SAFETY OF POULTRY MEAT

From Farm to Table

International Consultative Group on Food Irradiation (ICGFI)
established under the aegis of

FAO IAEA WHO

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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:

(a) To evaluate global developments in the field of food irradiation;
(b) To provide a focal point of advice on the application of food irradiation to Member States and the Organization; and
(c) To furnish information as required, through the Organization, to the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food, and to the Codex Alimentarius Commission.

As of August 1999 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, Malaysia, Mexico, Morocco, New Zealand, Pakistan, People's Republic of China, Peru, Philippines, Poland, Portugal, Republic of Korea, South Africa, Syrian Arab Republic, Thailand, Turkey, Ukraine, United Kingdom, United States of America, Viet Nam and Yugoslavia.

At the 12th ICGFI Annual Meeting (Vienna, 1995), the designated expert from Germany (Dr. K.W. Bögl) requested that a review be made on poultry production methods, in particular the Swedish method which was claimed to produce *Salmonella*-free poultry, and the need to process poultry, e.g. by irradiation, to render (contaminated) poultry meat free from such pathogens. Recognizing that there is increasing consumer demand to produce pathogen free poultry, the ICGFI accepted this challenge and commissioned Dr. R.W.A.W. Mulder of the Institute for Animal Science and Health, Netherlands, to conduct such a review in 1996. Dr. Mulder's work was supplemented by that of Dr. J. Schlundt of the Veterinary and Food Administration, Denmark, during 1997. The combined contributions of both authors were extensively reviewed by Dr. J. Corry, Division of Food Animal Science, University of Bristol, UK, and Dr. R. Molins of the ICGFI Secretariat.

This document represents the most up-to-date information on the safety of poultry meat: from farm to table. It covers all steps in the poultry production chain, including the microbiology of poultry and poultry products; pathogen control programmes in poultry production, with emphasis on the Swedish *Salmonella* control programme; poultry processing; prevention of colonization and contamination with various pathogens, and decontamination of poultry meat. This information should be highly valuable to policy makers in governments, food industry and consumer organizations in deciding whether to implement only a costly pathogen control programme at the farm and throughout the poultry production chain or resort to Hazard Analysis Critical Control Point in the production and processing of poultry, incorporating essential control points such as irradiation to render raw fresh or frozen poultry products pathogen free.

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SUMMARY

Poultry meat is a food which has been accepted worldwide throughout the ages. The consumption of poultry products is increasing every year and consumers want a safe product, without the presence of pathogenic microorganisms; thus, it is essential that the poultry industry achieves this goal.

Poultry products are often involved in human foodborne disease, and the costs of such disease are considerable. To reduce the level of infection and contamination of live and processed poultry, new technologies and methods, as well as the introduction of monitoring and control programmes, should be implemented. The necessary investments may be far lower than the costs incurred because of poultry-associated foodborne disease.

Measures to be taken by industry to avoid infection or contamination of live birds with potentially pathogenic microorganisms such as *Salmonella* and *Campylobacter* should be based on scientific data. Information on the potential of genetic resistance of poultry breeds, the capability of microorganisms to colonize the gastrointestinal tract of poultry, the use of vaccines and antimicrobials, as well as the development of competitive exclusion microflora, are examples in this respect.

Nowadays, the poultry industry in several countries, together with national governments, have introduced measures to be applied in breeder flocks to reduce the coloniza-tion and attachment of undesirable microorganisms in live animals. Continuation of these efforts through the entire production chain up to consumer-ready meat, eggs and egg products, may eventually help in reaching a pathogen-free status.

During the last 20 to 30 years a great number of changes have taken place in processing mechanization and automation. From the point of view of hygiene, these changes have led to better microbiological quality and increased shelf-life of products. However, the level of contamination of products with pathogenic microorganisms has changed little, due to incoming contaminated flocks and possible cross-contamination.

Sweden has implemented a 30-year programme for *Salmonella* control in poultry at the production level, based on sampling and destruction of contaminated flocks. Whether it would be possible to implement the Swedish model elsewhere would depend on available resources, production infrastructure from farm to table, and willingness to absorb the very high cost of such a programme. The infection levels in the poultry population and the overall size of poultry produc-tion can also determine how realistic a successful implementation of the Swedish model could be in other countries. It is also important to point out that a *Salmonella* control programme would not necessarily result in parallel control of other poultry-borne pathogens such as *Campylobacter*. The Swedish *Salmonella* control programme does not address the problem of other potentially pathogenic bacteria in poultry, particularly *Campylobacter*. Thus, consumers may derive a false sense of safety from *Salmonella*-free only products.

Attempts to decontaminate poultry have concentrated in three main aspects: 1) chemical methods (lactic acid, hydro-gen peroxide, trisodium phosphate); 2) physical methods (-ionizing radiation, non-destructive heat treatments), and 3) novel methods (biopeptides and new preserving technologies which are a combination of physical and chemical treatments of end-pro-ducts).

The chain of poultry production and processing should be described in terms of the Hazard Analysis Critical Control Point (HACCP) concept. Corrective measures, including end-product decontamination when necessary, must be introduced at defined critical points. Unlike liquid foods such as pasteurized milk, which has a critical control point (CCP) to ensure the absence of pathogens, raw fresh and frozen poultry lack such a CCP. Currently, irradiation is the only available control measure and hence CCP that can ensure the absence of pathogens in such products. It is up to the regulatory authorities and the consumer to decide whether to accept poultry in its present form or to introduce this effective decontamination measure to produce pathogen-free, raw fresh and frozen poultry. Directives or international and national regulations prohibiting the use of proven, safe, effective treatments to decontaminate poultry end-products need to be changed.

1. INTRODUCTION

Poultry meat is one of the most popular foods worldwide. The popularity of this product is due to sensory and dietary, as well as economic considerations. Poultry meat is a highly digestible, tasty and low-calorie food, often recommended by nutritionists over other meats. On the other hand, in most developed and some developing countries today, high-quality poultry meat is often less expensive than other types of meat. This is due mainly to the revolutionary industrialization of the poultry industry in the last 30 years, which has changed poultry meat from a rather exclusive product, only available to a limited group of consumers, into a popular and inexpensive product within everyone's budget. In addition, the availability of poultry meat in a large variety of processed ready-meals makes it easy to prepare, and thus meets the demands of modern consumers.

Despite the above, the poultry industry everywhere is under enormous pressure. In many countries, the price per kilogram of product is still too high to be competitive. Therefore, processing plants have introduced cost reduction programmes making even more use of high-speed and fully mechanized operations and automated production facilities. At the same time, there are at least two other major factors that exert pressure on the poultry industry. One concerns the influence of processing on the environment (the use of energy and water); the other is the quality and microbiological safety of the products.

This paper concentrates on the safety aspects of poultry production and its products. Poultry and poultry meat are often found contaminated with potentially pathogenic microorganisms such as *Salmonella*, *Campylobacter*, *Staphylococcus aureus*, *Escherichia coli* and *Listeria*. In some occasions also *Yersinia enterocolitica*, *Aeromonas* and *Clostridium perfringens* have the potential to be important pathogens in poultry products. However, *Salmonella*, *Campylobacter*, and to a lesser extent *Listeria*, are considered to be the major foodborne pathogens in the poultry industry.

Epidemiological reports all over the world incriminate poultry meat as a source of outbreaks of human foodborne disease. Since poultry meat is usually not consumed raw, these outbreaks are caused by undercooking or cross-contamination of ready-to-eat products with microbial contaminants from the raw poultry or others introduced during preparation of the food (Anon., 1996a). In the case of *Campylobacter*, the preparer of the food can be infected directly (hand to mouth) from the raw product.

The aim of the poultry industry is to find ways to avoid contamination of live poultry and poultry products with potential pathogens. However, the widespread presence in the environment of major bacterial pathogens such as *Salmonella* and *Campylobacter* makes production very vulnerable.

It is evident that preventive measures, including monitoring programmes, to reduce the numbers of *Salmonella*, *Campylobacter*, and possibly other pathogens, during the growing period should focus on changes in husbandry practices, as well as on the use of technologies and products that have been shown to be effective against colonization by these organisms. The aim should be to deliver live poultry free of pathogens to the processing plant. However, at present, the processing industry has to cope with contaminated flocks coming to slaughterhouses, where there are many operations that present opportunities for cross-contamination; microbial contaminants are thus transmitted from contaminated to non-contaminated carcasses or equipment. Consequently, additional treatment of products before or after they leave the processing plant, and intensive consumer information and education about the potential risk of the consumption of poultry products, should be part of the poultry industry strategy for the future.

This report was written to provide information on the contamination of poultry with major pathogenic microorganisms and the consequences of this contamination to human health. From this information, options on the use of specific production and processing techniques or decontamination methods to prevent further transmission of these pathogens from poultry and poultry products to consumers may be identified.

1.2 POULTRY AND FOOD SAFETY

Microbiological safety of poultry can be achieved by various means. In this paper, risk management options to obtain this goal are discussed. The discussion should be

seen as an overview of the area, and further discussion of specific subjects should be sought in the open literature.

The general microbiological situation in poultry production has changed over the last decades. This change is global in nature and involves the spread of particular *Salmonella* serotypes in production systems. There is a relatively high prevalence of *Salmonella typhimurium*, *Salmonella enteritidis* and *Campylobacter* spp. in poultry in many countries.

In the same period, the number of human cases of foodborne enteritis also has increased significantly in many countries (Anon., 1995a). This increase has resulted in higher awarenes of microbiological food safety, and the question of 'emerging' and 're-emerging' foodborne pathogens has been discussed in a number of scientific and risk management settings in the 1990's.

The relationship between the prevalence of pathogens in the production system and the incidence of foodborne pathogens in the human population is difficult to elucidate. Attempts to quantify this relationship are generally not done in national settings; however, Denmark has initiated a sort of pathogen accounting in this area, and from preliminary data it seems that poultry-related *Salmonella* serotypes account for approximately 70% of human cases of salmonellosis in this country (Anon., 1996b).

The causes behind the apparent worsening of the poultry-borne pathogen situation have not been determined clearly enough. However, much of the increase in numbers of cases of infection can be attributed to the increase in consumption of poultry meat, rather than to increases in the proportion of contaminated poultry. New production systems at the primary production level as well as in the manufacturing sector are also likely to have had an influence. In the post-Second World War era, general hygienic principles were developed and implemented in food production, and for a long period the level of hygiene was thought appropriate to control microbial foodborne disease. However, in the 1980's and 1990's, emerging (or re-emerging) pathogens have caused new and increasing problems all over the world. It has been said that "technology has overtaken hygiene." Additionally, the significant increase in international food (and food animal) trade will probably highlight these problems in the future.

The notable increase in global trade in food has prompted a number of new international initiatives in the area of food safety, among which are those related to defining a risk analysis framework.

