Chapter 2

FOOD PRESERVATION BY RADIATION

2/12/2018

2.1 INTRODUCTION

According to the USA Center of Disease Control and Prevention (CDC), about 48 million cases of food borne illnesses occur in the USA in a year, with 128,000 hospitalized and 3,000 killed. Among these, 9.4 million become ill after consuming food contaminated by at least one of 31 known bacteria, parasites and other pathogens. The remaining majority of 38 million victims are poisoned by unknown pathogens.

Patients experience a variety of symptoms including abdominal cramps, vomiting, nausea, diarrhea, severe headaches and fever. Serious cases can include kidney failure. Food-borne illness costs the USA $77 billion a year in medical treatment, lost productivity and reduced sales of products implicated in the food contamination episodes.

One in six Americans gets sick from food every year, according to the Center for Disease Control and Prevention. Incidentally, these are preventable diseases. The figures are lower than those in a 1999 report, which estimated that one in four Americans got sick from food each year and that 5,000 died.

The USA had 37 recalls of fruits and vegetables in 2011, up from two in 2005. Many of the victims of contaminated food are those with under-developed or weakened immune systems, such as children and the elderly.

Among the known food contaminants that can cause illness in humans, the leader is salmonella, which causes 28 percent of deaths from food-borne illness and 35 percent of hospitalizations. The rate of infections linked to foodborne salmonella rose 10 percent from 2006 to 2010. Salmonella is so common that USA retailer Wal-Mart accepts ground turkey after tests find 49.9 percent of samples have bacteria. That is the maximum allowed by law. Retailer Costco rejects shipments with any trace of salmonella.

The USA is expected to import half of its food by 2030, up from 20 percent tin 2012, from Growers in China, Mexico and Vietnam. The 2011 Food Safety Modernization Act, which passed the USA Congress allows the Food and Drug Administration (FDA) to certify private companies to audit producers of imported food on its behalf. The law mandates that these auditors submit their reports to the agency. These rules do not apply to domestic inspection companies, which still would not be approved by the FDA and do not report their findings. The FDA tries to make imported food safer by helping exporting countries ensure safe farming practices. The 2011 food law will help by requiring importers to prove they can match the same safety standards as USA producers.

The USA government played a role in food inspection for a century. In 1905, author Upton Sinclair wrote “The Jungle” as a scathing book about the Chicago meatpacking industry, with workers falling into vats of boiling beef trimmings and other horrors. The next year, the USA Congress passed the Pure Food and Drug Act, which proved ineffective. In 1938, after more than

100 people died from the antibiotic sulfanilamide, Congress passed the Food, Drug and Cosmetic Act, strengthening the FDA. For the first time, a federal agency had the power to inspect, approve or reject all food and pharmaceutical products. From the outset, though, the FDA lacked the resources to inspect all of the country's food producers and the food industry moved to fill that vacuum with private auditors in the 1990s and in some cases companies use their own auditors to check their suppliers.

2.2 FOOD SUPPLY SAFETY

Preserving food by canning in bottles and jars dates back to 1810, when it was perfected by French confectioner Nicholas Appert. Canned goods were invented in 1880s. This expanded the scope of the human diet and safe food supply in the 19th century until refrigeration came along. In the early part of the 20th century until the 1950s, food preservation by refrigeration was carried out in an "ice box" powered by a block of ice sold at stores and by street peddlers, before the electrical modern refrigerators came into the picture.

For environmental considerations, chlorofluorocarbons (CFCs) refrigerants were banned in favor of tetrafluoroethane in the USA by the Environmental Protection Agency (EPA). Tetrafluoroethane is banned in the Eurozone nations beginning 2011 in new automobiles as a refrigerant for environmental reasons, and may become banned for refrigerators as well. The state of California is restricting its use. To reduce energy consumption, "Energy Star" refrigerators in 2011 use 40 percent less energy than they did in 2001. This may have reduced the effectiveness of new refrigerators on the market, reducing the level of food preservation against spoilage.

Cases of Haemolytic Uraemic Syndrome (HUS) and the more serious Enterhemorrhagic E. Coli (EHEC) started in Germany in May, 2011 and spread to other countries. The serotype STEC 0104 from E. Coli 01104 has caused food-borne outbreaks before and carries genes that make it resistant to common antibiotics and produces toxins that could cause kidney failure, requiring dialysis and can affect the central nervous system. The toxins damage the stomach lining and pass into the bloodstream causing seizures, strokes and comas. Cooking food to 158 ^{o}F or 70 ^{o}C destroys the bacterium. The drug Eculizumab is effective against the hemolytic-uremic syndrome.

Twelve persons died in a 1996 outbreak that affected 12,000 people in Japan, and 7 in Canada in 2000. A 1994 outbreak in Montana, USA was related to the H4 variant of Escherichia Coli 0104:H4 and a single case in the far-east in 2006.

The United States Department of Agriculture (USDA) oversees the Food Safety and Inspection Service (FSIS) which routinely inspects raw beef manufacturing trim, the major component of ground beef. It has a zero-tolerance policy for several strains of E. coli responsible for human illness. Trim found to be contaminated with these pathogens is not allowed into commerce and are subject to recall. The strains treated as adulterants include the Shiga-toxin producing E. coli serogroups O26, O45, O103, O111, O121 and O145. Like E. coli O157:H7 these serogroups can cause severe illness and even death with young children and the elderly being at highest risk. Illness due to E. coli serogroups other than O157:H7, which caused a high profile illness outbreak in 1993, outnumber those attributed to O157:H7 which was declared by the FSIS as an adulterant in 1994.

The USA Food and Drug Administration, which investigates food contamination, said the CDC received reports of approximately 200 salmonella cases every week during late June and early July of 2010. Normally, the CDC receives an average of some 50 reports of salmonella

illness each week for the past five years. Many states have also reported increases of this pattern since May 2010. A total of 380 million eggs were recalled because of concerns they may be tainted with the potentially-deadly salmonella bacteria.

Consumer Reports compared 525 chickens from 27 brands in January 2007 and reported that only 17 percent of them were free from salmonella and campylobacter food disease bacteria.

Foods that are approved for radiation treatment to protect against pathogens contamination and to increase shelf life include meat, poultry, spices, spinach, lettuce and mollusk shellfish such as oysters, mussels and clams.

In the USA, in spite of a safe and abundant food supply that is the envy of the world, bacteria-tainted food needlessly causes the death of about 9,000 persons per year. About 6.5 million serious cases of food related illness occur each year. A figure of food borne illnesses has been claimed in the 200 to 250 million cases per year range. A characteristic of food-borne disease is that it has an incubation period before symptoms can be noticed.

A 2009 outbreak of Salmonella lead to recalls of more than 390 products using peanut butter with 500 people reported sick and were linked to at least 8 deaths. Around this time period, the author received two recall letters about pastries purchased from a prominent food supply chain, that were already consumed and was subjected to two days of serious vomiting and sickness. The products ranged from pastries, ice cream, cooking sauces and even dog treats. The Food and Drug Administration (FDA) inspection report identified cockroaches, mold and signs of a leaking roof at a Blakeley, Georgia plant operated by Peanut Corporation of America. The plant's owners found traces of salmonella in several tests of shipped material in the previous two years, rerun the tests to get a negative result, and then shipped the products anyway. "Inspectors found that plant did not take enough steps to prevent finished products from being contaminated by raw peanuts. Roasting is supposed to kill the bacteria, but raw peanuts can harbor salmonella."

Outbreaks of food illness have affected a variety of products including E. Coli in leafy greens such as spinach and lettuce, Salmonella in hot peppers from Mexico, Salmonella in cheese and Listeria in delicatessen meats in Canada. Listeria monocytogenes is a bacterium that can lead to a blood infection and damage to the brain and spinal cord.

