASTEURIZATION OF FOOD

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SUMMARY

Radiation pasteurization of foods with low doses of gamma rays, X-rays, and electrons will effectively control foodborne pathogens on beef, pork, lamb, and fish. As used here *radiation pasteurization* means the destruction of pathogenic non-spore forming foodborne bacteria and parasitic organisms, such as trichina. Radiation pasteurization therefore can protect the public from diseases such as salmonellosis, hemorrhagic diarrhea caused by *Escherichia coli* O157:H7, and gastroenteritis from *Vibrio vulnificus*. Irradiation can extend the shelf lives of fruits and vegetables, and arthropod pests, e.g., insects and mites, can be sterilized or killed in a more environmentally friendly manner than is possible with ozone depleting, highly toxic fumigants. Moreover, long-term animal feeding studies have demonstrated that radiation pasteurized or sterilized foods are safe and nutritious for humans. The process has been endorsed by by the U.S. Food and Drug Administration (FDA), the U.S. Department of Agriculture (USDA), the U.S. Army, the World Health Organization (WHO), the Codex Alimentarius Commission, the American Medical Association, the American Dietetic Association, the Institute of Food Technologists, and the health authorities of approximately 40 countries.

INTRODUCTION

Although largely preventable, foodborne illness remains a serious problem in the United States. A report by the Council for Agricultural Science and Technology has estimated that foodborne diseases caused by pathogenic bacteria such as *Campylobacter*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella*, and *Staphylococcus aureus* may cause as many as 9,000 deaths each year and 6.5 to 33 million cases of diarrheal disease in the United States. The annual economic losses associated with foodborne disease may be as large as $5 billion to $6 billion. Recent outbreaks of disease caused by the ingestion of *E. coli* O157:H7 in hamburger, particularly in the northwestern United States where there were more than 700 cases and four deaths from a single outbreak, have alarmed the public. Unfortunately, this organism may cause 8,000 to 20,000 cases of disease annually in the United States.

The most common foodborne bacterial pathogens that may be found on meat and poultry are *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, various *Salmonella* spp., and *Staphylococcus aureus*. The symptoms of campylobacteriosis caused by *C. jejuni* generally are a mild diarrhea beginning 1 to 7 days after ingestion of contaminated food and may last from 1 to 7 days. Infections from *E. coli* O157:H7 can cause severe abdominal cramps and pain, bloody diarrhea, and occasional renal failure starting 3 to 7 days after ingestion of the contaminated food, lasting days to weeks, and possibly resulting in death. Listeriosis caused by infection with *L. monocytogenes* is an acute infection of the brain with or without accompanying persistence of the organism in the blood. Symptoms appear suddenly and include fever, intense headache, nausea, and vomiting. The bloodborne form of the disease is an acute, mild illness with influenza like symptoms, which in pregnant women usually results in infection of the fetus and miscarriage. Most foodborne cases of listeriosis occur among individuals with suppressed immune systems. In these individuals the mortality rate may reach 43%; overall it is 30%. *Listeria monocytogenes* can multiply in foods stored at refrigeration temperatures, so risk may increase during storage, despite proper refrigeration. Salmonellosis, caused by infection with any of over 2,500 different strains of *Salmonella*, is characterized by a mild to severe acute gastroenteritis starting 6 to 72 hours after ingestion of contaminated food and lasting for days to weeks, and causing fever, pain, diarrhea, nausea, and vomiting. *Staphylococcus aureus* can produce a heat-stable toxin in improperly stored food that, if ingested, will produce mild to severe symptoms of nausea, cramps, vomiting, diarrhea, and prostration in 2 to 7 hours lasting 1 to 2 days.

> THE RADIATION PASTEURIZATION PROCESS FOR MANY FOODS HAS BEEN APPROVED OR ENDORSED BY THE MAJOR U.S. AND WORLD AGENCIES AND ASSOCIATIONS.

