Enhancing Food Safety Through Irradiation

International Consultative Group on Food Irradiation

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1999

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Foreword

The International Consultative Group on Food Irradiation (ICGFI) was established on 9 May 1984 under the aegis of FAO, IAEA and WHO. ICGFI is composed of experts and other representatives designated by governments which have accepted the terms of the "Declaration" establishing ICGFI and have pledged to make voluntary contributions, in cash or in kind, to carry out the activities of ICGFI.

The functions of ICGFI are as follows:

❒ to evaluate global developments in the field of food irradiation;

❒ to provide a focal point of advice on the application of food irradiation to Member States and the Organizations; and

❒ to furnish information as required, through the Organizations, to the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food, and the Codex Alimentarius Commission.

As of May 1998, the following countries are members of ICGFI:

Argentina, Australia, Bangladesh, Belgium, Brazil, Bulgaria, Canada, Chile, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Czech Republic, Ecuador, Egypt, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Iraq, Israel, Italy, Republic of Korea, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Pakistan, People's Republic of China, Peru, Philippines, Poland, Portugal, South Africa, Syrian Arab Republic, Thailand, Tunisia, Turkey, Ukraine, United Kingdom, United States of America, Viet Nam, and Yugoslavia.

The 11th Annual Meeting of ICGFI held in Bali, Indonesia, November 1994 requested that a comprehensive Programme of Work and Budget of ICGFI for 1996-98 be developed to facilitate the consideration of ICGFI member governments on the extension of its mandate. A Working Group was therefore convened for this purpose in Vienna in April 1995 which recommended, among other things, that urgent consideration be given to the development of ICGFI documents which would clearly define the role that irradiation can play in achieving the general policy goals endorsed by Member States of various UN Organizations. Five such policy documents in the areas of Food Safety, Food Security, Trade Development, Environment, and Energy Conservation were recommended by the Working Group. However, in view of the financial constraints, the 12th ICGFI Annual Meeting held in Vienna, November 1995, decided to prepare only the first three such documents.

Issues affecting food safety have driven the agenda of many governments, the food industry and consumer organizations during the 1990's and are likely to continue doing so during the next decade. Irradiation as a method to ensure hygienic quality of food, especially those of animal origin, is gaining acceptance and application in a number of countries. It is increasingly recognized as a "cold pasteurization" process for "solid" food such as meat, poultry, seafood and spices, similar to thermal pasteurization of liquid food, e.g. milk, which is widely accepted by the consumer.

This publication was prepared by Dr. Elsa A. Murano and Dr. H. Russell Cross, of the Institute of Food Science and Engineering, Centre for Food Safety, Texas A&M University, USA, on behalf of ICGFI. It clearly explains the effectiveness of irradiation as a method to ensure hygienic quality of food. It provides valuable information for regulatory authorities, the food industry and consumers on the use of irradiation for this purpose. After undergoing a peer review and comments by national contact points of ICGFI and subsequent revisions by the author, this document was approved for publication as one of the information documents by the 14th ICGFI Meeting. The ICGFI Secretariat gratefully acknowledge the valuable contribution of Dr. Murano and Dr. Cross and those who were involved in reviewing this document. This document was professionally edited by Mr. R. Peniston-Bird, a former editor of IAEA.

Executive Summary

Food safety is one of the leading health issues concerning consumers, the food industry, academia, and government officials worldwide. Bacteria such as Salmonella and *Escherichia coli* O157:H7 are the primary cause of food poisoning in industrialized countries, with an estimated 9000 deaths per year in the USA alone. In developing countries, parasitic diseases constitute a major problem, and together with bacterial and viral foodborne illness, account for hundreds of millions of cases per year. The true incidence of diseases transmitted via foods is very difficult to determine, mainly due to the lack of adequate reporting mechanisms. In addition, many patients do not seek medical attention during the illness, resulting in underestimation of the problem. To illustrate this point, from 1990 to 1992, there were ten times fewer outbreaks of foodborne illness reported in Italy than in France, in spite of similar population sizes.

Foodborne diseases are caused by various microorganisms: parasites, bacteria, and viruses. Parasites such as the pork tapeworm, *Taenia solium*, are endemic in many rural areas of Latin America, Asia, and Africa. Another parasite, *Trichinella spiralis*, is involved in outbreaks due to consumption of game meats in Europe, and of pork in the former Soviet Union and the People's Republic of China. Renewed interest in foodborne parasites has emerged in the USA, due to recent outbreaks caused by *Cyclospora cayetanensis* from contaminated imported fruits and vegetables originating in Latin America.

Bacteria are by far the leading cause of foodborne illness worldwide. The majority of outbreaks are caused by *Salmonella*, *Shigella*, and *Staphylococcus aureus*, pathogens found primarily in foods of animal origin. *Vibrio cholerae*, an organism associated with water and seafood, has caused over one million cases of illness in Latin America and Asia since 1995. The organism *E. coli* serotype O157:H7 has revolutionized the meat inspection system in the USA, and outbreaks in Japan and Wales due to this organism have resulted in thousands of cases and dozens of deaths from consumption of contaminated, undercooked meat. In considering the causes for foodborne illness, improper holding temperature and poor personal hygiene rank highest.

Food irradiation is a technology that has been proven safe, resulting in wholesome products, through research, spanning over 40 years, conducted worldwide. The doses used for eliminating foodborne pathogens are in the medium range, between 1 and 10 kGy. These doses can readily decrease the number of microorganisms by at least 5 $\log_{10}$, resulting in the total elimination of pathogenic bacteria in most cases. As a critical control point during processing of fresh foods, irradiation is easy to monitor, has quantifiable parameters, and science-based critical limits. For this reason, food irradiation fits well within the Hazard Analysis Critical Control Points (HACCP) system recently mandated throughout the meat and seafood industries in the USA.

Specific benefits of this technology in improving food safety include: (1) effectiveness in destroying microorganisms of public health significance, (2) elimination of post-processing contamination due to irradiation of product already packaged, and (3) maintenance of food quality, as long as the process is applied correctly. Regarding cost, economists have calculated that it would cost just under US $0.02 per pound for a plant to irradiate 52 million pounds of food per year at a dose of 2.5 kGy. Although these costs may not be accurate, it has been shown that consumers are willing to pay as much as US$0.30, once the benefits of irradiation are presented to them.

Application of food irradiation can have a tremendous impact on food safety. Organizations like the World Health Organization (WHO), the Institute of Food Technologists, and the American Medical Association, among many, have endorsed this technology for enhancement of food safety, which it offers. Education of all consumers is the first step towards its implementation. However, governments must not delay the approval of irradiated foods any longer than necessary. Incentives should be provided for those willing to use the technology. Finally, academia, government, industry, and consumer advocacy groups should work together to bring irradiated foods to the marketplace, offering consumers the choice of safer products made so by the intelligent application of this technology.

Introduction

Foodborne illness is a problem recognized by many as one of the leading health concerns facing consumers worldwide. The World Health Organization (WHO) has estimated that 70% of all cases of diarrhoea in infants and young are attributable to consumption of contaminated food. Bacteria, such as Salmonella and Campylobacter and others, are primarily responsible for a rise in the number of cases of foodborne illness in industrialized countries from 1965 to 1990, with an estimated 7000 annual deaths from salmonellosis in the USA alone. In developing countries, foodborne bacterial, viral and parasitic diseases are a major problem, affecting hundreds of millions of people every year (Käferstein, 1997).

The World Summit for Children in 1990 addressed foodborne illness, by stating that providing adequate diets for children, ones which are, nutritionally acceptable as well as safe, is one of the steps that must be included in any plan of action to protect and help the children of the world. In 1992, the United Nations Conference on the Environment and Development adopted a measure to protect and promote health through the control of infectious diseases, including those transmitted by food. In the same year, the International Conference on Nutrition hosted by the Food and Agriculture Organization (FAO) and the WHO stated that access to nutritionally adequate and safe food was a right of every individual (Motarjemi and Käferstein,1996).

Food irradiation is a technology that has been studied for over 40 years worldwide, offering several important benefits. The most important of these is the effectiveness of irradiation in reducing, if not totally eliminating, microbial pathogens in food. This is especially significant when applied to minimally processed foods, or to foods intended to be consumed raw. Elimination or reduction of foodborne pathogens in such foods is especially important to people with compromised immune systems, such as the elderly, cancer patients and AIDS patients. Food irradiation provides them with a source of fresh, wholesome, nutritious and, most importantly, safe food not otherwise available.

The doses that have been approved in various countries for the decontamination of most foods range from 1.5 to 7.0 kGy. These are sufficient to eliminate from 3 to 10 log10 cycles per gram of bacterial pathogens, depending on the organism. Most disease-causing bacteria are found in numbers ranging from <10 to 100 cells per gram of food. Thus, population reductions as described above would certainly render contaminated products free, or almost free, from pathogenic contaminants, having reduced their numbers to such low levels that foodborne illness does not develop.

