Development of Irradiated Shelf-Stable Meat and Poultry Products

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13.1. INTRODUCTION

The processes required to produce nutritious and acceptable radiation-sterilized, shelf-stable meat or poultry products are enzyme inactivation by heating, proper processing of restructured meats, vacuum packaging in high-barrier pouches or cans, and irradiation in the deep-frozen state to a dose (~45 kGy) providing a 12*D* assurance for *Clostridium botulinum*. No evidence of genetic toxicity or teratogenic effects was found for either gamma- or electron-radiation-sterilized, enzyme-inactivated chicken meat when fed to mice, hamsters, rats, and rabbits. No treatment-related abnormalities or changes were observed during multigenerational studies when dogs or mice were fed the irradiated meats. Radiation-sterilized, shelf-stable foods of several types have been produced commercially and used in the field by military forces and by astronauts.

13.2. HISTORY

The potential for treating food with ionizing radiation to eliminate pathogens and to preserve it was recognized almost immediately on discovery of the X rays in 1895 by Röentgen, and of radioactivity by Becquerel. Minck (1896) suggested that X rays might have possible therapeutic action on bacteria. Research started almost immediately on the effects of radiation on bacteria and other living cells. A patent was issued in the United Kingdom to Appleby and Banks (1905) to use ionizing radiation to improve the condition of foodstuffs. A patent was issued to Gillett (1918), in the United States, for an apparatus using 16 X-ray tubes to destroy insects or other animal life (trichina) on organic materials. Schwartz (1921) reported the results of a series of studies by the U.S. Department of Agriculture (USDA) demonstrating the inactivation of trichina by X rays. Schepmann and Fleck (1927) discovered that the bactericidal action of X rays depends on their wavelength. The French scientist Wüst (1930) was granted a patent for X-ray preservation of food packed in sealed metallic containers. Craig (1935) was granted a patent for preserving food materials by the use of X rays. He described the application of hard X rays as generating secondary radiation from the cans, which acted on the contents of food materials such as fruits and vegetables.

13.3. ATOMS FOR PEACE

During the period from 1940 to 1953, exploratory research on food irradiation was sponsored by the Department of the Army, the Atomic Energy Commission, the Department of Agriculture, and private industry. In 1950, the Atomic Energy Commission (AEC) established contracts for research on food irradiation with the Massachusetts Institute of Technology, the University of Michigan Food Research Institute, Columbia University, the American Meat Institute Foundation, the Stanford Research Institute, Brookhaven National Laboratory, the National Canners Association, and the Vitro Corp. The U.S. Army Quartermaster Corps initiated research on radiation preservation of foods in 1951. Proctor and Goldblith (1952) reviewed the literature pertaining to the application of ionizing radiation to food, citing several hundred references.

The "Atoms for Peace" program was announced by President Eisenhower when he addressed the General Assembly of the United Nations on December 8, 1953. This made it possible for many nations to obtain radiation sources and to initiate research on food irradiation. In 1953, the U.S. Army started a comprehensive research and development program of irradiated food. In 1960 the Army shifted its program to concentrate on high-dose sterilization. The AEC at this time had shifted its research to prolonging the shelf life of perishable items with low-dose irradiation to achieve pasteurization of foods.

13.4. EARLY SUPPORTING RESEARCH

Proctor and Goldblith (1951) concluded, as the result of a large number of studies starting in 1943 at the Massachusetts Institute of Technology, that food could be sterilized using ionizing radiation if appropriate processing conditions were used. They observed that (1) the food in which the microorganisms were irradiated influenced the radiation dose required to inactivate bacteria, (2) enzymes were more radiation-resistant than bacteria, and (3) irradiation in the frozen state minimized irradiation-induced off-flavor in milk and orange juice. By the early 1950s, investigators had discovered that if air was excluded and if the product was hard-frozen (i.e., at −18°C) during irradiation, the sensorial properties were superior to those of the same product irradiated in air at ambient temperature (Proctor and Goldblith 1957). While the sensorial properties of radiation-sterilized meat and poultry were markedly improved, radiation resistance of bacteria also increased markedly in either the absence of air or on freezing (El-Bisi et al. 1966, Groninger et al. 1956, Shults and Wierbicki 1974). Research studies (Niven 1958) identified the factors affecting the radiation sensitivity of microorganisms as irradiation temperature, water availability, irradiation atmosphere (especially the presence of oxygen), stage of development of the microorganism, and other processing-induced injuries.

