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Use of irradiation for microbial decontamination of meat: situation and perspectives

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1. Introduction

Food irradiation is generally defined as the process in which foods are exposed to ionizing energy from radioactive sources such as cobalt 60 or with machine sources such as high energy electron beams or X-rays. Gamma(γ)-rays, like X-rays and high energy electron beams are all forms of ionizing radiation because they are capable of knocking electrons out of their normal orbits in atoms or molecules. This action results in an atom or molecule that is no longer electrically neutral and goes looking around for another electron in order to balance itself out again. There are other ways that nature has provided for atoms or molecules to lose or even gain electrons in the course of their normal reactions and whenever atoms or molecules are in this electrically charged state, they are called ions or free radicals. This condition is the intermediate stage of most common reactions that routinely occur in nature.

To put this concept more simply, all changes of state of matter involve reactions of some type. When you fry an egg or if you bake or toast bread or digest your food, you are changing the nature of matter involved. Free radicals are produced in the process and free-radical reactions are one of the basic biochemical reactions of the body.

Food irradiation is therefore a means of ionizing atoms or molecules prior to carrying out reactions. Heat or light can do the very same thing—the difference being that gamma (γ)-radiation is particularly effective since its penetrating power allows it to ionize atoms or molecules uniformly throughout a material. Heat does not have the same penetrating power, and by the time you achieve the desired thermal effect in the middle of the product, the outside has been modified so drastically that it is thoroughly cooked. Light can also provide ionizing energy, but the penetration is too small for any substantive changes to take place unless you are exposing thin films such as liquids.

By properly adjusting the food irradiation process it is possible to achieve a specific effect such as reducing the levels of pathogenic bacteria that commonly occur in certain meat and poultry products. The products in question are subjected to an amount of ionizing radiation sufficient to ensure that the pathogens are either dead or incapable of causing infection. The end result is a product which is safe from the bacteria, but has not been cooked or had its flavor effected, thus allowing the consumer the opportunity to prepare the food in the manner desired—in the same way as the original product.

The food irradiation process is carried out in specially built plants where the food product is exposed for a precise period of time to the irradiation source using some form of conveyance system. Cobalt-60 is a highly penetrating source of ionizing radiation and can also be used to treat food inside its finished packaging. Electron beams are less penetrating and with single-sided treatment, 10 MeV electrons can give satisfactory treatment for thicknesses up to about 35 mm of unit density material. Using a conveyor belt with double-sided treatment can give a bit more than double the single sided depth because of the way the two depth-dose curves superimpose, hence a product thickness of 8 cm can be used. Products can also be irradiated while in a frozen state, making it practical for a range of commercial consumer and fast food items such as frozen

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hamburger patties. At no time during process does the food come in contact with the radiation source and it is not possible to induce radioactivity in the product. Irradiated foods are not radioactive. The amount of time the food is exposed to the source of irradiation establishes the amount of radiation received which is measured in units called kiloGrays (kGy).

The idea of food irradiation is more than a century old and immediately followed the discovery of radioactivity in 1895 by Henri Becquerel. In fact, in the very same year that Becquerel published his work, the suggestion to use ionizing radiation to destroy microorganisms in food was published in a German medical journal (Minsch, 1896). Within a few years, patents describing the use of ionizing radiation to destroy bacteria in food were issued in both the United States (Lieber, 1905) and Britain (Appleby & Barks, 1905). The authors of the 1905 British patent *wanted to bring about an improvement in the condition of foodstuffs* and their keeping quality. They felt that this technique was an advantage because the improvements could be made without using any chemical additives—a concept which remains valid today. A little later, in 1921, irradiation in the form of X-rays was employed to eliminate Trichinosis parasites in pork (Schwartz, 1921). Food irradiation could not be commercially considered, however, because the radioactive sources used (radium and X-rays) were not easily available or cost-effective at the time.