Beef, pork, and other meats sometimes are contaminated by parasitic organisms that may cause disease in humans when ingested. Among these are the parasitic nematode *Trichinella spiralis*, the bovine and pork tapeworms *Cysticercus bovis* and *Cysticercus cellulosae*, and the protozoan parasite *Toxoplasma gondii*. *Trichinella spiralis* localizes in the muscles of pigs and many wild animals and when ingested by humans can cause trichinosis. Fortunately, this disease is rare in the United States. Adult tapeworms may be several feet long and occasionally infections may result from attachment of *Cysticercus bovis* to the wall of the intestine. If the larvae emerge within the intestine, they may penetrate the wall; when that happens the eyes, heart, liver, lungs, and brain may become infected. Other symptoms of infection may be abdominal pain, nausea, weakness, weight loss, hunger pains, and nervousness. In 1993, *T. gondii* caused 2,056 cases of foodborne illness in the United States at an estimated cost of $2.7 billion. In most otherwise healthy individuals, its associated disease usually is mild and self limiting. It can, however, cause diseases ranging from a rash to hepatitis in adults. Babies may be infected before birth by cross infection from the mother. These congenital infections sometimes lead to infections of the brain with death occurring in 5 to 10% of the cases. In those persons whose immune systems are not functioning at normal levels, previously benign infections of *Toxoplasma gondii* may progress to encephalitis and other infections of the central nervous system.

The Issue

Radiation pasteurization when used in conjunction with proper food processing and preparation techniques, greatly decreases the probability that foodborne pathogens associated with meat, poultry, and other foods will reach consumers.

Sources of Ionizing Radiation Approved for Food Irradiation

The FDA has approved the following sources of ionizing radiation for the treatment of foods: gamma rays produced by the natural decay of radioactive isotopes of cobalt-60 or cesium-137, x-rays with a maximum energy of five million electron volts (MeV), and electrons with a maximum energy of 10 MeV. (The electron volt [eV] is the amount of energy acquired by an electron when it is accelerated by one volt in a vacuum.) X-rays are produced when high energy electrons strike a thin metal film and are identical in their action to gamma rays. The term *ionizing* means that this form of radiation has sufficient energy to create positive and negative charges leading to the death of bacteria and other pathogens in food. Other forms of radiant energy include light, heat, microwave, and radio waves.

Safety

While food is being irradiated it is never in contact with any radioactive material, and the gamma rays, x-rays, or electrons used to treat it cannot make it radioactive. Readers can relate this to personal experience from exposure to sunlight or to being x-rayed. Although excessive exposure to sunlight and to x-rays can be harmful, appropriate exposure to radiation can be used to kill rapidly growing cells such as those in cancers. It is the rapidly growing cells of insects or spoilage and pathogenic bacteria that are killed when food is irradiated. There is little effect on the food itself because its cells are not multiplying. There are minor effects of radiation on some very sensitive vitamins, e.g., B_1 in pork. However, it has been estimated that even if all of the pork in the United States were to be irradiated, only 2.3% of vitamin B_1 in the diet of Americans would be lost. Also, a small amount of ascorbic acid (vitamin C) in fruits is converted to another equally usable form of the vitamin. In fact, multigeneration studies with animals have demonstrated that ingestion of irradiated foods is completely safe and that the nutritive value remains essentially unaltered.

MULTIGENERATION STUDIES WITH ANIMALS HAVE DEMONSTRATED THAT INGESTION OF IRRADIATED FOODS IS COMPLETELY SAFE AND THAT THE NUTRITIVE VALUE REMAINS ESSENTIALLY UNALTERED.

Spices, Herbs, and Dry Vegetable Seasonings

Even though herbs, spices, and vegetable seasonings are used in small amounts, they may introduce bacteria sufficient to cause spoilage or foodborne disease organisms in food products that must be stored or transported before consumption. Most spices are dried in the open air and become severely contaminated by air- and soil-borne bacteria, fungi, and insects. Bacterial plate counts of one to 100 million per gram of spice are not unusual. Many commercial food processors therefore fumigate spices with methyl bromide to eliminate insects or with ethylene oxide to eliminate bacteria and mold. Both methyl bromide and ethylene oxide are extremely toxic, and methyl bromide is potentially capable of depleting the atmospheric ozone layer. Ethylene oxide has been banned in Europe because of safety and environmental concerns, and its use for the treatment of ground spice has been revoked in the United States. The U.S. Clean Air Act and the Montreal Protocol of the Vienna Convention require that any substance listed as ozone depleting be withdrawn from production and use by the year 2001.

