A review of the safety of cold pasteurization through irradiation

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Perhaps no food process has been researched and reviewed more than food irradiation. The scientific basis and mechanisms of food irradiation are as thoroughly understood by the scientific community and regulatory agencies as traditional food processes. While irradiation provides many benefits, it cannot replace proper food handling as the single most critical food safety measure. Irradiation does not prevent contamination but it controls it.

A broad spectrum of national and international studies conclude that food irradiation can accomplish the following:

- inhibit sprouting in crops like potatoes, onions and garlic;
- destroy insects and parasites in cereal grains, dried beans, dried and fresh fruits, meat and seafood;
- delay the ripening and spoilage of fresh fruits and vegetables;
- extend the shelf-life of perishable products like beef, poultry and seafood;
- eliminate disease-causing microorganisms in food; bacterial and fungal spores and viruses are not affected by the most commonly used dose levels; and
- sterilize at doses above 10 kGy herbs, spices and other ingredients like dried vegetables, in addition to foods prescribed for immuno-compromised hospital patients and for astronauts during space flight.

Scientific research has also determined that food irradiation does not make food 'radioactive' and at low to medium doses, has little negative effect on vitamins and other nutrients humans obtain from their food supply. In cases where the level of certain vitamins are reduced, similar losses are experienced with other processing treatments such as thermal heat and canning. However, irradiation cannot destroy toxins.

Scientists have also studied the creation of radiolytic products, including 'free radicals', by food irradiation. There is broad agreement among world renowned researchers, health organizations and agencies that radiolytic products formed during irradiation pose no danger to humans. This conclusion is based upon hundreds of toxicological studies, some of which have found that more radiolytic products are created when toasting bread or barbecuing steak than when applying low-dose irradiation.

Several US government agencies have studied irradiation from an overall public safety standpoint – transport of materials and protection of plant workers. These tests and other independent research have concluded that workers and commu-
An extensive review of science related to microbiological safety indicates that irradiation is an effective solution to the problem of microbial contamination. Under good manufacturing practices assuring proper handling of the product, irradiation eliminates harmful bacteria that can cause lethal food poisoning and food spoilage. Irradiation is endorsed as a food safety process by independent health organizations and regulatory agencies around the world.

In spite of these conclusions, food irradiation is only being conducted on a commercial scale in a limited number of countries. However, there are more than 40 irradiation plants in operation today in the USA, all of which are dedicated to sterilization of certain industrial products and medical supplies like implants, intravenous fluids, instruments, gloves, bandages, gowns, sutures and drugs. There is only one commercial food irradiation plant operating in the USA.

The slow growth of food irradiation processing in this country is attributable to several factors related to consumer perceptions. Studies and newspaper articles make note of the fact that many of the arguments used against food irradiation are very similar to those used against pasteurization when it was introduced as a milk processing method 100 years ago. Anti-irradiation groups today have been effective at generating negative publicity against producers and retailers who have considered producing or selling irradiated foods. To some extent, their advertising campaigns, boycotts and public protests have kept consumers wary of irradiated foods. Health professionals and other sources of health and medical information also are generally uninformed about food irradiation risks and benefits, and thus have not actively or effectively countered misinformation. There are also some economic considerations that may have slowed the development of a food irradiation industry. These concerns centre on consumer acceptance and an existing market place orientation that plans for produce spoilage and replacement.

Surveys show that Americans know very little about the food irradiation process and are inclined to answer ‘no’ when asked if they would purchase irradiated foods. However, those same surveys indicate that when consumers are told about the benefits and safety of irradiation, their acceptance level increases. Surveys also show that when told of the benefits of food irradiation, particularly as a means to prevent food contamination, consumers are willing to pay more for irradiated products. Irradiated food is available for sale in several countries including the USA and has met consumer acceptance where marketed.

While there is very strong support for food irradiation among the informed scientific community and health organizations, extensive education is needed for broad public acceptance. A strategic, multi-year, broad-scale education campaign, targeting both professional and lay audiences, is necessary.

It is clear from the herein reviewed scientific literature that food irradiation, up to 10 kGy doses – the maximum used for most commercial applications, is a safe and effective method to improve the integrity and security of the food supply.

INTRODUCTION

Irradiation processing of food is a scientific technology that has been studied extensively. As a result, it is as well understood as the more common preservation processes of canning, freezing and dehydration.

The broad consensus of the scientific community and the world’s most prominent health organizations is that food irradiation offers important public health benefits that society is increasingly demanding. This demand is fuelled in part by consumer groups, the media and governments as well as identification of new strains of virulent pathogens, all of which are increasingly challenging the food industry to produce ‘safe’ food.