This situation continued until after the Second World War and the ensuing "Atomic Age". The use of isotopes as ionization sources greatly increased when exhausted fuel rods from nuclear reactors became available. When food irradiation finally became a commercially feasible process, the timing could not have been worse. The delay of commercial development by 50 years resulted in food irradiation being linked with the atomic bomb and nuclear radiation in the minds of all those who were not familiar with the technology. Had this not been the case, food irradiation would be just as common today as pasteurization is.

Indeed, it is useful to compare the original complaints against pasteurization with those that have more recently been leveled at food irradiation.

Original Objections to Pasteurization

Public Health, Safety and Sanitation

- Pasteurization may be used to mask low-quality milk
- Heat destroys great numbers of bacteria in milk and thus conceals the evidence of dirt
- Pasteurization fails to destroy bacterial toxins in milk
- Pasteurization promotes carelessness and discourages the efforts to produce clean milk
- Pasteurization is an excuse for the sale of dirty milk

Physical and Bacteriological Quality

- Pasteurization influences the composition of milk
- Pasteurization destroys the healthy lactic acid bacteria in milk, and pasteurized milk goes putrid instead of sour
- Pasteurization destroys good enzymes, antibodies, and hormones, and takes the "life" out of milk.

Economics

- Pasteurization legalizes the right to sell stale milk
- Pasteurization will increase the price of milk
- Pasteurization will required many small raw milk dealers to go to the expense of buying pasteurizing apparatus or go out of business

Nutrition

- Pasteurization impairs the flavour of milk
- Pasteurization significantly lowers the nutritive value of milk
- Infants do not develop well on pasteurized milk
- Raw milk is better than no milk
- Pasteurization gives rise to a false sense of security
- It is wrong to interfere in any way with Nature's perfect food

During the past two decades, the Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO) have become closely involved with the issue of food irradiation, because several aspects of food irradiation technology fall within their operating mandates. Among the principal activities of the IAEA is the encouragement of peaceful uses of nuclear energy. FAO is tasked with ensuring a global reduction of post-harvest losses as well as improvement of food quality, safety and nutrition. The WHO is particularly concerned with global public health improvement through the reduction of foodborne diseases.

Under the aegis of these three UN agencies, irradiation has become one of the most extensively investigated and controversial methods of food processing. Expert Committees which have been convened by all three organizations have regularly evaluated studies on the safety and wholesomeness of irradiated foods and have always concluded that the process and the resulting foods are safe. In 1981, the FAO/IAEA/WHO Joint Expert Committee on Food Irradiation stated that "irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard and introduces no special nutritional or microbiological changes" (World Health Organization, 1981). The 10 kGy ceiling was simply used because that level was considered sufficient for most food applications, including the commercial pasteurization of solid foods. A dosage of this level was capable of killing vegetative pathogens common to foods, but is insufficient to kill all spores or viruses.

More recently the WHO convened a Study Group to review all data on products irradiated above the 10 kGy ceiling and found the products to be safe and wholesome. As a result WHO has recommended removing any dosage limit so that it would be possible to achieve commercial sterility, as in canning (Anonymous, 1999). Products of this type have been consumed by the astronauts of the NASA programs as well as by campers or military personnel in certain countries. High dose irradiated foods are particularly suitable for immunocompromised people, who often require a sterile diet.

If we concentrate on the use of irradiation for the purposes of microbial contamination, we must understand a few basic assumptions. The first is that food materials are almost all produced in an open setting where they are exposed to all the organisms, harmful and otherwise, that exist in the surrounding soil or atmosphere. (The only exceptions are fruits and vegetables which are produced in a closed hothouse environment and raised on sterile soils.) Grain, legumes, fruits, vegetables, meat and dairy animals, poultry, fish and seafood are all grown and harvested in a fully open environment or in production complexes which are open to the atmosphere.

Our surrounding environment contains a great multitude of organisms which have the potential to cause us harm. The soil, water and even the air we breathe contains a multitude of these organisms. Dust is the decomposition of the mineral, fecal and organic matter that we routinely produce. When we dump untreated sewage into the waterways, it comes back to us by infecting our fish or seafood animals. A good example of this is fish infected with *Salmonella*. We originally thought this to be a symptom of post-harvest contamination, but we are now finding out that the continuous dumping of contaminated sewage has resulted in salt-tolerant *Salmonella* which now actively contaminate fish and seafood stocks.