In the United States, spices, herbs, and dry vegetable seasonings currently are treated with ionizing radiation to eliminate both insects and bacteria. The FDA has approved ionizing radiation doses not to exceed 30 kilogray (kGy) for microbial decontamination of dry or dehydrated herbs, spices, and vegetable seasonings that are used in small amounts as food ingredients for flavoring or aroma. (This is a very mild treatment as a radiation dose of 1 kGy [1,000 gray], which represents the absorption of only enough energy to increase the temperature of the product by 0.43°F.) Food irradiation is replacing the use of ethylene oxide and methyl bromide and is less harmful to the spice than either heat or ethylene oxide, is more effective against bacteria than ethylene oxide, and does not leave chemical residues on products.

Fruits and Vegetables

Fruits and vegetables are being irradiated in the United States to eliminate insects and spoilage organisms and to prevent overripening and in the case of tubers and bulbs, sprouting. The use of ionizing radiation with a minimum dose of 0.3 kGy and a maximum dose not exceeding 1 kGy has been approved by the FDA for growth and maturation inhibition of fresh foods and for disinfestation of arthropod pests in food. In addition, Japan and other countries that ban the use of chemical sprout inhibitors, irradiate potatoes and onions to prevent sprouting. The shelf life of specialty, very perishable sweet varieties of onions can be extended to 3 months. Irradiation of tomatoes not only extends their shelf life but also allows them to be harvested when fully ripe. Irradiated mushrooms have a 3-week shelf life without browning or cap separation. Irradiation of strawberries extends their refrigerated shelf life to 3 weeks without decay or shrinkage. Irradiated fruit and vegetables now are available in some U.S. stores.

So that insect pests such as the fruit fly are eliminated, fruit from Hawaii and Puerto Rico and from other countries must be fumigated or treated by hot water dips before being imported into the continental United States. Even on the mainland, many fruits, grains, and vegetables must be fumigated before being transported, stored, or processed. The primary fumigant used for fruit is methyl bromide, which may be banned in 2001. Irradiation can replace fumigation for some of these commodities. Most arthropod pests, e.g., fruit flies, codling moths, mango and avocado seed weevils, scale insects, mealy bugs, and mites can be sterilized or killed by very low doses of radiation. Irradiation is a promising alternative to methyl bromide as a quarantine treatment for the codling moth on apples.

Just as with other disinfestation techniques, however, the food irradiation process must be optimized for the particular variety of fruit and its stage of maturity. Some varieties of fruit are very sensitive to radiation and the skin of the fruit is damaged. They therefore may be poorly suited for irradiation, whereas other varieties of the same fruit respond well. And, too, commodities tend to be harvested over very short periods, a practice creating huge volumes requiring rapid treatment. Very low doses of ionizing radiation can prevent the emergence of adult insects and thereby meet treatment demands. Because irradiation leaves no residues, products must be protected from reinfestation after treatment and during transport.

Use of irradiation as a quarantine control measure requires approval by both state agencies and the USDA–Animal and Plant Health Inspection Service (APHIS). If the product is to be exported, the importing country must approve the quarantine process. Because the appropriate radiation doses will cause sexual sterility of insect pests, but not necessarily kill them outright, regulatory agencies are considering the type of regulations needed to achieve quarantine security. Currently, the only applicable U.S. quarantine regulation is for the irradiation of fresh papaya fruit in Hawaii to prevent fruit fly importation to the mainland (Table 1).

