The Irradiation of Beef Products

Contents

I. Introduction: The History of Food Irradiation

Keeping our food supply safe and abundant is a challenging task. For centuries, great efforts have been devoted to finding ways of preserving food and protecting it against microbial contamination and spoilage. Drying was one of the first techniques developed. Heating, fermenting, salting and smoking also have long histories of use in food preservation. Later innovations include the use of preservatives other than salt, canning, freezing, refrigeration and the use of crop-protecting chemicals. Now, the technique of irradiation has joined the array of food protection methods.

Food irradiation has a longer history of scientific research and evaluation prior to approval than any other food technology. Research has been global in scope and comprehensive, and has included wholesomeness, toxicological and microbiological evaluation.

Key Events: Food Irradiation Timeline

1905	Scientists receive patents for a food preservation process that uses ionizing radiation to kill bacteria in food.
1921	A U.S. Patent is granted for a process to kill *Trichinella spiralis* in meat using x-rays.
1925–27	Animal feeding studies are performed to assess the wholesomeness of irradiated food.
1943	Scientists at the Massachusetts Institute of Technology show that x-rays can be used to preserve ground beef.
1950's	Beginning of era of food irradiation in the U.S. and Europe, with studies involving wholesomeness and application of the technology dominating the research.
1953	Formation of the U.S. National Food Irradiation Program, a project of the U.S. Army and the Atomic Energy Committee.
1955–1965	The Army Medical Department oversees a program to study the safety and wholesomeness of 21 irradiated foods. The Army Surgeon General concludes that foods irradiated up to a specific dose pose no significant health risks to humans.
1958	Congress classifies irradiation as an additive; therefore, a food additive petition detailing each application is required before irradiation can be used.
1976	The Joint Expert Committee on the Wholesomeness of Foods, formed by the World Health Organization, International Atomic Energy Agency, and Food and Agriculture Organization of the United Nations, convenes with scientists and other experts to recommend that food irradiation should be classified as a process, not an additive.
1980	The Joint Expert Committee designates that foods irradiated up to 10 kGy be considered safe and wholesome.
1997	The Joint Expert Committee designates that foods irradiated at any dose should be considered as safe and as wholesome as foods treated by any other conventional process.

F.D.A.–Approved Uses of Irradiation in the Preservation of Foods

1963	Wheat and wheat powder, to disinfest from insects
1965	White potatoes, to inhibit sprouting
1983	Spices and dry vegetable seasonings, to control contamination
1985	Pork carcasses or fresh processed cuts of pork, to destroy *Trichinella spiralis*
1986	Fresh fruits and vegetables, to delay ripening and disinfest from insects
1990	Poultry, to control illness-causing microorganisms
1997	Red meats, to control foodborne pathogens and extend shelf-life

II. The FDA Decision

Although proper handling practices and cooking to recommended internal temperatures are effective interventions in preventing foodborne illness, much research has gone into the development of other interventions aimed at reducing the presence of microbial pathogens. Irradiation is one such intervention.

On December 2, 1997, the FDA approved the irradiation of meat products (fresh and frozen beef, lamb and pork) for controlling disease-causing microorganisms such as *Escherichia coli O157:H7, Salmonella, Listeria* and other foodborne pathogens.

The FDA concluded that irradiation is effective in reducing pathogenic microorganisms in or on meat, and that it does not compromise the nutritional quality, taste or texture of treated products.

The decision was based on the FDA's thorough scientific review of national and international research on the effects of irradiation on a wide variety of meat products. The scope of studies examined by the FDA included the chemical effects of irradiation on meat, the potential toxicity of irradiated meat, the effect of irradiation on microorganisms in or on meat and the impact of this process on the nutritional value of red meats.

In 1992, the USDA approved fresh and frozen poultry irradiation at doses from 1.5 kGy to 3.0 kGy. Approval is also pending for red meat irradiation at 4.5 kGy and 7.0 kGy for frozen beef, pork, veal and lamb.

FDA Ruling (December 2, 1997):

The Food and Drug Administration (FDA) is amending the food additive regulations to provide for the safe use of a source of ionizing radiation to treat refrigerated (4.5 kGy maximum permitted dose) or frozen (7.0 kGy maximum permitted dose) uncooked meat, meat by-products and certain meat food products (e.g., ground beef and hamburger) to control foodborne pathogens and extend product shelf-life.

III. The Process of Beef Irradiation

Food irradiation is the controlled treatment of foods with ionizing energy, a part of the electromagnetic energy spectrum that also includes radio and television waves, microwaves, infrared radiation, visible light and ultraviolet radiation. Ionizing radiation has a shorter wavelength and consequently higher energy than other radiation in the spectrum.

Levels of absorbed radiation are measured in kilograys (kGy). The scientific community has defined three levels of food irradiation (Table 1).[1] Again, the FDA has approved medium-dose treatments for fresh and frozen meats.

Table 1

Scientific Definitions of Radiation Doses for Food Irradiation

Level	Dose	Effect
Low dose	≤ 1 kGy	Kills insects on fruits and grains, and kills or prevents the maturation of *Trichinella* (the parasite that causes trichinosis) in pork.
Medium dose	1–10 kGy	Kills most of the bacteria that cause foodborne illness and spoilage.
High dose	>10 kGy	Sterilizes meat and other foods and decontaminates herbs and spices. Spices may also be irradiated at doses less than 10 kGy.