Another major factor in the contamination of our foods is the manner in which they are produced. In the case of fruits and vegetables, irrigating crops with water containing pathogenic organisms, is a common source of contamination. The water used in farming is generally not treated and its quality is not controlled as strictly as it should be. Another more recent problem results from the modern practice of organic farming. Manure is a useful fertilizer in organic farming and occasionally material is used that has not been sterilized or treated in a way to kill potential pathogens. This can result in the contamination of food products which are not normally reservoirs of human pathogens.

Mass production of foods is an additional reason for the spread of disease organisms. The close proximity of animals to each other makes the rapid spread of contagious organisms very easy. Common water and food troughs and the incomplete disposal of fecal matter also serve to spread disease. Because fecal matter and processing by-products still contains a significant amount of nutrient material, it is a practice in some industries, particularly smaller ones to feed it back to poultry and animals as a proportion of the total feed ration. If it is not sterilized or treated properly, viable pathogens can make their way to the birds or animals.

The problem is complicated by the fact that certain organisms, which are pathogenic to humans, do not have the same effect on the plants or animals we eat. As an example, many cattle demonstrate no obvious ill effects from *Escherichia coli* O157:H7, an organism that is extremely dangerous to humans. Certain *Salmonella* bacteria are considered commensal or normal to poultry, but are hazardous pathogens to people.

Thus, there are several ways in which our basic food materials can become exposed to harmful organisms.

2. Poultry

The birds which fall under the definition of poultry normally consist of chickens, turkeys, ducks and geese, but may also include quail, pigeons, partridge, pheasant, grouse, guinea fowl, ostriches and other. On the average, the moisture level of the edible portion of poultry varies from 70 to 75% depending upon the type and age of bird. Unfortunately, this high level of moisture makes poultry an excellent substrate for a wide range of microorganisms. For the purpose of illustration, we will focus primarily upon *Salmonella* in commercial market poultry, but other organisms, particularly *Campylobacter* are of equal importance.

As you all know, modern production of poultry starts at the farm or chicken house with eggs which may be contaminated before being laid. These are incubated for 3 weeks (4 weeks for turkeys), at a constant temperature. Once hatched, the chicks are moved into production units where they are reared until ready for slaughter (6 for broilers and 14 weeks for turkeys), after which they are transported to a processing plant. At the processing plant, the birds are slaughtered by severing the carotid artery so that the blood can drain away. Feathers, viscera and feet are removed and the carcass is washed and chilled or frozen prior to shipping. Packaging can take place at the processing operation or at the retail outlet.

Modern poultry production and processing operations have accomplished technical wonders and are responsible for bringing consumers highly nutritious products at an incredibly low price. The entire flow of products from the producer to the consumer does not appear to pose a problem. Yet, *Salmonella* is routinely found in 15–70% of poultry. High rates of contamination with *Campylobacter* have also been reported. If all types of pathogens are considered, it is likely that more than 80% of the chickens currently on sale are contaminated with one form of pathogen or another. Why does poultry have such a high rate of contamination at the retail level?

The cloaca of a bird serves as the common route for both eggs and feces. As a result, the surface of an egg can become contaminated very easily on the way to being laid. If this shell contamination is not immediately and completely removed, it can spread contamination to the entire environment where the chicks are hatched. Even if a producer would start with the much more expensive *Salmonella*-free eggs, other basic problems of contamination still remain.

Commercial poultry feeds contain a wide variety of ingredients to ensure rapid and cost-effective growth of the young birds. Many of these materials such as rendered animal by-products, fish meal and recycled by-products are prime sources of contamination if they are not thoroughly treated to kill all pathogens. Thus, the feed material can also be a source of contamination, even if it contains antibiotics to prevent infection. Once they become infected, the growing birds can easily re-infect their neighbors, through the common eating and drinking facilities. For instance, the water troughs become a continual source of contamination until specific steps are taken to disinfect the entire system.