13.5. BEEF

Cain et al. (1958) discussed the need to inactivate enzymes in beef steaks or roasts by heating to 71.1–82.2°C in addition to irradiation while frozen to prevent off-flavors from developing in sterilized products. Several investigators determined that the quality of the products increased as irradiation temperature decreased (Coleby et al. 1961, Snyder 1960, Wadsworth and Shults 1966, Harlan et al. 1967, Shults and Wierbicki 1974, and Shults et al. 1998a,b). Numerous irradiation studies were conducted on precooked beef, including some in which the beef was packaged under nitrogen while still hot, and then irradiated. These studies reinforced the conclusion that it was necessary to irradiate at −30°C to maintain good product quality (Cain et al. 1958). Batzer and co-workers (Batzer and Doty 1955, Batzer et al. 1957, 1959) identified many of the irradiation off-flavor components from raw beef, and the importance of dosage, pre- and poststorage time and temperature, and the influence of the grade of beef on these factors. Many of the off-flavor components were identified as sulfur compounds such as methyl mercaptan and H_2S, and carbonyls arising from the fats. Pearson et al. (1959) identified the relationship between panel scores and the presence of these components in irradiated precooked meats.

Clostridium botulinum is the microbial pathogen of interest in radiation sterilization of meat products, because the products are vacuum-packaged and stored at ambient temperature, thereby providing excellent conditions for its multiplication and toxin production. The endospore of *C. botulinum* has the highest radiation resistance of any bacterial foodborne pathogen except for viruses. Foodborne viruses generally are significantly more resistant to radiation than *C. botulinum*, but they are inactivated when the product is cooked before irradiation (Blackwell et al. 1985). The necessary radiation dose for a given product is determined through inoculated pack studies. Kempe and Graikoski (1962) found that 38 kGy was required to sterilize cooked ground beef inoculated with 5×10^6 spores/g of *C. botulinum*. Anellis et al. (1975) conducted an inoculated pack (1240 cans) study of enzyme-inactivated beef, and determined the 12*D* value for *C. botulinum* type A or B to be 43 kGy, in vacuo at −30Å, 10°C.

Radiation-pasteurized and -sterilized beef were evaluated in many different toxicological studies. An early problem in these wholesomeness studies, bleeding in male rats, was linked to a vitamin K_3 deficiency in the irradiated beef, which rats require, but that humans do not (Chalam et al. 1959, Malhotra et al. 1965, Mameesh et al. 1962). Blood et al. (1966) reported that feeding irradiated and nonirradiated beef to rats in amounts equal to 35% of total solids for up to 2 years during a four-generation study, did not produce adverse effects on the animals.

Josephson et al. (1978) compared the vitamin loss during storage of frozen, thermally processed, gamma-sterilized, and electron-sterilized beef, and found less thiamin loss in the irradiated products than in the thermally processed meat. Reber et al. (1960, 1962) detected no adverse effects in dogs that were fed beef sterilized at 27.9 kGy or at 55.8 kGy for 104 weeks or 24 weeks, respectively. Large-scale, multigenerational animal feeding studies using electron- or gamma-sterilized beef (47–71 kGy) were initiated by the U.S. Army through a contract with a commercial firm. A 3-year feeding study with dogs and a four-generation study with mice and rats were planned that would have required 1500 dogs, 20,000 mice, and 27,000 rats (Josephson et al. 1975, Raica and Baker 1972, Rees and Caspersen 1976). Unfortunately, late in the study, the major contractor was found to be using careless laboratory practices and falsified data (Comptroller General 1978). Fortunately, the study of enzyme-inactivated, gamma- and electron-radiation sterilized chicken had been placed with a different contractor and proceeded. It was also at about this time that the concept of chemiclearance was proposed by Basson (1977). The concept of extrapolating wholesomeness data based on the chemiclearance principle was discussed by Taub et al. (1976). This general approach was followed in several studies, and regulatory agencies in the United States accepted the concept in granting approvals for irradiation of foods. The toxicological consequences of the ingestion of over 100 radiolytic products identified in beef were determined not to be of significance in the quantities present in irradiated foods (Chinn 1977, 1979a,b). Kamarei et al. (1979) found that ionizing radiation reduces the heme iron of the brown pigment of cooked meat (globin metmyohemichromogen) to an unstable red pigment (globin myohemochromogen). Exposure to air causes these to revert to the original ferric (brown) pigment.