Source: Food Marketing Institute

There are three main types of ionizing radiation:

- gamma rays from a radioactive source, such as Cobalt-60 (^{60}Co) or Cesium-137 (^{137}Cs)
- high-energy electrons produced by an electron beam accelerator
- X-rays

Food irradiation in the U.S. relies primarily on the use of ^{60}Co,[2] which decays quickly because it has a relatively short half-life of about five years. However, linear accelerators, which generate electrons, and X-rays are also used. For example, there is an X-ray facility being built in Hawaii, as well as a new e-beam facility for meat.

When beef is irradiated, it is enclosed in an aluminum box and placed on a conveyor belt. The aluminum box passes through an enclosed chamber, or "irradiator." In the case of a gamma facility, the food is exposed to an ionizing energy source contained in stainless-steel tubes. In the case of a linear accelerator facility, the food is exposed to electrons or X-rays, which are delivered in rapid pulses. The irradiator emits short wavelengths of energy that pass through the aluminum box and the food. With either source, the box continues on the conveyor belt, separated from untreated food by a barrier wall. Some electron accelerators can be designed to generate only electrons and thus can be used inside a food processing plant with just a few inches of shielding surrounding the source.

High-energy ionizing radiation produces positive and negative charges that disable bacterial reproduction, thereby eliminating the threat to human health. The process of food irradiation is often called "cold pasteurization," because it kills most bacteria without the use of heat. This means that food can be irradiated within its packaging and remain protected against recontamination until opened by users.

1. Food Marketing Institute. "Food Irradiation Backgrounder." 1997.
2. American Dietetic Association Position Paper on Food Irradiation. 1995.

The duration of exposure to an energy source (gamma, electron beam, X-rays), the density of a food and the amount of energy emitted by an irradiator determine the dose of radiation to which a food is exposed. Regulated doses are set at the maximum doses allowed to achieve specified purposes or benefits (Table 2). Radiation dosages allowed by the FDA are among the lowest allowed in countries where irradiation is approved.

The same irradiation process is used to sterilize contact lens solutions, pacifiers and hospital supplies such as gloves, sutures and gowns. Just as the process does not add radioactive material to these products, the amount of energy in the approved doses does not add radioactive material to foods. Chemicals called radiolytic products are created when any material is irradiated, but they are not radioactive and the FDA has found them to pose no significant health hazard. In fact, the same kinds of chemicals are formed when food is cooked, often in higher quantities than if irradiated. A good example is the formation of benzene, which is produced in boiled eggs at levels 2,000 times higher than in irradiated eggs. American astronauts have eaten irradiated foods treated with high sterilization doses on missions since 1972.

As part of its approval, the FDA requires that irradiated foods include labeling with the statement "treated with radiation" or "treated by irradiation" and the international symbol for irradiation, the "radura" (shown below).

Table 2

Current FDA–Approved Irradiation Doses

Food	Approved Use	Dose
Spices and dry vegetable seasonings	Decontaminates/controls insects and microorganisms	30 kGy
Dry or dehydrated enzyme preparations	Controls insects and microorganisms	10 kGy
Fresh foods	Delays maturation	1 kGy
Poultry	Controls disease-causing microorganisms	3 kGy
Red meats (such as beef, lamb and pork)	Controls spoilage and disease-causing microorganisms	Fresh: 4.5 kGy Frozen: 7 kGy

Source: Henkel, John. "Irradiation: A Safe Measure for Safer Food," *FDA Consumer Magazine,* May–June 1998.

Environmental Safety of Food Irradiation

The irradiation of food poses minimal risk to workers in irradiation plants or communities where irradiation plants are located.[3] The equipment and plants used in the irradiation of food are similar to those used safely in the radiation sterilization of medical devices. In fact, the radiation sources used in food irradiation cannot overheat, explode, leak or in any other way be released. This means that it is virtually impossible for a food irradiation plant to "melt down."[4] The safety record of the irradiation industry is superior to that of almost all other industries.

3. International Consultative Group on Food Irradiation. "Facts About Food Irradiation." Vienna: International Atomic Energy Agency. 1991.

4. Ibid.

IV. Irradiation and Food Safety

The safety of food irradiation has been studied as extensively as any other food preservation process, including canning, freezing, dehydration and the use of chemical additives.[5] The results of this scientific research have shown that irradiated foods are as safe or safer than foods treated by the other processes. Health authorities worldwide have based their approvals of irradiation on the results of sound scientific and medical research, including investigations in the following areas:

- Radiation chemistry (see right)
- General toxicology and animal testing (see section V)
- Microbiology (see section V)
- Nutrition and aesthetics (see section VI)

A joint committee of international governmental authorities[6] concluded that "irradiation of any food commodity at any dose introduces no toxicological hazard; hence, toxicological testing of food so treated is no longer required."[7] The Joint Expert Committee on the Wholesomeness of Irradiated Food (JECFI) also stated that irradiation of food up to a dose of 10 kGy (higher than most doses used in food irradiation) introduces no special microbiological or nutritional problems. Investigations since 1981 have continued to support JECFI's confidence in the safety of food irradiation.[8]

It is important to note that irradiation does not make foods radioactive. The food irradiation process moves food through a radiant energy field, but the food never touches the energy source. The amount of energy used to irradiate foods is enough to kill foodborne bacteria but not enough to make the food itself radioactive. Think of the irradiation process as the way a luggage scanner works when you go through a security checkpoint at the airport.