1.2.1 Risk Analysis

Risk analysis consists of risk assessment, risk management and risk communication. Risk is defined as "a function of the probability of an adverse effect and the magnitude of that effect, consequential to a hazard in food" (Anon, 1995b). In recent years, the concept of risk analysis has developed in response to the need for scientifically based evaluation of microorganisms in a number of different regulatory areas: Gene technology, microbial pesticides, microbial production organisms (industrial and agricultural), and foodborne pathogens.

Throughout the 1980's and 1990's, a number of classical and emerging foodborne pathogens have created new problems in food, e.g. *Salmonella*, *Campylobacter*, *Yersinia*, enterohaemorrhagic *Escherichia coli* (EHEC), and *Listeria monocytogenes*. Foodborne pathogens move with the food over borders, and no testing regime would be able to fully prevent their presence. Therefore, most countries favour international co-operation in this area, and such co-operation must be science-based. The new international trade agreements under the World Trade Organization (WTO) have put additional emphasis on the use of scientifically based risk analysis: ".. sanitary or phytosanitary measure is based on scientific principles and is not maintained without sufficient scientific evidence..," from the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), Article 2, paragraph 2 (Anon., 1995c). It has been stated that risk analysis should be used to determine realistic and achievable risk levels for foodborne hazards, and to base food safety policies on the practical application of the results of such analyses.

The management of microbial risks has to be seen in an overall societal context. Therefore, an important premise which should precede or be included in the risk management process is the definition of (national) food safety objectives. An important part of food safety objectives, in turn, is the setting of specific targets regarding tolerable or acceptable risk levels; such levels should generally be expressed as incidence of human cases. After completion of a risk assessment, a risk estimate will be available (Anon., 1996a). The information from the risk assessment combined with acceptable risk levels will form the basis for risk management decisions. It should be kept in mind that the risk level will (almost) never reach zero.

Local or regional conditions in relation to microbial risk and risk acceptance can and will differ. Region to region variation in microbial incidence or pathogen occurence in food will emphasize this. Additionally, regional differences in socioeconomic and technological factors, including cost-benefit evaluations, will underline the necessity to accept the concept of "regionality" in risk management strategies.

The determination of safe, realistic and achievable hazard and risk levels depend not only upon science, but also upon a number of socio-economic and technological factors. The best management initiative could be control of foodborne pathogens at the source, action plans in the production level, mandatory criteria in the final product, mandatory treatment strategies of the final product, or a combination of these.

1.2.2 Risk Management of Poultry Pathogens

The risk management strategies for zoonotic pathogens vary between regions and nations. The concept of dealing with pathogens "from farm to table" (Anon., 1997) inherently represents a societal context where infrastructure and control systems enable a relatively high level of control in all levels of the system. However, the poultry production systems where some of the emerging or re-emerging pathogens are important are probably the industrialized systems where high levels of control are manageable, be that in industrialized or developing countries.

Overall risk management systems in poultry production should be seen in line with other food hygiene initiatives. New principles in this area also include specific hazard control systems, such as the Hazard Analysis Critical Control Point (HACCP) system. Under HACCP, specific hazards (in this case specific pathogens) are assessed, and the points to control these hazards are defined.

2. POULTRY PRODUCTION AND CONSUMPTION

Over the last several decades, poultry meat has been a very successful product. In the western world, the *per capita* consumption of poultry meat has increased steadily whereas corresponding *per capita* consumption of beef, pork and other meats seem to have reached a plateau (Table 1).

It is likely that consumption of poultry meat will continue to increase worldwide in the coming years as a result of the demand for affordable and palatable animal protein. Poultry meat refers primarily to broiler (roasting chicken) and turkey meat, and to meat from ducks, pheasants, geese and other farmed birds. The largest proportion of poultry meat production, is from broilers, and the data provided will refer to this type of poultry meat. In the period 1990-1995, *per capita* meat consumption in the United States increased by approximately 5.5 kg, which was accounted for entirely by consumption of broiler meat.

TABLE 1

World Meat Consumption 1985-1991

	1985	1989	1991
Total(million tonnes)	148	172	179
% Beef, veal	31	30	29
% Pork	39	40	40
% Poultry	21	22	23
% Other	9	8	8

(Source: Anon., 1996c).

World poultry meat production is increasing from year to year. In 1995 it was 45,000 million kilograms, an increase of 6.4% compared to 1994 (Table 2). The largest producers are the United States (+4.4%), the European Union (+4.5%), China (+12.5%) and Brazil (+12.6%) (Table 3).

There are large differences in poultry meat production within regions. Taking Europe as an example, the most important poultry producing countries are France, the United Kingdom, Italy, Spain, Germany and The Netherlands. The lowest production is in Austria, Switzerland and Scandinavian countries. Comparing poultry production in several European countries in 1995, that of France was 1,200,000 metric tonnes, whereas in The Netherlands this figure was around 530,000 metric tonnes, and Sweden and Finland produced only 65,000 and 43,000 metric tonnes, respectively.

It is difficult to compare costs of broiler production in different countries of the world. However, although the conditions and circumstances of production in industrialized and developing countries can hardly be compared (for instance, the scale of operation may differ enormously), it seems that the relative costs of production and processing is not influenced too much. Recently (Anon., 1996b), a cost comparison of broiler production in several poultry exporting and importing countries, together with data on wholesale prices, were published. Table 4 gives these costs for several countries, data which should only be taken as an approximate guide to relative costs.

TABLE 2

World Production and Consumption of Poultry Meat

	Production (000 metric tonnes)		Consumption (kg/capita 1992)
	1994	1995	
Africa	1.9	2.1	3.1
North America	8.8	14.1	31.0
South America	4.0	6.3	15.3
Asia	9.1	13.8	3.8
Europe	5.2	6.9	15.3
Oceania	0.4	0.6	19.8

(Source: Anon., 1996c).

The competition in the world market is enormous, and therefore production costs are very important. The data in Table 4 indicate that countries like the United States and Brazil can produce poultry at a very low cost, whereas European countries have relatively high production costs. Table 4 also shows that countries like the United States and Brazil could perhaps afford the extra cost necessary for added poultry safety and remain competitive in the international market.

The average world annual *per capita* poultry meat consumption is about 8 kg (Table 2) and it is increasing fast. Worldwide, the production of broilers reached nearly 33,000 million birds in 1995, and the average

broiler body weight was 1.4 kg. The most important broiler producing countries in the world and their production in 1995 are shown in Table 3.

TABLE 3

Main Poultry Producing Countries, 1995

Country	Production (000 metric tonnes)
USA	11,633
China	6,755
Brazil	3,800
Japan	1,280
France	1,197
Russian Federation	1,142
Mexico	1,070
UK	865
Italy	803
Thailand	750

(Source: Anon., 1996c).

TABLE 4

Cost and Wholesale Price Comparison of Broiler Production in Various Countries (1997)

Country	Raising costs US cents/kg live	Wholesale price US cents/kg
USA	57	123-213
Brazil	55	94-108
China	80	133
Thailand	100	140
France	90	205-442
Netherlands	83	194-320
Japan	132	287-1021
Russian Fed.	185	265
Saudi Arabia	222	379
Sweden	110	270-400
Finland	152	412

(Source: Mulder, R.W.A.W., 1997. Personal data).

Although the growth of poultry production differs from country to country, a larger increase can be seen in low-income compared to high-income countries. In developed countries there is a clear trend for consumers to purchase poultry portions and further processed (e.g. cooked and/or marinated) products rather than whole raw carcasses.

Large poultry industry integration is becoming more important. Sixtyfive companies control 65% of the world's poultry production. In Europe, 10 companies account for 32% of total production (Anon, 1996c).

MICROBIOLOGY OF POULTRY AND POULTRY PRODUCTS

The presence of spoilage and pathogenic microorganisms on poultry products makes handling during marketing of these products critically important. The need for good hygienic practices in the entire production chain becomes more and more pressing as poultry products are increasingly implicated as vehicles of foodborne infections.

The impact of poultry husbandry practices and processing technology on the microbial contamination of the meat is enormous. The microbial flora present on carcasses after processing is a reflection of the hygienic measures taken at the farm, during transport and at slaughter.

The heterogenous population of microorganisms which inhabit the environment of poultry farms and processing plants include both microorganisms responsible for spoilage of products (e.g. *Pseudomonas*, *Acinetobacter*, *Brochothrix*, and lactic acid bacteria) and potentially pathogenic microorganisms (e.g., *Salmonella*, *Campylobacter*, *Listeria* and *Staphylococcus aureus*) that may cause diseases in humans. Concerns about *Salmonella*- and *Campylobacter*-contaminated poultry products far outweigh concerns about other potentially pathogenic microorganisms. Although the literature reports the isolation of *Staphylococcus aureus*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Aeromonas hydrophila* and *Clostridia* (*Clostridium perfringens*) from poultry products, the public health importance of these "other pathogens of concern" is not reflected in statistics of human foodborne diseases (Nurmi et al., 1992). Table 5 summarizes the literature with respect to the prevalence of contamination of raw chicken with these "other pathogens of concern".

There is only one report in the literature of the isolation of *E. coli* O157:H7 from poultry (Doyle and Schoeni, 1987), and, in this case there was evidence that the chicken could have been contaminated by an infected food handler. However, it is possible to infect poultry experimentally with this organism, and there is a possibility of it becoming a major hazard. The possibility of other EHEC (enterohaemorraghic *E. coli*) of other serotypes should also be borne in mind. Similarly, the finding that up to 60% of poultry products are found positive for *Listeria monocytogenes* in some countries should be noted. Since *Listeria monocytogenes* is ubiquitous, it is not surprising that reported incidence rates of this microorganism in poultry products in many studies vary so much. Yersiniosis, in turn, is often underreported in official statistics due to misinterpretation of disease symptoms by physicians. Some years ago, Denmark and Spain were the only European countries with official reports on human foodborne yersiniosis. The literature, however, indicates, that poultry is often contaminated with non-pathogenic strains of *Yersinia enterocolitica* (De Boer et al., 1991).

For these reasons, this report will concentrate on *Salmonella* and *Campylobacter* in relation to foodborne disease and contamination of poultry and poultry products. In those cases where suggested treatments have shown additional effects against other potentially pathogenic microorganisms in poultry, these effects will be mentioned.

The World Health Organization Surveillance Programme for Control of Foodborne Infections and Intoxications in Europe (WHO, 1992) collected data on foodborne diseases from all participating countries, and although the data were not collected in a uniform way, it is clear that *Salmonella*, *Clostridium perfringens* and *Campylobacter* are the important disease-causing microorganisms in poultry.