Several other fruits that are available in Hawaii, but not on the mainland, have been imported and irradiated for customer acceptance trials, with excellent results. The Agricultural Research Service (ARS), APHIS, and the food industry are participating in these trials, and the federal agencies actively are considering regulations for implementation of radiation disinfestation. This technology, which for some commodities may

Table 1. U.S. approvals (kilograys) for irradiated foods

Product	Agency	Date	Dose (kGy)	Purpose
Wheat, wheat flour	FDA	1963	0.2–0.5	Insect disinfestation
White potatoes	FDA	1964	0.05–0.15	Sprout inhibition
Spice and vegetable seasonings	FDA	1983	max. 10	Microbial decontamination
Pork	FDA	1986	0.3–1.0	Trichina inactivation
Fruits and vegetables	FDA	1986	max.1.0	Insect and/or growth and maturation delay
Papaya fruit	USDA	1987	min. 0.150	Insect disinfestation
Herbs, spice, and dry vegetable seasonings	FDA	1986	max. 30	Insect disinfestation and/or microbial decontamination
Dehydrated enzymes	FDA	1986	max. 10	Microbial decontamination
Animal and pet food	FDA	1986	max. 25	Microbial decontamination
Poultry	FDA	1990	max. 3.0	Microbial decontamination
	USDA	1992	1.5–3.0	Microbial decontamination
Red meat, nonfrozen	FDA	Pending	max. 4.5	Microbial decontamination
Red meat, frozen	FDA	Pending	max. 7.0	Microbial decontamination

be the only suitable and environmentally safe replacement for methyl bromide fumigation, has the additional advantage of increasing shelf life by eliminating spoilage organisms.

Wheat and Flour

As much as 400,000 tons per year of imported wheat are irradiated with an electron beam to kill insects at the port of Odessa, Ukraine. This process was developed through U.S. Army/ARS research and approved for use in the United States in 1963 (Table 1). It has not been used in the United States because of the availability of fumigants and physical methods for separating insects from grain. All these methods have advantages and disadvantages, but neither irradiation nor physical methods leave residuals to prevent reinfestation.

In the United States, spices, herbs, dry vegetable seasonings, and fruits and vegetables currently are treated with ionizing radiation to eliminate insects, bacteria, and spoilage organisms.

Beef, Lamb, Pork, and Poultry

Relatively low doses of ionizing radiation can be used for radiation pasteurization treatments of meat or poultry to control parasites, fungi, and all but the most resistant of foodborne pathogens and food spoilage bacteria. To control *Trichinella spiralis*, both the FDA and the USDA, Food Safety and Inspection Service (FSIS) approved in 1986 the irradiation of fresh or previously frozen pork to a minimum dose of 0.3 kGy and a maximum dose not to exceed 1.0 kGy. Regulations permitting poultry irradiation to control foodborne pathogens were approved by the FDA in 1990 and by the FSIS in 1992 (Table 1). The FDA established the maximum dose as 3.0 kGy, and the FSIS established the minimum dose as 1.5 kGy. The FDA is reviewing a petition to allow radiation pasteurization of edible tissue of domesticated mammalian human food sources, primarily beef, pork, sheep, and horse.

The potential for consumer infection by pathogens is decreased greatly and shelf life is extended by radiation pasteurization of meat and poultry. This benefit can be achieved only if the highest-quality products are irradiated, preferably after packaging, to prevent recontamination. Radiation pasteurized products are neither sterile nor shelf-stable and must be properly refrigerated, cooked, and served. Irradiation serves as one of the processor's final quality control steps, assuring both the processor and the consumer of product safety. Another important advantage of radiation pasteurization of meat and poultry products is that cross contamination of other products during meal preparation is prevented. Irradiation is an effective addition to the overall control of extremely virulent pathogens, e.g., *Escherichia coli* O157:H7, in raw ground beef.

It is unlikely that all meat and poultry products ever will be irradiated; rather, irradiated meat and poultry likely will be chosen by customers who desire or require a greater degree of food safety, and by food service establishments to protect children and other high risk consumers from foodborne pathogens. The largest market for irradiated chicken currently is hospitals and nursing homes. Irradiated chicken has sold well, when offered, in retail markets.