Despite its strong endorsements as an effective weapon for preventing food-borne illness, food irradi-
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Summary of Recent Research

After several years of testing, the US Army Surgeon General concluded in 1965 that irradiated foods were safe for consumption at levels up to 56 kiloGrays (kGy). Fifteen years later, the Joint Expert Committee on Food Irradiation, convened by the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO), concluded that ‘irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard; hence toxicological testing of foods so treated is no longer required’. It also found that irradiation up to 10 kGy ‘introduces no special nutritional or microbiological problems in foods’ (WHO, 1981).
These conclusions were the result of an exhaustive 20-year review of hundreds of scientific studies conducted on food irradiation worldwide.

Since the joint committee's conclusion in 1980, irradiated food processing technology has been adopted around the world, albeit on a somewhat limited basis. In recent years there have been many studies which have bolstered the conclusions of the US Army and the FAO/IAEA/WHO joint committee.

'Safety and Nutritional Adequacy of Irradiated Food', published in 1994 by the WHO, is a definitive report that reviews research conducted on the safety and nutritional quality of irradiated food since 1980 (WHO, 1994). Additionally, the report examines the chemistry and potential applications of food irradiation. It also reviews toxicological studies and the effects of irradiation on microorganisms. The conclusion states that food irradiation is a thoroughly tested process and that when established guidelines and procedures are followed, it can help ensure a safer and more plentiful food supply.

Although the WHO report documents the overwhelming amount of scientific research supporting the conclusion that food irradiation is safe and important, it also stresses that irradiation is not the preservation method of choice for all commodities. In the areas of greatest concern among consumers and policy-makers - nutritional adequacy and safety - the report provides three conclusive assessments: (i) food irradiation will not lead to toxicological changes in the composition of food that would have an adverse effect on human health; (ii) the technology will not increase the microbiological risk to the consumer; and (iii) food irradiation will not lead to nutrient losses that would have an adverse effect on the nutritional status of individuals or populations (WHO, 1994).

'Food Irradiation: A Practical Sourcebook for the Industry', authored by a research team at Iowa State University, is currently in press and scheduled for release shortly (Hayes et al., in press). The book is written for consumers, the media, regulators, industry and policy-makers and provides an overall assessment of irradiation technology, including practical uses for foods, consumer attitudes, plant and worker safety, nutrient impact and microbial reduction. The authors provide scientific evidence that in all of these categories, food irradiation is a safe and effective food technology which can help prevent disease and extend the shelf-life of many foods. They also provide a detailed review of the design and safety features that are built into irradiation plants.

General safety, defined as the issues of protecting workers, proper transport of low-level radiation sources and precautions against environmental hazards, has been examined by a number of sources. The FDA has determined the total risk from a transport mishap with radiation sources was acceptably low and that there has never been a release of radioactive materials from food irradiation sources in the USA (USDA, 1992). USDA's final rule on poultry further states that irradiation facilities do not release radioactivity into the environment. Overall, the International Consultative Group on Food Irradiation (ICGFI), reports that during the past 25 years there have been few major accidents at irradiation facilities around the world which caused injury or death to workers because of accidental exposure. In these cases, established safety guidelines were deliberately avoided by personnel affected (ICGFI, 1991).

In 1994, J.F. Diehl and E.S. Josephson (1994) presented their review of much of the scientific literature on food irradiation. Their study examines the arguments against food irradiation and summarizes scientific evidence which demonstrates the radiological, microbiological and toxicological safety of this technology. The study also reviews opponents' arguments about nutritional quality and presents scientific evidence which rebuts these claims. Their review upheld conclusions that food irradiation up to 10 kGy is safe and does not significantly alter food nutrition or composition.

The tragic 1993 deaths of children who ate undercooked hamburgers in Washington state sent shock waves through the ranks of consumers, food retailers and government. The outbreak, the most recent in a series of such events, was the result of the presence of Escherichia coli 0157:H7 in the ground beef, and led to tighter federal regulations for meat inspection and commercial cooking and spawned consumer concern around the country. There have been similar epidemics in Scotland and England.

Numerous studies have demonstrated that low to medium dose food irradiation and proper packaging and storage are very effective weapons against E. coli (as well as Campylobacter, Salmonella, Yersinia, Listeria, Taenia solium and Taenia saginata (beef and pork tapeworms), as well as the swine parasite Trichinella spiralis). At least one former Assistant US Surgeon General has suggested the unfortunate deaths of the Washington state children could have been avoided if food irradiation were being applied to ground beef on a commercial scale (Steele, 1993).