Radiation Chemistry

Substantial information has been collected on the chemical changes that occur when foods are irradiated. Sensitive analytical techniques have identified many of the radiolytic products, and most have proved to be familiar substances that exist in non-irradiated foods or are produced in foods by conventional processes such as cooking. No truly unique substances have been identified, and no significant evidence of a hazard to human health has been found.[9]

In reviews of the irradiation process, FDA scientists concluded that irradiation reduces or eliminates pathogenic bacteria, insects and parasites.[10] It also reduces spoilage and, in certain fruits and vegetables, inhibits sprouting and delays the ripening process.[11] It does not make food radioactive, compromise nutritional quality

5. Greenberg, R. "Irradiated Foods." New York: American Council on Science and Health. 1996.
6. JECFI, a committee of the FAO (Food and Agricultural Organization of the United Nations); the IAEA (International Atomic Energy Agency) and WHO (World Health Organization).
7. Joint FAO/WHO/IAEA Expert Committee. "Wholesomeness of Irradiated Food." Report No. 659, World Health Organization. Geneva, Switzerland; 1981.
8. "Safety and Nutritional Adequacy of Irradiated Food." Report No. 659, World Health Organization. Geneva, Switzerland; 1994.
9. Thayer, D.W. "Wholesomeness of Irradiated Foods." *Food Technology*. 1994;48:124.
10. Institute of Food Technologies. "Food Irradiation: A Backgrounder of the Institute of Food Technologists." December 1997.
11. Ibid.

or noticeably change food taste, smell, texture or appearance as long as it is applied properly to a suitable product.[12] In fact, irradiation cannot make foods radioactive because the energy level used in food irradiation is about 10 times less than that needed to activate materials even for a fraction of a second.

Factors Affecting the Radiation Chemistry of Foods

The radiation chemistry of foods is affected by three major factors: dose, physical state of a food and ambient atmosphere.

- **Dose:** the amounts of radiolytic products generated in a particular food have been shown to be directly proportional to the radiation dose.[13,14,15]
- **Physical state of a food:** the extent of chemical change that occurs in a particular food in the frozen state is less than the change that occurs in the same food in the non-frozen state. This is a result of the reduced mobility, in the frozen state, of the initial products of irradiation (free radicals). Because of their reduced mobility, these free radicals tend to recombine to form the original substance rather than to diffuse through the food to react with other components of the food matrix and thereby form different substances.[16,17] This also means that higher radiation doses are needed to accomplish the same antimicrobial effect in a frozen food versus a non-frozen food of the same type.
- **Ambient atmosphere:** irradiation in an atmosphere of high oxygen content generally produces both a greater variety and a greater amount of radiolytic products. This is because irradiation initiates certain oxidation reactions that occur with greater frequency in foods with high fat content.[18,19] The final products of radiation-induced oxidation reactions in foods are similar to those produced by oxidation reactions induced by other processes (e.g., storage or heating in air). Therefore, irradiation is often conducted at reduced oxygen levels or on food in the frozen state.

12. Institute of Food Technologies. “Food Irradiation: A Backgrounder of the Institute of Food Technologists.” December 1997.
13. Merritt, C., Jr. “Qualitative and Quantitative Aspects of Trace Volatile Components In Irradiated Foods and Food Substances.” *Radiation Research Reviews*, 3:353-368, 1972.
14. Morehouse, K. M., “The Quantitative Determination of Radiolytically Generated Hydrocarbons in Meats.” Final report for U.S. Army, Natick Research Development and Engineering Center, Sustainability Directorate, under Interagency Agreement FDA 224-93-2448.
15. Merritt, C., Jr., et al., “Effect of Radiation Parameters on the Formation of Radiolysis Products in Meat Substances.” *Journal of Agricultural and Food Chemistry*, 26:29-35, 1978.
16. Ibid.
17. Taub, I. A. et al., “Factors Affecting Radiolytic Effects In Food.” *Radiation Physics and Chemistry,* 14:639-653, 1979.
18. Diehl, J. F., “Radiolytic Effects in Foods.” pp. 279-357, in *Preservation of Foods By Ionizing Radiation,* Vol. 1, E. S. Josephson and M. S. Peterson, eds., CRC Press, Boca Raton, Fl., 1982.
19. Diehl, J. F., “Chemical Effects of Ionizing Radiation.” pp. 43-88, in *Safety of Irradiated Foods,* Marcel Dekker, New York, 1995.

V. Impact of Food Irradiation on Human Health

Many studies have been conducted to evaluate the safety of irradiated foods and their effects on the growth, reproduction and general health of animals. Animal feeding studies have consistently found no evidence of a health hazard.

As discussed in detail in section VI, irradiation does cause changes in food, but these all have been found to be benign. More than 40 years of multispecies, multigenerational animal studies have shown no toxic effects from eating irradiated foods.[20] Having reviewed the data, the FDA determined that irradiation at doses of up to 4.5 kGy for refrigerated products and doses of up to 7.0 kGy for frozen products would significantly reduce the number of pathogenic microorganisms in or on meat.[21]

Toxicological Studies

Based on chemical analyses, animal feeding tests and consumption by human volunteers, sound scientific studies indicate that the radiolytic products produced by irradiation pose no risk to humans. In fact, people requiring the safest food, hospital patients in the U.S. and the U.K. receiving bone marrow transplants, are given irradiated foods at higher dosages.