13.6. PORK

Anellis et al. (1977) conducted a study using 2300 cans of enzyme-inactivated pork inoculated with 10^6 spores of each of 10 strains of *C. botulinum* (5 type A and 5 type B). The cans were gamma-irradiated at −30°C and incubated at 30°C for 6 months. They were then examined for swelling, toxin, and recoverable *C. botulinum* cells. Using extreme value statistics, the 12*D* dose for pork was computed to be 42.7 kGy, with a shoulder of 1.1 kGy.

Shults et al. (1976) found that the sensory characteristics of irradiated pork rolls and chops could be significantly improved by the addition of 0.75% NaCl and 0.3–0.5% of sodium tripolyphosphate.

13.7. HAM

Anellis et al. (1967), using an inoculated pack study with 6350 cans of diced cured ham inoculated with *C. botulinum* (type A and B) and irradiated to various doses at temperatures between 2 and 24°C, determined that 45 kGy was an adequate sterilization dose. The 12*D* value for *C. botulinum* spores in ham containing 25 mg/kg of nitrite and 100 mg of nitrate was determined through an inoculated pack study to be 32 kGy when the ham was gamma-irradiated at −30°C (Anellis et al. 1977). In 1969, the FDA, the meat industry, and the USDA began to reevaluate the use of nitrites and nitrates in curing mixes for meats, poultry, and fish. This led to a number of studies that explored the possibility of using radiation processing to allow reduction of nitrite concentrations in cured-meat products. It was discovered that the characteristic color of cured meats, and their safety, could be maintained by the use of approximately 25 ppm nitrite. Wierbicki and Heiligman (1973) described the use of radiation sterilization to an absorbed dose of 37–47 kGy at −40°C as an effective means for reducing the requirements for nitrites and nitrates in cured ham. Mittler (1979) gamma-irradiated ham to an absorbed dose of between 37 and 42 kGy, and included it in the diet fed to *Drosophila melanogaster* to test for genetic abnormalities; none was observed. Kamarei et al. (1981) reported that nitrate-cured samples become bright red when irradiated, due to reduction of globin myohemichromogen.

13.8. BACON

Sliced, cured bacon, packed in 2200 cans was seeded with *C. botulinum* and gamma-irradiated to various doses, and the 12*D* value was determined to be 45 kGy, as described above (Anellis et al. 1965). Rowley et al. (1983), in turn, found that a dose of 15 kGy was sufficient to prevent swelling and toxicity of bacon containing 40 μg/g $NaNO_2$ when it was inoculated with 2 spores/g of *C. botulinum*. Eleven dogs were fed a diet containing, on a dry-weight basis, 35% of non-irradiated or irradiated (27.9 or 55.8 kGy), cooked bacon, for 104 weeks (Hale et al. 1960). Irradiated bacon was stored at ambient temperatures for more than 6 months prior to feeding. The animals consumed equal amounts of irradiated and nonirradiated bacon. No treatment-related differences were observed in weight maintenance, hemoglobin, packed-cell volume, white blood cell counts, and reproduction. Twelve dogs were divided into three groups, each consisting of two males and two females, and were fed irradiated (27.9 or 55.8 kGy) or nonirradiated bacon. Five animals developed lymphocytic thyroiditis during the 2-year feeding study. Five petitions were submitted between August 17, 1962 and July 23, 1964 to the Food and Drug Administration (FDA) for approval of irradiation of bacon at doses of 45–56 kGy by gamma irradiation, electron beam, and X rays (Larrick 1963a,b, 1964, Harvey 1964). All of these petitions were approved by December 1964. Manowitz et al. (1966) reported the results of the irradiation of 30,000 lb of bacon for the Department of Defense. The bacon was to be gamma irradiated in cans to a dose of

45–56 kGy, with the specification that the product temperature not exceed 80°F during irradiation. The irradiation system at the Brookhaven National Laboratory worked well, with the exceptions of the carrier and the dosimetry systems that were used. In 1968, the FDA rescinded the approval of the irradiated canned bacon regulation, stating that a careful analysis of all submitted data indicated significant adverse effects in animals fed irradiated food, and that major deficiencies existed in the design rather than in the conclusions of some experiments (Anonymous 1968, Spiher 1968). Fiddler et al. (1981) investigated the effects of a 30-kGy gamma irradiation dose at −40°C on nitrosamine formation and preformed nitrosamines in bacon. The results indicated that residual nitrite was reduced in the bacon, which reduced the formation of volatile nitrosamines after frying. Irradiation also destroyed preformed volatile nitrosamines. Thayer et al. (1989) found that the destruction of thiamin was directly related to both radiation dose and cooking; frying the bacon before irradiation decreased the loss of thiamin. The radiation preservation of low-nitrite bacon was extensively reviewed by Singh (1988).