A significant development regarding red meat irradiation has occurred recently. The FDA on 8 March 1995, approved irradiation sterilization of frozen, packaged meats, including beefsteaks, for use in NASA's space flight programme (FDA, 1995). FDA evaluated data and other relevant material and determined that radiation-sterilized meats will be 'at least' as nutritious as meats sterilized by conventional means. The agency also found that radiolytic products produced during the irradiation process were 'too small to be of any toxicological significance'.

The USDA approved a final rule permitting the irradiation of fresh or frozen packaged poultry products in 1992. This final rule followed a 1990 FDA rule which would have allowed irradiation of poultry at levels up to 3 kGy. The agency stated that 'irradia-
tion of poultry at doses up to 3 kGy will not have an adverse impact on the nutritional value of a person's diet (FDA, 1990).

A series of landmark poultry studies, which began in 1976 and concluded 7 years later, were conducted by Raltech Scientific Services (Raltech), in conjunction with the US Army Medical Department, and are often cited in food irradiation research (Thayer et al., 1987). The extensive studies examined the wholesomeness and nutritional quality of irradiated chicken meat as well as its potential human toxicity, carcinogenicity, effect on reproduction, teratogenicity and genetic toxicity. Raltech's studies, which are among the world's most comprehensive, expensive ($8 million) and lengthy of their kind, included feeding studies in mice and dogs, a battery of sex-linked recessive tests in fruit flies and the Ames mutagenicity test (Thayer et al., 1987). The FDA and USDA have concluded on the basis of their independent evaluations of the Raltech data that there is no evidence of adverse effects that could be attributed to irradiation of chicken at doses of up to 58 kGy.

KEY ISSUES

The debate over the safety and wholesomeness of irradiated foods continues to be waged along several fronts. Questions most frequently focus on the following scientific areas: (i) radiation dosages – pasteurization vs sterilization; (ii) microbiological safety of irradiated foods; (iii) nutrient loss during irradiation; (iv) free radical formation and radiolytic by-products of irradiation; and (v) product quality – taste, texture, odour and other sensory attributes.

This section will summarize current scientific research and opinions on each of these issue areas. The materials cited will by no means exhaust the entire body of research that has been performed in each area but are indicative of these studies.

<table>
<thead>
<tr>
<th>Dose level</th>
<th>Purpose</th>
<th>Product examples</th>
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<tbody>
<tr>
<td>Low dose disinfection/delay in</td>
<td>Inhibits the growth of sprouts on potatoes and other</td>
<td>Potatoes, onions, garlic, root ginger, bananas,</td>
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<tr>
<td>ripening (up to 1 kGy)</td>
<td>foods</td>
<td>mangoes and certain other non-citrus fruit, cereals</td>
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<td></td>
<td>Kills insects and larvae that can be found in</td>
<td>and pulses, dehydrated vegetables, dried fish and</td>
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<td></td>
<td>wheat, flour, fruits and vegetables after harvesting</td>
<td>meat, fresh pork</td>
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<tr>
<td></td>
<td>Slows the ripening process</td>
<td></td>
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<tr>
<td></td>
<td>Kills certain harmful parasites associated with</td>
<td></td>
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<td></td>
<td>foods</td>
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<tr>
<td>Medium dose pasteurization</td>
<td>Dramatically reduces the number of or eliminates</td>
<td>Fresh fish, strawberries, grapes, dehydrated</td>
</tr>
<tr>
<td>(1-10 kGy)</td>
<td>certain microbes and parasites that cause food to</td>
<td>vegetables, fresh or frozen seafood, raw or frozen</td>
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<tr>
<td></td>
<td>spoil</td>
<td>poultry and meat</td>
</tr>
<tr>
<td>High dose sterilization</td>
<td>Sterilizes food for a variety of uses, such as</td>
<td>Meat, poultry, seafood and other food prepared for</td>
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<tr>
<td>(10-50 kGy)</td>
<td>meals for hospital patients who suffer from immune</td>
<td>sterilized hospital diets, spices, enzyme preparations,</td>
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<td></td>
<td>disorders and can eat only bacteria-free foods</td>
<td>natural gum</td>
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<td></td>
<td>Eliminates some disease-causing viruses</td>
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<td></td>
<td>Decontaminates certain food additives and</td>
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Radiation dosage: pasteurization vs sterilization

The most important element in food irradiation is the dose used on the product. The exposure must be adequate to produce desired results, yet low enough to maintain the quality of foods. In most countries, including the USA, guidelines exist and define the minimum and maximum exposures for various commodities. Most of the claims of adverse effects of irradiation do not apply to the typical doses approved for pasteurization and they generally only apply in theory to the much higher doses required for sterilization. There are three irradiation dosage levels commonly referred to, depending upon the application, as shown in Table 1.