Analyses of irradiated flesh foods show that a toxicological hazard due to the consumption of irradiated flesh foods is highly unlikely because no substance resulting from irradiation has been found at levels that justify toxicological concern.

Feeding Studies:

Feeding studies (evaluated by both the FDA and WHO) conducted in rats, mice and dogs with flesh foods irradiated at doses between 6 and 74 kGy indicate no toxic effects attributed to radiation treatment.[22] One of the most notable of these studies was a six-year feeding study conducted for the U.S. Army and U.S. Department of Agriculture (USDA) involving high-dose irradiated chicken. More than 600,000 lbs. of irradiated chicken were fed to several generations of test mice, hamsters, rats, rabbits and dogs. These investigations also included a human feeding trial in China in which 21 male and 22 female volunteers consumed irradiated foods as 62-71 percent of their total caloric intake for 15 weeks.[23] No evidence was found that irradiated chicken would pose any toxicological hazard to humans.[24]

Reproduction and Teratology Studies:

The FDA has also reviewed reproduction/teratology studies in which flesh foods, irradiated at doses of 6 kGy or higher, were fed to laboratory animals. These studies concluded that irradiated flesh foods show no adverse effects on reproductive or developmental endpoints that can be attributed to radiation treatment.

20. Nawar, W. W. "Volatiles from Food Irradiation." *Food Reviews International,* 2:45-78, 1986.

21. Olson, D. "Irradiation of Food." *Food Technology,* January 1998, Vol. 52, No.1.

22. WHO, "Safety and Nutritional Adequacy of Irradiated Food." World Health Organization, Geneva, 1994.

23. Loaharanu P., Chi H., Shiping G., et al. "A feeding trial of irradiated diet in human volunteers." FAO/ISEA Seminar for Asia and the Pacific on Practical Applications of Food Irradiation. Shanghai, China; 1986.

24. Thayer D.W., Christopher J.P., Campbell L.A., et al. "Toxicology studies of irradiation-sterilized chicken." *Journal of Food Protection*. 1987;50:278.

Genetic Toxicity Studies:

Although chronic feeding studies are the primary basis for assessing potential carcinogenicity of a substance, genetic toxicity tests are often used to screen for possible carcinogenic effects. A large number of genetic toxicity studies with irradiated chicken, ham, beef or fish have been conducted. All of these studies report that no genotoxic effects were observed, leading the FDA to conclude that irradiated flesh foods are not genotoxic.

Microbiological Studies

Meat is a nutrient-rich substrate that can support the growth of a variety of microorganisms. During the initial processing steps (e.g., harvesting, chilling, fabricating, etc.), the microbiological profile may include a wide variety of nonpathogenic and pathogenic organisms.

The effects of irradiation have been studied on many microorganisms, including various species of *Salmonella, E. coli O157:H7*, *Staphylococcus aureus, Listeria monocytogenes, Bacillus cereus, Campylobacter jejuni* and the protozoan parasite *Toxoplasma gondii*. These studies have established that the radiation dose necessary to reduce the initial population of any of the bacterial pathogens by 90 percent (called the "D-value") ranges from 0.1 kGy to just under 1 kGy. For any individual pathogen, the D-value varies depending on such factors as the specific food, physical state (frozen versus non-frozen), temperature and ambient oxygen level. D-values for the principal nonpathogenic microorganisms commonly found in or on meat (spoilage bacteria) cover a wider range, from approximately 0.3 to 2.0 kGy.

The primary method for controlling the growth of pathogenic microorganisms is storage at refrigeration or freezer temperatures. The temperature and humidity at which meat is stored influence the type, growth pattern and number of different microorganisms likely to be present.

After harvesting, beef is chilled and subsequently stored under refrigeration (37-45°F) immediately following the initial processing steps.[25] During cold storage, the predominant microorganisms are the spoilage bacteria, primarily *Pseudomonas sp.*, which are capable of growth at these temperatures. If the chilled meat is packaged in an environment with reduced oxygen content, other spoilage bacteria, such as *Lactobacillus sp., Brochothrix thermosphacta* and other lactic acid-producing microorganisms, predominate.[26]

The growth of *Salmonella* and *E. coli O157:H7* can be controlled by cooling meat quickly after harvesting and maintaining the product at refrigerated temperatures during subsequent transport and storage. None of these pathogens is normally capable of growth in meat stored under refrigeration. In addition, competition with the more

25. *Federal Register:* December 3, 1997: Vol. 62, No. 232.
26. Ibid.

numerous and faster-growing spoilage bacteria that predominate at refrigeration temperatures further inhibits the growth of these pathogens. Both *Salmonella* and *E. coli O157:H7* are capable of significant growth, however, in meat stored above refrigeration temperatures (>50°F). Temperature control is thus a primary tool in reducing the growth of, and consequently minimizing the risk from, these pathogens.

Nevertheless, the FDA has considered the effects of temperature abuse on the growth of these pathogens in irradiated meat. In one such study,[27] pork was packaged and irradiated at 1.75 kGy under a modified atmosphere containing no oxygen following inoculation with high levels of any one of several pathogens. In this study, the authors reported that growth of these pathogens (*Salmonella* and *E. coli,* among others) was in fact decreased by irradiation even when temperature conditions were favorable for growth (approximately 60°F).