The producer is not necessarily aware of the presence of *Salmonella* or other pathogens because the birds do not appear sick. (There are only two specific varieties of *Salmonella* that are actually pathogenic to chickens, while very many others can affect humans.) As a result, these bacteria are almost impossible to eliminate. It would be the equivalent of eliminating all bacteria from the barnyard, or the chicken house. The only possibility of *Salmonella* exclusion would be through the sterilization or irradiation of feed, the full sterilization of pens and litter, the complete exclusion of insects and the use of pathogen-free air—in other words, a sterile laboratory environment. This is neither possible, nor practical or necessary.

Disease transmission can be reduced with adequate spacing of birds, effective and continual air filtration, immediate removal of any dead birds, devices to prevent cross-contamination of drinking water, frequent cleaning and sanitation and active measures eliminate external contaminants. Day-old chicks have even had their crops (esophagus) inoculated with crop or intestinal material of adults in an effort to prevent colonization with Salmonellae. With great care and attention, *Salmonella* can be reduced significantly, but it cannot be eliminated without losing some measure of operational cost-effectiveness. Then, you have to deal with the other pathogens such as *Campylobacter*.

Once raised to maturity, the load of chickens, some of which are already contaminated with *Salmonella*, are then shipped from the producer to the processor. The proximity of the chickens to each other during transport allows a considerable amount of cross contamination to take place. Dust, feathers, and litter residue all contain bacteria and are obvious sources of *Salmonella* cross-contamination.

After the birds get to the processing plant, there are many opportunities for *Salmonella* to survive and spread the contamination further. It has long been known that *Salmonella* bacteria have the particular ability to securely attach themselves to the skin of chickens (Notermans & Kampelmacher, 1974). When the opportunity arises, this attachment happens quickly and firmly. In fact, this attachment is so strong, that tests have demonstrated that even after 40 consecutive carcass rinses, the level of *Salmonella* on the poultry skin hardly decreases at all (Lillard, 1989).

Considerable wing flapping during the slaughter process creates and spreads a significant amount of dust throughout all areas that do not have dust barriers. The birds are then quickly immersed in a scalding tank in order to make the removal of feathers easier. The ideal temperatures for the scalding of various poultry vary from 52.5 to 60 °C, temperatures which permit *Salmonella* and other pathogens to survive. Soil, dust and fecal matter are continually released into the scalding tanks and the bacteria thus released are free to contaminate other birds.

Immediately after scalding, the chickens are transported to the defeathering machine, which is simply a device with rubber fingers on a revolving cylinder. Aside from removing the feathers, this machine also removes much of the yellow epidermal layer of a bird's skin. This renders the remaining cuticle-free skin more susceptible to bacterial attack. It isn't difficult to understand why this operation is another prime source of cross-contamination because the revolving rubber fingers can transfer bacteria from the skin and feathers of one chicken to the skin of another.

The birds are then eviscerated. Even though the vacuum equipment used is designed to minimize contamination, this operation often releases some of the intestinal contents on to the skin or meat of the bird thereby increasing the degree of contamination. After evisceration, the carcasses are spray-washed in order to clean them, but as mentioned above, this hardly removes any *Salmonella* at all. In some operations, the birds are then immersed in chill tanks to quickly lower the carcass temperature and retard the spoilage process. Since *Salmonella* easily tolerate the temperatures employed, this chilling step is a final stage where cross-contamination occurs in the plant. In most European operations, this step is accomplished with chilled sprays or cold air cooling to prevent the spread of contamination. In North America, however, the chill tank is still commonly used, perhaps because the skin of the birds absorbs sufficient water to add 5–7% to the overall weight of the bird.

Processing the birds into parts further spreads contamination by exposing more birds and susceptible fleshy parts to the same cutting tables. Knives, utensils and gloves that touch poultry serve to cross-contaminate everything. Even the final act of piling the parts together in consumer or bulk packages contributes to cross-contamination.