There is ample evidence that the benefits of applying this technology will more than offset its costs. Food irradiation offers opportunities to reduce significantly the incidence of foodborne illness throughout the world. The benefits of increased implementation of this technology should be seriously considered by governments, industry and consumers. This document provides information on the global problem of foodborne illness, the methods currently used to counter it, the cost that outbreaks represent for society, and how food irradiation can be used to enhance food safety.

Worldwide Incidence of Foodborne Illness

The worldwide incidence of foodborne illness is very difficult to establish, mainly owing to the low rate of reporting by many countries, especially those with very limited resources. Countries must often rely on poorly organized entities within their health agencies to collect data on outbreaks. Such data, if obtainable at all, are usually gathered only by the physicians involved, so do not include people who allow the disease to 'run its course', choosing not to seek medical attention. In the USA, foodborne diseases are reported to local and state health departments, which then report this information to the Centers for Disease Control and Prevention in Atlanta, Georgia. Since this is a passive system, cases frequently go unreported.

It has been estimated by many experts that in the USA only 10% of the actual cases of foodborne illness are reported, despite the fact that this country possesses one of the most advanced reporting networks of all industrialized nations. Figure 1 represents the average number of annual cases reported in the USA, while Figure 2 depicts the estimates made by Bennett and Todd in 1987 and 1989, respectively, on what the actual numbers may be. Even if we follow the more conservative figures, it is clear that the number of cases is exceedingly high.

The Pan-American Institute of Food Protection and Zoonoses (INPPAZ) has published information on the number of cases of foodborne illness in several developing nations in Latin America during the first half of 1995 (Table I). The inconsistency in reporting in this part of the world is evident, with Cuba showing vastly higher numbers of cases than much larger countries. This is principally due to a superior system of reporting in Cuba compared to its neighbours. This emphasizes the fact that, until better systems can be developed, any number of cases of foodborne illness in Latin America must be thought of as indicative of a larger problem. Table II lists the outbreaks of foodborne illness reported by various European health agencies. Upon close examination, it is easy to suspect underreporting by some countries. For instance, Italy reported ten times fewer outbreaks than France, although their population sizes are similar (57 million for the former, and 55 million for the latter). In addition, we must be aware of the fact that the system followed for reporting of foodborne illness episodes (cases or outbreaks) are different in each country, making comparisons of the data highly speculative.

In a report by 20 European countries, including those mentioned in Table II, as well as Albania, the Czech Republic, the Netherlands, Slovakia, Switzerland, England and Wales, the causative agent was known in 80.5% of the outbreaks. Of these, 94.9% were caused by bacteria, 2.3% were caused by chemicals and mushroom intoxications, 1.5% were caused by parasites and 0.6% were caused by viruses (WHO, 1995).

This is not to say that diseases caused by agents other than bacteria are not significant in their morbidity and their impact on society. The pork tapeworm, *Taenia solium*, is endemic in many rural areas of Latin America, Asia, and Africa. A similar organism, *Taenia saginata,* found in beef, infects about 200 million people worldwide (Steele and Engel, 1992). From 1988 to 1992, in the USA alone, there were 195 reported cases of foodborne disease caused by the parasite *Trichinella spiralis*, and 184 cases caused by *Giardia lamblia* (CDC, 1996a). However, in Europe trichinellosis is recorded very rarely, with most of the cases now due to consumption of game meats such as bear. This is mainly attributable to the fact that inspection of pork in those countries involves trichinoscopy, or the microscopical examination of small pieces of muscle from swine carcasses, a practice not performed in the USA. Outbreaks of varying severity are still occurring in eastern Europe, the former Soviet Union, and China (Hui et al., 1994).

Parasites have actually gained new momentum in terms of outbreaks of foodborne illness due to the consumption of contaminated fruits and vegetables. Before 1996, most documented cases of cyclosporiasis in the USA (caused by *Cyclospora cayetanensis*) were limited to individuals returning from travel in Third World countries (CDC, 1996b). However, with the expansion of global markets and increased food imports, this parasite has gained prominence as an emerging foodborne pathogen. In 1997, at least 21 clusters of cases of cyclosporiasis were reported in eight states in the USA, and in one province of Canada. Fresh raspberries were served at 19 of the 21 events. These were reported to originate from Guatemala, prompting the US Food and Drug Administration (FDA) to request voluntary suspension of exports of fresh raspberries to the USA (CDC, 1997).

In the case of toxins produced by molds, mycotoxicoses affecting humans have been recorded since the Middle Ages. These organisms can grow on a variety of substrates and conditions, making foods very susceptible to mold infection if not stored properly. In the USA, grains are easily and frequently contaminated with *Fusarium* toxins, with zearalenone and others being found in corn (NAS, 1983). Deoxynivalenol has been detected in wheat in the USA after infestation of the grain by F. *gramineareum* (Trenholm et al., 1985). There is very little information on the risk of illness, including toxicity, carcinogenicity, and teratogenicity of mycotoxins. Even though safe levels have not been established, the FDA sets ‘practical limits’ for aflatoxins in foods and feeds.

The relationship between ingestion of mycotoxins and human disease is not very easy to determine, mainly because there is little direct evidence in terms of controlled experiments with human subjects. However, ergotism, alimentary toxic aleukia, acute cardiac beriberi, Balkan endemic nephropathy, and aflatoxicosis are all attributable to consumption of fungal toxins in foods such as cereal grains (peanuts, corn, wheat, rice), cheese and rotted apples (Bullerman, 1979). Mold growth on food can be minimized through good sanitation during production and handling, as well as by proper storage. Thus, it is no surprise that the greatest potential for human disease caused by mycotoxins is in countries that are least able to reject low-quality foods, and with the most inadequate conditions for storage of grains.

Regarding bacteria, in countries such as the USA, Canada, England and Wales, the leading causes of foodborne illness outbreaks are *Salmonella, Staphylococcus aureus and Clostridium perfringens* (Figs 1, 3(a) and (b)). This is in contrast to what happens in Latin America, where *Shigella* species, *Salmonella*, and *Escherichia coli* (excluding enterohaemorrhagic serotypes) are responsible for the majority of the outbreaks (Figure 3(c)). An entirely different picture is seen in countries such as Taiwan, where the leading cause of foodborne illness is *Vibrio parahaemolyticus* (Figure 3(d)). It is worth noting that the organism *Vibrio cholerae* has been a significant disease agent in Latin America and Asia in the last six years. From 1991 to 1994, infection with *V. cholerae* has caused over a million cases of profuse, watery diarrhoea, with 9642 deaths reported in the western hemisphere alone (CDC, 1995). These cases, however, are attributed mainly to contamination of drinking water, and not directly to food.

Of concern to many health officials is the emergence of new causative agents of foodborne illness. The organism responsible for haemorrhagic colitis, E. coli serotype O157:H7, is one such example, with cases numbering eight per 100 000 in Washington State in the USA alone, compared with 21 for *Salmonella*. Outbreaks have been numerous throughout the world, especially in industrialized nations. In 1996 alone, Japan suffered over 9500 cases of haemorrhagic colitis, with at least 11 deaths in only three months (IASR, 1996).

The type of organism involved in a case of foodborne illness can point to specific practices, diets, or eating habits that may be responsible for it. These practices can be thought of as risk factors, and their identification can help us determine how these can be controlled in order to prevent foodborne illness. Organisms found in the intestinal tract of animals and humans, such as *Salmonella, Shigella* and pathogenic serotypes of *E. coli,* are usually involved in cases where mishandling, cross-contamination of cooked product with raw product, or undercooking are seen. In such cases, strict observation of proper sanitation practices, application of the Hazard Analysis Critical Control Points (HACCP) system, achieving the proper internal temperature during cooking, and maintaining proper temperature during holding or storage are critical in preventing foodborne illness. The same can be said for *Vibrio*, which is a problem in countries where raw or undercooked seafood is consumed. In the case of *Staphylococcus aureus*, an organism found in human skin and mucous membranes, care in handling raw product is the key. With *Clostridium perfringens*, rapid cooling of heated foods containing this organism is important in preventing germination of the spores during storage.

Data submitted by seven European countries with advanced reporting systems confirm the above, pointing to temperature abuse as the leading factor that contributes to outbreaks of foodborne illness (Table III). Similarly, it has been recently reported in the USA that improper holding temperatures and poor personal hygiene are responsible for most of the outbreaks in that country (Table IV).

Another risk factor that could be considered, besides food preparation practices, is the place in which the outbreaks of foodborne illness occur. Figure 4 (a - d) shows some variation in where most of the problems lie, according to country. In the USA, where a large portion of the population dines outside the home, restaurants are the leading source. There have also been several outbreaks of foodborne illness from food consumed at public gatherings, such as church picnics (Figure 4(a)). Thus, foodborne illness is mostly caused by undercooking and poor sanitation practices, most of which are usually found where food is prepared and served, not where it is manufactured. However, it must be stressed that these data represent only the reported cases, not the actual number of cases. Thus, conclusions drawn on the risk of consuming foods in the various locations listed may not be completely accurate.