TABLE 5

Prevalence of Potential Human Pathogenic Bacteria in Raw Chicken

Microorganism	Prevalence (%)	Reference
Campylobacter jejuni	0-100	Bryan and Doyle, 1995
Clostridium perfringens	63	Roberts, 1972
Clostridium botulinum	0.3	Anon., 1971
Escherichia coli O157:H7	1.5	Doyle and Schoeni, 1987
Salmonella spp.	0-100	Bryan and Doyle, 1995
Staphylococcus aureus	88	Roberts, 1972
"	29	Isigidi et al., 1991
"	7	De Boer et al., 1991
Listeria monocytogenes	5	De Boer et al., 1991
"	60	Pini and Gilbert, 1988
Yersinia enterocolitica	8	De Boer et al., 1991

A large proportion of poultry products are marketed as fresh (i.e. chilled and not frozen) in many European countries. This change in production technology has taken place during the last 10 to 15 years and also prompted a change in packaging technology and in presentation of products to the consumer. From a microbiological point of view, these changes have increased the importance of the ecology and control of spoilage organisms in both live poultry and the processing plant.

Although factors affecting survival and adherence of potentially pathogenic microorganisms (and to a lesser extent of spoilage microorganisms) to poultry product surfaces have been studied in detail in industrial processing, the European Union Directive 92/117/EEC on "Zoonoses" is influencing thinking in Europe on hygiene in the whole poultry production chain. At this moment, intensive sampling and monitoring schemes for *Salmonella* are proposed only at the breeder level. In the near future, however, the whole production chain will have to be monitored for *Salmonella* and *Campylobacter*.The finding of *Salmonella*-positive samples will have serious financial repercussions. Therefore, when this Directive becomes effective, the level of hygiene on farms and in processing plants should improve.

3.1 MAJOR PATHOGENIC MICROORGANISMS IN POULTRY PRODUCTS

Bryan and Doyle (1995) reviewed the literature on *Salmonella* and *Campylobacter* contamination of poultry products. The data presented on *Salmonella* contamination of poultry (i.e., broilers and turkeys at the retail level) in that review indicated that over the years between 2 and 100% of the products were contaminated with *Salmonella*. The variation in results was attributed to differences in numbers of samples taken, the sampling itself and the *Salmonella* detection methods used, as well as to the chance factor of sampling a *Salmonella*-positive flock or lot. The median was 30% *Salmonella* positive. Looking at the data for *Campylobacter* contamination, the situation was similar; contamination percentages ranged between 0 and 100%, with the median at 62%. This figure for *Campylobacter* agreed with those reported by Jacobs-Reitsma (1994) and by Berntson (1996).

Generally speaking, the numbers given in the literature reviews mentioned above are in line with results of recent UK and Dutch surveys on contamination of retail poultry meat products with pathogens. The UK Government Advisory Committee on the Microbiological Safety of Food (Anon., 1996a) reported that the prevalence of salmonellae in whole UK raw chicken had fallen from 54% in 1990 to 41% in 1994 for frozen birds, and from 41% to 33% for chilled birds. The predominant serotypes were *S. enteritidis* PT4, followed by *S. enteritidis* PT7. Another important observation was the detection of antibiotic-resistant *Salmonella* strains, including serotypes of *S. indiana*, *S. virchow* and *S. typhimurium*. The Dutch study (Van der Zee and De Boer, 1995) reported *Salmonella* and *Campylobacter* contamination in chickens and chicken products sampled in three consecutive years (1993-5) and examined with the same methods. The results are summarized in Table 6.

TABLE 6

Salmonella and *Campylobacter* in Poultry Products in The Netherlands(1993-1995)

	1993	1994	1995
No. of Samples	840	907	822
Salmonella spp.	32.1%	32.5%	33.3%
S. enteritidis	3.2%	5.6%	6.9%
Campylobacter	34.2%	23.4%	26.6%

(Source: Van der Zee and De Boer, 1995).

Table 6 shows that *Salmonella* contamination of Dutch poultry was constant over the period studied and that contamination with *Campylobacter*, which had decreased in 1994, increased again in 1995. No inference for the future can be formulated on the basis of these data. With respect to the presence of *S. enteritidis* in retail poultry products, it can be concluded that the *S. enteritidis* eradication programme in the breeding and reproduction sector in The Netherlands, which started in 1989, rather than improving the situation, isolation of *S. enteritidis* at the retail level increased. *Salmonella* serotypes detected in Dutch poultry products in the same period are summarized in Table 7.

TABLE 7

Salmonella Serotypes in Retail Poultry Products in The Netherlands (1993-1995)

	1993	1994	1995
No.of Samples	250	250	250
S. enteritidis	8.3%	14.7%	13.6%
S. hadar	11.1%	30.6%	26.4%
S. indiana	-	-	7.2%
S. typhimurium	12.9%	6.4%	5.2%
S. virchow	26.3%	16.1%	5.6%

(Source: Van der Zee & De Boer, 1995).

It is remarkable that some serotypes among the main five appear at a constant isolation rate whereas others appear and disappear again. The same serotypes as in the UK study were isolated from Dutch poultry. To enable a better comparison of circumstances and conditions in the UK and The Netherlands, as well as in other countries, it would be helpful to know the antibiotic resistance pattern of the isolates, data which are not in the open literature.

The same "top 5" isolates are found in other countries of the world, which means that the spread of *Salmonella* through the world poultry population has no borders. This may be explained by the internationalization of poultry breeding, production, processing and marketing.

However,the serotypes isolated from humans and live poultry in The Netherlands are somewhat different (Table 8). In 1994 and 1995, *S. enteritidis* in humans accounted for 49.6 and 48.5% of the total isolates, respectively. In poultry, this figure was 6% in flocks for 1995 (Van de Giessen, 1996). From these data one could conclude that the *S. enteritidis* eradication programme in the breeding and reproduction sector was somewhat succesful during the first years. Although four of the "top 5" serotypes were found both in humans and in poultry, there seemed to be no direct connection between the serotypes of human isolates and those of contamination in retail poultry products. Table 9 presents similar data for Australia.

Pohl *et al.*(1996) reported similar data for Belgium. In 1995, 43% of the *Salmonella* isolates were *S. hadar*, 23% *S. enteritidis*, 6% *S. infantis*, 6% *S. typhimurium* and 3% were *S. virchow.*

TABLE 8

Salmonella Serotypes in Humans and Poultry in The Netherlands, 1989-1990

	% in Human		% in Poultry	
	1989	1990	1989	1990
S. typhimurium	44.9	39.7	16.9	18.4
S. enteritidis	20.1	29.5	19.5	10.0
S. virchow	6.2	6.8	8.6	13.1
S. hadar	2.2	2.6	9.9	18.8
S. infantis	2.4	1.9	11.3	14.2

(Source: Notermans & Van de Giessen, 1993).

TABLE 9

Salmonella Serotypes in Humans in 1990 and in Poultry in Australia, 1984-1990

	% in Human	% in Poultry
S.typhimurium	38.0	22.2
S. virchow	4.9	1.2
S. bovis morbificans	4.1	0.9
S. saint-paul	4.0	0.9
S. anatum	2.8	4.3

(Source: Murray, 1992).

In recent years, multiresistant (ampicillin, streptomycin, chloramphenicol, sulfonamides, and tetracycline resistant and some 4-quinolone) strains of *Salmonella typhimurium* DT104 have become a predominant serotype in relation to human disease in several countries, including the United Kingdom, Germany and the United States. In the United Kingdom, *S. typhimurium* DT104 comprises 81% of all *S. typhimurium* isolates from human, and has increased from 259 human cases in 1990 to 4006 human cases in 1996 (Wall *et al.*, 1997).

S. typhimurium DT104 differs from the serotype *enteritidis* in that the latter, in general, does not carry antibiotic resistance. Therefore DT104 may become a more serious problem to the consumer than *S. enteritidis* PT4 because of problems in selecting drugs for therapeutic use. Although the serotype is considered to be mainly bovine related, the prevalence of *S. typhimurium* DT104 has increased 10-fold in UK swine production from 1990 to1996 (Wray and Davies, 1997). Whether this is the case for poultry is not known, but poultry and poultry products have been related to human cases in the UK (Ward and Threllfall, 1997). In Denmark, *S. typhimurium* DT104 has not yet been detected in chicken, but four swine herds have been destroyed to control this bacterium (Baggesen, 1997, personal communication). It is too early to judge whether the Danish action in this field will be effective, but experience from other countries where *S. typhimurium* DT104 has increased dramatically during the last years leaves little hope of controlling this specific phage type. So far, human cases in that country are suggested to be related mainly to imported poultry.

Campylobacter infections in humans have increased in the last five years in Denmark, and the number of cases now approaches the number of *Salmonella* cases in 1996 (approximately 3000 cases). A survey on thermophilic *Campylobacter* in cattle, swine and broilers was conducted in 1996, showing a prevalence of 35.3 % in broilers (mainly *C. jejuni*) and 43% and 48% in cattle and pigs

respectively (mainly *C. coli*). Substantial variability in the prevalence of *C. jejuni* exists in different flocks, some of which tend to remain free (Anon., 1994). At retail, the corresponding prevalences were 29-48% in chicken and 2 % in beef and pork, with the same distribution of species as seen on a herd basis.

The low prevalence of *Campylobacter* in Danish beef and pork at retail compared to that in herds may reflect problems of survival for the microorganism through slaughter and retail handling. The drying out of beef and pork surfaces may be especially critical to *Campylobacter*.The surface of poultry does not dry to the same degree as that of pork and beef, even with the use of air chilling as an alternative to spin- chilling. Survival of *Campylobacter* in feather follicles may also be an important factor.

3.2 HUMAN FOODBORNE INFECTIONS BY *SALMONELLA* AND *CAMPYLOBACTER*

The *Salmonella* bacterium is a Gram-negative rod, closely related to *Escherichia coli*, also belonging to the *Enterobacteriaceae*. There are many serotypes known, which can be subdivided in many phage types. Serotyping is a routine immunological method used for identifying *Salmonella* species. Some serotypes just cause disease in poultry (e.g., *Salmonella pullorum*); others play an important role in poultry-borne human food infections. The dominant examples are *Salmonella enteritidis* and *Salmonella typhimurium*.

Campylobacter is a member of the family *Campylobacteriaceae* and comprises Gram-negative, slender, curved bacteria that are motile by means of a single polar flagellum. *C. jejuni* and *C. coli* are thermophilic bacteria and are the species most often associated with foodborne infections. Serotyping schemes for differentiating *C. jejuni* isolates facilitate epidemiological studies, but this technique still needs improvement. A modified serotyping scheme, in combination with phage typing is being introduced for routine use in England and Wales. Pulsed field gel electrophoresis is also useful for strain differentiation.

Before humans become infected with *Salmonella*e, several criteria have to be met. In case of serotypes that have not yet adapted to man, ingestion of up to 10 million cells of the microorganism may be required to initiate infection. In some adapted, virulent types, doses of less than 1000 colony-forming units (cfu) are known to have caused symptoms of severe salmonellosis. The infectious dose may vary according to the composition of the meal. High fat content of the food is suggested to be protective for *Salmonella* and leading to low infectious doses. Low infectious doses have been reported in outbreaks related to chocolate (Torres-Vitela,1995) and alfalfa sprouts (the infectious dose was estimated by Aabo and Baggesen, 1997 to be 5-460 cfu).