Over 25,000 illnesses were caused by the mutation Escherichia Coli or in short E. Coli O157:H7, a gram-negative rod shaped bacterium, in 2006 alone according to the Food and Drug Administration (FDA). The letter O refers to the somatic antigen number, and stands for "Ohne Hauch" or "without breath" or "without film" in German. The letter H refers to the flagella antigen. Most strains of E. Coli are harmless and exist in the intestines of animals. This strain is a member of a class called enterhemorrhagic Escherichia coli or EHEC. It produces Shiga-like toxins that can cause severe illness. It was first recognized in 1982 in an outbreak from contaminated hamburgers, even though the serotype was isolated from a patient in 1975, hence it is called the "hamburger disease," since it appears primarily in home-made hamburgers.

Infection occurs from undercooked, ground beef, poultry, eggs, unpasteurized milk, juice, raw sprouts, lettuce, salami and contact with live animals. Transmission can occur from swimming in contaminated ponds, lakes, swimming pools, or inadequately treated water. It can be transmitted from person to person, particularly in children day care centers. A potential vector is filth flies which include the house fly, Musca domestica.

It should be noted that here are hundreds of different types of Escherichia Coli, E. Coli, strains, most of which are harmless for humans. Strains are differentiated by their serotypes which are variations within a subspecies of bacteria with the designations O and H. O refers to the

lipopolysaccharides, a type of sugar-fat molecule, found on the outer surface of the bacteria. H stands for the type of flagella, which are the hairs that the bacterium uses to move. The E. coli bacteria are designated as enterohemorrhagic when they cause the occurrence of bloody diarrhea in humans. This is caused by some subtypes which produce Shiga toxins.

In 2006, an unprecedented array of product recalls occurred:

a) E. Coli O157:H7 in bagged spinach sickened 200 people in 26 states.
b) Salmonella in tomatoes took a toll on 183 people in 21 states,
c) E. Coli O157:H7 in shredded lettuce at the Taco Bell restaurant chain made 152 people sick.
d) Salmonella turned up in peanut butter, triggering a nationwide recall.

Between 1970 and 2004 Americans ate 25 percent more fruits and vegetables. Since 1993 there occurred 26 outbreaks of E. Coli O157:H7 traced to leafy green vegetables. Sealing in pathogen friendly bags for two to three weeks has replaced consumption within a few days of harvest. Cattle, manure and fresh leafy greens make for a volatile mix. Good agricultural practice requires 30 feet of separation between grazing cattle and leafy greens, but this appears not to be sufficient, suggesting the need for a ½ mile separation. Fresh produce should not be grown in fields periodically flooded by streams and rivers. Sprinkler irrigation splashes more E. Coli bacteria from soils and water than surface irrigation. Reliance on grain-fed beef in overcrowded feed-lots instead of grass fed beef boosts the production of E. Coli. The risk is not eliminated when meat processors co-mingle both sources of meat.

The USA Department of Agriculture (USDA) oversees 20 percent of the food supply, whilst 80 percent is overseen by the Federal Drug Administration (FDA), including seafood. Thirteen other government agencies govern food safety. With intensified regulation and microbiological tests, Salmonella rates in poultry dropped to 9 percent in 2000, but increased to 16 percent in 2005, despite improved surveillance.

A Government Accounting Office (GAO) report and USA House Agricultural Appropriations Subcommittee raised the issue of the safety of food imports which increased from 100,000 shipments in 1970s to 12 x 10^6 by 2006, with 1/3 of them from China as seafood, fruits and vegetables. Melamine added as a protein additive to wheat gluten and fed to hogs and poultry and used in pet food was a big concern in 2007. More than ½ of the seafood, such as farm raised shrimp, imported into the USA is from countries lacking infrastructure for effective refrigeration, transportation and sanitation.

Irradiation is the most effective method capable of eliminating the deadly new mutation known as E. Coli 0157:H7 bacteria in raw meat. It can also significantly reduce levels of other pathogens, including Listeria, Salmonella, Shigella, Campylobacter and others.

While there is no single technique to cure all food problems, irradiation is accepted as both safe and effective. It has been approved for raw beef, pork and lamb as well as poultry and other food products.

In the USA, the regulatory agencies involved in food irradiation are the USA Department of Agriculture (USDA) and the Food and Drug Administration (FDA). Irradiated foods are to be labeled by the international symbol of irradiation, known as the Radura shown in Fig. 1, and a statement that they were irradiated. The symbol is colored green on a white background, and includes two leaves resting on a semicircle, with a green dot above it beneath a broken-lined semicircle.

Figure 1. The International Radura symbol for food irradiation.

2.3 ECONOMIC COST OF FOOD BORNE DISEASE

The USDA Economic Research Service estimates that diseases caused by the five major bacterial pathogens cost at least $6.9 billion in 2000 dollars per year as medical costs and productivity losses.

This is caused by a shift in the USA to ready-to-eat foods, increased imports, and more meals consumed away from home by American consumers.

Table 1. Economical cost of food borne illness in the USA. Source: USDA Economic Research Service.

Bacterial pathogen	Cost (2000, 10^9 dollars)
Campylobacter spp.	1.2
Salmonella	2.4
E. Coli O157:H7	0.7
E. Coli non O157:H7	0.3
Listeria monocytogenes	2.3

2.4 ESCHERICHIA COLI INFECTIONS

In September of 2006, tainted bagged organic baby spinach and salad greens grown in the packing plants of Salinas and King City in the Salinas Valley, California raised concerns about the safety of the USA food supply. This originated in writer John Steinbeck's country reminiscent of the farming themes of "Grapes of Wrath" and "Cannery Row" stories. An unusually violent outbreak of the Escherichia Coli O157:H7 strain killed three persons including an infant and an elderly person, and sickened 171 people in 25 states with 92 requiring hospitalization, including 23 who had developed hemolytic uremic syndrome, a serious kidney disease.

Escherichia Coli is a common ordinarily harmless bacterium occurring in the feces of humans as well as livestock. However, certain strains can cause abdominal cramps, fever, bloody diarrhea, kidney failure, blindness, paralysis, and can cause death. Symptoms usually show up 3-4 days

after a person eats contaminated food, although in some cases it can be as long as 8 days. Most E. Coli infections are associated with undercooked meat. The bacteria also can be found on sprouts or leafy vegetables such as spinach. A possible mechanism for the outbreak is the presence of E. Coli bacteria in cow and chicken manure used as fertilizers. In some other countries, human sewage is used as a fertilizer. The bacteria can spread to crops from flooding, in wind-carried dust or from domestic and wild bird droppings as well as from unsanitary working conditions in the packing plants. The bacteria can be passed from person to person and by food service personnel if they do not thoroughly wash their hands after going to the bathroom. It has turned out in hamburgers, tacos, alfalfa sprouts, apple juice, raw milk, spinach and lettuce. It has also shown up in country fairs foods.

Escherichia Coli is normally found in the digestive tracts of humans and warm blooded animals, but the rare and toxic strain, E. Coli O157:H7, damages the intestinal lining, leading to internal bleeding and kidney failure and can be fatal.