Scientists have also done studies to determine whether combined treatments of irradiation and bacteria-fighting substances are effective in eliminating *Salmonella.* For example, one study subjected chicken carcasses infected with *Salmonella virchow* to three different disinfectants: calcium hypochlorite, lactic acid and hydrogen peroxide. Five carcasses and one control carcass were used to test each concentration of disinfectant at varying ascending doses of irradiation (from 2 to 7 kGy). All irradiated carcasses showed a decrease in the presence of *Salmonella virchow;* however, it was only with an irradiation dose of 7 kGy that *Salmonella* was eliminated.[28] Another study, also using chicken, combined irradiation treatments, both in a vacuum and in air, with natural plant extracts to determine if a combination treatment would lower the dosage of irradiation necessary to eradicate *Salmonella.* In the study, chicken legs were irradiated at doses of 0, 3 and 5 kGy. By itself, irradiation in air at 3 kGy appeared to extend the shelf-life of the chicken by a factor of 2. The study found that when the chicken marinated in natural plant juices was irradiated at 3 kGy, or was irradiated at 5 kGy without marinating, the microbial shelf-life was extended by a factor of 7 to 8, and no *Salmonella* was observed until the twelfth day. This study also found that irradiation performed under a vacuum impedes the effective eradication of *Salmonella.*[29]

A third study utilized high- and low-fat ground beef samples to determine the resistance of *Salmonella, E. coli O157:H7* and *Campylobacter jejuni* to gamma irradiation in frozen or refrigerated beef. Irradiation doses used in the study ranged from 0 to 2.5 kGy. *Campylobacter jejuni* was found to have the lowest resistance to irradiation (D-value, 0.175-0.235), and *Salmonella* the highest (D-value, 0.618–0.800). *E. coli O157:H7* demonstrated a moderate level of

27. Grant, I. R. and M. F. Patterson, "Effect of Irradiation and Modified Atmosphere Packaging on the Microbiological Safety of Minced Pork Under Temperature Abuse Conditions." *International Journal of Food Science and Technology,* 26:521-533, 1991.

28. Nassar TJ, et al., "Decontamination of Chicken Carcasses Artificially Contaminated with Salmonella." *Rev Sci Tech* (France), 16(3), pp. 891-7, December 1997.

29. Mahrour, A, et al., "Antimicrobial Properties of Natural Substances in Irradiated Fresh Poultry." *Radiation Physics and Chemistry*, 52/1-6 (81-84), 1998.

resistance (D-value, 0.241-0.307), requiring higher doses of irradiation when frozen. It is interesting to note that the fat content of the beef samples did not change the dose of irradiation needed to eradicate *E. coli O157:H7*. However, the treatment of *Campylobacter jejuni* was affected by fat content and temperature—the pathogen was more resistant to irradiation in low-fat frozen beef.[30]

While these studies indicate that most pathogens are highly sensitive to irradiation treatment, they also suggest that food irradiation is not a substitute for proper food storage and handling procedures.

30. Clavero, M.R., et al., "Inactivation of Escherichia coli O157:H7, salmonellae, and Campylobacter jejuni in Raw Ground Beef by Gamma Irradiation," *Appl Environ Microbiol,* 60 (6), pp. 2069-75, June 1994.

VI. Impact of Food Irradiation on the Nutritional Value and Aesthetic Qualities of Foods

Studies have shown that low- and medium-dose irradiation treatments, such as the type used for meats, do not cause significant decreases in the nutritional quality of foods. High-dose treatments (sterilization) cause small, but measurable losses of some vitamins; however, these losses are similar to those caused by other processing techniques, such as canning, drying and heat pasteurization, which produce a similar degree of preservation.[31] Such losses therefore are not considered a drawback to the use of irradiation for food preservation.

Beef, like other flesh foods, has a very low carbohydrate content, and it is composed primarily of water (56-65 percent), proteins (17-20 percent) and lipids (15-25 percent). Beef is a rich source of protein, iron, zinc and phosphorus, and contributes significantly as a dietary source of B-vitamins.

In foods with a high water content, such as beef, free radicals produced by radiolysis of water form the majority of the initial products of the radiation-induced chemical reactions. These free radicals, in turn, react with the other components of the food to form the final stable radiolytic products. The resulting small amounts of radiolytic products derived from proteins are similar to those found in foods that have not been irradiated.

- **Proteins** are composed of amino acids joined by peptide bonds. The sequence of amino acids is known as the primary structure; the extent and nature of the coiling or pleating of segments is known as the secondary structure; and the overall 3-D shape is known as the tertiary structure.
- **Denaturation** is a change in structure (usually secondary or tertiary) that results in loss of biological properties.

Effect of Irradiation on Proteins

Irradiation can cause several types of reactions:

1. breaking of a small number of peptide bonds to form shorter polypeptides;[32,33]

2. radiation-induced aggregation or cross-linking of individual polypeptide chains, resulting in protein denaturation;[34]

3. reaction of amino acids in the polypeptide chain with the free radicals produced from water, without the breaking of peptide bonds.[35]

Studies have established that there is little change in the amino acid composition of flesh foods irradiated at doses below 50 kGy,[36] a dose approximately seven times greater than the highest dose approved by the FDA. These changes are similar to those that occur as a result of heating, but in the case of irradiation, such changes are far less pronounced and the amounts of radiolytic products generated are far lower.