Research has demonstrated that the number of living cells of most foodborne pathogens, including *E. coli* O157:H7, can be significantly decreased, and in many cases completely killed on meat or poultry, by treatment with ionizing radiation (Table 2). Radiation doses required to decrease pathogen numbers by 90% in beef are

Table 2. Radiation dose (kilograys) required to reduce the population of foodborne pathogens by 90% in beef at 5°C

Pathogen	Dose (kGy)
Bacillus cereus endospore	2.46 ± 0.31
Campylobacter jejuni	0.16 – 0.20
Clostridium botulinum endospore	3.43 @ –30°C
Escherichia coli O157:H7	0.30 ± 0.02
Listeria monocytogenes	0.45 ± 0.03
Salmonella species[a]	0.70 ± 0.04
Staphylococcus aureus	0.46 ± 0.02

[a] *Salmonella dublin, S. enteritidis, S. newport, S. senftenberg, and S. typhimurium.*

listed in Table 2. The parasitic nematode *Trichinella spiralis*, the bovine and pork tapeworms *Cysticercus bovis* and *Cysticercus cellulosae*, and the protozoan parasite *Toxoplasma gondii* are all inactivated by ionizing radiation doses below 1.5 kGy. *Escherichia coli* O157:H7, *Listeria monocytogenes, Salmonellae* spp., *Staphylococcus aureus*, and other foodborne bacterial pathogens can be eliminated or decreased significantly in number by treatment of meat or poultry with pasteurizing ionizing radiation doses above 1.5 kGy but below 10 kGy (Table 2).

The approved minimum ionizing radiation dose for treatment of poultry is 1.5 kGy, and the maximum dose is 3.0 kGy. The FDA currently is considering a petition from industry for approval to irradiate nonfrozen red meats with a maximum dose of 4.5 kGy and frozen red meats with a maximum dose of 7.0 kGy to control foodborne pathogens. Let us assume that a target dose of 2.5 kGy might be chosen for the irradiation of beef. Such a target will be set so that the minimum and maximum doses received by the product meet regulatory requirements. If the majority of the product received 2.5 kGy, then approximately 99.9999+% of

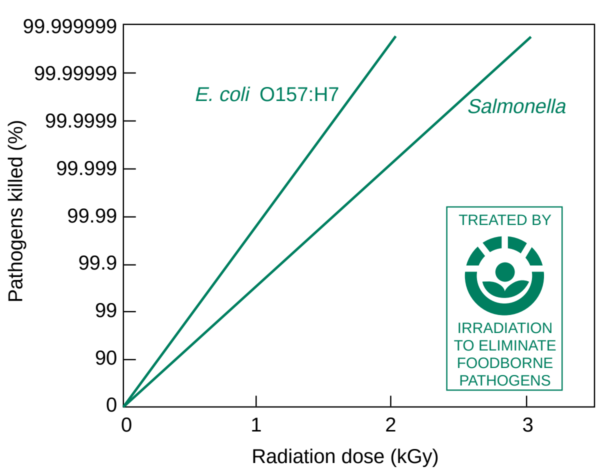

Figure 1. The percentage of *Escherichia coli* O157:H7 or *Salmonella* contaminating meat or poultry by treatment with ionizing radiation doses of 0 to 3 kilograys (kGy) at a temperature of 41°F. The symbol at the lower right of the figure is the radura symbol that has been adopted internationally as a label for irradiated food. In addition, the U.S. Food and Drug Administration requires that the label include the words "treated with radiation" or "treated by irradiation" and "keep refrigerated" or "keep frozen."

Campylobacter, 99.999+% of *E. coli* O157:H7 (Figure 1), 99.9+% of *Salmonella* (Figure 1), and 99.999+% of *Staphylococcus* cells would be killed. These results were calculated assuming irradiation at a temperature of 41°F. Further, for *Salmonella*, a rather high resistance value of 0.70 kGy was used for *Salmonella* based on the radiation resistance of a mixture of five *Salmonella* strains. Some strains of *Salmonella* are much less radiation resistant than this mixture and when present in foods such as eggs, which have higher water contents than meats do, will be even more sensitive to irradiation. Submission of a petition to the FDA and USDA to approve low dose irradiation (0.6 to 1.5 kGy) to control *Salmonella* infections in fresh whole eggs in intact shells is pending.