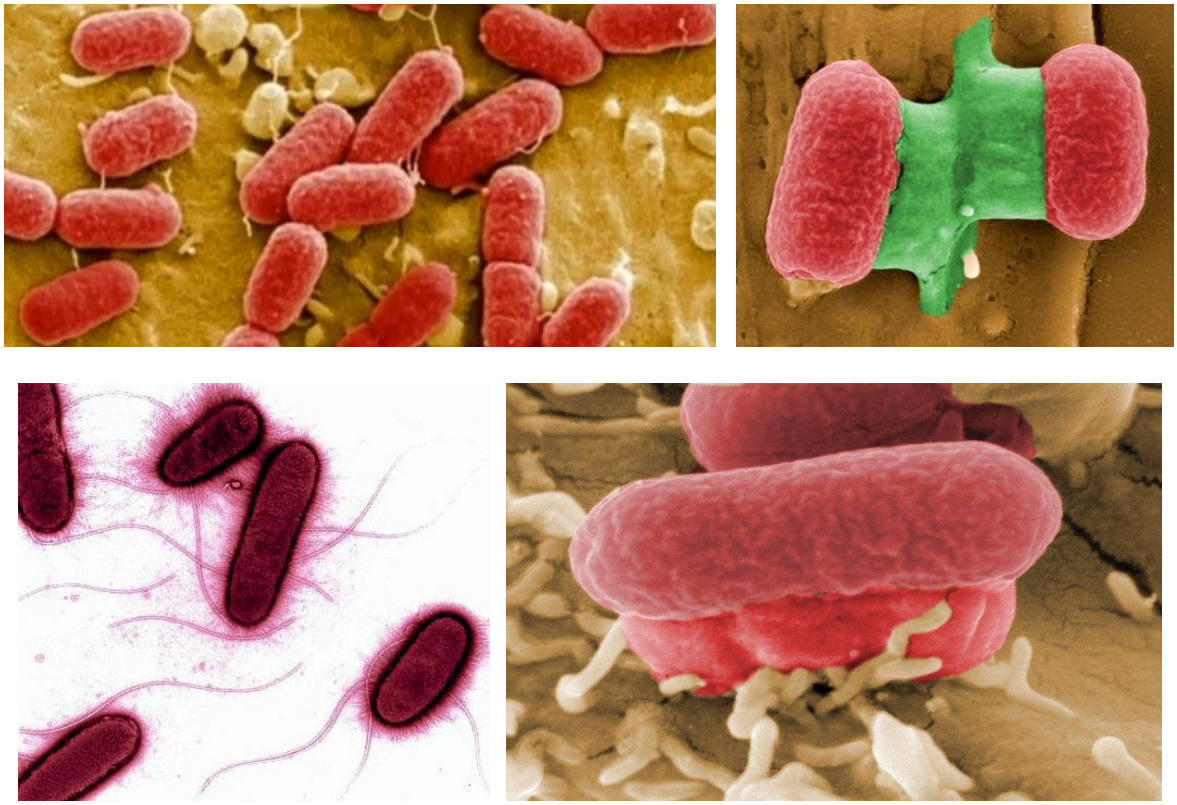

Figure 2. E. Coli O157:H7 bacterium magnified 10,961 times. Center for Disease Control and Prevention photographs.

At the same time an E. Coli outbreak traced back to organic raw milk appeared in California. Such products have grown in popularity with the organic and natural-foods movement under the belief that raw dairy products have more nutrients and beneficial bacteria. The Center for Disease Control (CDC) and Prevention recommends avoiding unpasteurized milk.

According to the Center for Disease Control and Prevention, the dangerous E. coli strain O157:H7 infects about 73,000 Americans per year and causes the death of 61 people.

2.5 SALMONELLA INFECTIONS

Every year about 40,000 Americans get sick and 600 die from being infected with food borne Salmonella of various types. Approximately 2,500 Salmonella serotypes can cause Salmonellosis, an illness characterized by diarrhea, fever, and abdominal cramps, typically 12-72 hours after infection.

In February of 2007 the Food and Drug Administration (FDA) warned USA consumers not to eat jars of peanut butter because they could be contaminated with a particular strain of the food borne bacteria known as Salmonella Tennessee. An investigation reported cases of food related infections in 39 states that were traced to eating peanut butter. The people affected were residents of New York, Pennsylvania, Virginia, Tennessee and Missouri. No deaths were reported, although 20 percent of those affected had to be admitted to hospitals for treatment with symptoms of Salmonella including fever, stomach ache and diarrhea.

In November 2006, public health officials at the Center for Disease Control (CDC) and state health departments detected a substantial increase in the reported incidence of isolates of Salmonella serotype Tennessee. In a multistate case control study conducted during February 5-13, 2007, illness was strongly associated with consumption of either of two brands: Peter Pan or Great Value, of peanut butter produced at the same plant. Based on these findings, the plant ceased production and recalled both products on February 14, 2007. The outbreak strain of Salmonella Tennessee subsequently was isolated from several opened and unopened jars of peanut butter and from two environmental samples obtained from the plant. As of May 22, 2007, a total of 628 persons infected with an outbreak strain of Salmonella serotype Tennessee had been reported from 47 states since August 1, 2006.

Symptoms of infection included diarrhea (72 percent), abdominal cramps (65 percent), fever (43 percent), and dysuria (45 percent). Symptom onset dates were known for 481 of 628 patients and ranged from August 1, 2006 to April 23, 2007. Twenty percent of patients were hospitalized; no deaths were attributed to the infection.

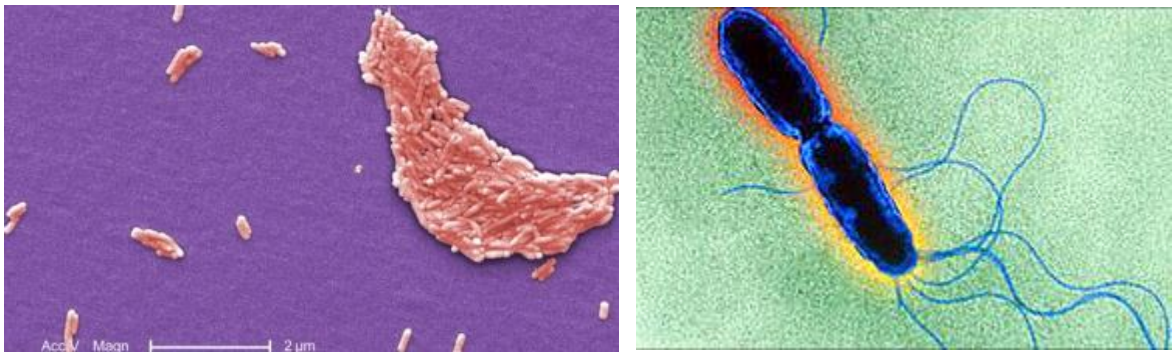

Figure 3. Salmonella Tiphymurium, tem-spl bacterium. Source: CDC.

Peanuts can become contaminated with salmonellae during growth, harvest, or storage; and the organisms are able to survive high temperatures in a high fat, low water activity environment. Peanut butter provides such an environment, and although it typically undergoes heat treatment to temperatures >158 °F (>70 °C), such heating might not always eliminate salmonellae. In addition,

after heat treatment, peanut butter that is being processed might be contaminated by salmonellae that are introduced into the production environment on raw peanuts or another source such as animals in the production plant, salmonellae brought into the plant on containers or humans from the outside environment, or other ingredients used to make peanut butter.

This outbreak demonstrated the potential for widespread illness from a broadly distributed contaminated product, one that has not been previously implicated in a food borne illness outbreak in the USA. In addition, the outbreak demonstrated that processed food can become contaminated even when the production process includes a heat treatment step, underscoring the need for effective preventive controls in food processing plants to prevent contamination and the desirability of using irradiation.

Salmonella is not normally life threatening in healthy people, but it can be very serious for anyone with a compromised immune system, such as someone who is elderly and frail, or already ill with a serious infection, or very underweight. The species of Salmonella that causes food borne illnesses has many different serological varieties or serovars, each of which is classified according to the type of reaction that it causes in the body, or more specifically, the type of surface antigens infected cells produce to help the immune system fight the infection.

Salmonella Tennessee belongs to the serogroup C1. It is a rare strain of Salmonella and has some unexpected properties, such as its ability to ferment lactose as well as sucrose. Nowadays Salmonella serovars are identified using DNA fingerprinting, but in earlier times detection of this strain was often missed because scientists were not expecting to find a Salmonella strain that could ferment lactose. The USA is the world's largest peanut butter supplier and consumer with Alabama, Florida and Georgia growing 60 percent of the peanuts used in peanut butter.