Similar criteria play a role in campylobacteriosis. Dose-response studies have shown that even 100 cfu *Campylobacter* may cause symptoms of disease, but also that even one billion cfu could not.

Generally speaking, the very young, the very old and those persons who already have another illness are more susceptible to *Salmonella* and *Campylobacter* infections. The risk of this type of infection in humans is obviously higher under conditions of poor hygiene, especially in hot and humid climates. Unfortunately, this combination of criteria occurs in many areas of the world. The probability of a person becoming infected with *Salmonella* or *Campylobacter*, the two most important bacteria implicated in human foodborne disease, is estimated at one in 65 people per year. Worldwide, the annual medical costs and costs for absenteeism caused by these diseases are estimated to be in the billions of US dollars.

Table 10 offers a view of the role of meat and meat products, including poultry, in foodborne disease (WHO, 1992). Depending on the reporting country, meat and poultry are involved in a fairly large proportion of outbreaks. It is noteworthy that, despite the long existence of *Salmonella* eradication programmes in countries like Finland and Sweden, there are still outbreaks in which poultry are the incriminated food commodities.

TABLE 10

Meat- and Poultry-Associated Foodborne Disease in Several European Countries 1985-1989

	% outbreaks			% outbreaks	
	Meat	Poultry		Meat	Poultry
Finland	47	2	Belgium	53	7
Germany	42	9	Denmark	32	7
Israel	25	8	France	29	-
Poland	26	2	Netherlands	15	4
Spain	5	-	Sweden	34	7
England and Wales	62	26			

(Source: WHO, 1992).

Although the number of outbreaks where the incriminated food is identified is relatively small, outbreaks can provide valuable information on the most important primary sources of human infection. It is, however, difficult to extrapolate outbreak data covering relatively few human cases to a high number of sporadic cases. One way to correlate the sporadic human cases to primary sources of infection is to compare subtyping results (e.g. phage typing and genomic finger prints, including pulsed-field gel electrophoresis). Based on extensive subtyping, the estimated sources of human salmonellosis in Denmark in 1995 and 1996 have been reported (Anon., 1995e; 1996b). In 1996, eggs were estimated to account for 40-50 % of human cases; pork, 15-20%; poultry, 2-7%; beef, 1-4%; travel, 10-20%, and unknown sources, 15-20%. It is important to emphazise that the ability to differentiate the various sources relies on differences in types, i.e. clonality, of the bacteria. This highlights the importance of developing typing methods with high discriminatory power.

For thermophilic *Campylobacter*, a zoonosis account similar to the one for *Salmonella* awaits valid typing methods, although serotyping studies in Denmark (Nielsen et al. 1997) do indicate that poultry is an important source of *Campylobacter* infections. Direct links between human cases and primary sources must be known before any firm conclusions can be reached. Case-control studies, where bacteriologically confirmed sporadic cases of campylobacteriosis and controls, matched for age, sex and social status, are interviewed, have indicated that eating (undercooked) chicken is an importent risk factor, along with drinking raw milk or untreated water (Notermans and Borgsdorff, 1997).

3.3 ECONOMIC AND HEALTH IMPACT OF POULTRY-ASSOCIATED FOODBORNE DISEASE

The need for pathogen control or for the introduction of eradication programmes is highlighted by the economic and health impact of poultry-borne human disease. The economic impact of foodborne disease occurs in two areas: a) the costs of disease in human health terms, and b) the cost in trade or commercial terms. The public health impact of foodborne disease, on the other hand, is felt in the utilization of scarce medical and hospital resources by cases of preventable or avoidable disease.

There are various methods of estimating the cost of foodborne disease. Aldrich (1994) reported two approaches. One was related to medical costs and lost wages, and the other to the value of avoiding death. Table 11 summarizes the estimated economic and health costs of foodborne disease in the United States. It can be seen from this that although the total number of cases of *Salmonella* and *Campylobacter* were estimated to be similar in 1994, the risk of dying from salmonellosis was estimated to be five to eight times higher than dying from campylobacteriosis.

The cost of foodborne illnesses in the United States in 1994 was estimated at 5-6 billion dollars (Roberts and Unnevehr, 1994). However, based on the data in a report by the U.S. General Accounting Office, this figure should have been raised to 22 billion dollars per year (Raloff, 1996).

The cost of poultry-associated human foodborne illnesses has also been calculated for various countries and years (Table 12).

TABLE 11

Estimation of Economic and Medical Costs of Salmonella and Campylobacter Foodborne Infections

		Medical Costs and Lost Wages (Million US$)		
No. of Cases	No. of Deaths	Medical Costs for All Cases	Lost Wages for Survivors	Lost Wages due to deaths
Salmonella				
1,920,000	960-1,920	839-889	349-669	3,840-13,440
Campylobacter				
2,100,000	120- 360	863-885	44-131	480- 2,520

(Source: Aldrich, 1994)

The economic and health impact of poultry-associated foodborne diseases is often obscure, as only the number of reported human cases is known but not the real number of cases or the number of cases specifically related to poultry. The number of campylobacteriosis cases has been shown by sentinel studies to be grossly underreported (more so than salmonellosis cases) in the UK (Palmer *et al.*, 1996) and in The Netherlands (Notemans and Hoogenboom-Verdegaal, 1992; Hoogenboom-Verdegaal *et al.*, 1992). The zoonosis account being kept in Denmark provides a more precise determination of the relative importance of poultry. In 1996, 2-7% of registered human salmonellosis cases were related to poultry. Consequently, the relative economic impact of *Salmonella* in poultry may be estimated to be 2-7 % of the total costs of human salmonellosis in that country. However, no estimate of the total costs of human *Salmonella* infections in Denmark has so far been reported.

As the percentages of *Salmonella*- and *Campylobacter*-contaminated poultry have not changed dramatically, one can expect that the data on costs of poultry-associated human foodborne disease are a good indicator of the present situation. Bearing these figures in mind, the cost of preventive programmes acquire another dimension. The economic benefits of controlling foodborne disease can be grouped as follows:

1. Reduction of costs due to human illness (medical, income and productivity costs).

2. Industry benefits in several areas:

   (i) fewer food safety crises, including lower costs for recalls, downgrading, cleaning up processing plants, etc. and also in legal claims for compensation from victims;
   (ii) production would improve when poultry mortality rates decrease due to preventive measures; feed efficiency would also improve, as would growth rates, and,
   (iii) marketing possibilities would be better due to restored consumer confidence.

TABLE 12

Estimated Annual Costs from Poultry-Associated Human Foodborne Disease

Disease	Cost (millions)	Country	Reference
Salmonellosis	US$ 4,800	USA	Buzby and Roberts, 1997
Salmonellosis	BP 1,557	England and Wales	Persson and Jendteg, 1992
Salmonellosis	BP 195	Sweden	Persson and Jendteg, 1992
Salmonellosis (incl. eggs)	NLG 80	Netherlands	Notermans *et al.*, 1996
Campylobacteriosis	US$ 1,200	USA	Buzby and Roberts, 1997

3. The public health sector would benefit as there would be less need (and expense) for investigating outbreaks and for following up the results. Fund allocation for future surveillance programmes, therefore, could be reduced.

With such positive aspects in relation to the economic and health costs of poultry-associated foodborne disease, it is difficult to understand why preventive programmes have not yet been fully implemented.

4. POULTRY PRODUCTION AND PROCESSING

The structure of poultry production is pyramidal. The poultry industry starts with small numbers of birds at the top of the production pyramid and ends with large numbers of birds at the product level. Hence, the primary breeding company keeps small numbers of pedigree birds which are selected for various commercial characteristics, such as feed conversion and body conformation. These generate the basic grand-parent stock from which a parent breeding stock will be produced, sold and further multiplied to rear large numbers of broiler chicken. As the breeding pyramid descends, there is a gradual increase in stocking densities.

In modern poultry husbandry, broilers are kept in houses with numbers up to 100,000 birds per unit. Broilers are usually kept on litter for a six-week period, although some broilers are slaughtered at an earlier age. The climatically controlled conditions, including the high stocking densities which in some countries are necessary for economically, efficient production, create an environment which favours feed efficiency and better bird performance. However, there is also the possibillity of increased spread of any introduced microorganisms and diseases.

The poultry farmer should strive to obtain the best possible combination, i.e., the most efficient production resulting in high-quality products free from any pathogenic organism. To reach this goal, poultry houses should be kept clean; cleaning and disinfection are important also after the birds have left, to prevent infection of subsequent flocks. The structure of buildings as well as the environment near the houses are also important in this respect.

The farmer should inspect regularly the birds and their faeces for any signs of disease. Since vermin (rodents and insects) can be carriers of human pathogenic micro-organisms such as *Salmonella* and *Campylobacter*, it is important to have a control programme against them.

Stress caused by catching and loading at the farm, by transportation, and by holding at the slaughterhouse may cause increased excretion of potentially pathogenic microorganisms, if present. This may cause additional contamination of equipment and products. Cleaning and disinfection of transport crates or containers after each journey is therefore essential, and should be optimized in terms of use of energy, water, detergents and dis-infectants.

Modern poultry processing implies a high rate of throughput. Slaughter capacities of more than 6,000 birds per hour can only be realized with complete mechanized and automated processing lines. Depending on the degree of automation, individual processing steps may or may not involve human labour. From a microbiological point of view, several steps are critical in controlling the microbiological contamination of products and equip-ment; these include the catching, transportation and holding conditions before slaughtering. These conditions are of enormous influence in the contamination of feathers and skin of the birds with faecal material.

Several stages in poultry processing operations influence the hygienic quality of products. In the context of a Hazard Analysis Critical Control Point concept, the scalding, defeathering and evisceration steps in processing are considered critical control points.

5. PATHOGEN CONTROL PROGRAMMES IN POULTRY PRODUCTION

Competitiveness forces processing plants to make use of high-speed and fully automated slaughter-lines. At the same time, however, processors are under pressure to deliver products having high-quality attributes (with safety, as one), such as those produced under a brand name or belonging to a quality-controlled production organization and/or just free from *Salmonella*, as favoured by some consumer groups.

Most poultry producing countries apply some form of programme for control of potentially pathogenic microorganisms in flocks and herds. Based on the Swedish programme on *Salmonella* eradication in animal production, which started in the early 1950's, many countries or organizations expected that the implementation of such control programmes in the poultry industry would solve the problem of contamination of products with microorganisms causing foodborne disease. It is unlikely that the Swedish success can be reproduced in many other countries. There are several reasons for this, but the main one is probably the rather small scale of Swedish production in a geographically favourable area, as opposed to the more intensive production systems in other countries.

The number of birds housed per square meter varies in different parts of the world. For instance in the USA and Brazil the use of open houses makes more space available, and poultry contamination with *Salmonella*. However, contamination rates in these countries do not differ significantly from those in countries where larger numbers of broilers per square meter are kept.