In general, the radiation sensitivities of a bacterial pathogen in meat and in poultry are not substantially different. Addition or removal of substantial amounts of water or of salt, however, may alter the radiation sensitivities of pathogens in processed meat or poultry. Actual number and percentage of cells that will be killed by irradiation depend on various factors such as pathogen, growth stage, absorbed radiation dose, irradiation-time temperature, oxygen presence, and water content. Resistance of bacterial pathogens is substantially greater at freezing temperatures; these effects, however, have been determined for most pathogens and are considered in the selection of appropriate radiation doses. Bacterial pathogens differ considerably in their sensitivity to ionizing radiation, and spore-forming bacteria and foodborne viruses are substantially more resistant than are purely vegetative forms of bacteria (Table 2).

Spore-forming bacterial pathogens of the genera *Bacillus* and *Clostridium* are more sensitive to heat after irradiation even though the actual numbers may be affected only slightly by pasteurization doses of radiation. The few nonspore-forming bacteria that may survive irradiation are injured severely and become much more sensitive to heat. They are, therefore, very unlikely to survive cooking.

Fish and Shellfish

Fish and shellfish are significant sources of foodborne pathogens. And irradiation has been demonstrated to control *Salmonella, Shigella, Staphylococcus aureus*, enteropathogenic *Escherichia coli, Vibrio* *cholerae, V. parahaemolyticus, V. vulnificus,* and hepatitis A virus, which all have been associated with fish and shellfish. *Vibrio vulnificus* may cause gastroenteritis or septicemia, which has a mortality rate exceeding 50%. This pathogen is associated primarily with the ingestion of contaminated raw oysters.

Frequent oyster contamination led the FDA in 1985 to advise against consumption of raw or undercooked seafood by people with hepatic disorders; this warning has affected the U.S. shellfish industry adversely. Recent data have shown that ionizing radiation doses of only 1 kGy are adequate to eliminate *Vibrio vulnificus* in oysters. When combined with a traditional *depuration*, or controlled purification, treatment, radiation doses of 2 kGy were demonstrated in 1991 to decrease significantly the number of hepatitis A virus in clams and oysters.

Although irradiation's ability to control foodborne pathogens in fish is well established, there is a concern that marine fish might be contaminated with *Clostridium botulinum* type E, which can grow at refrigeration temperatures as low as 38°F. As mentioned, *C. botulinum* is relatively resistant to radiation and will not be affected significantly by pasteurization doses; if contaminated irradiated fish are sealed in oxygen impermeable packages, *C. botulinum* type E may thrive because of decreased competition from other bacteria. The product then would become toxic without the usual signs of spoilage. This seems an unlikely event, however, considering the rarity of *C. botulinum* type E and the availability of oxygen-permeable packaging materials.

RADIATION PASTEURIZATION WHEN USED IN CONJUNCTION WITH PROPER FOOD PROCESSING AND PREPARATION TECHNIQUES, GREATLY DECREASES THE PROBABILITY THAT FOODBORNE PATHOGENS ASSOCIATED WITH MEAT, POULTRY, AND OTHER FOODS WILL REACH CONSUMERS.

STERILE PRODUCTS

Two types of food products require sterilization rather than radiation pasteurization. The first is *commercially sterile* foods, which require irradiation while frozen, must be stored frozen, and are intended for consumption by the severely immunocompromised patient. The second is both *sterile and shelf-stable* foods, or foods that can be stored for extended periods of time at room temperature without spoilage. The shelf-stable product is excellent for use by immunocompromised patients, campers, yachters, astronauts, and military personnel. Apollo 17 astronauts ate radiation sterilized ham on the moon. Radiation-sterilized, shelf-stable beef steak and smoked turkey are being consumed by astronauts, and with permission of the FDA, U.S. hospitals have used such products. Radiation sterilized meals and meal components are marketed commercially in South Africa and are used by the South African military forces. The South African process is very similar to that developed by the U.S. Army Natick Research and Development Center. The only sterile, shelf-stable meat and poultry products available commercially in the United States are canned (thermally processed) products.