31. Taub, I. A. et al., "Factors Affecting Radiolytic Effects In Food." *Radiation Physics and Chemistry,* 14:639-653, 1979.
32. Taub, I. A. et al., "Effect of Irradiation on Meat Proteins." *Food Technology,* pp. 184-193, May 1979.
33. Merritt, C., Jr., and Taub, I. A., "Commonality and Predictability of Radiolytic Products In Irradiated Meats." pp. 27-58, in *Recent Advances In Food Irradiation,* P. S. Elias and A. J. Cohen, eds., Elsevier, Amsterdam, 1983.
34. Taub, I. A. et al., "Effect of Irradiation on Meat Proteins." *Food Technology,* pp. 184-193, May 1979.
35. Taub, I. A., "Reaction Mechanisms, Irradiation Parameters, and Product Formation." pp. 125-166, in *Preservation of Food by Ionizing Radiation,* Vol. 2, E. S. Josephson and M. S. Peterson, eds., CRC Press, Boca Raton, Fl., 1982.
36. Josephson et al., "Nutritional Aspects of Food Irradiation: An Overview." *Journal of Food Processing and Preservation,* 2:299-313, 1979.

- The **lipids** (fats) in meat are composed primarily of triglycerides, each molecule of which contains three fatty acids.
- The predominant fatty acids in the triglycerides of beef are oleic, palmitic, linoleic and stearic acid.

Effect of Irradiation on Lipids

The radiation chemistry of lipids (fats) also is well established. Numerous studies have been performed with various oils and fats as well as on the lipid fraction of irradiated foods. A variety of radiolytic products derived from lipids have been identified, including fatty acids, esters, aldehydes, ketones, alkanes, alkenes and other hydrocarbons.

Results of these chemical analyses, performed on frozen beef irradiated under vacuum at a dose of 56 kGy, identified 65 volatile radiolytic products, most of which originated from the lipid fraction. These 65 radiolytic products were either identical or structurally similar to substances found in foods that have not been irradiated. Also, the individual radiolytic products were produced in very small amounts (generally 1 to 700 parts per billion of irradiated beef), even at a radiation dose eight times higher than the approved dose.[37]

Effect of Irradiation on Vitamins and Minerals

Minerals such as iron, phosphorus and calcium also are unaffected by irradiation.[38,39] Studies also have reported insignificant effects on the levels of B-vitamins (other than thiamine, which is not a major micro-nutrient in beef) when red meats are irradiated. For example, irradiated meat shows no detectable loss in cobalamin (a derivative of vitamin B_{12}) or niacin (5 kGy) levels,[40] or in pyridoxine or pantothenic acid levels.[41] Another study compared radiation-induced reductions in thiamin and riboflavin levels in beef, lamb, pork and turkey, all of which were irradiated at 41°F in the presence of oxygen, conditions that would tend to maximize vitamin loss. Even under such conditions, losses of riboflavin resulting from irradiation were virtually undetectable at radiation doses up to 3 kGy, and the losses did not differ significantly among the various flesh foods. Above 3 kGy, the average incremental loss of riboflavin was reported to be 2.5 percent per kGy, which was considered by the authors as insignificant in the context of the total diet.[42]

Effect of Irradiation on the Aesthetic Qualities of Food

Sensory qualities such as appearance, smell and flavor have been evaluated in the laboratory and in market studies with consumers. In general, when meats are irradiated at appropriate doses and

37. Chinn, H. I. (Chairman, Select Committee on Health Aspects of Irradiated Beef), "Evaluation of Health Aspects of Certain Compounds Found in Irradiated Beef." Federation of American Societies for Experimental Biology (FASEB), Bethesda, MD, 1977. Chinn, H. I., "Supplement I. Further Toxicological Considerations of Volatile Compounds." FASEB, Bethesda, MD, 1979. Chinn, H. I., "Supplement II. Possible Radiolytic Compounds." FASEB, Bethesda, MD, 1979.
38. Diehl, J. F., "Nutritional Adequacy of Irradiated Foods." pp. 241-282, in *Safety of Irradiated Foods,* Marcel Dekker, New York 1995.
39. Josephson, E. S. and M. H. Thomas, "Nutritional Aspects of Food Irradiation: An Overview." *Journal of Food Processing and Preservation,* 2:299-313, 1978.
40. Fox, J. B., Jr., et al., "Effect of Gamma Irradiation on the B Vitamins of Pork Chops and Chicken Breasts." *International Journal of Radiation Biology,* 55:689-703, 1989.
41. Thayer, D. W., J. B. Fox, Jr., and L. Lakritz, "Effects of Ionizing Radiation on Vitamins." pp. 285-325, in *Food Irradiation,* S. Thorne, ed., Elsevier Applied Science Publishers, London, 1991.
42. Fox, J.B., et al., "Effect of Gamma Radiation on Thiamine and Riboflavin in Beef, Lamb, Pork and Turkey." *Journal of Food Science* (60) 3:596-598, 1994.