A third risk factor to consider is the types of food that are involved in outbreaks of foodborne illness. In countries such as the USA, Canada, England and Wales, muscle foods are responsible for most outbreaks, with the actual number of cases due to consumption of seafood, red meat and poultry differing somewhat among these nations (Figs 5(a - c)). Salads also contribute significantly, but the leading vehicle of infection is unknown. Similarly, in Taiwan the source of most outbreaks is not known (Figure 5(d)). However, foods of animal origin contribute to the majority of cases of foodborne illness there as well.

Cost of Foodborne Illness

Estimating the cost of foodborne illness accurately is a difficult task, because there are many variables to consider, and for some of these, it is difficult to assign a cost. For example, deciding how much time was lost from work, or how much medical care was given as a result of foodborne illness, is simple to figure out. However, it is not so easy to decide how much the quality of life was diminished because of an outbreak, or how much the reputation of a restaurant or food supplier was affected.

In determining the cost of foodborne illness, economists consider costs such as medical care, loss of productivity, loss of leisure time, pain and suffering, death, investigation, loss of business, and legal action. There are several factors which influence these costs. One is the seriousness of the disease for those directly affected, and for those who are at risk of being exposed to the same hazard. For example, an outbreak involving *E. coli* O157:H7 will likely result in immediate government and industry action with national publicity, which will increase the cost compared with an outbreak involving *Staphylococcus aureus.*

A second factor is the type of establishment where mishandling of the food occurred. Problems at home or at restaurants are more likely to be self-limiting than one caused by an error at a food processing plant, and certainly the cost to an establishment is greater, the larger and more well-known it is. A third factor is the number of episodes of foodborne illness that are taken into consideration in calculating cost. The more evaluations, the more accurate are the figures.

A summary of the latest report published by the US Department of Agriculture (USDA) Economic Research Service on the cost of foodborne is presented in Table V.

One approach in estimating cost is to compare the cost of illness versus the cost of reduced quality of life. Using a method that estimates losses in quality-adjusted life-years based on changes in time spent by the individual in different health conditions (mild, moderate, and severe), Mauskopf and French (1991) determined the cost of avoiding a case of salmonellosis (Figure 6). Clearly, the more severe the condition the higher the cost, with figures ranging from US $250 to US $6800 for avoiding one case of salmonella food poisoning. Of course, this does not include the cost of loss of life, which was estimated at over US $600 000 by these economists.

All these figures are certainly reasonable, but only when actual costs (as determined in a real-life outbreak) are considered, can we be closer to knowing what foodborne illness means to the economy. One such study was conducted after an outbreak of salmonellosis in England, discovered by routine surveillance of laboratory reports. A total of 245 cases was reported, with 51 patients admitted to a hospital and 20 developing serious infection. Because of this discovery, warnings were issued to the public, distribution of the product stopped, and 80% of the product already in the market was recalled and destroyed. In performing a cost analysis, it was relatively simple to determine the actual costs (Figure 7). More importantly, it was feasible to determine the benefit, or savings, due to having stopped the outbreak so quickly. Therefore, an outbreak that would have cost approximately £1.8 million ended up costing about £400 000, pointing to the substantial savings that could have been enjoyed if the outbreak had been completely avoided.

Prevention of Foodborne Illness by Irradiation

The methods that are used worldwide to prevent outbreaks of foodborne illness are surprisingly simple. They are based on three principles: (1) slowing down or minimizing the growth of microorganisms already present in the food, usually by refrigeration or freezing, (2) eliminating or reducing the number of contaminants, usually by some form of heat treatment, acidification, addition of antimicrobial agents, drying, salting, or addition of sugar, and (3) preventing the contamination of the product in the first place (Motarjemi et al., 1995).

For products that are sold raw, either to homes via retail or to food services, care must be taken by the processor at the slaughter or harvesting plant, to deliver a product that is as free of contaminants as possible, knowing that contamination by foodborne pathogens by other users further down the line may be unavoidable. Subsequently, care must be taken by the food preparer to make sure that proper storage temperatures are maintained. In addition, whatever procedures are used in preparing the meal, all handling must be done in a sanitary manner, and avoiding temperature abuse of the product.

Adherence to slaughter or harvesting procedures that follow good manufacturing practices in order to avoid further contamination of the product, and to prevent growth of contaminants already present, is the first line of defence, and a prerequisite programme to the establishment of the HACCP system. This is a preventive tool that has been developed to help processors identify the significant hazards that may be introduced, minimized or enhanced during production. The steps along the production line which must be controlled in order to eliminate, minimize, or control these risks are then identified. These are termed 'critical control points' and are closely monitored so that they do not exceed a specific limit, thus maintaining control of the process. However, the system is designed in such a way that even when failure to maintain control of these points occurs, the processor is alerted, and specific, predescribed actions are taken to prevent the product from reaching the consumer (Molins and Motarjemi, 1997).

Red meat and poultry

The effectiveness of HACCP is enhanced by the introduction of intervention strategies along the line, so that if these are controlled, health risks are minimized or eliminated. There are several strategies that can be used. In animal slaughter plants, for instance, some degree of decontamination of carcasses can be achieved using hot water (Reagan et al., 1996), steam and a vacuum-and-wash systems (Dorsa et al., 1996), as well as organic acid rinses (Hardin et al., 1995). However, these do not completely eliminate pathogens and, because they are applied to the product before packaging, do not obviate post-processing contamination.

In contrast, irradiation has been shown to be an effective intervention measure for fresh meat. It readily decreases microbial counts by at least 5 log10 cycles at medium doses (Radomyski et al., 1994). Given that most foodborne pathogens are found in raw foods at levels not exceeding 102 to 103cells/g, irradiation can result in their total elimination. Irradiation lends itself well to the treatment of packaged wholesale cuts or ground meat, providing the last critical control point before the product reaches the consumer. And, as a critical control point during the processing operation, irradiation fits the ideal characteristics, given that it is a process that is easy to monitor, with quantifiable parameters, and that its critical limits are scientifically based, having been identified after many years of thorough research.

Seafood

Many outbreaks of foodborne illness in the world today are due to the intentional consumption of raw seafood, such as oysters. The consumer relies entirely on the sanitary conditions of the environment where the product was harvested, processed and prepared. There are various pathogenic organisms naturally found in the marine environment, such as *Vibrio* species, *Aeromonas* species and *Clostridium botulinum.* Thus, contamination of seafood by these is practically unavoidable. Seafood may also become exposed to microorganisms present in the human intestine due to the presence of sewage waste water in the environment. Examples of such organisms are salmonellae, hepatitis virus, *E. coli, Streptococcus* and *Shigella.* Bacteria can also be introduced through handling by the workers in a processing plant, with the major concern being *Staphylococcus aureus,* an organism commonly found on the hands and mucous membranes of many people. Good harvesting practices can preclude the fishing of seafood from contaminated waters, although not entirely.

As with red meat and poultry, irradiation can be useful in decontamination of seafood. It has been shown effectively to reduce bacterial pathogens such as those mentioned above, with *Vibrio* species being especially susceptible to it. In fact, based on a D value of 0.15 kGy, irradiation at medium doses would destroy at least 10 log10 cycles of this organism (Radomyski et al., 1994). This process might be the only method we can use to treat fresh, raw seafood, allowing us to have these products in the marketplace without fear of disease. Such products are consumed regularly, yet there is no effective intervention strategy preventing outbreaks of foodborne illness from occurring.

Fruits and vegetables

These commodities are frequently in contact with soil, and thus can easily become contaminated with soilborne organisms, as well as those found in manure and other materials that may be deposited on the soil. Thus, salmonellae, *E. coli, Clostridium botulinum, Bacillus cereus* and many other pathogenic organisms can contaminate these commodities. Contamination can also occur during harvesting, when produce comes in contact with dirty equipment, and when relatively clean items become commingled with highly contaminated ones. Processing of fruits and vegetables consists of washing with treated water, which can itself serve as a source of contaminants to the product if not chlorinated properly. Produce can also become contaminated if allowed to dry in environments where a high number of airborne microorganisms are present.

For fruits and vegetables intended to be consumed in the raw state, just as with seafood, consumers rely on the sanitary practices observed during the production, harvesting and processing of these products. As we have seen from health agency reports, improper and unsanitary handling practices are the leading cause of foodborne illness outbreaks, with significant numbers being attributed to consumption of raw vegetables. Irradiation can serve to decontaminate the surface of these commodities, supplying an added measure of safety and, as with raw animal products, is a critical control point in any HACCP system. Doses ranging from 0.15 to 1.0 kGy can be applied without appreciable loss of food quality, while they effectively, but not completely, decontaminate the surface, increasing the safety of these products (CAST, 1989).

Dairy products

Even the safety of processed foods such as cheese and other dairy products, can be compromised by bacterial contamination, resulting in outbreaks of foodborne illness.