Radiation sterilization allows preparation of meat and poultry products with flavor and texture characteristics different from those of thermally processed products. The techniques used to prepare sterile food by irradiation differ greatly from those used in radiation pasteurization. In sterilization, the radiation dose must ensure elimination of the most resistant bacterial pathogen, *Clostridium botulinum*. Because this is a very large dose—approximately 42 to 71 kGy depending on the product, it must be delivered to a vacuum packaged and deeply frozen product to avoid flavor change and nutrient loss. The dose selected is twelve times that required to kill 90% of the endospores of *C. botulinum.* If the product is intended to be shelf stable then it must be cooked, that is blanched, before irradiation to inactivate the meat's natural enzymes. If this is not done, the product will spoil through biochemical, enzymatic action. Prior cooking improves the flavor of radiation sterilized meat and poultry.

Excellent radiation sterilized, shelf-stable mixed vegetable and meat products are available on the South African retail market. Several radiation sterilized, shelf-stable foods used are well accepted by the South African military forces in the field.

Product Acceptance

An unfortunate misconception is that the American public will not accept irradiated food. Both attitude studies and market tests have demonstrated the contrary, i.e., when the consumer is provided accurate information about products and a choice between irradiated and nonirradiated food. In fact, recent studies have indicated that informed consumers are willing to pay a premium for irradiated poultry and pork.

> RECENT MARKET STUDIES HAVE INDICATED THAT INFORMED CONSUMERS ARE WILLING TO PAY A PREMIUM FOR

Technology

Technologies and types of equipment required to irradiate food are identical to those used to sterilize medical supplies. (See Table 3 for examples of medical items and consumer goods currently sterilized by irradiation.) Many commercial irradiation plants exist in the United States, and they have established an excellent safety record. Commercial plants using cobalt-60 as the source of radiation store it underwater when it is not in use. Cobalt pellets are encapsulated twice in stainless steel tubes arranged in racks. These racks are withdrawn from the water when materials are to be irradiated, and the food is passed through the radiation field. A maze constructed of thick concrete walls, numerous safety interlock systems, strict operating procedures, and proper training protect workers from radiation. A typical commercial irradiation plant design is shown in Figure 2.

Electron-beam and x-ray generating systems also can be used for food irradiation. Several such plants in the United States are used primarily for the sterilization of medical supplies. These systems also must provide significant amounts of shielding during operation, but require none when turned off. Electron-beams, however, have very low penetration ability and cannot be used for irradiation of thick materials. An electron-beam system is used commercially in France to irradiate minced chicken meat. Within an aseptic packaging system, low-power E-beam systems may be suitable to treat such items as single patties of hamburger. This technology may be practical because the radiation dose can be delivered to the product very rapidly. A new type of self-

Table 3. Examples of items currently sterilized with ionizing radiation

Medical/Pharmaceutical Products	
Airways and tubes	Intravenous administration sets
Alcohol wipes	Liquid detergents
Bandages	Lubrication gels
Blood	Operating room towels
Contact lenses	Petri dishes
Cotton balls	Prostheses (arterial, vascular, orthopedic)
Dental anchors, burrs, and sponges	Surgical gloves
Drug products	Surgical drapes and gowns
Drug mixing/dispensing systems	Sutures
Enzymes	Syringes and needles
Eye droppers and ointments	Thermometers/covers
Fetal probes	Tongue depressors
Instruments	Topical ointments
Consumer Products	
Adhesive bandages	Disposable nurser bottles
Animal vaccines	Food packaging
Baby bottle nipples	Pacifiers and teething rings
Contact lens cleaning solutions	Pet food
Cosmetics	Rawhide dog toys
Dairy and juice containers	Tampons

contained irradiator designed to use cesium-137 and suitable for use by small and medium-sized food processing plants is being developed. The term *self-contained* indicates that the radiation source is never exposed. In addition, both commercial and research organizations are actively developing electron-beam and x-ray generation equipment that may be suitable for food processing plants. Design and operation of food irradiators are regulated strictly by state and federal agencies.