2.6 LISTERIA INFECTIONS

Sixteen people died and dozens became seriously ill across the USA by an outbreak of listeria in cantaloupe melons in September 2011. Listeria, or listeriosis, occurs when people are infected with the listeria monocytogenes bacterium. While rarer than food-poisoning pathogens such as salmonella and E coli, listeria outbreaks are generally more serious. In the USA around 260 people die a year on average from it, according to the Centre for Disease Control and Prevention. In the UK, the Health Protection Agency recorded 156 cases in 2010.

In humans it is usually transmitted by contaminated food. Outbreaks generally involve uncooked meat or vegetables, or milk or cheese which have not been pasteurized. It can affect cooked and processed foods if the bacterium is present in a factory and enters later, for example during the packaging process. Listeria is hardy and can remain in a kitchen or factory for long periods, and can even grow at refrigerator temperatures.

For healthy adults listeria is generally not a significant risk causing mild flu-like symptoms or stomach problems. It is significantly more dangerous for those with weakened immune systems, such as older people, the very young, or those with cancer, diabetes, Aids or other significant illnesses. Pregnant women are particularly susceptible, being 20 times more likely than other healthy adults to get listeria. While the effect on them may be mild it can cause miscarriage, stillbirth or a serious infection for a new baby. This is why pregnant women are urged not to eat high-risk foods such as liver patés and soft cheeses.

Serious infections generally cause serious gastrointestinal and flu-like symptoms, often with muscle ache and a stiff neck, or sometimes confusion and loss of balance. This can then lead

to a meningitis-like inflammation around the brain or septicaemia. Listeria is generally treated with antibiotics, which need to be administered quickly in serious cases.

Meats should be thoroughly cooked, and raw fruit and vegetables washed. Uncooked meat should be stored separately, and products containing unpasteurized milk avoided. A key element is good kitchen hygiene, both keeping hands and equipment clean, and consuming refrigerated leftovers within a few days.

2.7 FOOD SPOILAGE AND POISONING

Food spoils because of complex physical, chemical and biological deterioration as well as through the activities of microorganisms and insects. It is obvious that for best nutrition, foods should be eaten as close to the time of harvest as possible. Once a plant or animal is dead, decomposition immediately begins, and its nutrients content is decreased. Living tissue ultimately decays to carbon dioxide, minerals, water and ammonia from which its organic molecules are composed.

As food is bruised in picking, microorganisms invade it. Molds and yeasts find a fertile ground in sugars converting them into alcohol through fermentation. Fruit flies are attracted to the alcohol, carrying vinegar bacteria, which burn up the alcohol. These processes demolish the structure of the food and spoil it.

Cases of food poisoning arise from intestinal infections caused by bacteria. Table 2 shows some of the bacterial agents causing food poisoning together with their sources, incubation period, and disease symptoms duration.

Table 2. Some bacterial agents causing food poisoning.

Bacterial Agent	Source	Duration of symptoms	Incubation period
Campylobacter	Undercooked poultry	2-10 days	2-5 days
E. Coli 0157:H7	Undercooked beef, raw produce, spinach.	4-7 days	1-3 days
Listeria monocytogenes	Deli meat, hot dogs, unpasteurized dairy	-	-
Salmonella	Undercooked eggs, or poultry, peanut butter.	4-7 days	1-3 days
Shigella	Raw produce, egg salad	4-7 days	1-2 days
Staphylococcus aureus	Meat, potato and egg salad	1-2 days	1-6 hours
Yersinia enterocolitica	Undercooked pork	1-3 weeks	1-2 days

The most common food borne disease is caused by Staphylococcus aureus. This bacterium is common on the human skin and in the nose and throat. Infection by this organism begins suddenly, but victims recover after several days. The prevention requires cleanliness, proper

cooking and preservation through some food preservation means such as drying, canning, or freezing.

Food poisoning can result from the Salmonella and Shigella bacteria found in eggs, poultry, sheep and cattle feces, insects, and the intestines of humans and animals. Their effect is felt 12 to 24 hours after the food is ingested. These are not serious illnesses, and people recover within days.

A toxin formed in foods by the bacterium Clostridium Botulinum causes a rare and most serious form of food sickness. This bacterium lives in soils and is not harmful, except when it multiplies under anaerobic (without air) conditions in foods. The only known treatment for botulism is to use an antitoxin, with death resulting if the disease is not diagnosed soon enough, and the antitoxin administered. This is more common in home canned foods than in commercial foods.

Lately, a new mutation or variant of the E. Coli bacteria has caused numerous deaths as a result of the contamination of meat production by intestinal feces during the slaughtering process: the deadly E. Coli 0157:H7 strain. Irradiation is the most effective means to eliminate it.

A new infective agent: prions is thought as the cause of mad cow disease or Bovine Spongiform Encephalopathy (BSE) which is similar to the Creutzfeld Jacob Syndrome in humans. With symptoms resembling Alzheimer's disease, it destroys the brain cells of the victims turning them into a spongy structure. This unfortunately cannot be affected by radiation since it is primarily caused by a protein, and the only way for prevention is to avoid the use of any contaminated foods.

Pork meat is particularly hazardous. A parasite Trichinella spiralis (Trichinea) is often found in pork products. The larvae of the parasite, Trichinea, are destroyed by cooking, by radiation, or by keeping the meat below freezing for over 20 days. This can lead to serious sickness, even though it is common. This is the origin of the avoidance of pork products by the ancient Egyptians; a smart tradition that was continued by the Jewish and Islamic faiths.

According to the Center for Disease Control (CDC), cysticercosis caused by brain worms is the latest border disease in South Texas. This is an infection caused by the pork tapeworm, Taenia solium. Infection occurs when the tapeworm larvae are ingested from contaminated pork meat that is not irradiated or fully cooked. They pass through the intestinal tract wall and enter the body to form cysticerci or cysts. The cysts migrate through the body resulting in symptoms that vary depending on whether they lodge in the muscles, the eyes, the brain or spinal cord.

2.8 IRRADIATION TECHNOLOGY STATUS

More than 35 countries worldwide allow the irradiation of food. In the USA, in addition to raw beef, pork and lamb, spices, wheat, flour, potatoes, pork, poultry, fruits, and vegetables, have been irradiated. Irradiation was approved to control Trichinea in pork in 1990, Salmonella in chickens in 1994, and E. coli in raw meat in 1999.

In Canada, irradiation is used to prepare meals for hospital patients. Cancer patients in particular cannot tolerate a dose of E. coli 0157:H7. French food processors also use irradiation.

The World Health Organization (WHO) designated food irradiation as a perfectly sound food preservation technology that is needed in a world where food borne diseases are on the increase, and where in between 1/4 to 1/3 of the global food supply is lost post-harvest.

The USA National Food Processors Association accepts it as a greater degree of protection for all consumers, especially the most vulnerable: young children, the elderly and the immune system

compromised. The American Medical Association (AMA) is on record as supporting food irradiation.

Since the 1960s, the National Aeronautics and Space Administration (NASA) included irradiated foods on the menus of its space flights. These foods were found to be as nutritious as non-irradiated foods. In addition, these foods pose no risk of food borne illness to the astronauts, since irradiated foods are free of harmful bacteria.

2.9 IRRADIATION FACILITIES

There exits many commercial irradiation facilities in the USA. Isomedix, an irradiation company in Whippany, New Jersey, operates 14 irradiation plants in the USA, Canada, and Puerto Rico. These facilities primarily sterilize disposable medical products such as disposable syringes, gauze, plastic tubing and gowns, and a broad range of consumer products including baby-care products.

Two other commercial companies operate in the USA. SteriGenics International in Tustin, California, and Food Technology Service Inc. (FTSI) in Mulberry, Florida, both irradiate food in the USA.