13.9. FRANKFURTERS

Sensory properties of irradiated (8 or 32 kGy) pork–beef frankfurters were improved by cooking to a final internal temperature of 65.5°C, by the use of at least 50 ppm NO_2, and by irradiation at −35°C (Terrell et al. 1981a). In a separate study, Terrell et al. (1981b) found that the addition of DL-α-tocopherol at a level of 206 ppm to the irradiated frankfurters caused greater processing shrinkage, more off-flavor, and less overall palatability. Adding 50 ppm of nitrite decreased processing shrinkage of turkey franks, increased the pH of pork–beef franks, and decreased the off-flavor of pork–beef, chicken, and turkey frankfurters when they were irradiated at −34.4°C to doses of 8 or 32 kGy (Terrell et al. 1982).

13.10. FISH

Sinnhuber et al. (1966, 1968) described the development of radiation-sterilized, pre-fried cod and halibut patties as "heat and serve" seafood products. The breaded pre-fried products were irradiated at 45 kGy at ambient temperatures. After six months of storage at 22°C, the sensory scores of the irradiated fish patties were equal to those of nonirradiated patties stored at −19°C. Heiligman and Rice (1972) prepared codfish cakes from enzyme-inactivated (80–85°C internal temperature) fish mince. The cakes were vacuum packaged in pouches or cans and irradiated using gamma radiation from ^{60}Co or with electrons to a dose of 35 kGy, at −30°C. The cakes were found to be stable at room temperature for long periods of time. Ando et al. (1968) determined that the average D_{10} value at temperatures from 0 to 20°C for *C. botulinum* type E in various media was 1.38 kGy (range 1.03–1.74 kGy). These authors noted that the radiation resistance increased at temperatures below −10°C. Anellis et al. (1972) conducted an inoculated pack study with the most resistant *C. Botulinum* strain, which had been determined in a separate study to be type 53B, in codfish cake. The 12*D* value was estimated to be 32.4 kGy.

13.11. CHICKEN

13.11.1. Determination of 12*D*

Anellis et al. (1977) conducted a study using 2000 cans of chicken. Each can was inoculated with 10^6 spores of each of 10 strains of *C. botulinum* (5 type A and 5 type B). The cans were treated with gamma radiation at −30°C and incubated at 30°C for 6 months, after which they were examined for swelling, toxin, and recoverable *C. botulinum* cells. Using extreme value statistics, the 12*D* dose for chicken was determined to be 42.7 kGy, with a shoulder of 5.1 kGy.

13.11.2. Enzyme-Inactivated, Radiation-Sterilized Chicken

Heiligman et al. (1967) identified the deficiencies in the first generation of irradiation-sterilized products as those associated with off-color, texture deterioration, and irradiation flavor. These authors noted the improvements in quality associated with better methods of enzyme inactivation, packaging techniques, and irradiation at low temperatures. In 1976, the U.S. Army initiated a comprehensive nutritional, genetic, teratogenic, and toxicological study of enzyme-inactivated, radiation-sterilized chicken meat (Thayer et al. 1987), which required that 230,000 broiler chickens (135,405 kg) be processed into chicken rolls. Five separate diets were evaluated: commercial animal feed (CLD); canned, frozen, enzyme-inactivated (heated to an internal temperature of 73–80°C) chicken [FC (Frozen canned group)]; chicken canned and thermally processed at 115.6°C to a sterility level of $F_o = 6$ (TP); canned, enzyme-inactivated, gamma-radiation-sterilized chicken (GAM); and chicken vacuum-packaged in flexible pouch, enzyme-inactivated, electron-beam-sterilized (ELE). The radiation doses were administered at −25 Å 15°C, with a minimum dose of 46 kGy and a maximum of 68 kGy.

13.11.2.1. Mutagenicity Mutagenic activity was not found in any of the four processed meats by the *Salmonella* microsomal mutagenicity test and the *Drosophila melanogaster* test for sex-linked recessive lethal mutations.

13.11.2.2. Teratogenicity Teratology studies were conducted using 240 mice, 360 hamsters, 396 rats, and 240 rabbits. Pregnant females were fed the test meats at 35 and 70% (dry weight) of their total diet during the period of maximum organogenesis. None of the four processed chicken meat diets induced teratogenic effects when fed to the pregnant animals; however, all of the positive controls produced evidence of teratogenic effects (resorbed embryos or congenital malformations). (The positive control substances were all-trans retinoic acid for mice, hamsters, and rats, and thalidomide for rabbits.)