High doses of irradiation sterilize food, killing all microorganisms except for viruses. This process produces similar results for pathogen elimination as food that is treated with high heat for commercial canning. However, radiation-sterilized meat and poultry products produced by current methods have been rated by experts as superior to their canned counterparts in texture, appearance, and, in some instances, vitamin retention and taste (Steele and Engel, 1992). Similar findings were related to sterilized ice cream and frozen yogurt, which were tested and found highly acceptable and safe for immunosuppressed patients recovering from bone marrow transplants (Dong et al., 1992).

Irradiation at low doses is used to produce many of the same effects of pasteurization achieved by conventional heating of products. About 100 years ago, pasteurization was introduced to destroy disease and/or spillage-producing bacteria that might be in beer, milk and wine. Low to medium-dose irradiation can produce the same pasteurization effects by destroying food-borne bacteria and parasites found in meat and poultry (Campylobacter, Salmonella, Listeria, E. coli, Yersinia, Aeromonas, Taenia solium and Taenia saginata and Trichinella) (Hayes et al., in press) delaying spillage of highly perishable foods.
and extending the shelf-life of fruits and berries. Irradiation of foods approved for pasteurization doses has little or no effect on flavour (Steele and Engel, 1992). Sterilization doses can also affect taste and texture on many products. Some foods such as milk and most dairy products are unsuitable for irradiation, while most species of fresh fruit and vegetables will not tolerate doses above 2 or 3 kGy.

Microbiological safety of irradiated foods

Public attention to foodborne illness has increased dramatically in the last decade, heightened in large part by greater media coverage of food contamination outbreaks. These outbreaks have originated with practically every type of food commodity – dairy products, eggs, fruits, meat, seafood and vegetables. Most studies estimate that only about 10% of these outbreaks are actually reported. According to USDA's Economic Research Service, the cost of medical treatment and lost worker productivity for five foodborne diseases – trichinosis, toxoplasmosis, salmonellosis, campylobacteriosis and beef tapeworm – totals more than $5 billion annually (Lee, 1994).

There is a large body of scientific knowledge concerning the effects of irradiation on microorganisms found in food. As scientists have pointed out, 'Fortunately, the most common and – from a public health standpoint – most troublesome bacteria, such as Salmonella, Shigella, Yersinia, Campylobacter and Listeria, are most sensitive to radiation and can be reliably eliminated by doses far below 10 kGy' (Diehl and Josephson, 1994).

Medium dose irradiation is also effective in the control of E. coli 0157:H7, the strain identified as responsible for the food poisoning deaths of four children in the Northwest in 1993. This strain is spread from improper sanitation and found rarely in chopped ground meat and other foods (Thayer and Boyd, 1993). There are several other toxigenic strains of E. coli that can cause disease.

Irradiation has also proved effective against Staphylococcus aureus, another primary source of food contamination in meat (beef, ham, pork, turkey and chicken). Irradiation killed all S. aureus in mechanically deboned chicken at a low-dose level of 1.5 kGy (Thayer and Boyd, 1992). It should be noted, however, irradiation will not destroy S. aureus toxin that may have already been produced by the organism.

Because some microbes like Clostridium botulinum that form spores, might survive irradiation just as with other forms of processing, scientific studies and health organizations frequently point out that food irradiation is not a substitute for proper food handling by consumers. For example, proper refrigeration and safe food handling practices – thorough cooking, washing hands, cleaning utensils and work areas – are also important elements in the prevention of pathogenic foodborne illness.

Some concerns have been expressed that irradiation will result in the increased induction of new strains of microorganisms. Irradiation can produce some changes like other food processing methods, but scientists consider these insignificant. Moreover, surveys of scientific literature, by the World Health Organization (1994), have uncovered no evidence of new strains of microorganisms being produced. In fact, it has been shown that irradiation can result in the loss of virulence and infectivity of pathogens (Feingold and Martin, 1982). WHO asserts these losses are not surprising because damaged organisms are less well adapted to their environment and are less competitive than their natural counterparts in the absence of continuing irradiation. Heat processing, food preservatives and even drying also produce these effects in microorganisms (Mosely, 1992).

Yet another concern, voiced primarily by opponents of food irradiation, is that irradiation may be used to 'cover up' food spoilage. This is an area that has drawn a good deal of research and has been investigated by US and international scientific organizations. Microorganisms that signal spoilage produce bad odours or discoloration, thereby warning consumers that food may be unsafe to eat. Irradiation may suppress the growth of microorganisms in food that is already spoiled. However, it cannot suppress odours or other signs of spoilage and thus cannot be used as a means to 'hide' or 'cover up' spoiled food (ICGFI, 1991).