SteriGenics started in 1986 irradiating dry-food items such as pepper, onion powder, and dehydrated vegetable powder. About 50 million pounds of spices are irradiated each year.

Two methods are used to irradiate food products.

GAMMA RAY IRRADIATION:

This method uses sources of gamma rays such as the isotopes Cesium^{137} or Cobalt^{60}. Gamma rays can penetrate the food product to a great depth exposing the pathogens in deep layers of the irradiated product. Gamma irradiation machines can irradiate whole pallets of food products. Such a machine has a large capacity but operates at low speed. The process is better than any means of pasteurization currently available, even though it is not 100 percent effective.

The radiation source is normally Cobalt^{60} pencils installed on either side of an 8 by 16 foot stainless steel rack. The pencils are stainless steel tubes containing two zirconium alloy tubes that encapsulate nickel-coated pellets of Cobalt^{60}.

The isotope Cesium^{137} can also be used. Like Co^{60} it has been used as a gamma ray source in medical applications. A medical radiation source was discarded and found its way for recycling at a junkyard in Brazil. Upon dismantling it in September 18, 1987, from an abandoned cancer therapy device, the workers were fascinated by the glowing bluish stone inside it and were completely unaware of its hazard. They distributed pieces to friends, relatives and neighbors. Hundreds of people were exposed to the radiation and 40 contaminated homes were demolished as a safety measure.

LINEAR ACCELERATOR IRRADIATION:

A linear particle accelerator is used to create an electron beam, which would kill 99.9 percent of the pathogens in meat. The electron machine is high speed, but low capacity as compared with the gamma ray machine. This device generates a beam of electrons that directly

contact the product, or convert the accelerated electrons into x-rays which can penetrate the irradiated product deeper, but are less efficient than the electron beam.

As an example, a Circe-3 irradiator built by Thomson CFE in Saint-Gobin, France, is used experimentally at Iowa State University. This accelerator comprises an electron gun consisting of a cathode and anode that generate electrons, which are pulsed in an accelerating tube. At the same time, radio frequency power is pulsed into the tube by a klystron, forming waves that the electrons follow. A series of alternating magnets in the tube accelerate the electrons to the high energy levels required for irradiation. At the end of the tube, they pass through a Glaser lens that focuses them into a beam. The beam is bent by a magnet by 107 degrees, so as to choose only those electrons from a specific energy range. Those filtered electrons pass through a scanning magnet and sweep across the irradiated product surface. Several energy levels can be selected at: 5, 7.5, and 10 MeV. These can penetrate, 3/4, 1, and 1.5 inches on one side, respectively. If both sides are irradiated, the penetration is 1 3/4, 2 1/4 and 3 1/2 inches respectively.

In either approach to irradiation, as shown in Fig. 3, the product, usually already packaged, is loaded onto a conveyor belt and is moved toward an irradiation room, which is a concrete bunker that contains the radioactive source.

The cell walls and ceiling are 6 1/2 foot thick concrete poured around steel rebar to ensure that no cracks can penetrate the walls.

When the product enters the room on the conveyor belt, a technician at the control console pushes a lever and the rack is lifted into the room. Everything entering this room is exposed to the radiation for a predetermined interval of time, usually in the few minutes range, depending on the nature of the product, its density, thickness, and other factors.

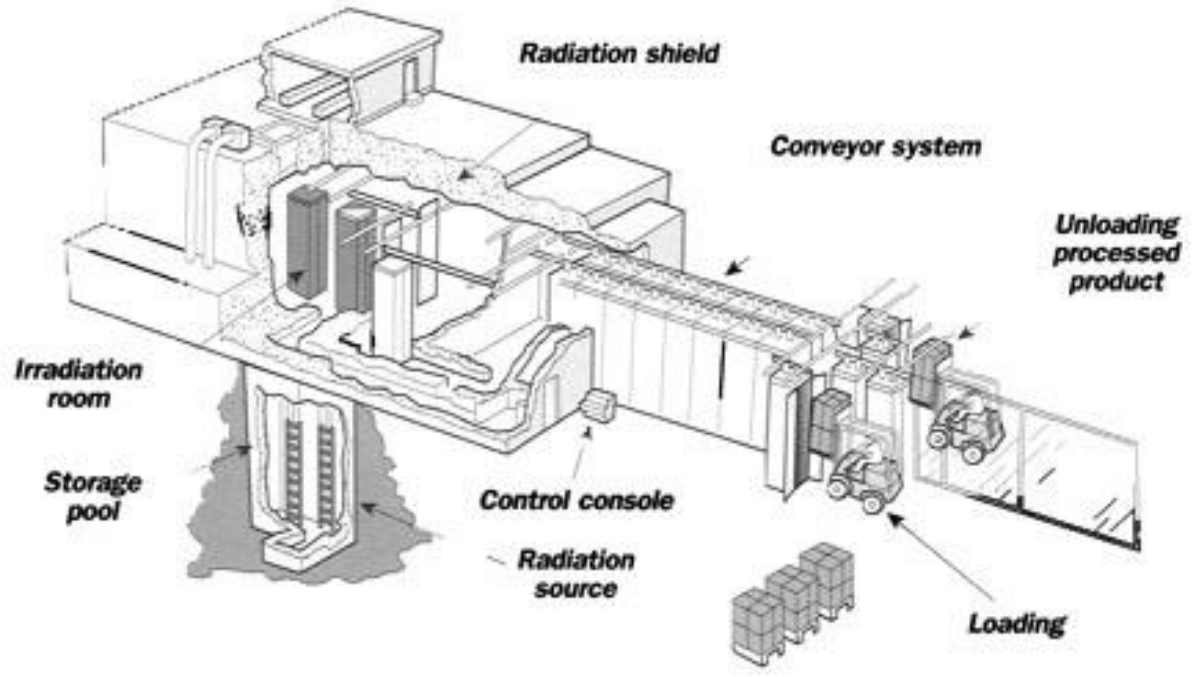

Figure 4. A typical Gamma Irradiation Facility.

In the case of gamma irradiation, the radioactive source is lowered into a storage pool containing deionized water as an effective shielding material. The pool is 26 feet deep. Figure 4 shows the design of an irradiator research facility. Figure 5 shows a Cobalt^{60} gamma radiation source shielded under water, and Fig. 6 shows the source raised to irradiate a product.

After irradiation, the product moves out of the room along a conveyor belt. It can be handled immediately by workers since it does not contain any residual activity, and is loaded onto trucks for shipping.

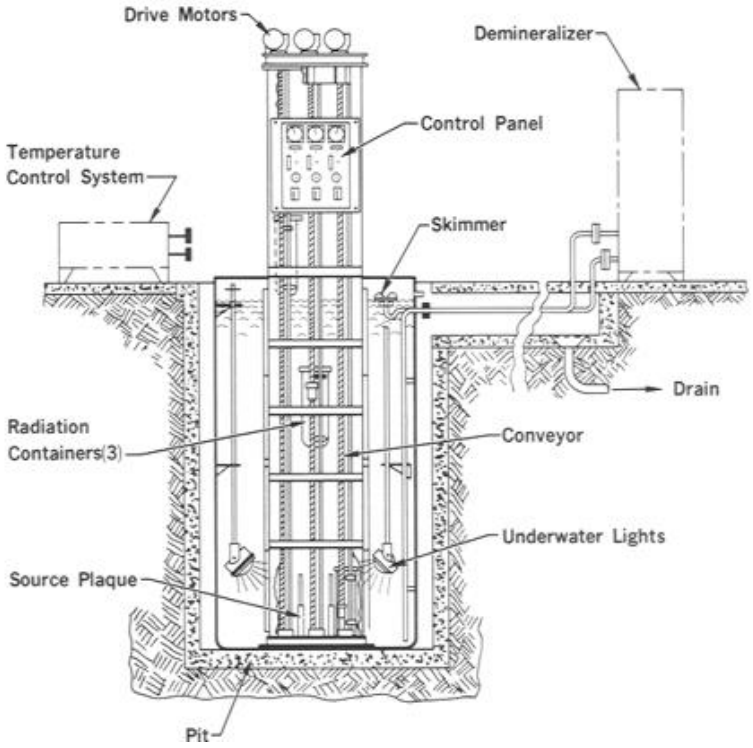

Figure 5. Water shielded irradiator configuration.