Examples are the outbreaks of listeriosis in the 1980s in the USA, where Jalisco-brand cheese was the carrier of the organism. In this case, there was much speculation regarding whether *Listeria monocytogenes* could survive milk pasteurization, or whether the outbreak occurred due to failure to carry out the process adequately. In any event, irradiation of the final product would have given the final step of assurance that this pathogen had been eliminated from the product. Studies have shown that irradiation at 1.4 kGy can significantly reduce, if not eliminate, this organism from mozzarella cheese (Hashisaka, 1989). In other dairy products such as ice cream, where one of the ingredients sometimes used is raw egg, irradiation would again ensure that any pathogenic organism surviving the freezing treatment would be significantly reduced, if not eliminated. In addition, the fact that this product is frozen aids in preventing the development of flavour changes that could occur due to irradiation. It is for this latter reason that fluid milk is not suitable for irradiation, since organoleptic changes due to lipid oxidation of the product can occur by this process.

Egg products

Raw shell eggs are normally given a chlorinated water wash or a wash with an antiseptic solution to remove faecal contamination residing on the shell. However, it has been documented that microorganisms such as Salmonella enteritidis may be introduced into the yolk through infected ovaries and oviducts of the hen (Humphrey et al., 1989; Hopper andMawer,1998).,

Heat treatment and dehydration can reduce or eliminate these contaminants. However, these treatments irreversibly change the nature of the product. Low-dose irradiation is an alternate process that can be used to decontaminate the inside, as well as the outside, of shell eggs without altering them in any significant way (Ley et al., 1962). Studies have shown that irradiation at 1.5 kGy is sufficient to significantly reduce (by at least four log cycles) *S. enteritidis* in liquid whole eggs, while not affecting its quality (Serrano et al., 1997). Similarly, a dose of 5 kGy is sufficient to reduce this organism by at least eight log cycles in frozen whole eggs and in dried egg albumen (Thornley, 1963).

Spices

Spices usually harbour microorganisms that are associated with soil and which are resistant to the dehydration process used in producing condiments. Spores of *Clostridium botulinum* and *Bacillus cereus*, among others, can be found on spices, with the potential of germinating and producing potent toxins in foods to which the spices are added. In addition, spices can become contaminated with enteric pathogens such as salmonellae through the process of open-air drying (CAST, 1996). Ethylene oxide is a commonly used gas which can eliminate bacteria as well as mold from these products. Ionizing radiation is an alternative process, which can also effectively eliminate these organisms from spices. There is a current trend favouring the use of processes other than fumigation, mainly because of the potential of gases like ethylene oxide to deplete the ozone, as well as its high flammability and toxicity (CAST, 1996). A dose of about 10 kGy can be used to achieve virtually total decontamination of spices by irradiation (CAST, 1989).

Specific Benefits of Food Irradiation

Many studies carried out over the last 50 years have proven the efficacy of irradiation in destroying in foods, microorganisms of importance to public health. Irradiation of fresh poultry at 5 kGy, for instance, lowers the number of salmonellae by 10 log10 cycles per gram, a very significant reduction (Idziak and Incze, 1968). Irradiation of ground beef, turkey and other products at 2 kGy has been shown to be very effective against another pathogen of concern, *Campylobacter jejuni* (Lambert and Maxcy, 1984). *Listeria monocytogenes* and *E. coli* serotype O157:H7, pathogens which have attracted much attention from health officials and the food industry in the last decade, can be easily eliminated by irradiation at medium doses in a variety of products (Radomyski et al., 1994). In addition, the parasite *Trichinella spiralis,* the beef and pork tapeworms, and the protozoan *Toxoplasma gondii* are all inactivated by irradiation at doses up to 1.5 kGy (CAST, 1996). Table VI provides the range of doses needed to reduce the number of various organisms in specific foods of interest by one log10 cycle (D value).

Bacteria and parasites are very easily eliminated by irradiation. *Toxoplasma gondii* cannot tolerate irradiation above 0.1 kGy, at which dose all infectivity of this parasite is eliminated, with 0.3 kGy being sufficient to kill it. The adult form of *Trichinella spiralis* and other worms can be sterilized at 0.3 kGy, which also inhibits their ability to invade muscle tissue (CAST, 1989).

A second benefit of irradiation is the fact that food can be processed in the package, minimizing the possibility of cross-contamination until it is ready to be used. Within the context of a HACCP system, irradiation would make an effective critical control point in wholesale meat cuts, ground meat, seafood, cut vegetables, and fruit, providing a crucial step in enhancing their safety. This would also apply to irradiation of foods intended to be minimally processed, such as offal and sausages.

Unfortunately, mycotoxins produced by foodborne molds are only slightly affected by ionizing radiation, and only when relatively high doses are applied. In a study by O'Neill et al. (1993), destruction of only 10–20% of the toxins deoxynivalenol and 3-acetyl deoxynivalenol was achieved, even after irradiation of infected corn at 50 kGy.

A third benefit of irradiation, which can be considered an advantage over other processing methods, is that the quality of the product can be maintained because the process is carried out under specific and well-defined conditions. For example, keeping the temperature low and excluding oxygen are two ways in which changes due to lipid oxidation during irradiation can be minimized. The lower the dose, the less the need for these measures, resulting in a product that is indistinguishable by sensory evaluation from non-irradiated samples. Such is the case with ground beef irradiated at 1.0 kGy, with no significant difference being observed from non-irradiated controls (Tarkowski et al., 1984). Similarly, ground beef patties irradiated at 2.0 kGy under vacuum were deemed more juicy and more acceptable than non-irradiated controls by sensory panellists seven days after irradiation (Murano et al., 1995). A fourth benefit of irradiation is that it eliminates the need for fumigants in disinfesting fruits and vegetables, just as with spices, and can be used instead of certain food additives and preservatives.

Cost of Food Irradiation

One of the questions that processors and consumers usually ask regarding irradiation is how much it is going to cost. It is fairly straightforward to calculate the costs involved in using this technology. One need only consider the facility capital costs, the radiation source cost (which varies according to whether isotopes or machine sources are used), maintenance, overheads and labour. Cleland and Pageau (1987) calculated that, taking all these costs into consideration, the unit cost of material irradiated in a facility with a throughput of 4 million ft3 at a dose of 2.5 kGy would be US $0.64 per ft3 (US $ 22.6 per m3) for a gamma facility and $0.52 (US $18.4) for one using X-rays. The total annual costs would be between US $2–2.5 million.

As one would expect, these costs are affected by the size of the facility and increase with the dose. Roberts (1989) published a report in which these factors were taken into consideration. Table VII contains the information in terms of costs as calculated in 1988 by Roberts, as well as an estimate of these figures for 1996, based on the International Consumer Price Indices (CPIs) published by the US Department of Labor. These figures can be obtained from their homepage via the World Wide Web at the following Internet address: http://stats.bls.gov/cpihome.htm. From the CPIs for each year, the percentage change in dollars from 1988 to 1996 was calculated to be 15.24%.

Thus, a plant irradiating 52 million pounds per year at a dose of 2.5 kGy would generate a cost of US $0.017/lb or US $0.037/kg (that is, less than 2 cents per pound or 4 cents per kilo). The same facility operating to irradiate 416 million pounds (189 000 tonnes) per year at that same dose would have a cost of $0.006/lb (less than 1 cent per pound, or just over 1 cent per kilo).

Another way of examining the question of the cost of irradiation is to determine how much consumers are willing to pay for this technology. Auction-type experiments have been conducted to answer such a question (Hayes, 1995). Subjects are informed of the risk of their contracting foodborne illness if they eat a certain product. Then, they are asked to bid to exchange this product for one that has been irradiated. The overwhelming response has been for participants to bid in favour of exchanging their food, and when doing so, they are willing to pay as much as $0.30/lb more for the irradiated product.

Irradiation is Not a Panacea

Food irradiation has its limitations, just like other technologies. It has not been shown to be effective for inactivating toxins or other chemicals that may pose a threat to our food supply. Similarly, it has not been found to be effective in destroying viruses at the doses that are in use for decontamination of foods from bacterial pathogens. Irradiation, although very effective in eliminating bacterial contaminants, cannot guard the food against contamination after processing through contact with unsanitized surfaces or hands. Thus, like all other intervention strategies, irradiation must be applied as part of a total sanitation programme, where handwashing and proper operating procedures are followed to prevent contamination of product, whether irradiated or not.

What irradiation offers, however, is an opportunity to begin with a product that is practically, if not completely, devoid of pathogens, so that if errors are committed during cooking the risk of foodborne illness is minimized. Food irradiation, if implemented correctly, can be used as an intervention strategy that would serve as a critical control point during the processing of fresh foods of animal origin. Using it would markedly increase the safety of such products, just as pasteurization does for milk. In addition, irradiation would give consumers the freedom to eat foods in the raw or semi-raw state, as is the practice with seafood and offal in some cultures, with a reduced risk of becoming ill from doing so.