The proper application of sampling, monitoring and eradication programmes is probably the most important factor, since *Salmonella* eradication has proven possible this way. Recently, although the data are not yet confirmed in the literature, there is evidence that *Salmonella* contamination of live and processed poultry in Denmark is decreasing since a Swedish firm entered it and the Swedish approach is being implemented. Also, a Danish poultry processing plant has announced that because of a very comprehensive hygiene programme (the company is ISO 9000 certified), a near *Salmonella*-free status can be claimed for its products. Important in the quality control programme is the testing of live birds three weeks before slaughter (Anon., 1996d).

5.1 THE SWEDISH *SALMONELLA* CONTROL PROGRAMME IN POULTRY

During the past 30 years Sweden has implemented a *Salmonella* control system in poultry production which has lead to very low contamination rates. A recent study showed only a 1% contamination rate in Swedish poultry at retail (Wierup and Engstrom, 1992). The control programme was initiated in 1970, motivated by several large foodborne outbreaks of *Salmonella montevideo* and *S. typhimurium*. It must be noted that *S. enteritidis* (SE) was not a problem in those days, and that the experience gained from the Swedish control system so far does not allow for firm conclusions about its efficacy against the eventual spread of this particular *Salmonella* serotype.

To control contamination and spread of *Salmonella*, key points in the Swedish system have been the control of *Salmonella* in breeding stock and in feed mills, as well as extensive hygienic measures in hatcheries. From 1970 to 1984 the control of *Salmonella* in poultry in Sweden was based on voluntary participation by producers. Full compensation from the government was granted provided chicks were supplied by hatcheries affiliated to the voluntary control programme. Since 1984 the system has comprised voluntary and compulsory parts. The latter includes control and quarantine of grandparent stock and pre-slaughter control of broilers. Control in relation to parent stock, hatcheries and layers is still conducted on a voluntary basis. An exception to this is the mandatory testing of layers during production and before slaughter (in force since 1994). "Control" involves testing for *Salmonella* spp. If they are detected, the action taken varies depending on the circumstances (see below). "Control"also includes all the practical measures taken in order to prevent salmonellae infecting the poultry – from eggs in the hatchery to the raw poultry product.

The number of infected poultry flocks per year has decreased from 40 in 1970 (i.e., 2-3%) to two flocks (approximately 0.05%) in 1997. Poultry production has increased from approximately 25 million broilers in 1970 to some 60 million broilers in 1997, for a total of ca. 65,000 metric tonnes. The relatively few infected flocks at the start of the control programme limited the costs for refunds on destroyed flocks and the impact on the

market. The Swedish *Salmonella* situation in broilers 25 years ago therefore seemed to favour a strategy of zero-tolerance for *Salmonella* in poultry with full compensation to the producers.

In 1993, 96% of broilers and turkeys in Sweden were affiliated to the prophylactic control programme. When *Salmonella* of any serotype is found in grandparents, parents or meat-producing poultry, the birds are killed and destroyed. This contrasts to the situation with commercial layers, however, which are killed only if invasive types of *Salmonella* are found (normally *S. enteritidis* and *S. typhimurium*). All generations of birds have been subjected to bacteriological examination at a level which detects flocks with a *Salmonella* prevalence of more than 5% among birds.

Only *Salmonella*-free brooders may deliver eggs to hatcheries affiliated to the control programme. Hatcheries, in turn, must deliver *Salmonella*-free day-old chicks to empty, clean and disinfected houses.

Heat-treated feed is delivered from controlled feed mills and re-contamination must be avoided during delivery and during storage in the farm. The chicken house must be well protected from wild birds, rodents and other vermin. In the house, a hygienic barrier stops the staff and visitors from entering the poultry pen without changing shoes and putting on protective clothes. All poultry houses are cleaned and disinfected after each batch of birds as if *Salmonella* were present. Hatching eggs are disinfected and handled as if they were contaminated, although the hens are frequently tested for *Salmonella* and must be free from *Salmonella*.

5.1.1 Compulsory and Voluntary Measures in the Swedish *Salmonella* Control Programme

As mentioned earlier, from 1970 to 1984 the control of *Salmonella* in poultry in Sweden was based on voluntary participation by producers. After 1984, however, compulsory elements were introduced. These included control (of *Salmonella*) and quarantine of grandparent stock, and pre-slaughter control of broilers. Control in relation to parent stock, hatcheries and layers continues to be voluntary, but mandatory testing of layers during production and before slaughter has been required since 1994.

It is apparent that the most significant improvement in the number of infected flocks has taken place after introduction of compulsory controls. Whether other factors have influenced the positive trend is not clear. A control system as extensive as the Swedish requires a lot of effort by authorities and individual producers, and the necessity for constructive cooperation between these parties is evident.

To prevent obstruction from producers, it may be of value that the relevant national authorities and the producer associations reach a certain degree of consensus about the goals and the measures in the *Salmonella* control programme. It may also be important that part of the control system remains voluntary. Voluntary in this perspective could be control measures which are negotiated between the authorities and the producer associations, are sanctioned by the associations, and thereby become compulsory for individual producers. The "voluntary" part of the control may make producers more cooperative, a very important element when significant parts of the control system rely entirely on the producer (such as the responsibility for cleaning and disinfection, or sampling for bacteriological monitoring).

However, despite the fact that producers often dislike mandatory solutions, the introduction of compulsory control measures may be necessary to ensure satisfactory participation by producers.

5.1.2 The Potential for Reintroduction of *Salmonella*

The two main pillars of the Swedish *Salmonella* control system in poultry are the breeding flocks and hatcheries, and the feed mills. If *Salmonella* spreads via the grandparent and parent flocks or reaches the production units in contaminated feed from the feed mills, the control effort at production sites and subsequent stages in the food chain has little chance of success.

Control of *Salmonella* in animal feed is important to prevent feed-borne contamination of the production. However, *S. enteritidis* and *S. typhimurium* are not commonly isolated from feed. Instead, their presence in the production must be controlled by ensuring clean breeding stock in combination with proper hygienic measures at all levels of production.

Despite extensive control efforts, *Salmonella* will occasionally be re-introduced. The Swedish level of control seems to ensure *Salmonella* rates below 1% in poultry production. In 1991, Sweden faced the first infected hatchery since 1970. This breakdown led to an increased number of infected flocks. However, quarantine of imported animals, in combination with hygienic

measures and extensive monitoring and destruction of infected breeding flocks, seem to be highly effective in preventing introduction of *Salmonella* in the production system. Additionally, the location of the grandparent stock inside Sweden allows infections at the breeding level to be detected before birds reach the production system.

When a production facility has been infected, the likelihood that the following flock will be infected is high. In Denmark, the relapse rate is approximately 50%. This high relapse rate shows how difficult and vital proper cleaning of housing facilities is between flocks.

It is important to point out that the Swedish *Salmonella* control programme does not address the problem of other potentially pathogenic bacteria in poultry, particularly *Campylobacter*.Thus, consumers may derive a false sense of security from products only free of *Salmonella*.

5.1.3 The Public Cost of the Swedish *Salmonella* Control Programme

Until 1984 all expenses in relation to the control programme for *Salmonella* in poultry were covered by the Swedish government. In that year compulsory elements were introduced into the programme, and public compensation for the destroyed infected flocks was discontinued. Since then costs have been borne by the poultry industry with the aid of an insurance programme. This private insurance was established at a time when approximately 0.1% of the flocks for slaughter were infected with *Salmonella*. It is not clear, however, at which infection level the insurance fees would become too high or insurance companies would deny insurance, but it has to be relatively low. The number of destroyed flocks in recent years has been around 1-2 flocks per year. In 1993, the extra cost to the public treasury of *Salmonella* control measures was 0.79 Swedish crowns (9.7 US$ cents at 1998 exchange rates) per chicken.

5.1.4 Possibility of Implementing Some Elements of the Swedish System Elsewhere

Whether it is possible to implement the Swedish model in full scale elsewhere would depend mainly on available resources and on the production infrastructure from farm to table. The infection levels in the poultry population and the overall size of poultry production can also determine how realistic successful implementation of the Swedish model could be in other countries. Thus, vast poultry production systems like those in the United States, Brazil, China and Thailand may find the logistics and cost of such a programme impossible to absorb.

5.1.4.1 *Salmonella* Control Elements at the Breeding Level

The *Salmonella* control elements to be included at the breeding level would depend on the local situation. However, from the Swedish experience it is clear that *Salmonella* control in imported breeding stocks, breeding flocks and hatcheries, as well as control of feed contamination are the main factors responsible for the Swedish success. These elements are probably more efficiently implemented together than individually. One way to limit the costs might be to section the broiler industry so that not all producers are allocated to the full control scheme from the beginning.

The ability to build up the grandparent (GP) generation inside the country provides four levels at which animals can be monitored before the offspring enters production (i.e. quarantine at import, the GP-generation, the parent generation, and the hatchery). This has a highly protective impact.

5.1.4.2 *Salmonella* Control Elements at the Production level

In Sweden, competitive exclusion (CE) has been used since 1981 to limit re-infection/re-colonization of flocks introduced into environments which have recently been infected with *Salmonella*. CE involves dosing poultry, normally immediately after hatching, with a mixed normal intestinal microflora. This enables the birds to acquire a normal flora more rapidly than usual, and so makes them more resistant to infection by salmonellae. It is a simple method, easy to perform,and although its effectiveness is debated, it has been successfully used in Sweden.

During the period(s) when the number of *Salmonella* infected flocks is still high, heat treatment or irradiation of poultry meat may be considered as alternatives to destruction.

5.1.4.3 *Salmonella* Control Elements at Slaughter

Hygienic measures at the production sites, during transportation and at the abattoir influence the final *Salmonella* load in products for consumers. In an attempt to minimize contamination of clean flocks, infected ones are commonly slaughtered in Denmark at the end of the day. However, this practice may be problematic, as contamination of clean birds the following day may occur if sanitary practices at the abattoir are faulty. On the

other hand, if more infected birds are transported to the slaughterhouse than it is possible to slaughter on the day of arrival, the abattoir would have to postpone slaughter until the next day. In this case, thorough cleaning of the facility before slaughter of uninfected birds would be very difficult. Therefore, separate slaughterhouses for uninfected birds would be optimal to prevent cross contamination from *Salmonella*-infected birds to clean poultry after slaughter.

In Denmark, the Swedish involvement in broiler production includes the use of pre-slaughter monitoring of flocks to allocate contaminated flocks to specific slaughterhouses. This has enabled a few abattoirs to become and stay *Salmonella*-free now for more than a year. The Swedish involvement in Danish poultry production occurred at a time when infection rates of flocks were declining from levels of 25-35% to around 5%. Although the general decline in prevalence of *Salmonella* infection in Danish flocks has probably contributed to the success of the Swedish company, intensive monitoring of flocks delivered to slaughter, and separate abattoirs for clean and infected flocks have been essential for this success.