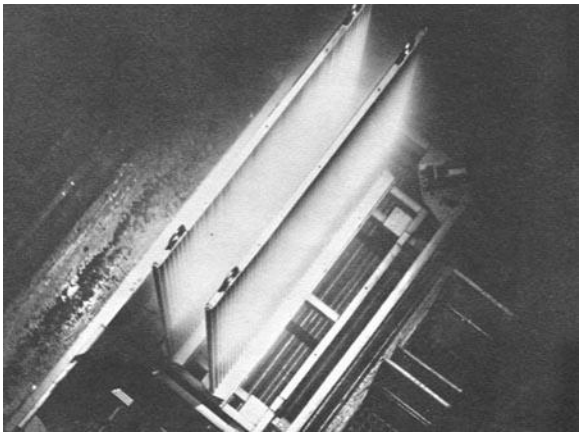

Figure 6. A Cobalt^{60} irradiation source under water shielding emitting Cerenkóv radiation.

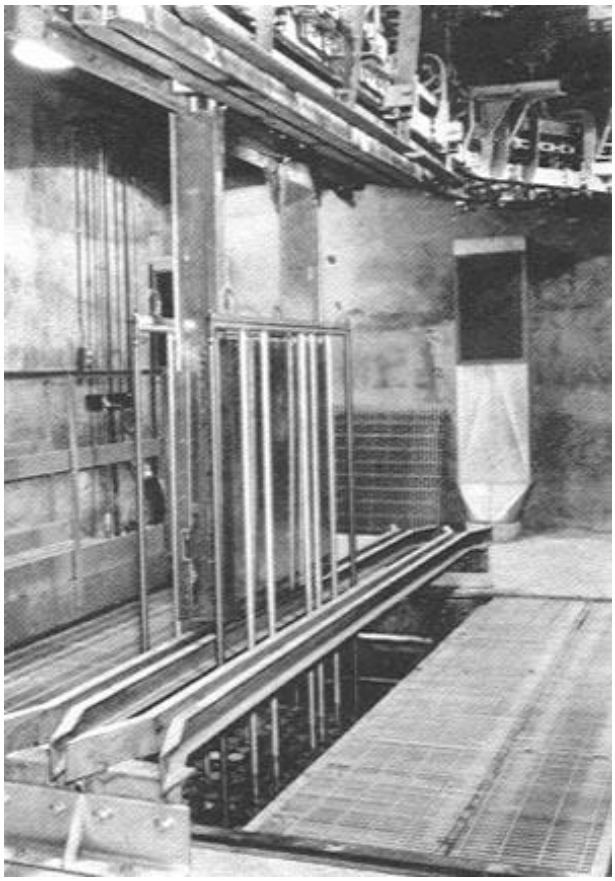

Figure 7. A conveyor rack passes between the raised Cobalt^{60} rods at the USA Army Natick Labs food irradiator.

2.10 ABSORBED DOSE FROM IONIZING RADIATION

If an atom is bombarded with radiation having sufficient energy to strip the electrons from the atoms away, the neutral atom is converted into a positively charged particle, or ion. Radiation moving through food ionizes some atoms in its path and causes an alteration of vital macro molecules which results in the destruction of bacteria and other microorganisms. The degree of ionization is proportional to the amount of energy deposited per unit mass of the material, or radiation dose.

If ionization occurs in food atoms, they do not become radioactive. With low doses of radiation, there is less loss of vitamins than in canning, freezing, or drying. At higher radiation doses, some vitamins are lost, but these can be replaced as they are sometimes replaced in other processed foods.

Dosage is controlled by the speed of the conveyor belt in an irradiation facility. For beef, the approved dose is 4 kilogray (kGy) in chilled meat, and 7 kGy in frozen meat. The maximum dose for spices is 30 kGy.

The absorbed dose unit of Gray (Gy) in the SI system of units delivers an energy equivalent in Joules per kilogram of the irradiated product as:

$$1 \text{ Gray [Gy]} = 1 \text{ [Joule/kg]}, \quad (1)$$

with: 1 kGy =1,000 Gy.

Another measurement unit for the radiation dose in the conventional system of units is the radiation absorbed dose or rad where:

$$1 \text{ rad} = 100 \text{ [ergs/gm]}. \quad (2)$$

The relationship between the Gray and rad units is:

$$1 \text{ Gy} = 100 \text{ rads}, \quad (3)$$

It is convenient to remember the relationship that:

$$1 \text{ cGy} = 1 \text{ rad}$$

Fresh vegetables, including avocados, onions, celery, bell peppers, and broccoli that are sold for retail sale or used for other products such as salsa, require a lower dose of less than 1 kGy of radiation. The shelf-life of these products can be extended by up to two weeks.

Radiation preservation of food can be accomplished through two processes:

1. **Pasteurization:**

This is accomplished with low doses of radiation in the range of 2-5 kGy, and is used for prolonging the shelf life or storage time.

2. **Sterilization:**

Requires high level doses in the range of 20-45 kGy, and allows long term storage without refrigeration.

Different foods have optimal radiation doses for preservation, as shown in Table 3.

Table 3. Radiation Doses for different Preservation Options.

Food	Dose (kGy)	Effect
Potatoes, Onions	0.04-0.10	Sprout Inhibition
Grains, Cereals	0.20-0.50	Disinfection from insects
Fruits	0.50-3.00	Sterilize larvae of lodging insects

Fish	2.00-8.00	Extend shelf life up to 30 days
Meats: Beef, Poultry	45.00-56.00	One year storage at room temperature.

2.11 TOXIC CHEMICALS, FOOD POISONING AND QUARANTINES

The Florida Citrus Commission has sought an alternative to methyl bromide as a quarantine treatment for citrus fruit. It was acting on an Environmental Protection Agency (EPA) suggestion that by 2001, it would ban this chemical, which is used to prevent the spread of fruit flies. This led to the formation of the food irradiation company: FTSI, which started in 1992 treating packaged products for local and national brokers and distributors.

In addition to avoiding the use of toxic chemicals, irradiating addresses concerns of public health such as food poisoning. The process extends shelf life. It eliminates sprouting in tubers such as potatoes, garlic, and onions. It delays the ripening of some fruits and vegetables such as strawberries, tomatoes and mushrooms.

As an example, the storage life of fresh strawberries is normally 7 to 10 days. This can be effectively extended to two weeks after 2 kGy of absorbed radiation dose. There is a small loss of the vitamin C content, but it is of little nutritional value. Figure 8 shows the difference between an irradiated strawberry batch at 2.15 kGy or 215,000 rads, and an unirradiated control.