Conclusions and Recommendations

We have seen the tremendous impact that foodborne illness has in our society, both from the social and economic points of view. In order for people to have the right to have access to food that is nutritious as well as safe, as stated at the FAO/WHO International Conference on Nutrition in Rome in 1992, we need to avail ourselves of technologies that can provide such access. Now is the time to include food irradiation in the arsenal of weapons in the fight against foodborne illness. It has been proven an efficacious and versatile tool, which can be cost effective. Organizations such as the WHO, the Institute of Food Technologists, and the American Medical Association, among many, have endorsed this technology for the enhancement of food safety that it offers. Governments and industry must examine their reasons for not using this technology, and in light of the morbidity and mortality that foodborne illness causes, determine a course of action.

To begin with, education of people at all levels is the first step. They must understand the problem before they can be expected to accept a solution. Education regarding foodborne illness and the effectiveness of irradiation should, therefore, go hand-in-hand. Products that have government approval must be made available to consumers. They will decide with their purchasing power whether irradiated products have a future. Government agencies must not delay the approval of those products, for which petitions have been submitted, any longer than necessary. Incentives should be provided for those willing to use the technology, as well as for those willing to buy products treated this way. Academia, government, industry and activists should work together to bring irradiated foods to the marketplace. These groups are also consumers: they should have the right to choose whether to purchase products made safer by this technology.

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Table I. Outbreaks of foodborne illness during first half of 1995 (INPPAZ, 1995)

Country	Outbreaks	Cases
Bahamas	3	302
Chile	78	939
Costa Rica	24	53
Cuba	197	10 924
Dominican Republic	3	19
Mexico	37	2 006
Nicaragua	8	35
Panama	6	95
Paraguay	2	10
Uruguay	3	347
Venezuela	1	9
TOTAL	362	14 739

Table II. Outbreaks of foodborne illness in various European countries (1990-1992)
(Adapted from WHO, 1995)

Country	Outbreaks
Austria	2743
Bulgaria	76
Denmark	125
Finland	89
France	2026
Germany	385
Hungary	735
Israel	111
Italy	227
Lithuania	146
Poland	2131
Romania	139
Scotland	512
Spain	2818
Sweden	104

Table III. Major factors contributing to outbreaks of foodborne illness in various European countries (1990-1992)
(Adapted from WHO, 1995)

Factor	Sum of Outbreaks (1990–1992)
Temperature misuse	
Inadequate refrigeration	962
Inadequate thawing	9
Inadequate cooking	541
Inadequate holding	21
Inadequate storage	141
Prepared too far in advance	464
Raw material	
Contaminated/unsafe source	563
Contaminated ingredients	8
Poisonous (mushrooms)	222
Chemical contamination	8
Inadequate handling	
Inadequate processing	487
Cross-contamination	181
Inadequate hygiene	84
Environmental factors	
Contamination by personnel	457
Contaminated equipment	287

Table IV. Factors contributing to outbreaks of foodborne illness in the USA (1988-1992)
(Adapted from CDC, 1996a)

Contributing factor	Average number of outbreaks per year
Improper holding temperature	170
Poor personal hygiene	103
Inadequate cooking	80
Contaminated equipment	46
Food from unsafe source	14

Table V. Cost summary for selected bacterial pathogens in the USA, 1993
(Adapted from Buzby et al., 1996)

Pathogen	Cases	Deaths	Cost (billion US$)
Campylobacter jejuni or coli	1 375 000 - 1 750 000	100 - 511	0.6 - 1.0
Clostridium perfringens	10 000	100	0.1
Escherichia coli O157:H7	8 000 - 16 000	160 - 400	0.2 - 0.6
Listeria monocytogenes	1526 - 1767	378 - 485	0.2 - 0.3
Salmonella	696 000 - 3 840 000	696 - 3840	0.6 - 3.5
Staphylococcus aureus	1 513 000	1210	1.2
TOTAL	3 603 526 - 7 130 767	2654 - 6546	2.9 - 6.7

Table VI. D-value of various microorganisms in fresh meat and seafood
(Adapted from Radomyski et al., 1994, and CAST, 1996)

Microorganism	Food (refrigerated)	D-value (kGy)
Salmonella	Poultry, pork, eggs, seafood	0.40 - 0.50
Campylobacter	Poultry, beef, eggs	0.14 - 0.32
Listeria	Pork, beef, dairy	0.40 - 0.60
Yersinia	Pork, beef	0.04 - 0.21
Aeromonas	Shellfish, finfish	0.14 - 0.19
Escherichia coli O157:H7	Beef	0.25 - 0.35
Vibrio	Prawns, clams, oysters	0.11 - 0.15
Staphylococcus aureus	Beef, pork, ham	0.29 - 0.32

Table VII. Cost of irradiation as affected by various processing parameters
(Adapted from Roberts, 1989)

Volume (million lb[a] per year)	Dose (kGy)	1988 Annual cost (million US$)	1996 Adjusted[a] cost (million US$)	1988 Cost per lb (cents)	1996 Adjusted[b] cost per lb (cents)
52	2.5	0.77	0.89	1.487	1.714
104	2.5	0.94	1.08	0.905	1.141
208	2.5	1.28	1.48	0.616	0.710
416	2.5	2.16	2.49	0.520	0.599
52	5.0	0.79	0.91	1.512	1.742
104	5.0	1.08	1.24	1.041	1.200
208	5.0	1.93	2.22	0.930	1.107

[a] 1 lb = 454 g
[b] Based on 15.24% change from 1988 to 1996 calculated from the International Price Index

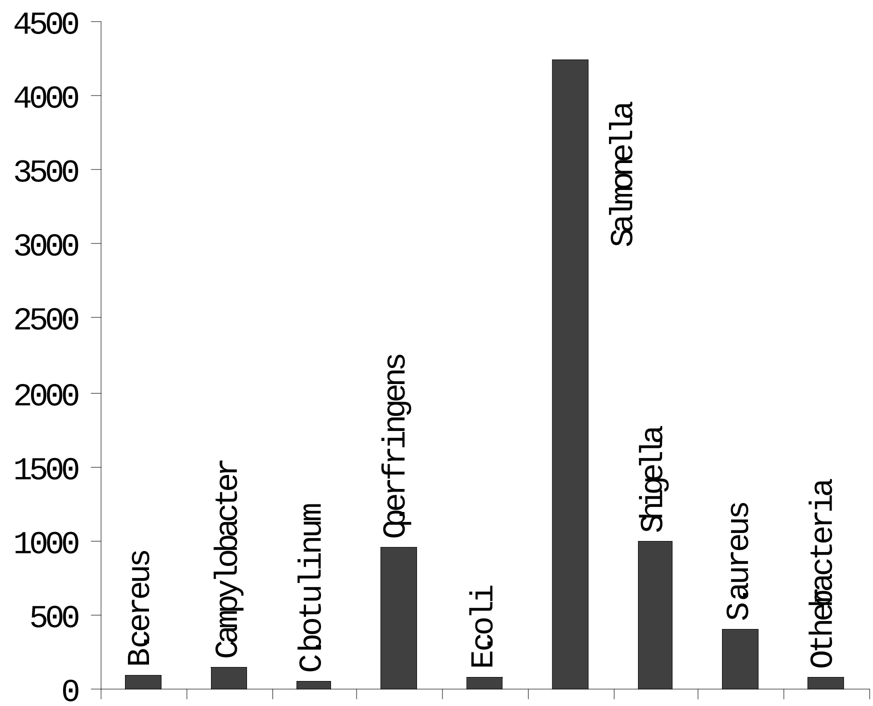


Figure 1 Number of annual cases of foodborne illness in the USA by bacterial agent (1988-1992) Adapted from CDC, 1996)