In a sense, the entire modern processing unintentionally acts like a blender to dilute and spread out the contamination among the greatest number of birds. The number of *Salmonella*-positive chickens leaving a plant is invariably greater than those coming into it. As a result, up to 80% of the retail chickens in the UK (Public Health Laboratory Service, 1990) and up to 71% of processed carcasses in the USA (Bailey, Nelson, & Blankenship, 1991) were found to be *Salmonella*-positive in the past. One of the most recent reviews has confirmed continued high levels (Kelly, Anderson, & Snary, 2000).

The process of mass-producing chickens in order to bring their price down to a more affordable level is not the original cause of contamination; it merely serves to spread the contamination out among a greater number of birds. *Salmonella* is common in the environment and can therefore easily infect poultry at high levels without making them sick. In the processing plant, incoming contamination occurs on a continual basis. Even if all the equipment is thoroughly cleaned and disinfected, arriving birds start the contamination process all over again on a daily basis. It is a chronic problem which is all too clearly demonstrated by the very high rates of contamination at retail level.

The mass-processing or for that matter any processing of poultry or meat does not employ a stage to exterminate bacteria. Obviously, chickens can not be heat pasteurized. Until a step for the destruction or significant reduction of bacteria is incorporated into the process, there is no way to avoid *Salmonella*, *Campylobacter* and *Listeria*-contaminated chickens on supermarket shelves.

Because poultry usually receives high heat treatment before it is eaten, the major consumer problem with poultry is cross-contamination of other foods that are not cooked. The problems begin the very moment the chicken is picked up at the supermarket. Most consumers have felt wet packaging where some of the poultry juices have leaked out. These juices contain all the poultry microorganisms and they immediately contaminate the hands of shoppers. Even if your hands feel dry, they remain contaminated until they are sanitized. If those contaminated hands now touch fruits or vegetables, cross-contamination is the inevitable result. Fruits or vegetables are not all cooked or sanitized before consumption. Pre-washed lettuce is used directly in salads or as garnished in sandwiches. Often, apples are only rinsed before eating. The cross-contamination pathogens are now consumed without any heat treatment at all. These are the ideal conditions for a food poisoning incident.

Every time a consumer picks up a package of poultry in the supermarket, a process begins that has an excellent potential to expose consumers to pathogenic organisms. In fact, one consumer who has been contaminated with pathogen-laden poultry juice can unintentionally cross-contaminate large amounts of foods which will unknowingly be selected and consumed by others in the supermarket. That is how vegetarians get *Salmonella* poisoning. What about the cashiers in supermarkets? They handle packaged poultry products along with every other product the consumer buys. Any contamination which exists will be spread out among all products. Thus, cross-contamination starts well before the consumer brings products into the home.

3. Meat products

Meat is generally defined as the muscle tissue of a limited number of commercial animals including cattle, pigs, sheep, goats and in certain specific areas, horses. Meat contains about 75% water and is clearly an excellent substrate to support the growth of all types of parasites and microorganisms. Furthermore, the low carbohydrate content of meat does not encourage the growth of lactic acid bacteria which can play an important role in excluding the growth of certain pathogens.

Normally, healthy animal tissue is free of microorganisms. Diseased animals will contain the agent organism which is making them sick and will also be more susceptible to attack from other pathogens. Even stress will decrease and animal's resistance to microorganisms. Routine veterinary inspection of animals will usually segregate diseased from healthy animals, but the procedures normally employed are limited and will not only let through the occasional sick animal, but will not prevent the use of animals that harbor specific human pathogens. Some diseases such as tuberculosis, anthrax, brucellosis and trichinosis can only be detected after slaughter. It is clear that conventional inspection protocols are no longer sufficient to protect consumers against more recently detected pathogens. *E. coli* O157:H7, a virulent and dangerous human pathogen is an example of just such a pathogen.