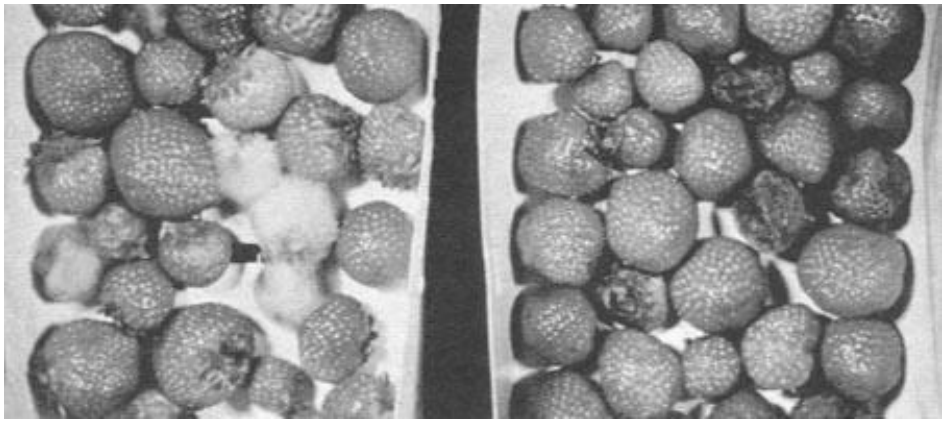

Figure 8. Difference between an irradiated and an unirradiated control.

As a quarantine measure, irradiation kills the larvae of insect pests such as fruit flies and seed weevils in mangoes, preventing them from spreading across national borders or between growing regions in a given country.

2.12 SAFETY CONTROL SYSTEMS

Safety controls and interlocks are provided for food irradiators to protect the operating personnel and members of the public.

A major manufacturer is MDS Nordion in Kanata, Ontario, Canada. Their control system design for food irradiators include radiation monitors, restricted openings, and a remote procedure to replace the $Cobalt^{60}$ pencils under water using magnifying lenses and manipulators. Several

hundred different conditions would automatically shut down the system in case of components failures, human errors, or system design inconsistencies.

Thick concrete walls reaching a thickness of 9 3/4 feet surround the irradiation areas. A multilayered safety system is used, starting from the maze through which the carts are conveyed, to avoid the streaming and leakage of radiation around corners. Multiple 90 degrees turns are used to intersect any streaming electrons, x-rays, or gamma radiation.

2.13 RISKS AND BENEFITS OF FOOD IRRADIATION

Irradiation is likely to be generally accepted in the future as useful to the public's health as pasteurization of milk is today. Its benefits exceed its risks from a Risk-Benefit analysis perspective. However, there are still lingering questions about some aspects of the new technology.

Irradiation uses electron beams, which could in turn generate x-rays as they interact with matter, or gamma ray sources to irradiate food products. X-rays and gamma rays are short wave length electromagnetic radiation that is not capable, at the energies used, of transmuting nuclei and forming radioactive isotopes in food. Thus they do not increase human exposure to radiation. Once the food has been irradiated, the food pathogens are destroyed, and the radiation does not remain in the irradiated food.

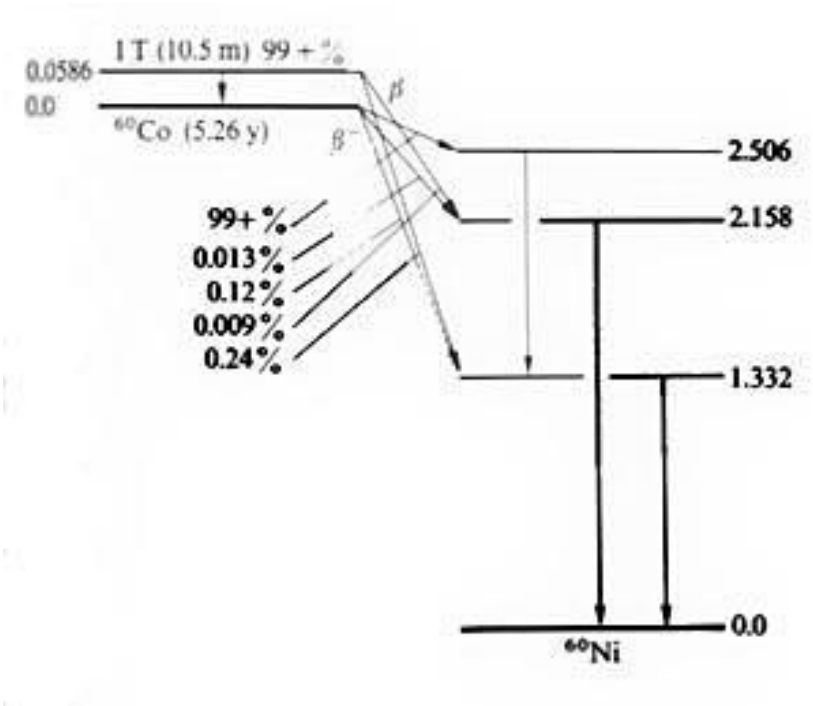

Figure 9. Decay Scheme of the Cobalt^{60} isotope, showing the energies of gamma rays emission.

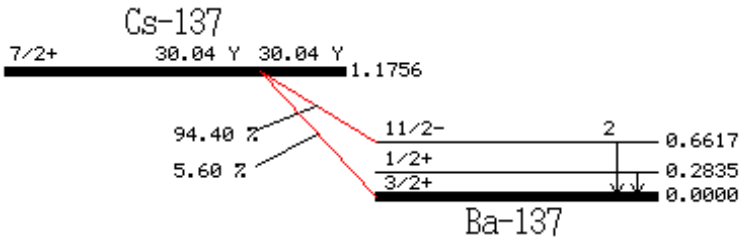

Figure 10. Decay Scheme of the Cesium^{137} isotope, showing the energies of gamma rays emission at 0.6617 and 0.2835 MeV.

Gamma ray sources use the Cobalt^{60} or the Cesium^{137} isotopes which are strong gamma ray emitters. The decay scheme for Co^{60} is shown in Fig. 9 and the one for Cs^{137} is shown in Fig. 10. The gamma ray energies and their relative intensities or percentage occurrence is shown in Table 4.

Table 4. Gamma ray energies and their relative intensities in Co^{60}, Cs^{137} and Tl^{208}.

Isotope	Gamma ray photons energy keV	Relative Intensity, percent
Co^{60}	346.93	0.0076
	826.28	0.0076
	1173.237	99.9736
	1332.501	99.9856
	2158.77	0.00111
	2505.000	2.0×10^{-6}
Cs^{137}	283.5	5.8×10^{-4}
	661.657	85.1
$^{*}Tl^{208}$	211.40	0.18
	233.36	0.31
	252.61	0.70
	277.358	6.36
	277.72	-
	485.95	0.050
	510.77	22.8
	583.191	85.2
	587.7	0.04
	650.1	0.036
	705.2	0.022
	722.04	0.203
	748.7	0.043
	763.13	1.83
	821.2	0.040
	860.564	12.53

	883.3	0.031
	927.6	0.132
	982.7	0.205
	1004	0.005
	1093.9	0.40
	1125.7	0.005
	1160.8	0.011
	1185.2	0.017
	1282.8	0.052
	1381.1	0.007
	1647.5	0.002
	1744.0	0.002
	2614.533	100.0

* For absolute intensity multiply by 0.9916

It can be noticed that the maximum gamma ray energy for Co^{60} is:

$$E_{max}^{Co^{60}} = 2.505 \text{ MeV}$$

The decay scheme for Cs^{137} is shown in Fig. 10 where its maximum gamma ray energy is lower than that of the Co^{60} isotope:

$$E_{max}^{Cs^{137}} = 0.6617 \text{ MeV}$$

One can consider the interaction by a few high-energy gamma photons through photo-nuclear (γ , n) reactions with some trace elements in the food. For instance one can consider the interaction of energetic gamma photons with $Beryllium^9$ through the reaction:

$$\gamma + {}_4Be^9 \rightarrow {}_0n^1 + {}_2He^4 + {}_2He^4. \qquad (4)$$

The threshold energy for this reaction, which is also the binding energy of the neutron in the $Beryllium^9$ nucleus is:

$$E_{th}^{Be^9} = 1.666 \pm 0.002 \ MeV$$

Neutrons would then activate other elements constituting the rest of the food. However, Beryllium is a toxic metal, and is not expected to be found in the foods being irradiated.