5.1.5 Implementation of Elements of the Swedish Control System in Denmark

The first *Salmonella* control system for poultry in Denmark was a voluntary system implemented in 1989 due to rejection of exported *Salmonella*-contaminated poultry. The program included prescription of hygienic measures in hatcheries and slaughterhouses, as well as heat treatment of feed at feed mills comparable to those used in Sweden.

Ante mortem monitoring of flocks three weeks before slaughter became compulsory in 1992, and the results were, and still are, used by abattoirs to plan the slaughtering. In general, the Danish slaughter routine has been to slaughter *Salmonella*-infected flocks at the end of the day, except for the Swedish company, which uses specific slaughterhouses for infected flocks.

In 1994, the European Union Zoonosis Directive (92/117/EEC) was implemented. The directive prescribed mandatory destruction of breeding flocks (but not production flocks) if infection with *S. typhimurium* or *S. enteritidis* was encountered (other *Salmonella* serotypes are not considered).

In late 1996, however, Denmark received EU notification of a three-year *Salmonella* control plan which aims at elimination of all *Salmonella* serotypes in brooders as well as breeding stocks (parent flocks). This part of the control programme is compulsory and enforced by appropriate legislation. The programme includes extensive monitoring followed by destruction of infected breeding flocks and their eggs. Denmark has no grandparent breeding flocks. At import of parent flocks, The producer association, on a voluntary basis, demands a quarantine period before introduction of imported parent birds into the breeding stock.

In Denmark, *Salmonella* prevalence in poultry at the broiler flock level has declined from approximately 25-30% in 1995 to a level of approximately 5-10% in 1996-97, mainly due to a significant reduction in *Salmonella typhimurium*-positive flocks. Interestingly, the decline in prevalence had its onset before both the introduction of a revised *Salmonella* control plan and Swedish involvement in Danish poultry production. The ban of Avoparcin as growth promoter in poultry in late 1995 has been suggested as partly responsible for this decrease. It is however difficult to determine precisely which factors have contributed most to the improvement in the *Salmonella* status of Danish poultry flocks. Thus, Denmark in 1996 had a *Salmonella* infection level in broilers close to that of Sweden in the 1970's, when the Swedish control programme was initiated. Although destruction of infected broiler flocks was not and is still not a part of the Danish strategy, Danish consumers are now offered *Salmonella*-free poultry products. The combination of a control plan comprising the breeding level, hatcheries and feed mills, slaughterhouses and *ante mortem* control at the production level, voluntary labelling of *Salmonella*-free products, and also the Swedish involvement in a significant part of the Danish poultry production, seems so far to have been successful.

When the prevalence of *Salmonella* in broilers at retail was still quite high, at 20-40%, Denmark introduced two retail labelling systems. Producers were allowed to label their products "*Salmonella*-free" if a random sample of 300 birds per batch was found negative, and the *Salmonella* control status of the flock was negative. Alternatively, a flock could be labelled "No more than 5% of chickens contain *Salmonella*" if a random sample of 45 chickens was negative. The label "*Salmonella*-free" is widely used, in contrast to the 5% label.

As in the Swedish programme, these statements might be misleading to consumers, as it could lead them to believe the product is free also of other pathogens of concern, particularly *Campylobacter*.

5.1.6 Prerequisites for Implementation of *Salmonella* Control Systems in Poultry Similar to the Swedish Programme

Although it is not an exhaustive list, some essential prerequisites for implementation of a *Salmonella* control programme similar to the Swedish one in other countries would be the following:

A. Appropriate legislation is essential. The authorities must be able to implement compulsory or voluntary control systems, and implement sanctions depending on the choice of control strategy.

B. Registration of poultry producers at all levels of production is necessary.

C. Producers must be organised so that control measures, financial compensation, and voluntary/compulsory activities can be negotiated with the authorities.

D. Imported parent or grandparent birds must only be accepted if certified *Salmonella*-free. Parent/grandparent stock must be quarantined and checked for *Salmonella* infection before introduction into breeding flocks.

E. Extensive hygienic measures and *Salmonella* control of hatcheries must be implemented. A *Salmonella* monitoring programme must be implemented at all levels of production.

F. There should be sufficient laboratory capacity for the *Salmonella* testing required. Laboratories testing for *Salmonella* should be officially approved as competent, and preferably accreditted, or at least participating in regular ring (quality assurance or proficiency) tests.

G. Local veterinary staff must be trained to supervise producers and evaluate the hygienic status of hatcheries and other production premises before introduction of new birds.

H. Protocols describing the hygienic measures required at every step in the production chain must be available. Relevant education of producers to optimise the control at farm level must be made available.

I. There must be technical capacity to survey every flock before slaughter to determine its *Salmonella* status. The possibility of allocating infected flocks to specific abattoirs must exist, so as to avoid heavy *Salmonella* contamination of *Salmonella*-negative poultry or poultry contaminated at a low level.

Table 14 summarizes the Swedish *Salmonella* control programme in poultry, and Table 15 lists the costs of participation for Swedish farmers. Costs are related to findings and outbreaks of *Salmonella* in flocks. Insurance costs and costs in the feed factory are also included. As can be seen from the scheme, the annual costs are 43.89 US$ cents per broiler. These data should be considered together with the data on broiler production costs (Table 2).

5.2 THE EUROPEAN UNION COUNCIL DIRECTIVE ON ZOONOSES 92/117/EEC

The European Union has issued Council Directive 92/117/EEC (Anon., 1992) which mandates the screening of flocks and herds for *Salmonella enteritidis* and *Salmonella typhimurium*. At the moment, sampling and monitoring plans from the following countries have been accepted: Denmark, Finland, Sweden and Ireland (partly accepted). All European countries have to follow a sampling scheme as set by the Directive in order to be able to reduce the contamination level of breeder and finally all (broiler and layer) poultry flocks.

Table 16 presents the number of samples and samplings to be carried out for *Salmonella* according to the above Directive. At the breeder level, samples must be taken at two ages, and at the breeder hatchery every delivery must be sampled. In The Netherlands, a more intensive approach has been chosen to prevent poultry from becoming contaminated. Several additional measures at the general management level, as well as on the application of general hygiene principles, are incorporated into codes of good hygienic practice, the Integrated Quality Control S(almonella) C(ontrol) programme. Sampling at the breeder-grow out level is later intensified, taking samples from the breeder flocks at least four times during their life, where the EU Directive does not prescribe any sampling;

In Denmark broiler flocks are monitored for *Salmonella* three weeks before they are due for slaughter. In 1995, on average 10-15 % of flocks were positive for *S. typhimurium*, while only 1-3% of the flocks were positive in 1996. According to the EU Zoonoses Directive, Danish breeding flocks positive for *S. typhimurium* and *S. enteritidis* should be slaughtered, with financial compensation from the EU. Implementation of this directive may account in part for

the decrease in *Salmonella* contamination in Danish broilers. However, as mentioned earlier, during the same period the Danish authorities withdrew Avoparcin from poultry feed. The decline in *S. typhimurium* in Danish poultry has also been attributed to the withdrawal of Avoparcin.

TABLE 14

The Swedish *Salmonella* Control Programme in Poultry

		% of production under compulsory (C) or voluntary (V) control	
		Broilers	Layers
Imported grandparents		C/100[a]	C/100[a]
Parents	rearing	V/100[b]	V/20[b]
	egg production	V/100[c]	V/20[c]
Hatcheries		V/100d	V/20[d]
Layers	rearing	-	V/0[e]
	egg production	-	V/0[f]
Broiler-Layer	pre-slaughter	C/100[g]	V/90[h]

a Quarantine 15 weeks. On arrival, all dead birds are tested (liver, yolk sack and caecum) plus cloacal swabs from 100 birds pooled to 20 samples, plus floor cover from transport boxes. In addition, 60 dead or culled birds are tested at 1-2, 3-5, 9-11 and 13 weeks of age. In case of low mortality, faecal samples are added - 5 samples for each missing bird.

b Two A and two B samples tested at 2, 6-10 and 14-18 weeks of age. A sample = 30 faecal droppings pooled to 1 sample; B sample = liver and caecum from 10 birds pooled to 1 sample.

c Two A and one B sample tested monthly.

d Each parent group tested monthly: pooled samples of dust, eggshell and dead in shell. Every third month test from hatchers, brooders, walls and floors, etc.

e Three A samples tested at 2-3 weeks of age and 2 weeks before movement to egg production unit.

f Three A samples tested at 25 and 55 weeks of age.

g One A sample and three samples each of caecal contents from 10 birds tested 1-2 weeks before slaughter.

h Three A samples 3-4 weeks before slaughter.

(Source: Wierup et al., 1995).

TABLE 15

Annual Producer Costs per Broiler for the Voluntary Swedish *Salmonella* Control Programme (1992) in US $ cents

Rearing of grandparents	1.02
Production of parent animals	
* hygiene	3.57
* testing	1.02
* feed	2.04
Hatchery	
* transport	0.51
* hygiene	1.53
Production of broilers	
* hygiene	10.20
* testing	2.55
* feed	13.77
Slaughter	4.08
Buildings	3.57
Total	43.89

TABLE 16

Salmonella enteritidis and _S. typhimurium_ Screening in Poultry Flocks According to EU Council Directive 92/117/EEC

92/117/EEC	The Netherlands
breeder flocks	
* 60 manure samples at 4 weeks	* 60 manure samples at 4 weeks
* 60 faecal samples at 20 weeks	* 60 blood samples at 12 weeks
	* 60 blood samples at 16 weeks
	* 60 blood samples every 4 weeks after start of egg-laying
hatcheries/breeder level	
* every delivery 50 samples (fluff, minimum 5 g)	* every delivery 50 samples (fluff, minimum 5 g)
breeder/grow-out	
	* 60 faecal samples at 4 weeks
	* 60 faecal samples at 12 weeks
	* 60 faecal samples at 16 weeks
	* 60 faecal samples at 20 weeks
	* after start of egg-laying 60 blood samples every 8 weeks
hatcheries	
* every delivery 50 samples (fluff, minimum 5 g)	* every delivery: on a voluntary basis (fluff, minimum 5 g)
* official sampling every 8 weeks (hygiene control for cleaning and disinfection)	* official sampling every month (hygiene control for cleaning and disinfection)

(Source: Mulder, 1996).

5.3 DETECTION AND IDENTIFICATION METHODS

Poultry production and processing can be described in terms of the Hazard Analysis Critical Control Point (HACCP) method. To carry this out, in order to identify microbial hazards and Critical Control Points (CCP), as well as for subsequent monitoring, there is a need to detect and identify potentially pathogenic micro-organisms. For these purposes, many conventional (cultural) methods as well as novel microbiological techniques are available.