The hygienic state of animals prior to slaughter can be critical to the finished product quality. Cleanliness depends upon a number of factors including rearing location, type of transport, and slaughterhouse conditions. Free-range animals are likely to have a significant number of soil organisms while animals finished in confined feed lots, in close proximity to one another will have a greater proportion of fecal and communicable organisms. The hide or skin of meat animals is an excellent depository for filth of all kinds, much of which finds its way to the slaughterhouse. Unless the animal is fully disinfected prior to slaughtering, the hide or skin becomes a primary vector for the importation of contamination to the slaughterhouse.

During processing, meat can become contaminated through contact with the hide, skin or feet of the slaughtered animals as well as the stomach or intestinal contents, dirty floors, equipment of personnel. The degree of post-slaughter contamination will reflect the standard of plant hygiene as well as the competence of the staff. Depending on the animal in question, minor differences in the slaughter procedure takes place. After stunning or immobilizing the animal, the first step in all cases is bleeding the animal through the jugular vein. This very first step can spread contamination from one animal to another if strict hygienic procedures are not followed.

Shortly after the animal is slaughtered, the skin is removed. This operation must be done carefully to make sure there is no damage to the valuable hide and cross-contamination with the carcass is minimized. Pigs have a tendency towards higher bacterial loads because the hair removal process is not very hygienic. Sometimes, anti-bacterial sprays are employed to reduce the surface contamination of the carcass.

Although exposed to many of the same processing problems as poultry, meat animals are generally not as susceptible to the same degree of contamination. In the first instance, the removal of intestinal contents is not as delicate an operation. Because of their larger size, the amount of exposed surface per unit of product weight is far less in meat animal carcasses than with poultry. On the other hand, the post-slaughter processing of meat is more complex than poultry and is consequently more susceptible to other forms of contamination.

Large meat animals undergo a significant amount of cutting and boning in order to result in finished products. Initially, carcasses are split down the middle to create sides. These sides can be shipped to retail shops where the butchers continue the process of breaking the animal down to consumer cuts or they can be processed centrally. Each time the carcass is cut, fresh new surfaces are exposed which are highly susceptible to contamination. Room temperature, holding and processing time, and the cleanliness of all working surfaces and utensils all contribute to the overall state of finished product hygiene. It is interesting to note that, right after slaughter, the principal types of bacteria found on the carcass are typical "animal" strains. By the time the final cuts reach the retail consumer level, however, 'human' strains become prevalent.

Spoilage of meat is fairly easily detected through changes in color, odor or surface sliminess. Unfortunately, contamination with pathogens can only be determined through microbiological tests that are far beyond the current ability of the consumer to carry out. The consumer is therefore totally dependent upon the formal food system to guarantee the delivery of uncontaminated products. The continual growth in incidents of foodborne diseases demonstrates that the system has been inadequate in achieving this role.

In general, the same precautions must be observed in the handling and preparation of meat as with poultry. Juices should not be allowed to cross-contaminate foods that will not be fully cooked such as fruits and vegetables. Given the current condition of the meat supply, products should be fully cooked to eliminate any risks of pathogens. In terms of contamination, the greater the degree of handling, the greater the threat. Therefore, ground or cubed meats constitute a considerably greater risk than large steaks or roasts. Commercially ground meat poses a particular set of problems since pathogens from one carcass can contaminate an entire batch or spread out to other batches of the equipment is not fully sanitized between batches. These days, large contract hamburger processors use meat from a wide variety of global sources, often in the same batch.

The pathogens of greatest concern in fresh and frozen meat are *E. coli*, *Salmonella*, and *Clostridium perfringens*. Cured meat concerns include *Salmonella*, *Staphylococcus* and the potential for *Clostridium botulinum* in sausages.

Because of irradiation's effectiveness in controlling common foodborne pathogens and in treating packaged food (thereby minimizing the possibility of cross-contamination prior to consumer use), most food safety officials and scientists view irradiation as an effective critical control point in a Hazard Analysis and Critical Control Points (HACCP) system established for meat and poultry processing. For example, it has been shown that a relatively low irradiation dose of 1.5 kGy is sufficient to give a 10,000 fold reduction in the numbers of *E. coli* O157:H7 at 5 °C. This treatment will also give a significant reduction in the numbers of *Salmonella* and *Campylobacter*. As stated earlier, because the food can be packaged before irradiation, the possibility of cross-contamination is greatly reduced.