13.11.2.3. Chronic Feeding Studies

13.11.2.3.1. The Beagle Dog. Chronic feeding studies were conducted in beagle dogs. In this study 10 male and 20 female dogs were fed the test meat (35% by dry weight of total diet) or CLD diet ad libidum until death or sacrifice at 36 months postweaning for females and 40 months postweaning for males. Offspring were selected from the F_1 generation at weaning for continued feeding to 6 months of age. The study was designed to measure both chronic toxicity and breeding performance. No treatment-related changes were observed during the study. All five diets supported beagle growth to maturity. The animals receiving the CLD diet were significantly lower in weight than those fed the meat diets. Hematological, clinical biochemical, and histopathological findings in F_0 and F_1 dogs were unremarkable with respect to any treatment effect (Besancenez et al. 1983).

13.11.2.3.2. The Mouse. A 2-year chronic toxicity and oncology study was conducted with CD-1 albino mice fed the test or control diets (Black et al. 1983). The test started with 110 pairs placed on each diet. At 10 weeks, 40 pairs were selected for reproduction from the F_0 generation, and one pair from each litter of the F_1 and F_2 generations were mated. The F_0 generation was administered the diets for 24 months postweaning. During the production of two litters from each of the F_1, F_2, and F_3 generations, the only evidence of impaired reproduction was comparatively decreased fertility in mice fed the TP meat. No significant ($P < .05$) differences were noted in frequency of stillbirths, numbers of viable offspring, and survival to weaning in the F_1 through F_3 generations between animals fed the irradiated meats or the FC. The authors concluded that there was no definitive evidence of treatment-related abnormalities or toxicological effects due to the ingestion of chicken meat sterilized by ionizing radiation.

13.11.2.4. Nutritional Value

13.11.2.4.1. Protein Efficiency Ratio. Because such large amounts of radiation-sterilized chicken meat were used in the study, a unique opportunity existed to compare the nutrients in meat processed by four different methods. Protein efficiency ratio (PER) studies were conducted on each lot of meat, and the results were compared to those of the control diet. The PER values were not affected adversely by any of the processing methods (Ronning et al. 1980); however, the PER of the males that were fed the TP diet was lower than that for any other test diet.

The reader is referred to the following references for discussions of the hundreds of studies of the wholesomeness of irradiated foods: Brynjolfsson (1995), Diehl (1995), Diehl and Josephson (1994), Kaferstein and Moy (1993), Skala et al. (1987), Thayer (1994), and WHO (1994).

13.11.2.4.2. Effects on Individual Nutrients. Thayer (1990) abstracted the individual analytical values from the toxicology reports and analyzed them statistically. The relative amounts of amino acids, individual fatty acids, free fatty acid, crude fat, and peroxide in the TP, ELE, and GAM were not different from those in the FC.

The percentages of thiamin in the TP and the GAM were significantly lower than that in the FC. The percentages of riboflavin and folic acid were higher in the ELE than in the FC. There was a higher percentage of B_{12} in the thermally processed and gamma-irradiated meats than in the frozen control. No other significant differences were discovered in the percentages of any other vitamin in the processed meats compared to the frozen controls.

13.11.2.5. Sensorial Properties The four chicken products received acceptable ratings for color, odor, flavor, texture, and overall acceptance by trained panels over a two-year period (Wierbicki 1985).

13.12. PRODUCTION OF RADIATION-STERILIZED FOOD

The following are key steps in the production of radiation-sterilized, shelf-stable meats:

1. Precook raw meat, poultry, and seafood items to an internal temperature of approximately 75°C to inactivate degradative tissue enzymes and thus prevent chemical spoilage [Desirable sensorial properties were obtained by adding salt and sodium tripolyphosphate to some of the processed meats (Josephson 1983).]
2. Hermetically vacuum-seal the product in a suitable multilayer barrier pouch or can (Killoran et al. 1979a,b). (Many ordinary barrier pouches will become brittle and crack either during irradiation processing or storage.
3. Rapidly freeze the pouches or cans of product to approximately −40°C, and irradiate the product in the hard-frozen state. A means of maintaining this temperature (i.e., packing in dry ice) must be provided for gamma sterilization because of the length of time required. Generally, electron-beam sterilization dose rates are so high that it is not necessary to provide for cooling during irradiation; however, because of the limited penetration of electron beams, it may be necessary to irradiate the package from two sides.
4. Irradiate to the prescribed minimum dose (25–45 kGy depending on the product) to provide a 10^{-12} level of antibotulinal sterility assurance. Use radiation dosimetry to ensure that the product has received the required minimum dose.