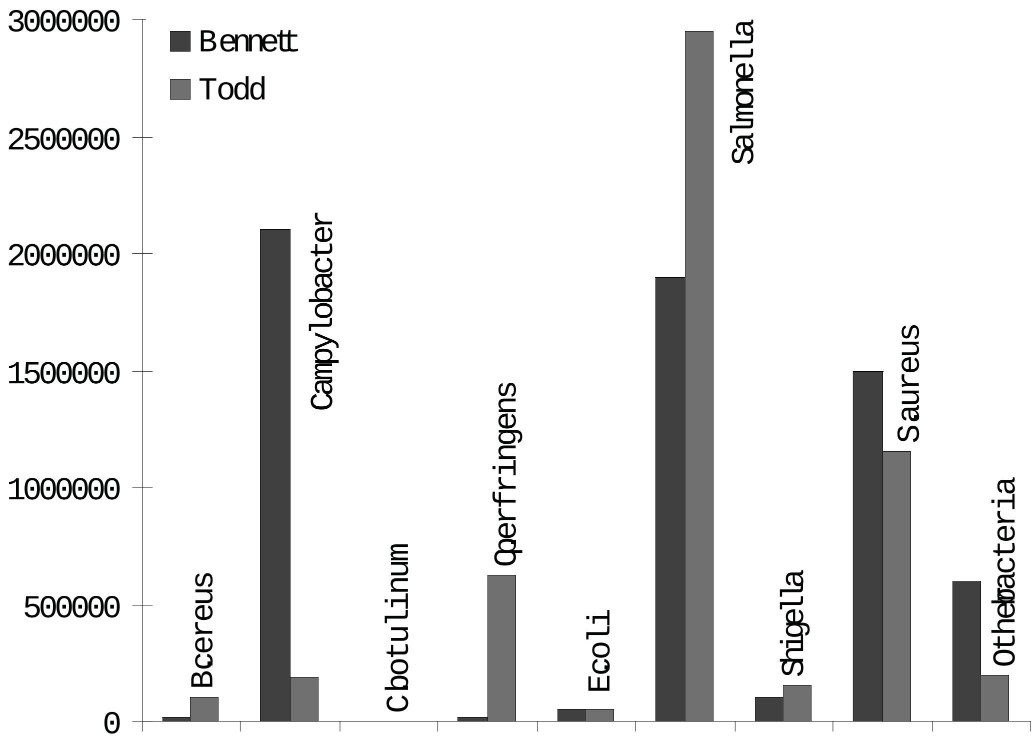
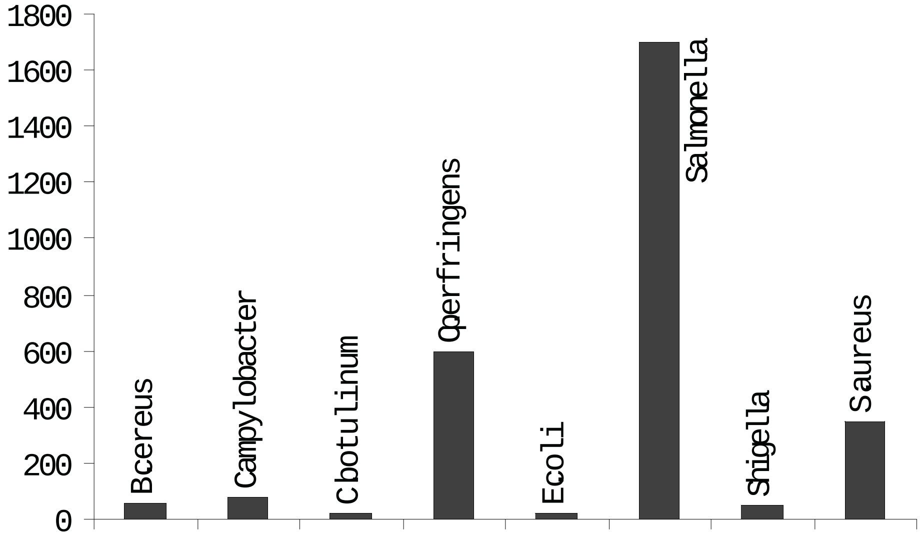
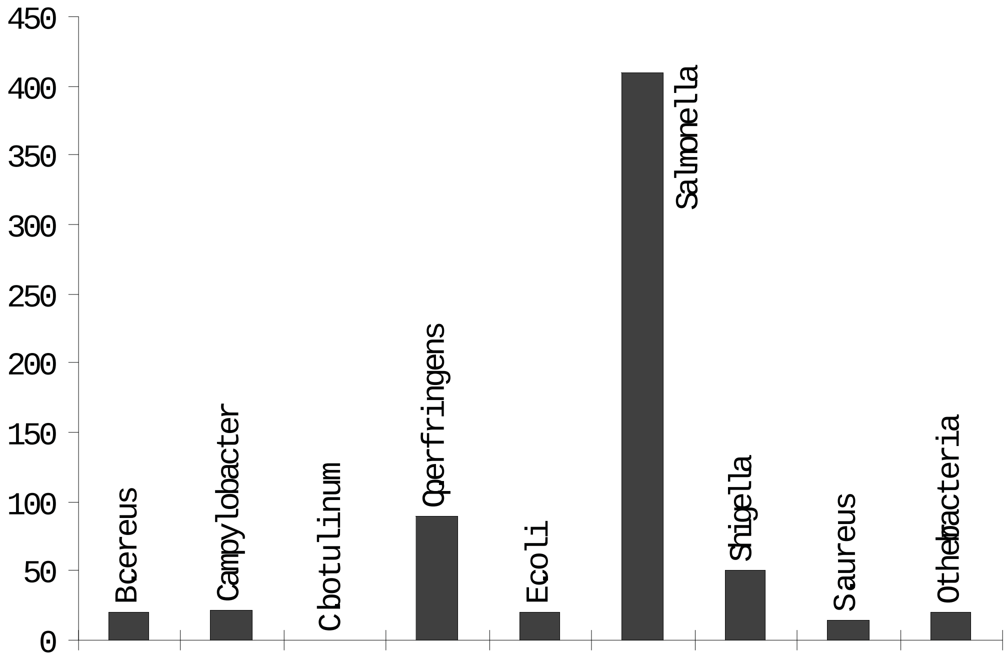


Figure 2 Estimated number of annual cases of foodborne illness by bacterial agent in the USA (as per Bennett et al., 1987; Todd, 1989)



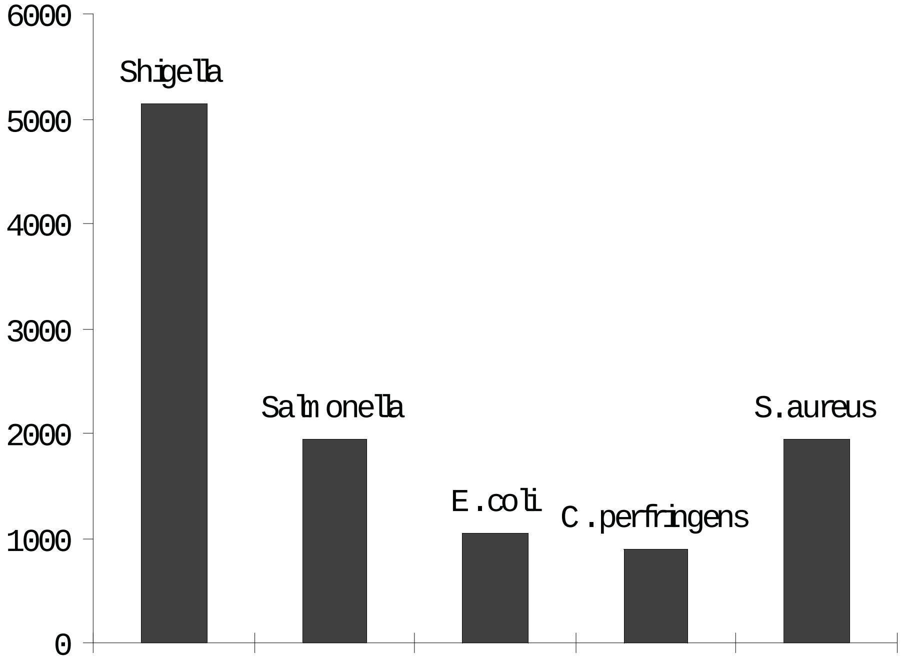
* E.coli data does not include haemorrhagic serotypes

Figure 3a Number of cases of foodborne illness by bacterial agent per year in Canada (1975-1984) (Adapted from Todd, 1992)



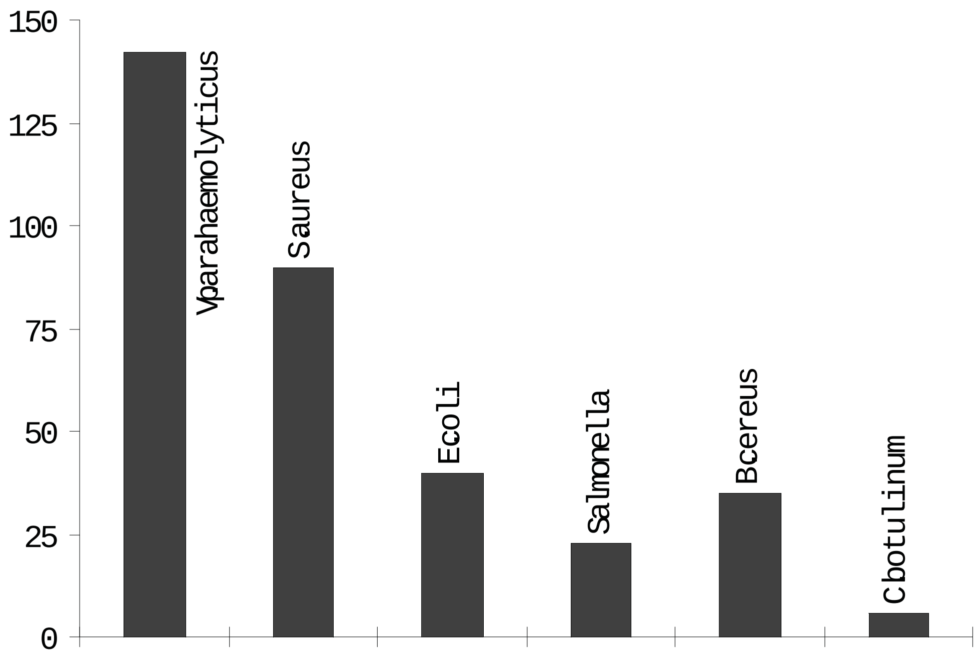
* E.coli data does not include haemorrhagic serotypes