under certain conditions (low oxygen or oxygen-free), with specific packaging (vacuum-sealed) or in the frozen state, there is no significant development of off-odors or flavors.[43] A 1972 study determined that the threshold doses for irradiation odor vary depending on type of meat: 1.5 kGy for turkey to 6.25 kGy for lamb.[44] Another study by Fu et al. noted an off-odor in ground beef irradiated at a level of 2 kGy.[45] Further studies found that the flavor of vacuum-packed raw or cured pork meat is not negatively affected by irradiation and that cooked pork ranks equally with non-irradiated samples for overall acceptance, meatiness, freshness, tenderness or juiciness.[46,47] It is difficult to ascertain the source of an off-odor because sensory changes may be related to changes occurring during post-irradiation storage. A 1998 study discovered that irradiated meat produces more volatiles than non-irradiated meat, and while these volatiles were not directly related to lipid oxidation, they could influence irradiation odor.[48]

Meat color can also be affected by irradiation, in combination with specific packaging atmosphere conditions. When irradiated ground beef is stored under vacuum, the meat is darker and more red than irradiated beef stored under air.[49] However, Taub et al. noted similar color changes in cooked beef when the metomyoglobin (heme-pigment) in the meat was reduced due to an absence of oxygen.[50] Myoglobin may also be affected by irradiation depending on the different heme-pigment and lipid contents in each meat sample and how the sample reacts to distinct irradiation and packaging conditions.[51]

As a panel, consumers were asked to compare samples of raw beef that had been irradiated under vacuum at 1.03 kGy to 1.54 kGy with non-irradiated samples. These consumers could detect no difference in the surface or interior color of the beef patties.[52] By day 15 of storage, the beef patties that had been irradiated at 1.54 kGy still had no spoilage odor and showed better interior color than the control samples. Consumers noticed that the irradiated samples had a slight odor immediately after irradiation; however, the odor quickly disappeared when the meat was exposed to air.

In conclusion, studies show that irradiated beef is not adversely affected by the irradiation process, quality and shelf-life are actually improved[53] by irradiation, and there is no noticeable difference between irradiated and non-irradiated meats when cooked.

43. Olson, Dennis G., "Irradiation of Food." Scientific Status Summary, Institution of Food Technologists Expert Panel on Food Safety and Nutrition, 1998.
44. Ibid
45. Murano, et al., "Irradiated Ground Beef: Sensory and Quality Changes During Storage Under Various Packaging Conditions." *Journal of Food Science* Vol. 63, No. 3, pp. 548-551, 1998.
46. Ibid
47. Ahn, et al., "Packaging and Irradiation Effects on Lipid Oxidation and Volatiles in Pork Patties." *Journal of Food Science,* Vol. 63, No. 1, pp. 15-19, 1998.
48. Ahn et al., "Effect of Muscle Type, Packaging, and Irradiation on Lipid Oxidation, Volatile Production, and Color in Raw Pork Patties." *Meat Science,* Vol. 49, No. 1, pp. 27-39, 1998.
49. Murano, et al., "Irradiated Ground Beef: Sensory and Quality Changes During Storage Under Various Packaging Conditions." *Journal of Food Science* Vol. 63, No 3, pp. 548-551, 1998.
50. Ibid
51. Ahn et al., "Effect of Muscle Type, Packaging, and Irradiation on Lipid Oxidation, Volatile Production, and Color in Raw Pork Patties." *Meat Science,* Vol. 49, No. 1, pp. 27-39, 1998.
52. Andrews, et al., "Food Preservation Using Ionizing Radiation." *Rev. Environ. Toxicol.* 154:1-53, 1998.
53. Murano, et al., "Irradiated Ground Beef: Sensory and Quality Changes During Storage Under Various Packaging Conditions." *Journal of Food Science,* Vol. 63, No. 3, pp. 548-551, 1998.

VII. Talking With Consumers: Frequently Asked Questions and Answers

Q1. Why irradiate food?

A1. Irradiation can improve the quality, variety and safety of foods. Although other processing plant measures can reduce bacteria levels in raw foods, irradiation is more effective because it can eliminate pathogens such as *E. coli 0157:H7*, especially important for consumers who prefer their meat medium or rare. Unlike cooking, which also can eliminate pathogens, irradiation does not change the fresh character of foods. In fact, it extends the freshness of foods, delays the ripening of fruit and prevents the sprouting of vegetables.[54]

Q2. What is food irradiation?

A2. Food irradiation is the process of exposing food products to ionizing radiation for a specified length of time. The amount of exposure is controlled to produce various preservation effects, such as retarding spoilage or killing any harmful bacteria. It serves as a complement to good manufacturing practices—quality control, pathogen reduction and control—and is part of an overall food safety protection system. Just as any spoilage or potentially harmful bacteria in milk are killed through pasteurization using heat, irradiation kills most harmful bacteria in other foods. In fact, food irradiation is often called "cold pasteurization," because it destroys bacteria without the use of heat.

Q3. Is irradiated food safe?

A3. Food irradiation has been studied for more than 40 years and has not been found to cause harm to human health. People requiring the safest food, hospital patients receiving bone marrow transplants, are given irradiated foods. American astronauts on space missions have eaten irradiated foods since 1972. Irradiated wheat flour, potatoes and spices have been available for more than 15 years.

Food irradiation is the most extensively studied food processing technology available. The first patents for food irradiation were granted in the United States and the United Kingdom in 1905. Since then, the U.S. government and other governments worldwide have reviewed hundreds of studies on the effects of food irradiation.

In the United States, the FDA has approved food irradiation to extend shelf-life and to kill microbial pathogens and insects. Food irradiation has been approved for fruits, vegetables, grains, spices, poultry, beef, pork and lamb. In fact, the U.S. has one of the most restrictive policies on food irradiation processes in the world among those countries that have approvals for food irradiation.