An FDA review of scientific studies on poultry contamination revealed another interesting aspect. Tests showed that on chicken irradiated at 3 kGy, natural surviving microflora grew faster than Clostridium botulinum, and that enough normal flora survived in poultry irradiated at 3 kGy so that spoilage occurred before toxin was detected (USDA, 1992). FDA also reviewed several studies examining the residual microbial flora on poultry parts and mechanically deboned chicken meat irradiated and then stored at temperatures ranging from 1–5°C and found that cold-tolerant Listeria monocytogenes would not grow to infective numbers before spoilage becomes evident (USDA, 1982).

The possibility that irradiation might sufficiently alter the properties of pathogenic organisms to allow them to escape their correct identification has been raised as a concern. However, studies show that the vast majority of characteristics of microorganisms remain unchanged after irradiation, making their identification easily possible (Feingold and Markin, 1982).

The vast review of science related to microbiological safety indicates that irradiation is an effective solution to the problem of microbial contamination. Under good manufacturing practices, irradiation
eliminates harmful bacteria that can cause lethal food poisoning and food spoilage. Irradiation is approved as a food safety process by independent health organizations and regulatory agencies around the world.

Nutrient loss during irradiation

Nutrition studies have shown that low-dose irradiation treatments do not cause noticeable decreases in the nutritional quality of food and that macronutrients such as protein, carbohydrates and fat remain relatively stable (ICGFI, 1991; Steele and Engel, 1992). Additionally, comprehensive review has also determined that essential amino acids, essential fatty acids, minerals and trace elements experience no significant losses in food irradiated under good management practices (Diehl et al., 1991).

Research has shown that the change in nutritional value caused by irradiation depends on a number of factors. Among these are radiation dose, type of food, packaging and processing conditions such as temperature and oxygen exposure during irradiation and storage time. For example, some vitamins, especially B1, are partially lost during irradiation; however, this loss can be minimized by choosing appropriate conditions, particularly the exclusion of air during irradiation and storage (Fox et al., 1989).

There are 13 essential vitamins: thiamin (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), cyanocobalamin (B12), folacin, biotin and ascorbic acid (vitamin E) and pyloquinone (vitamin K). Of this group, B12, B5 and folacin have been found to be quite resistant to breakdown during irradiation; the others are sensitive to the process but their degradative loss is similar to losses experienced during heating or other processes (Hayes et al., in press).

In the light of increased consumer concerns about foodborne illness resulting from consumption of various foods, and suggestions that irradiation is a good solution to microorganism contamination, it should be noted that various studies have been performed to examine nutrient losses in irradiated meats. Based on its review of nutritional studies during its final rule considerations for poultry, the FDA concluded that 'irradiation at the doses used does not have a deleterious effect on the levels of bioavailability of the nutrients in chicken…irradiation of poultry at doses of up to 3 kGy will not have an adverse impact on the nutritional value of a person's diet' (USDA, 1982).

Irradiated chicken breasts and pork chops have also been tested for losses of the B vitamins (WHO, 1981). The losses of riboflavin (B2) and niacin (B6) were on the order of a fraction of one percent.

Research has found that in high-dose irradiation sterilization there are measurable losses of some vitamins; however, the loss of riboflavin, niacin and thiamine is no greater than that experienced during thermal processing (Steele and Engel, 1992).

Free radical formation and other by-products of irradiation

In scientific terms, free radicals are atoms or molecules with an unpaired electron and can form during the irradiation process. The free radicals interact with other food chemicals and form breakdown radiolytic products which are transient. Although free radicals also occur in non-irradiated food, scientists know the human body produces or absorbs an array of free-radical scavengers such as superoxide dismutase, vitamins E and C, selenium and others. The current antioxidant fad in America has been typified by large increases in the consumption of vitamins E and C and the precursors or analogues of these vitamins.

In the area of food processing and preparation, the development of free radicals has often been considered reason for special concern about the safety of an irradiated product and whether any toxicological effects might be found as a result of ingesting such irradiated foods. Foods exposed to irradiation may undergo chemical changes. Radiolytic products, however, are not unique to irradiation but are produced in other food treatments such as toasting, baking and freeze drying. In fact, low-dose irradiation develops fewer radiolytic products than can be formed in a barbecued steak (ICGFI, 1991).

Free radicals disappear by reacting with each other in the presence of liquids, such as saliva in the mouth. Thus, their ingestion does not create any toxicological or other harmful effects (ICGFI, 1991). This has been confirmed by a laboratory study in which animals were fed dry milk powder irradiated at 45 kGy, more than ten times the usual dose for most food irradiation (ICGFI, 1991). No mutagenic effects were noted and no tumours were formed. Additionally, no toxic effects were apparent in the animals over nine successive generations.