Figure 3b: Number of cases of foodborne illness by bacterial agent in England and Wales (1992-1994) (From Djuretic et al., 1996)



* E.coli data does not include haemorrhagic serotypes

Figure 3c Number of cases of foodborne illness by bacterial agent in various countries in Latin America during first half of 1995 (Adapted from INPPAZ, 1995)



* E.coli data does not include haemorrhagic serotypes

Figure 3d Number of cases of foodborne illness by bacterial agent in Taiwan (1981-1989) (Adapted from Chiou et al, 1991)

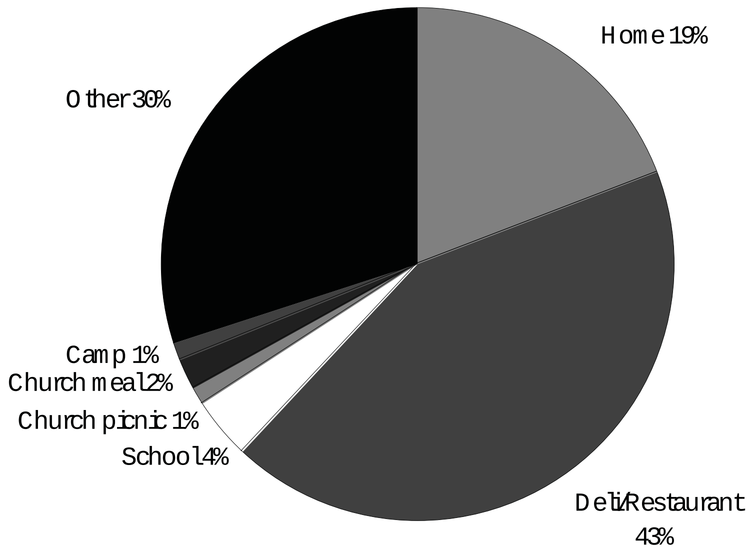


Figure 4a Percent of cases of foodborne illness in the USA by suspected location where meals were consumed (1988-1992) (Adapted from CDC, 1996)

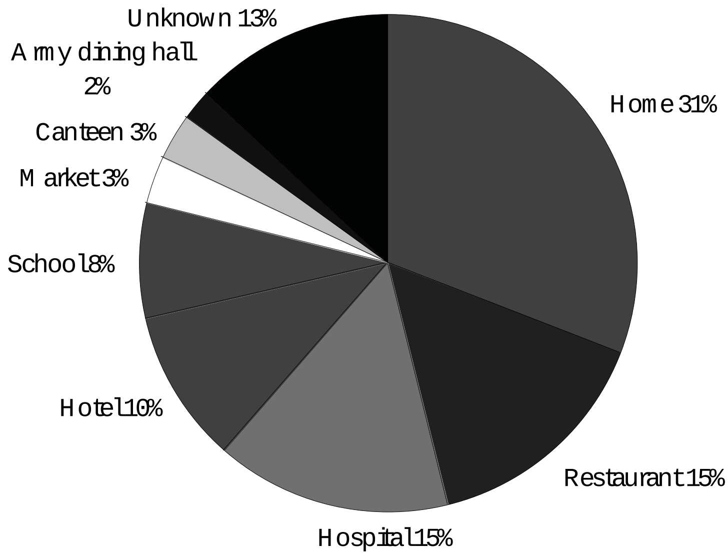


Figure 4b Percent of cases of foodborne illness in England and Wales by suspected location where meals were consumed (1992-1994) (Adapted from Djuretic et al., 1996)

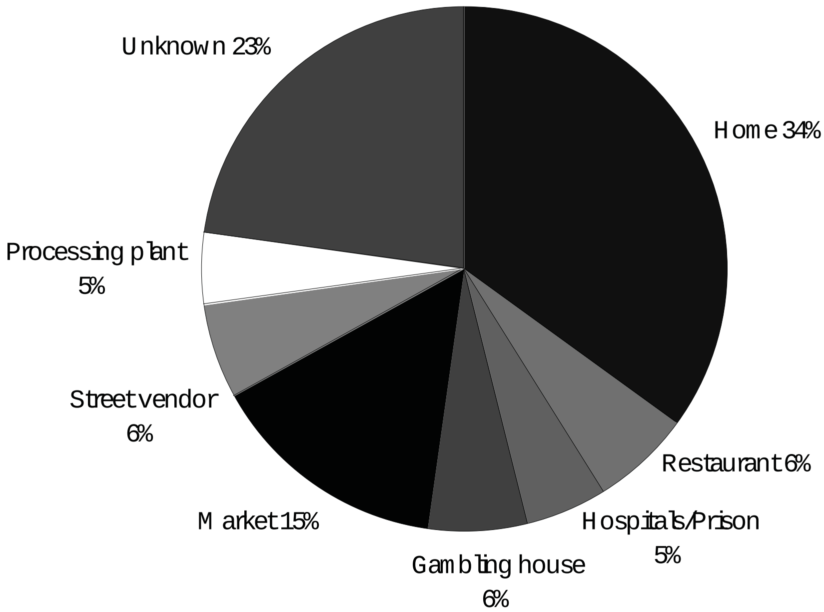


Figure 4c Percent of cases of foodborne illness in Latin America during first half of 1995 by suspected location where meals were consumed (Adapted from INPPAZ, 1995).

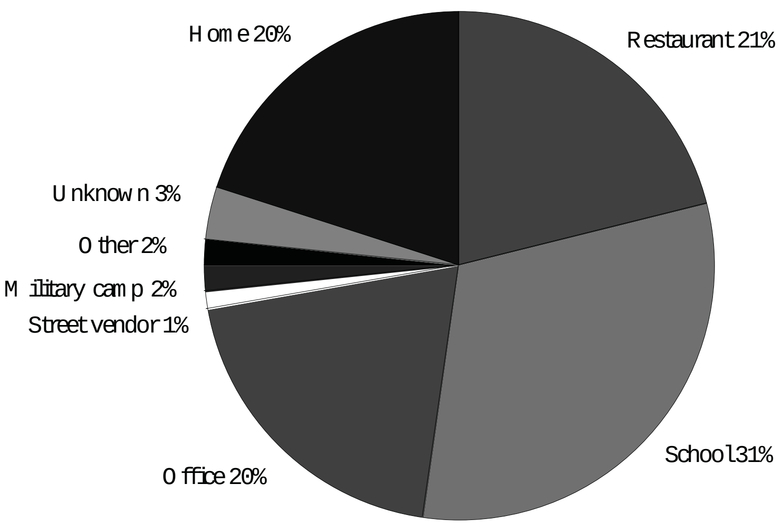


Figure 4d Percent of cases of foodborne illness in Taiwan by suspected location where meals were consumed (1981-1989) (Adapted from Chiou et al., 1991)

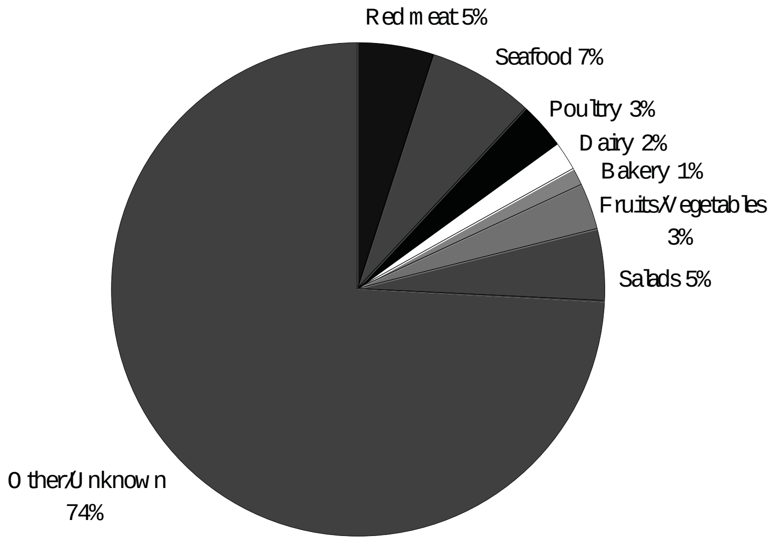


Figure 5a Percent of cases of foodborne illness by vehicle of infection in the USA (1988-1992) (Adapted from CDC, 1996)