13.13. U.S. ENZYME-INACTIVATED, RADIATION-STERILIZED PRODUCTS

Radiation-sterilized meat and poultry products have been used on space flights since the 1960s and are well received by astronauts. Radiation-sterilized, shelf-stable beef steaks, smoked turkey slices, corned beef, and ham have been used on space flights (Bourland 1993). The U.S. Army Natick Laboratories developed the following radiation-sterilized foods: bacon, beef rib steak, corned beef, beef roast, beef roll, chicken parts, chicken roll, smoked turkey slices, codfish cake, cooked salami, frankfurters, ham, lamb roll, pork roast, pork roll, pork sausages, and shrimp (Josephson 1983). In 1998 and 1999, some detailed technical reports of work completed in the 1970s were published by the U.S. Army Soldier and Biological Chemical Command, Soldier Systems Center in Natick, Massachusetts (Mason et al. 1999, Shults et al. 1998a,b,c, 1999).

13.14. THE SOUTH AFRICAN PROGRAM

Several radiation-sterilized foods were developed by the Atomic Energy Corporation of South Africa during the early 1980s, and were used by the South African Defense Force. McGill and de Bruyn (IAEA 1995) divide the meat dishes into five groups: (1) whole meats cooked in convection ovens, chilled, sliced, and packed with or without gravy, such as roast beef slices with gravy, roast leg of pork slices with gravy, roast chicken breasts with mayonnaise sauce and bacon; (2) steak, hamburger patties, and "Boerwors" (beef sausage) fried, chilled, and packed with or without a tomato and onion sauce; (3) precooked ground meat products, such as meatloaf, meatballs, lasagna, and "Bobotie" (a local minced meat dish); (4) casseroles and stews, such as beef curry, beef stroganoff, beef stew, chicken curry, chicken and vegetable stew, and chicken and tomato casserole; (5) commercially processed items that were packaged and irradiated, such as country sausage, smoked Vienna sausages, and smoked chicken. Poor results were obtained with mutton and fish. Some of the South African shelf-stable products are now available commercially.

In 1990, the South African Defense Force asked the Atomic Energy Corporation (AEC) of South Africa to develop shelf-stable prepared meals (IAEA 1995). The AEC encountered many more problems with the acceptability and shelf life of vegetables than with meat products: vegetables that were fully cooked before irradiation became very soft and mushy after processing. Following this discovery, vegetables were blanched only before being packaged, frozen and irradiated. Brassica-type vegetables (e.g., broccoli, cauliflower) developed a strong irradiation smell and taste, and were discolored. Radiation-sterilized celery, radishes, leeks, garlic, green peppers, bean sprouts, parsnips, potatoes, turnips, asparagus, gem squashes, and cucumbers were not acceptable because of a bad taste, color, or texture, or a combination of these defects. Successful results were obtained with peas, baby carrots, baby carrots with peas, tomato and onion mix, and mixed vegetables with sweet corn. AEC concluded that canned vegetables were of equivalent or better quality, and cheaper than, the irradiated products. Today, the AEC's Biogam produces 11 commercial shelf-stable, irradiated foods under the "Have a Pack" label.

13.15. FUTURE OF IRRADIATED SHELF-STABLE MEAT AND POULTRY PRODUCTS

Other than in South Africa, radiation-sterilized products are not commercially available. One may postulate that the acceptance of radiation-pasteurized foods needs to precede the public acceptance of irradiated shelf-stable foods. If so, that time may be near because of approvals for the irradiation of red meats in the late 1990s. The public is aware that some radiation-sterilized foods are being used by astronauts. The U.S. Army has stated that there is a need for products such as irradiated steak, hamburger, pork chop, or chicken breast to replace or supplement the thermally processed products in sauce and gravy (Tuttle 1992). Tuttle states that the irradiated products would be closer to those the soldier is accustomed to at home and thus would serve to enhance morale. There are also potential sport and leisure uses of such foods, such as by campers, but a far more important use may be for the immunosuppressed patient in hospitals or at home. Studies of radiation-sterilized foods for the immunosuppressed patient have generally been successful (Aker 1984, Grecz et al. 1985, Hashisaka 1990a,b, Lee et al. 1994, Pryke 1995).

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