In faecal samples, as described in the EC Council Directive, evidence of the presence of *Salmonella enteritidis, Salmonella typhimurium* and other *Salmonella* serotypes is at this moment acceptable only when demonstrated by traditional, conventional cultural methods. These methods, properly used, are as sensitive as any other method, although no two methods will yield identical results. For screening purposes, several enzyme-linked immunosorbent assays (ELISA) have been proposed for use on blood and/or egg yolk samples and even implemented in national mandatory screening programmes. The efficacy of ELISA tests, however, is questionable. The possible explanation is a delay in the ability to demonstrate, by ELISA tests, antibodies after the first infection occurs in poultry. Use of ELISA would also not be appropriate for vaccinated flocks.

6. CHALLENGES AND PERSPECTIVES

To meet the requirements of the EC Council Directive on Zoonoses and to guarantee product safety to consumers, steps have to be taken along the entire poultry production chain. However, it cannot be expected that within one or two years researchers will develop new applicable technology to solve the problem of product contamination with potentially pathogenic microorganisms, when many research groups have already worked for more than 35 years on this subject with only minor success.

In general, industry should implement those techniques or methods which have already proven effective in reducing or eliminating *Salmonella* and *Campylobacter* from poultry under laboratory or simulated-field conditions. The techniques which quantitatively contribute the most to reduction or elimination of these pathogens sould be chosen.

Table 17 lists the areas and techniques or methods which are expected or have proven to have a positive effect against pathogens in poultry, and Table 18 presents the most promising of these. Such measures should not be applied on an individual basis but as a group, to reach the final goal of eliminating *Salmonella* and *Campylobacter* from poultry. The feasibility of implementing the measures listed in Table 17 must be studied "a prioritaire."

TABLE 17

Techniques or Methods to Be Implemented in the Poultry Production Chain

Area	Technology/method
Hatchery	a. Dipping of eggs - gentamicin sulphate - neomycin sulphate b. Fumigation of eggs - formaldehyde c. No re-use of transport trays, alternatively thorough cleaning and disinfection d. Cleaning and disinfection of containers
Genetics	a. Production of resistant breeds
Husbandry/Management	a. New litter systems b. Application of colonization resistant (CE-competitive exclusion) microflora c. Specific pathogen-free housing
Feed	a. Pelleting, heating and heat extrusion techniques b. Addition of organic acids c. Addition of probiotics (e.g oligosaccharides or microbes)
Processing	a. Flock monitoring b. Effective transport crate washing and disinfection c. Clean-in-place systems d. Combined scalding and plucking e. Cleaning and scalding in multistage scalders f. New evisceration techniques g. Rapid detection tests
End Product	a. Lactates/Lactic acid b. Inorganic phosphates c. Ionizing radiation

(Source: Mulder et al., 1993)

TABLE 18

Selection of Measures Having a Quantifiable Effect on Contamination of Products

Area	Measure
Hatchery	Dipping or fumigation of eggs
Husbandry/Management	Application of colonization resistant (CE) microflora Flock monitoring
Feed	Pelleting and heat extrusion
Processing	Cleaning and scalding in multistage scalders
End Product	Inorganic phosphates Ionizing radiation

(Ref: Mulder et al., 1993)

6.1 PREVENTION OF COLONIZATION AND CONTAMINATION

It is known that the microflora of the gastrointestinal tract of poultry can be influenced by ingestion of other microorganisms. The result of such a treatment can be the replacement of the existing microflora or a decrease or increase in numbers of some groups of microorganisms already present, thus producing a less favourable environment for colonization, at a later stage, by potentially pathogenic microorganisms (see Section 6.1.2). In this respect, *Salmonella* and *Campylobacter* are considered the most important pathogenic species. Treatment with vaccines and antimicrobials may also result in a less favourable environment for colonization by these pathogens.

As the mechanisms of colonization of microorganisms, as well as the metabolic interactions occurring in the gastrointestinal tract, are not well understood, researchers should concentrate more on these aspects. Intervention

strategies are more likely to be successful if the basic mechanisms are understood.

It is possible to categorise the various known factors which influence colonization of the gastrointestinal tract of poultry by pathogens, although their quantitative contribution to the colonization process is unclear:

1. Host-related factors (e.g., body temperature; pH and redox potential levels; bile acids and enzymes; genetic resistance in different breeds);

2. microbe-related factors (e.g., the effects of antagonistic microorganisms; bacteriophages; bacteriocins), and

3. diet- and environment-related factors (e.g., the use of oligosaccharides (mannose, lactose and other sugars and mixtures of sugars); stress factors resulting from conditions at the farm level).

Salmonella and *Campylobacter* do not follow entirely the same route in contaminating poultry at the primary production level. Both microorganisms can be transmitted through contaminated faeces, but only *Salmonella* is transmitted vertically from hen to egg. In contrast to *Salmonella*, *Campylobacter* is not considered to be feedborne, but introduction into a flock through drinking water is possible.

Control by hygienic measures seems to be more effective for *Campylobacter* than for *Salmonella*. The experience from Sweden shows that simple hygienic measures at the entrance to the poultry flock have a significant preventive effects on infection of the flock with *Campylobacter*.These measures cannot provide the same protective effect against *Salmonella*, since *Salmonella* may be able to enter by other routes such as the feed and by vertical transmission.

Reinfection of new birds has to be stopped by extensive cleaning of housing facilities after the slaughter of an infected flock. *Campylobacter* is a more fragile organism than *Salmonella* in relation to physical and chemical stress, and the cleaning of empty house before a new flock is introduced may be more effective in controlling *Campylobacter* than *Salmonella*. To obtain the maximum benefit from cleaning measures, poultry housing must be constructed in ways which facilitate cleaning. Primitive production facilities used in many countries make thorough cleaning difficult or impossible. After cleaning, the period before introduction of new animals may be more important for *Campylobacter* than for *Salmonella*.

6.1.1 Genetic Resistance

In the poultry breeding industry, especially in broiler production, meat yield and feed conversion efficiency have until now been the most important factors in determining the success of a breed. In the future, however, resistance to pathogens, will also become very important.

Several research groups (universities, institutes, industries) have tackled the problem of the genetic resistance of poultry to colonization by potentially pathogenic microorganisms like *Salmonella* and *Campylobacter*. Mulder *et al.*, (1991), Guillot *et al.*, (1993) and Beaumont *et al.*, (1994) described the work on genetic resistance to *Salmonella* in several experimental and commercial poultry lines (Table 19).

The meat-type (broiler) poultry strain Y11 was the most resistant to *Salmonella enteritidis* challenge. The commercial strains were egg-type (layer) strains and were amongst the most susceptible. The conclusion of preliminary work conducted in France is that the identification and characterization of genes responsible for resistance to *Salmonella* colonization are necessary.

TABLE 19

Susceptibility of Chicken Lines to Intramuscular *Salmonella* Challenge in 1-Day Old Chicks

Strain	Estimated LD50	Confidence Interval	Rank (order of increasing resistance
B13	<2.0 (no lethality rate <0.57)		1
PA12	4.35	3.26-15.15	8
Y11	>5.0 (no lethality rate >0.28)		9
Commercial 1	2.34	0.25-2.95	4
Commercial 2	2.12	1.08-2.7	3
Commercial 3	<2.08 (no lethality rate <0.11)		2
H-SRBC	3.9	3.0-5.1	5
L-SRBC	3.8	3.2-4.5	6
C-SRBC	4.1	-	7

(Source: Guillot et al., 1993).

In the Dutch study (Mulder *et al.*, 1991), two experimental lines of broilers were used, one selected for feed conversion and the other for growth restriction. In two experiments, one-day old chicks of these lines and from a commercial source were infected orally with 0-10,000 colony forming units (cfu) of *Campylobacter jejuni*. Since the results were the same for the two experimental lines, Table 20 only gives the results from one experimental line compared to the commercial source.

At the present time, four research groups in France, The Netherlands and the United Kingdom are working on a EU-AIR project on Genetic resistance. Results, however, are not yet available.

TABLE 20

Percentage Colonization by *Campylobacter jejuni* in Two Genetically Different Broiler Lines

	CFU *Campylobacter jejuni*									
	0		810		7,800		9,500		72,000	
Day	A	B	A	B	A	B	A	B	A	B
1	0	0	0	0	0	0	0	10	0	0
3	0	0	0	10	0	0	0	40	0	40
6	0	0	0	0	0	0	60	90	80	50
8	0	0	0	0	0	0	60	90	60	40
13	0	0	0	-	-	-	-	-	100	100

NOTE: A = Experimental flock; B = Control flock; - = not detected.

(Source: Mulder et al., 1991).

6.1.2 Competitive Exclusion

Colonization by *Salmonella* and *Campylobacter* can be prevented by the administration to young birds of a protective microflora. Tables 21 and 22 show the results of studies in which one-day old chicks were treated with an experimental competitive exclusion (CE) preparation (Table 21), and with a commercially-available product (Table 22).

The study of competitive exclusion in poultry was initiated in the early seventies. The first research results came from Finland, later followed by Canada, the United States, The Netherlands and the United Kingdom. Commercial products are now available, but lack of profitability in the poultry production sector may be one of the reasons for the limited use of this type of products in major poultry producing countries. Another drawback is that it has not proved possible to devise a product whose composition is completely defined. All available preparations consist of mixed cultures derived (by serial anaerobic) subculture from the caecal microflora of specific pathogen-free adult poultry. This has hampered approval by some national regulatory authorities. Also, the fact that a competitive exclusion microflora is only beneficial when it is applied together with other measures has hampered its use.

Competitive exclusion is sometimes used after antibiotic treatment to control *Salmonella* infections in flocks. The flock is treated with therapeutic levels of antibiotics, moved immediately to a thoroughly cleaned and disinfected house, and then dosed with CE. This treatment nowadays replaces the mandatory slaughtering of infected flocks in The Netherlands.

TABLE 21

Effect of Competitive Exclusion (CE) Treatment on *Salmonella* and *Campylobacter* Contamination of Broilers

Salmonella: effect on caeca		
	Number of samples	Number positive
Non CE treated	14,099	486 (3.5%)
CE treated	14,400	134 (0.9%)
Campylobacter: effect on flocks		
	Number of flocks	Number positive
Non CE treated	29	18 (62%)
CE treated	29	12 (41%)

(Source: Goren et al., 1991; Mulder and Bolder, 1991).

TABLE 22

Salmonella and _Campylobacter_ Prevalence in Flocks (%) After Treatment with Broilact Under Practical Conditions

	Salmonella	*Campylobacter*	
	cloacal swab samples at 4 weeks of age	caecal contents at slaughter	caecal contents at slaughter
Control	22.8	23.7	44.8
Broilact	12.3	19.8	32.4
Total	17.0	21.7	38.4

(Source: Bolder et al., 1995).

Nuotio and Nurmi (1994) stated that on the basis of use of present commercial preparations of competitive exclusion microflora, the problem of *Salmonella* contamination in poultry will not be solved. Future research should focus on obtaining more knowledge about the underlying protective mechanisms.

6.1.3 Vaccines

One of the principal aims of vaccination is to prevent lateral spread and amplification of infections in flocks. Cooper and Venables (1993) described the results of experiments with live, attenuated *Salmonella enteritidis* vaccines and demonstrated "that in comparison with control birds the vaccinates were not heavily colonized and also did not shed the challenge strain in large numbers."