Food irradiation cannot be used to destroy microbial toxins nor will viruses and spores be killed at the low doses used to kill vegetative pathogens (below 10 kGy). That is why irradiation treatments below 10 kGy are regarded similarly to heat pasteurization. However, irradiation is not a stand-alone process that can guarantee safe food. It must be integrated as part of an overall good manufacturing practice program.

E. coli O157:H7 has been a particular cause of concern in the USA in recent years. It is not as common a cause of foodborne illness as *Salmonella* or *Campylobacter* but its extreme virulence has caused several outbreaks and mortality rates as high as 30% have been recorded, especially in the young. Most of these illnesses have been associated with eating undercooked, contaminated ground beef used in hamburgers and several major recalls of this product have be made because of this.

In 1997, because of the *E. coli* O157:H7 problems in the USA the use of food irradiation brought the debate into the public domain. Changes were made in the legislation to permit the irradiation of red meat. In 1997 the Food and Drug Administration (FDA) approved the irradiation of red meat and by February 2000, the Food Safety and Inspection Service within the USDA permitted the use of ionizing radiation for refrigerated or frozen uncooked meat to reduce the levels of foodborne pathogens.

There are now at least 10 categories of food products approved for irradiation treatment in the USA, including uncooked poultry, beef, lamb, goat and pork.

Large scale beef irradiation in the US began in May 2000 using high energy electron beam facilities. Initially 200 mt of frozen ground meat were irradiated each week and sold to 84 stores. By June 2001, the irradiated and labeled products were being sold in more than 1000 stores in 22 States. This level of growth continues.

There has been a flood of activity during the past years in the USA representing the full range of gamma, e-beam and X-ray operations. Most recently, facilities have gone up in Hawaii for papayas and other tropical fruit, in Sioux City, Iowa for fresh and frozen ground beef, in Los Angeles for fresh produce, spices and pet foods and most recently at the Institute of Food Science and Engineering at Texas A&M University, where a semi-commercial pilot plant has gone up to handle work on a wide range of research, development and pilot trials on a full range of products. Plans for additional operations based on all three irradiation sources are aggressively in the works.

From an operational point of view, e-beam machines are very well suited for the irradiation of thin products, such as ground meat and patties. The advantage is that you simply turn the irradiation on and off like a light bulb. Highly penetrating cobalt sources are well suited for larger packaged cuts and full pallets, but are most cost effective if operations run 24 h a day, seven days a week—since the source irradiates continually and has to be quenched in water or some other type of shielding device when not in use. My own sense is that X-ray machines have the greatest future potential, because they combine the advantages of e-beams while being able to irradiate very large products including animal sides and quarters.

In the EU, the situation is far different that the USA with legislation only permitting the irradiation of dried aromatic herbs, spices and vegetable seasonings to an overall maximum dose of 10 kGy. Some individual countries have additional irradiation authorizations such as the UK, where a range of fruit, vegetables, cereals, bulbs and tubers, spices and condiments, fish, shellfish and poultry have been approved for irradiation to different specified doses. However, beef is currently not included.

The key motivation for beef irradiation in the USA was the presence of *E. coli* O157:H7 in ground beef. In 1999, the UK had a higher *E. coli* O157:H7 incidence rate per 100,000 population than the USA. In one outbreak alone, 22 elderly people died.

The majority of European consumers are not strongly in favor of the use of irradiation. This is the same situation that occurred originally with milk pasteurization in the past. Politics and consumer advocacy combined to delay the institution of pasteurization in Europe long after it was commonplace in North America. It is likely to be the same situation with food irradiation. Virtually every recognized national and international health, medical and scientific authority agrees that food irradiation is a safe process that results in safer food products. This has been published repeatedly to the point where no company can plead ignorance. With the potential threat of legal actions taken by consumers against food companies and retailers who do not employ what is recognized by health authorities to be the most effective technologies to produce the safest foods, it will be interesting to see what will develop in future.

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