Tests for toxicological reactions from irradiated foods were a focus of the Raltech Laboratory studies, labelled as ‘undoubtedly the most extensive toxicological evaluation of any food or process ever conducted’ (Diehl and Josephson, 1994). The 7 year study, which fed laboratory animals more than 134 tonnes of chicken meat, found no adverse effects attributable to the ingestion of the irradiated chicken meat.

Scientific tests over the past 30 years have attempted to isolate and identify radiolytic products caused by irradiation. No substances of toxicological significance truly unique to irradiated foods have been found. The same radiolytic products are always identified, albeit in varying amounts, in fruits, vegetables, meats and fish, and in many other types of processed and unprocessed foods. The nature and
concentration of the radiolytic products formed during irradiation indicate there is no evidence of any toxicological hazard (FDA, 1995).

FDA has estimated that the total amount of undetected radiolytic products that might be formed when food is irradiated at a dose of 1 kGy would be less than 3 milligrams per kilogram of food, or less than 3 parts per million (ICGFI, 1991).

The FDA has reviewed the radiolysis research and concludes, ‘...at the radiation doses FDA has proposed for the treatment of foods, the irradiated food is virtually indistinguishable from the equivalent non-irradiated food, and the types and amounts of radiolytic products formed are such as to make the foods indistinguishable with respect to safety' (WHO, 1981).

**Product quality**

Sensory evaluations of irradiated food have been conducted and reported in a number of scientific studies. Researchers at Iowa State University (ISU) have reviewed a number of these sensory (odour, appearance, flavour, texture and overall acceptability) studies (Hayes et al., in press). They report that the eating quality of native egg solids, as well as scrambled eggs and mayonnaise made from the egg solids, was found to be indistinguishable from samples irradiated in air to 3.0 kGy and in the absence of oxygen to 5.0 kGy. The ISU researchers also conducted sensory evaluation of irradiated (at 1 kGy) fish flesh colour and flavour after 5 days storage. Panelists were unable to detect flavour differences between controls and irradiated test samples. In another study with fish it was learned that a 1 kGy dose could extend the shelf-life of various marine species without affecting sensory quality. Sensory quality decreased slightly as irradiation approached the 5 kGy dose (Hayes et al., in press). In a study of vacuum packaged pork loins irradiated at 1 kGy, there was minimal sensory changes and no detectable differences between treated and control samples after 14 days of storage (Hayes et al., in press). A study of frankfurters irradiated from 0.5 kGy to 10 kGy at two temperatures of irradiation (2°C and −30°C) generally resulted in the same product quality, with no significant differences in tenderness, freshness, off-flavour and overall acceptability (Hayes et al., in press).

At the ISU laboratory, several studies were conducted to determine whether consumers could detect the difference between irradiated and non-irradiated ground beef patties (Hayes et al., in press). These studies have found that the only significant difference between irradiated and non-irradiated patties was in texture and juiciness, with the irradiated samples being rated as more tender and juicy than the non-irradiated samples.

A similar finding was made at a hospital feeding immune-compromised patients meats, sterilized by irradiation (WHO, 1981). The patients found the irradiated meats to be tender and moist, with no irregular appearance. In contrast, the hospital reported that patients found meat sterilized by autoclaving was overcooked and dry. The patients preferred the irradiated meats.

Irradiation doses are prescribed by regulatory agencies under good management practices. At the heart of these practices are dosage recommendations to destroy and reduce pathogens. A chief consideration, however, is what even low doses of radiation will do to the appearance and taste of a food product. Through testing, researchers have learned which foods will or will not accept low-dose irradiation.

Dairy products, for example, cannot be irradiated at any level due to the undesirable flavour that would be produced. Following good management practices, irradiated food is virtually indistinguishable from its non-irradiated counterparts (ICGFI, 1991). Sound, although non-empirical, evidence of this comes from countries in which commercially offered irradiated foods have been sold on a regular basis. For example, in France, the Netherlands, South Africa, Thailand and even the USA, commercial quantities of some irradiated food items are routinely sold in food stores, including: strawberries, mangoes, bananas, shrimp, frog legs, spices and fermented pork sausages. The irradiated items, which are labelled to indicate the treatment and purpose, have been successfully selling alongside non-irradiated items.

**PLANT AND WORKER SAFETY**

Questions have been raised about the safety of a community if a food irradiation plant was constructed within its boundaries. A primary concern centres on whether people might be exposed to dangerous radiation when radioactive materials are transported to and from a plant. Paralleling the transportation issue are questions about accidental worker exposures to radiation and general public exposure in case of a 'meltdown'.

A recent article summed up the answers to those questions with the following: ‘A food irradiation plant would not endanger a community any more than do the medical products irradiation plants and more than 1000 hospital radiation therapy units now operating in the United States, nor would it pose any more hazard to a community than the hundreds of industrial X-ray units currently operating in many communities across the country’ (Steele and Engel, 1992).