Endorsements

The FDA has approved the irradiation of pork, poultry, fruits, vegetables, spices, dry vegetable seasonings, wheat, and wheat flour for general use, and shelf-stable steak and smoked turkey for use by astronauts. The USDA has approved regulations for irradiation of pork, poultry, and papaya fruit. The U.S. Department of Health and Human Services, the U.S. Public Health Service, the U.S. Army, the National Association of State Departments of Agriculture, the American Medical Association, the American Dietetic Association, and the Institute of Food Technologists have endorsed irradiation technology to enhance food safety. The United Nations Food and Agricultural Organization, the WHO, and the Codex Alimentarius Commission support the use of the technology for preservation of wholesomeness of food.

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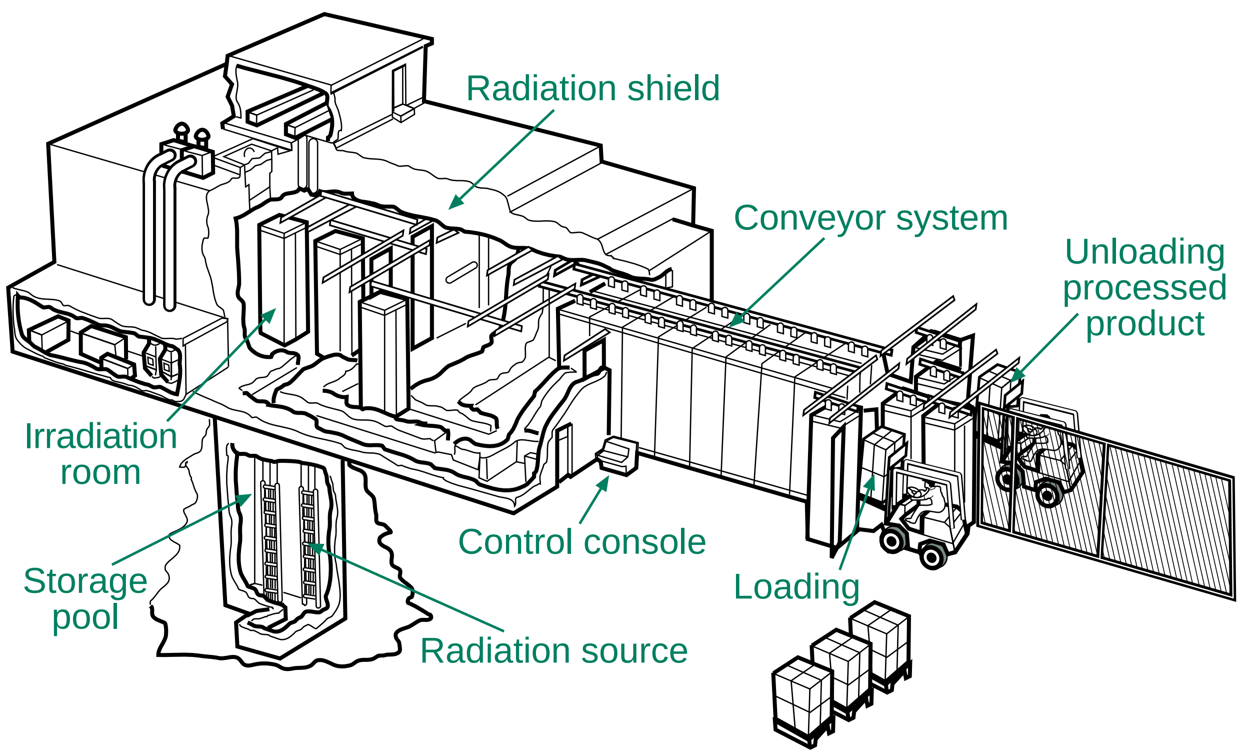

Figure 2. A typical cobalt-60 commercial irradiation facility. Several other designs are used commercially. Illustration courtesy of Nordion International, Inc., Kanata, Ontario, Canada.

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