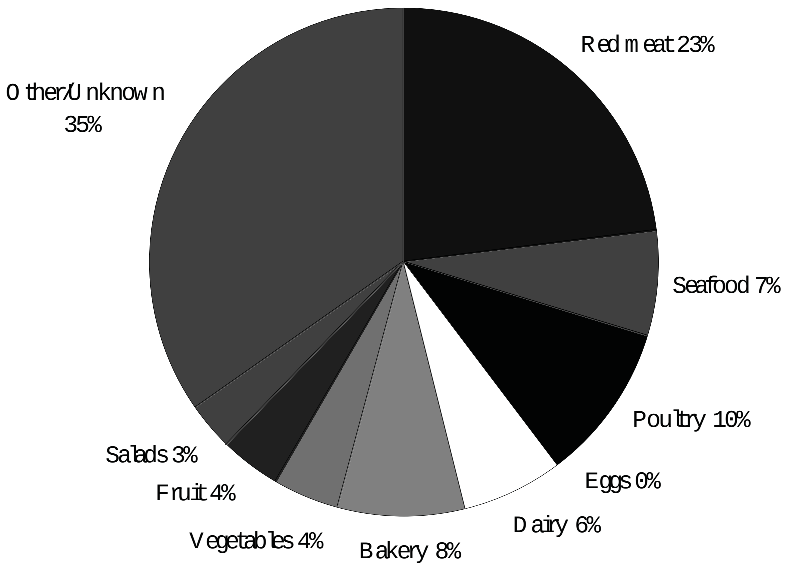


Figure 5b Percent of cases of foodborne illness by vehicle of infection in Canada (1975-1984) (Adapted from Todd, 1992)

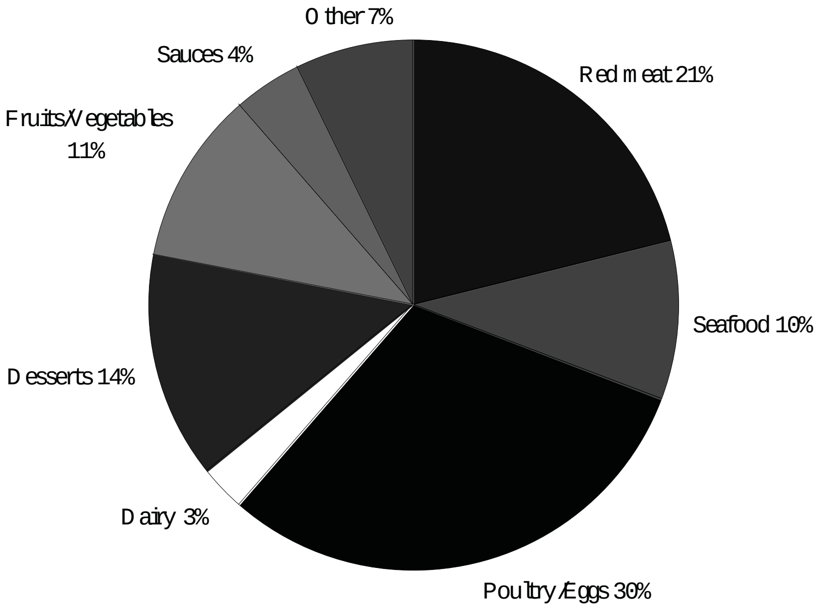


Figure 5c Percent of cases of foodborne illness by vehicle of infection in England and Wales (1992-1994) (Adapted from Djuretic et al., 1996)

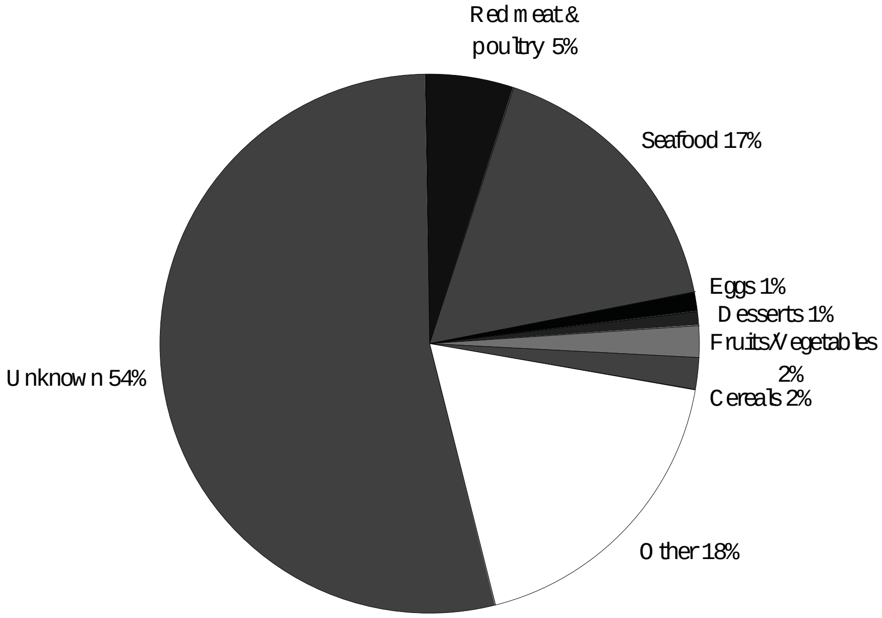


Figure 5d: Percent of cases of foodborne illness by vehicle of infection in Taiwan (1981-1989) (Adapted from Chiou et al., 1991)

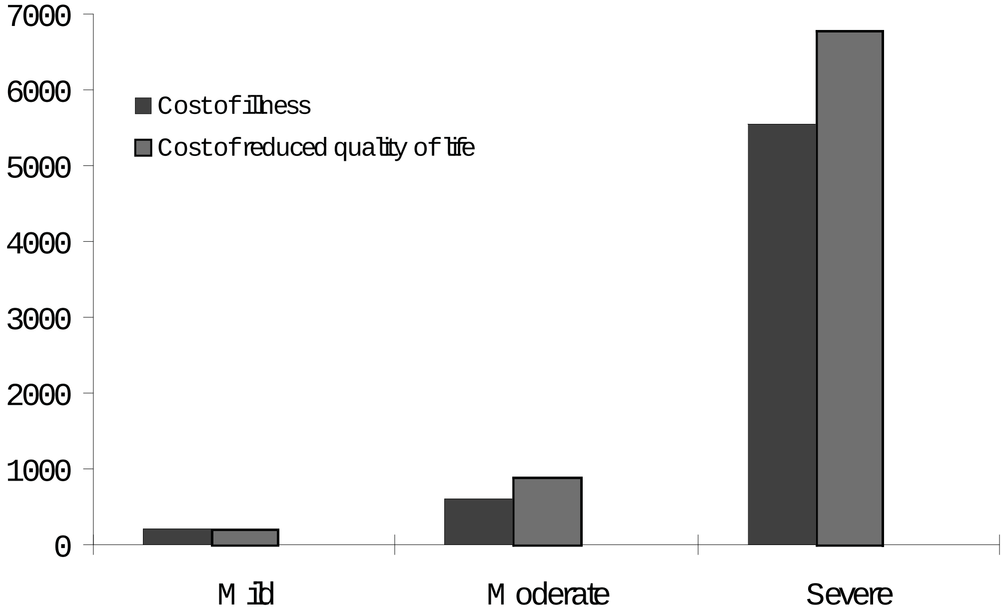


Figure 6 Dollar estimates for avoiding a case of salmonellosis according to cost due to illness vs. cost due to loss in quality of life in the USA
(Adapted from Mauskopf and French, 1991)

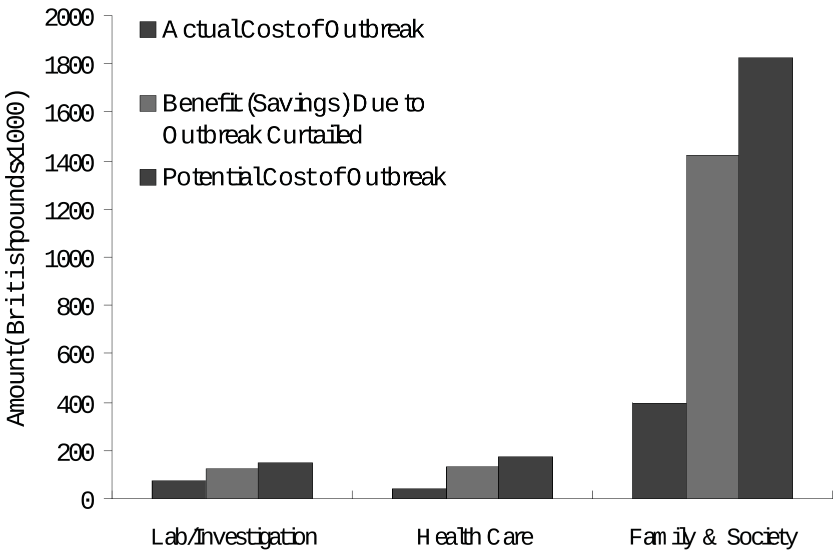


Figure 7 Cost/Benefit Analysis of a Nationwide Outbreak of Salmonellosis in England (1982)
(Adapted from Roberts et al., 1989)