There are more than 40 irradiation facilities that sterilize medical devices and supplies (surgical instruments, intravenous fluids, implants, gowns, bandages and medicine) in the USA (Hayes et al., in press). The design of food irradiators is similar to the medical irradiation plants, primarily because the
licensing requirements to build a food irradiation plant are similar.

Irradiation areas are surrounded by 6–10 ft thick concrete walls, including the floor and ceiling, depending on the nature of the radiation source – usually gamma rays from cobalt-60 or x-rays from an electron-volt source. These walls serve as a biological shield so that gamma rays cannot penetrate either the walls, floor or ceiling, and contaminate workers. Products are exposed to irradiation by travelling on a conveyor belt into an irradiation area.

A 'meltdown' or explosion cannot occur in a gamma irradiator because the source of radiation energy (radionuclide cobalt-60) cannot produce neutrons, the substances which make materials radioactive. Without neutrons, a nuclear 'chain reaction' cannot occur.

Radioactive waste does not accumulate at irradiation facilities because no radioactivity is produced. The radionuclides decay over time and once the radioactive level declines to between 6–12%, they are removed and returned to the supplier. The supplier may either recharge the materials or store them. Canada has calculated that all the cobalt-60 it supplied for use in 1988 (about 100 million curies) would require a storage space roughly the size of a small business desk (ICGFI, 1991). Cobalt pencils supplied for use in 1988 (about 100 million curies) may either recharge the materials or store them. Canada has calculated that all the cobalt-60 it supplied for use in 1988 (about 100 million curies) would require a storage space roughly the size of a small business desk (ICGFI, 1991). Cobalt pencils used for medical sterilization can be reused for food irradiation as their strength decreases, since far lower doses are required for food pasteurization.

Numerous tests and studies have been performed on containers used to ship the radioactive materials used in industrial irradiation. A US national laboratory performed studies on the shipping casks in real-life situations, such as (Sandia National Laboratories, 1978); (i) dropping a cask from a height of 2000 ft. The cask was dented but there was no loss of radioactive material; (ii) a truck carrying a cask was crashed into a concrete wall while travelling at more than 80 miles per h. The truck was demolished but the cask survived without a loss of integrity; and (iii) a truck was intentionally struck by a 120-ton locomotive at 80 miles per h. The truck was demolished but the cask survived without a loss of integrity.

About one million shipments of radioisotopes for industrial, hospital and research use were made in North America between 1955 and 1988 (ICGFI, 1991). There has never been a release of radioactive materials during shipping, even in cases where a transporting vehicle was involved in an accident (ICGFI, 1991; USDA, 1992).

Regarding worker safety in irradiation plants, as previously noted, there have been few major accidents at irradiation facilities over the last 25 years. The radiation exposure incidents that have occurred (none have been recorded at a food irradiation plant) have been the result of workers deliberately bypassing proper safety and control procedures (Steele and Engel, 1992).

CONSUMER ACCEPTANCE

Numerous studies and articles in the media have made much of the fact that consumers today have little knowledge about food irradiation processing, although awareness of the benefits appears to be increasing. Despite endorsements of the safety and benefits of food irradiation by health professional groups such as the American Medical Association, American Gastroenterological Association, US Public Health Service and Institute of Food Technologists, wide public skepticism still exists. Opinion polls vary somewhat but generally indicate approximately 25–30% of consumers have initially favourable impressions of food irradiation, 55–65% are uncertain about the process and 5–10% are opposed to it (Hayes et al., in press). A 1993 Gallup Poll conducted for the American Meat Institute found the strongest indication of consumer acceptance. Some 54% of respondents said they would purchase irradiated meat over non-irradiated meat. Of these persons 60% said they would pay a 5% premium for irradiated hamburger.

Actual market tests have found that consumers are inclined to purchase irradiated foods after they have been educated about the safety and benefits of the irradiation process. In-store demonstrations in 1987 examined consumer responses to irradiated papayas (Bruhn and Noell, 1987). About 50% of persons walking by test areas stopped and purchased more than 10 times the amount of irradiated papayas than non-irradiated ones. In a separate test, more than 4000 pounds of irradiated mangoes were sold within a week at one store in Miami Beach, Florida (Diehl, 1996). These and other findings have led some researchers to pronounce that consumers will purchase enough irradiated foods to make the process commercially feasible (Hayes et al., in press).