One can also consider the photo disintegration reaction with:

$$\gamma + {}_1D^2 \rightarrow {}_0n^1 + {}_1H^1 \qquad (5)$$

The generated neutrons could then activate some other elements in the irradiated food creating some radioactive species. The binding energy of the deuteron is known to be equal to:

$$E_{th}^{D^2} = 2.226 \pm 0.003\ MeV$$

The gamma photons from Co^{60} would be able to disintegrate the deuteron nucleus since:

$$E_{max} > E_{th}.$$

However it occurs with a low intensity of 2.0×10^{-6} percent.

It is known that the deuteron nucleus possesses the lowest binding energy per nucleon at 1.113 [MeV/nucleon] among the other nuclides, whose binding energy per nucleon averages 8.5 [MeV/nucleon]. The deuterium nucleus occurs in water, as heavy water, at a very low abundance of 150 parts per million (ppm) of D to H.

2.14 NATURAL SOURCES OF GAMMA RAYS

It can be thought that some photonuclear reactions could occur in food, not from the gamma ray sources, but from neutrons originating from natural environmental causes such as cosmic ray showers. Also from energetic gamma rays from natural sources such as Thallium^{208}, a member of the Thorium^{232} natural decay chain, which emits gamma rays at an energy above the thresholds for Be^9 and D^2. In fact the maximum photon energy from Tl^{208} is 2.614 MeV above the deuteron binding energy threshold of 2.26 MeV, and it occurs with an intensity of 100 percent.

Since certain foods like Brazil nuts are known to concentrate thorium in their tissue, this matter may be worthy of investigation as a source of activity in foods caused by natural phenomena, rather than by the food irradiation process per se.

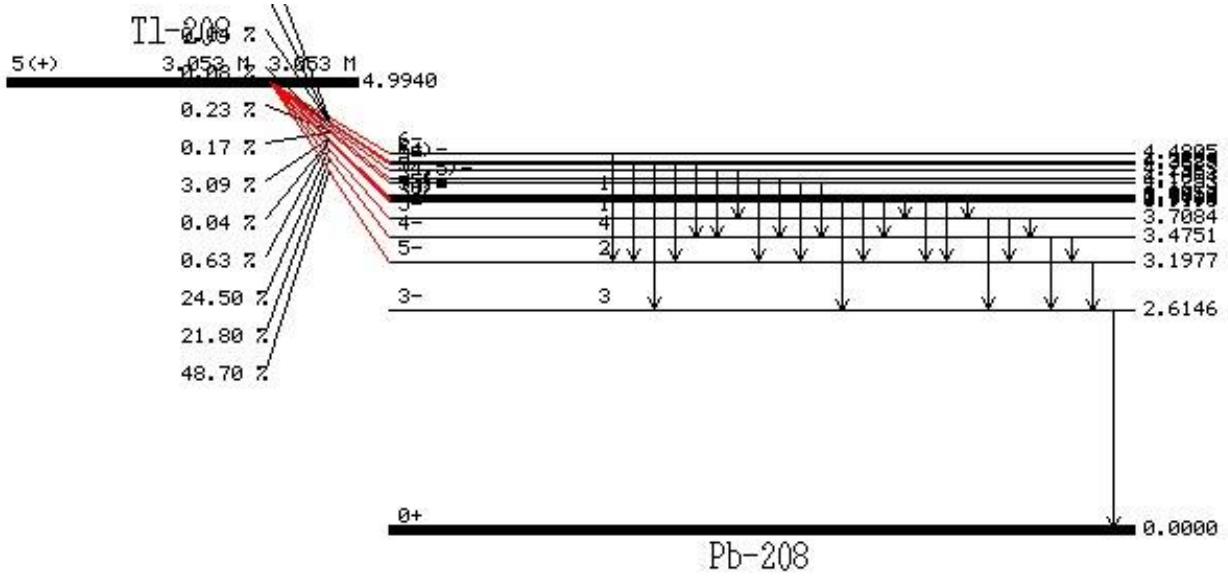

Figure 11. Gamma rays emissions from the Tl^{208} isotope.

It is a fact that irradiation changes the molecular structure of food, much like other forms of electromagnetic radiation such as microwaves do. However, it does not produce significant neutron activation products in the process. Like grilling, using microwave ovens, freezing and canning, irradiation can rearrange the molecules of foods but to a degree that it considered as insignificant by scientists. A controversy exists about the creation of some unique radiolytic products. For instance, gamma radiation can split the water molecule into free radical ions which are chemically reactive through the reaction:

$$\gamma + H_2O \rightarrow OH^- + H^+ \quad (6)$$

After decades of studies, toxic substances that are unique to the irradiation process remain to be found.

There are some claims that irradiation contributes to the creation of radioactive waste related to the use of $Cobalt^{60}$ and $Cesium^{137}$ as gamma radiation sources. One should notice that these isotopes decay to nonradioactive isotopes and the isotope filled rods have to be recharged for reuse. This fear is related to a radiological accident caused by the illegal recycling in Mexico and dismantling of some gamma ray Cs^{137} medical radiation sources, which caused inadvertent human exposure.

Some vitamins and nutrients are slightly depleted in the irradiation process, particularly vitamins A, B, C, E and Thiamin. The depletion is of the same order of magnitude as caused by the cooking of foods.

Opposition to the acceptance of food irradiation appears to exist among people opposed to any aspect of the nuclear industry, even though food irradiation is a well studied technology that has been more researched than any food processing technique. Opposition to food irradiation also appears to be a part of the general concern about food safety, where consumers rightly prefer for instance, to have no contaminants added to meat during the handling process, than to have contaminants sterilized by radiation. Irradiation is a complement and not a replacement for proper food handling practices by producers, processors, and consumers.

2.15 FUTURE DEVELOPMENTS

Through the process the x-ray conversion, future electron accelerators may be able in the future of producing high energy x-rays by irradiating heavy element targets such as tungsten with electrons. These hard x-rays could have a greater penetration range in materials, overcoming the disadvantage of low penetration of current electron accelerators.

Many products are not taking advantage of the benefits of food irradiation such as fish, shrimp, crabs, etc. Shipboard fish irradiators may be installed in the future on fishing vessels and harbors.

Starting 2007, the Food and Drug Administration (FDA) required California almonds sold in California to be pasteurized. One of the methods allowed is gassing the almonds with propylene oxide, a highly toxic flammable chemical compound, once used as a racing fuel before it became prohibited for safety reasons. It is also used in thermobaric weapons. It is an epoxide, which is not Generally Recognized As Safe (GRAS) for human ingestion. The Environmental Protection Agency (EPA) classifies propylene oxide as a Group B2, probable human carcinogen.

Grain supplies in transit in railcars and ship-holds as well as countryside grain elevators, are currently protected against storage insects such as weevils, mites and rodents with extremely potent toxic gaseous, liquid and solid fumigant chemicals, among others:

1. Phosphine (PH_3OS),
2. Methyl Bromide,
3. Sulfuryl Fluoride
4. Chloropicrin,
5. Methylisothiocyanate oil,
6. Synergised pyrethrins,
7. Aluminum Phosphide,

which are used to fumigate the grain supplies once they are withdrawn from storage, and contaminate the whole food supply system. Insecticides such as 6 percent Malathion Dust and rodenticides are also used. Bulk and package grain irradiators may in the future replace the chemical treatment and dot the grain producing plains as grain elevators now do.

As the process becomes more accepted, food preservation through radiation contribution to food safety will eventually reach the same recognition as the sterilization of medical products has in terms of preventing the spread of infectious disease.

EXERCISE

1. Consider the 99.92 percent of the time emission of the 2.5 MeV photon from the radioactive decay of the Co^{60} isotope. Calculate the activity of 1 kilogram of Co^{60}, then estimate the ensuing dose rate, assuming the photons are all absorbed in the material in units of rad/hr and Gray/hr.

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