In addition to receiving FDA approval, the safety of food irradiation and its use for a wide range of food products has been

54. Institute of Food Technologies. "Food Irradiation: A Backgrounder of the Institute of Food Technologies." December 1997.

accepted by the World Health Organization, the American Medical Association's Council on Scientific Affairs, the Centers for Disease Control and Prevention, The American Dietetic Association, the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency. Worldwide, food irradiation has been approved by about 40 countries.

Q4. Are irradiated foods in the marketplace?

A4. Irradiated wheat flour, potatoes and spices have been available for more than 15 years. More recently, irradiated produce and poultry have been sold in some American supermarkets. Following the FDA approval of food irradiation for beef, pork and lamb in December 1997, meat processing guidelines were developed by the USDA and additional irradiated meat is expected to be in the U.S. marketplace soon. In Europe, over 40 types of irradiated food are being marketed to consumers.

Q5. Does irradiation make foods radioactive?

A5. No. The food irradiation process moves food through a radiant energy field, but the food never touches the energy source. The amount of energy and type of radiation used to irradiate foods is enough to kill foodborne bacteria but does not make the food itself radioactive. In fact, electron sources and X-rays do not even use a radioactive isotope. Think of the irradiation process as the way a luggage scanner works when you go through a security checkpoint at the airport.

Q6. Does irradiation change the nutrient content or flavor of foods?

A6. Irradiation produces virtually no heat within food and does not "cook" foods. Foods processed with irradiation are just as nutritious and flavorful as other foods in the marketplace. In fact, processing by irradiation produces changes in nutrient content and flavor that are the same as or lower than those produced by cooking, canning or freezing.

Q7. Is irradiated food sterile?

A7. Although irradiation at the doses approved by the FDA does not sterilize food, it protects food from spoilage or potentially harmful bacteria in the same way milk is protected through pasteurization. Food irradiated for astronauts is sterile, but food for consumers is given a lower pasteurization treatment. Like milk, irradiated food can spoil over time or foster growth of bacteria if it has been handled or prepared improperly. As with any food product, foodservice workers and consumers must follow safe handling and preparation guidelines to ensure food safety. These safe food handling measures include washing hands and preparation surfaces often, separating foods to avoid cross contamination, cooking foods thoroughly, and refrigerating and storing foods properly.

Q8. Will consumers accept irradiated food?

A8. Since food irradiation was approved in the United States in the early 1960s, there have been numerous studies on consumer understanding and acceptance of food irradiation. An early 1990s study at Purdue University demonstrated that once consumers understand the food irradiation process (in this study, by watching an educational videotape at the supermarket) over 90 percent are willing to purchase foods processed with irradiation. A 1998 nationwide study found that 80 percent of consumers would purchase food labeled "irradiated to destroy harmful bacteria."

One-third to one-half of consumers have some degree of awareness of the process of food irradiation. Of those who have a higher level of awareness of the process, about two-thirds indicate they would be willing to purchase food treated with irradiation for its safety benefits.

Q9. Is irradiated food cost effective?

A9. Irradiated food is extremely cost effective. The United States Department of Agriculture estimates that American consumers will receive approximately $2 in benefits such as reduced spoilage and less illness for each $1 spent on food irradiation.[55]

Q10. How are irradiated foods identified in the marketplace?

A10. Federal law requires that all irradiated foods be labeled with the international symbol for irradiation, the radura (shown below). This symbol must be accompanied by the words, "Treated by Irradiation" or "Treated with Radiation."

Q11. Why do irradiated foods require a symbol?

A11. The symbol is displayed in order for consumers to quickly identify treated products, so that they make an informed decision about food safety when purchasing items.

55. Greenberg, R. "Irradiated Foods." New York: American Council on Science and Health, 1996.

VIII. Glossary

D-value: The dose of irradiation necessary to reduce the initial population of bacterial pathogens by 90 percent.

Gray: The International System of Units (SI) measurement of absorbed radiation, one joule of energy absorbed per kilogram of matter being irradiated; 1,000 Gray (Gy) = 1 kiloGray (1 kGy).

Ionizing radiation: Energy that creates electrically charged particles called ions which, in turn, can have effects on matter, including living things. X-Rays, gamma rays, cosmic rays, beta rays, alpha rays and neutrons are all examples of ionizing radiation.

Irradiation: The process of applying radiation to a material. The purposes of irradiation vary: kill or damage bacteria, kill or prevent insects from reproducing, inhibit sprouting, kill or damage cancer cells, or cure paint, crosslink plastics, etc.

Irradiation dose: The amount of ionizing radiation used to irradiate a product.

Irradiator: The part of a radiation facility that houses the source of irradiation.

Metomyoglobin: A red iron-containing protein pigment in muscles that is similar to hemoglobin. The differences lie in the globin portion of its molecule, in the smaller size of its molecule (as in the mammalian heart muscle, which has only one-fourth the molecular weight of the hemoglobin in the blood of the same animal), in its greater tendency to combine with oxygen, and in its absorption of light at longer wavelengths.

Radiation: Energy sent out in the form of waves or particles.

Radiolytic product: A substance produced in any material by irradiation.

Temperature abuse: Storing food products at warm or extremely warm temperatures; used as a research treatment to mimic improper holding temperatures that can occur wherever food is stored, e.g., in households, foodservice operations, etc.