Indeed, surveys generally indicate that when consumers are informed about the irradiation process and its uses in food, the acceptance of both the theory and practice of irradiating foods rises markedly (Conley, 1992). Moreover, earlier studies that reported higher numbers of people expressing major concern about irradiation were often surveys that did not also provide information about the process. However, the Food Marketing Institute’s ‘1994 Trends’ report showed that 36% of people surveyed were very or somewhat likely to purchase irradiated foods after being given a brief description of potential benefits (Food Marketing Institute, 1994). Some consumer studies attribute the perception that consumers do not want irradiated foods to anti-irradiation organizations. These groups have been very effective at working with the news media. The food industry has been threatened with boycotts and protests if irradiated foods were either produced or sold. The most vocal of these groups has been ‘Food and Water’. Less extreme positions have been taken by the Safe Food Coalition which bases its concern...
that irradiation would be used instead of proper sanitation in processing plants. This coalition includes the Center for Science in the Public Interest, Consumer Federation of America, Government Accountability Project, National Consumers League and United Food and Commercial Workers Union.

While the anti-irradiation groups have perhaps been partially responsible for the slow take-off of food irradiation in the USA and around the world, the evidence indicates that thus far they have had a minimal impact on consumer attitudes (Malone, 1990). Other factors attributed to food irradiation's slow growth fall into the areas of economics and retailer uncertainty. Produce suppliers and growers have marketing concerns which stem from the fact that a large part of American produce production is based on spoilage loss. A reduction in spoilage due to food irradiation would undoubtedly mean more produce gets delivered to the marketplace, which could have an impact on pricing and long-term production planning. In the poultry industry, there are questions about how consumer buying habits might change if irradiated chicken is placed alongside non-irradiated chicken.

As the previously mentioned surveys and marketing tests indicate, researchers have been attempting to answer these kinds of questions. One nationwide survey discovered that while there was little knowledge of the food irradiation process (about 75% of respondents had not heard of food irradiation), household purchasers were willing to pay more money for irradiated products based on food safety and food longevity (Malone, 1990). The extension of shelf-life at home for strawberries, peaches and mushrooms was important; however, it did not appear to be as important as the reduction of foodborne diseases (in this case, trichinosis) in pork.

A separate study at Iowa State University found that a majority of participants in a representative survey were in favour of eating irradiated beef patties and chicken, and many of the respondents were prepared to pay as much as 30 cents per pound for this opportunity (Hayes et al., in press).

A Northbrook, Illinois retailer, Carrot Top, has been conducting an ongoing market test since 1991 (Hammel, 1995). Jim Corrigan, president of Carrot Top, recently summarized his experience of selling irradiated produce and poultry as being positive as well as profitable. Despite receiving threats of boycotts and radio advertisements, no one attended a rally that had been scheduled to protest his irradiated produce upon introduction. Corrigan cites discussions with customers, education through a newsletter, in-store point-of-purchase materials and other marketing ideas as responsible for his success. Carrot Top pays 2–3 cents per pound more for irradiated versus non-irradiated strawberries, but sells them for the same price. However, lower net costs have been realized due to reduced spoilage and increased per customer strawberry sales.

FUTURE CONSUMER QUESTIONS

Other consumer issues may require additional research:

- Does the term ‘irradiation’ itself contribute to consumer misperceptions? Can the term ‘pasteurization’ or ‘cold pasteurization’ be used instead of, or in addition to, ‘irradiation’?
- Do FDA’s current labelling requirements for irradiated foods help or hinder the potential for consumer acceptance? Does the green international symbol for irradiation, required by FDA to be prominent on the label of irradiated foods, reassure, frighten or have any other impact on consumers’ purchasing behaviour?
- Can isolated market tests adequately predict consumer purchasing behaviour in the absence of a public education campaign on food irradiation?
- What type of consumer education campaign (in terms of dollars, resources, public and private sector support) is required?

CONCLUSIONS

Food irradiation is recognized by the world health community as another method for preserving food and ensuring its wholesomeness. In the last 50 years, research activities have examined this process and concluded that when used under good manufacturing practices, irradiation will: (i) increase food safety and reduce foodborne illness; (ii) lengthen the shelf-life of many perishable products; and (iii) reduce the risks of post-processing contamination of intact, packaged products.

The consensus of international scientific opinion, and the reviewers of this paper, is that food irradiation is safe and should be considered as a strong tool among a number of important steps to combat foodborne illness. Proper food handling is still paramount, however, regardless of whether food irradiation is utilized.

Food irradiation was the subject of commentary by the current Director of the US Public Health Service, Philip R. Lee, M.D., in a July 1994 issue of the Journal of the American Medical Association (Lee, 1994). Dr Lee concluded, ‘Food irradiation, like pasteurization of milk, can prevent countless infections because it destroys the pathogens that cause foodborne illness...The technology of food irradiation has languished too long already’.

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