Although the results are only preliminary, vaccination should be regarded as a promising treatment, and improved vaccines should be developed. Results using commercially available vaccines are presented in Tables 23 and 24.

TABLE 23

Effect of Zoosaloral H Against Oral Challenge with *Salmonella enteritidis* nal 1

Day after challenge	Chick No.	log cfu/g caecal contents	
		Group 1	Group 2
4	1	6.26	2.86
	2	6.06	4.01
	3	6.59	2.26
	4	5.76	3.43
	5	4.78	2.38
7	1	4.92	0
	2	5.27	3.82
	3	4.59	1.48
	4	4.80	1.00
	5	4.33	2.08

(Source: Springer and Selbitz, 1996).

TABLE 24

Protection After *Salmonella* Vaccination

	No. of birds	Mortality (%)	Reisolation of challenge strain in organs
Vaccinates	20	02/20 (0)	3/20
Controls	20	13/20 (65)	1/7

Vaccine: TAD *Salmonella* vac T.

Vaccination: 1st day of life; 1x108 cfu/bird, orally-crop instillation.

Challenge: 4th week of life; *S. typhimurium* (K81/92); 3x-108 cfu/bird i.m.

(Source: Vielitz et al., 1996).

6.1.4 Feed and Probiotics

Feed is a major source of *Salmonella* in several countries. In the United Kingdom, 2.8% of pig and poultry meals were found positive (0.6% of poultry extrusions and 7.4% of protein concentrates) in 1995 (Hinton and Nursey, 1996).

Heat is one of the few reliable treatments for decontamination of feed, but unfortunately post-processing re-contamination still may occur. Irradiation can produce pathogen-free feed, and this can be done in a final package to avoid re-contamination. In the absence of these treatments, addition of organic acids, (e.g. formic and propionic) has been shown to be effective against *Salmonella*. The acids kill *Salmonella* already present and prevent re-infection. *Campylobacter* has not been isolated from feeds. Technologically speaking, the tools are there to produce pathogen-free feeds; however, management in daily production sometimes is lacking, resulting in contaminated products.

Probiotics are defined as cultures of living organisms which are able to proliferate in the host intestinal tract, resulting in a balanced microflora. Probiotic products are mainly composed of (mixtures) lactobacilli, streptococci, bifidobacteria, bacilli and yeasts. These micro-organisms are able to inhibit growth of potentially pathogenic microorganisms by lowering the pH of the intestine through production of lactic acid and volatile fatty acids, and possibly by the production of bacteriocins.

Bacteriocins are antimicrobial metabolites produced by various bacteria. They are the most interesting metabolites of probiotic bacteria. The effect of many bacteriocins is limited to closely related strains; they are never toxic against the producing strain. For example, colicins produced by *Escherichia coli* strains are able to inhibit growth of *Salmonella*. In experiments in which colicin was administered in the diet of broilers, however, no beneficial effect towards inhibition of *Salmonella* could be demonstrated. The inhibition was very evident when in vitro tests were conducted. Another bacteriocin is reuterin (3-hydroxy propionaldehyde), an intermediary metabolite secreted by *Lactobacillus reuteri*. Reuterin was shown to have broad-spectrum antimicrobial activity against *Salmonella*, *Campylobacter*, *Escherichia coli*, *Staphylococcus aureus* and *Listeria monocytogenes*. *Lactobacillus reuteri* given to turkey poults reduced early mortality from "natural causes" as well as mortality from *Salmonella* challenge. The control of *Salmonella* in the caeca was also positively influenced by this microorganism. The product can be given as feed supplement (Edens *et al.*, 1991).

The effects of these products will depend on the conditions under which poultry are raised. Under the conditions existing in The Netherlands, for example, these products have no effect and are useless as an intervention strategy against *Salmonella* colonization. In other countries they may have a role to maintain the health status of the live animals as a replacer of antibiotics, the use of which should be eliminated from poultry production because of increasing bacterial resistance (Mulder *et al.*, 1996).

6.1.5 Processing

Developments in broiler processing, as well as consequences or interactions with quality and shelflife factors, are schematically summarized in Table 25. Compared to the slaughtering process for pigs and cattle, the poultry processing industry has been significantly more innovative, especially during the last 40-45 years since the beginning of industrialized poultry production.

Poultry slaughtering on a small scale has existed for many thousands of years. However, the more industrialized form of poultry slaughtering and processing began with the introduction of transport chains with shackles and continued with the development of scald tanks and equipment for plucking and mechanical evisceration of carcasses. Besides reducing costs and increasing productivity, these developments made it possible to improve the hygienic quality of processing and, as a consequence, to improve product quality and shelf-life.

In 1970-1985, in response to consumer demand, many European processors changed from deep frozen poultry to fresh (chilled) products. The consequences of this for processing were as follows:

a. Good shelf-life of refrigerated poultry products required improved hygiene; therefore, scalding and plucking operations causing cross-contamination had to be improved.

b. Scalding temperatures were reduced from about 58°C to 52°C because the higher scald temperature caused the upper epidermis that protects the meat from drying out during chilling and storage to be removed during plucking. Other modifications were introduced to the scalding process, plucking procedures and the number of pluckers were adjusted, and the chilling process was changed completely.

c. Fresh products were dry rather than wet chilled. Chilling by water immersion, although very economical, was questionable with regard to water uptake and the hygienic quality of chilled carcasses, so was replaced by air-chilling or evaporative chilling procedures whenever possible.

d. 'Further processed' products (e.g. portions) to be marketed as 'fresh' needed special attention with regard to packaging technology.

TABLE 25

Technological Developments in the Processing of Broilers

Year	Technological Development
1890	"Ultra" high scalding, wet plucking, chilling in water
1910	Bleeding, dry plucking, air chilling
1925	Low-temperature scalding, mechanical plucking + paraffin wax plucking
1930-1935	Cold evisceration, evisceration/chilling/freezing
1940-1945	Warm evisceration
1945-1950	High-temperature scalding/chilling in iced water with agitation/packaging in ice
1958	Immersion chilling
1978	Evaporative chilling
1985 on	Air-agitated multistage scalding
1993	New evisceration technology

(Source: Mulder, 1994)

At present, the most important developments in poultry processing in the top producing countries can be classed as labour-saving, with parallel efforts towards issues such as improved meat quality and hygiene. Prevention of contamination with *Salmonella* and *Campylobacter* is included in the latter.

The trends in poultry processing are increased process automation and total product flow control, which includes by-products. With respect to hygiene and prevention of further spread of potentially pathogenic microorganisms via equipment and carcasses, awareness of the necessity of more hygienic equipment design has become evident. The main developments are:

a. Harvesting machines and containers for loading and transport of live broilers, including the necessary adjustments in the arrival and shakling areas in slaughterhouses, which have improved the quality of the animals at slaughter as well as the environmental conditions in these working areas. With respect to *Salmonella* and *Campylobacter* contamination, it was shown that due to this change in transport conditions, the stress on live birds was reduced, and hence there was reduced shedding of pathogens (Brown *et al.*, 1995; Berndtson *et al.*, 1996). Air contamination was also much reduced (Stals, 1996; Tinker *et al.*, 1996).

b. Multistage, counter-current scalding was not introduced as a labour saving development. The main advantages of this first decontamination process in poultry processing can be found in energy and water

savings, with a direct benefit in improved hygiene of water and carcasses.

c. Developments with respect to labour saving are in-line rehanging systems, mechanization and automation of the whole evisceration procedure. From a hygienic point of view, these developments are important. Less manual handling improves hygienic quality, an aspect in which current developments in evisceration are considered the most significant. The most recent developments in evisceration technology consist of separating the viscera and giblets from carcasses, thus facilitating total inspection. This development should reduce carcass contamination with pathogens, particularly *Salmonella* and *Campylobacter* of carcasses, although there are no published reports to this effect.

d. The changes in poultry carcass chilling procedures from water chilling to air- and evaporative-air chilling also has an effect on hygiene and potential contamination with pathogens. Although very questionable in other aspects, water chilling allows very good rinsing of carcasses. In certain countries, the addition of chlorine to water helped obtain an acceptable shelf-life of products, although it has been reported that *Salmonella* and *Campylobacter* contamination rates of poultry products in countries where chlorination of chilling water is allowed do not differ from those where it is not. From the point of view of *Salmonella* contamination, air- and evaporative air-chilling processes are no better than water-chilling. With respect to *Campylobacter* contamination, air-chilling processes have the advantage that *Campylobacter* is very sensitive to drying out and to intensive contact with oxygen, so numbers on carcasses decrease because of the treatment (Oosterom *et al.*, 1983a; 1983b). The situation differs with evaporative air-chilling, where temperatures are relatively high and water content in the air is also high, making survival of potentially pathogenic organisms likely (Mulder and Veerkamp, 1990). Bearing in mind that these chilling methods allow use of lower scalding temperatures at which almost no bactericidal effect from heat can be expected, these developments do not benefit the microbiological quality of poultry products.

e. The development of automatic portioning lines makes an increase in productivity possible and need not adversely affect the microbiological quality (Holder *et al.* 1997). The disadvantage, however, is that cleaning and disinfection of equipment during and after production is difficult.

f. "Automation causes difficulties in tracing poultry products at the end of the line (e.g. to farm and flock of origin), and hence can adversely affect product quality and safety. Information and control systems are required to rectify this."

Despite all these developments, the poultry processing industry at present is not able to produce *Salmonella*-negative products from *Salmonella*-positive flocks coming into the process. The situation with regard to *Campylobacter* is similar. It can only reduce further spreading (cross-contamination) of potential pathogens, including *Salmonella* and *Campylobacter*.

6.1.6 Decontamination of Broiler Carcasses

Colonisation of live birds by pathogens should be prevented at the earliest stage of production, while good processing practices would ensure end-products of good overall microbiological quality. Even when all the statutory precautions have been taken during rearing, transport and slaughter of poultry a certain proportion of the end-product may remain contaminated with potentially pathogenic bacteria. Thus, the necessity of applying end-product decontamination treatments becomes evident.

It may be appropriate to mention that any treatment which partially eliminates the indigenous microflora of food could allow a surviving population of pathogenic organisms to grow faster than in untreated food, except perhaps for chemicals having a continued effect in the treated food. For this reason, the interactions between indigenous flora and pathogens potentially present should be investigated in relation to all chemical and physical decontamination treatments used. There seem to be few data to describe such interactions in the literature.

The toxicology of chemicals used for food preservation has been the subject of many investigations. Lactic acid and phosphates are generally considered safe for food use, whereas the use of chlorine-related substances is under suspicion because of production of toxicologically active chloramines. This paper does not deal with toxicological assessment of the treatments discussed.

The search for suitable poultry decontamination methods goes back some 30 years. The treatments discussed here are the use of chemical methods, physical methods, and novel preservatives.

6.1.6.1 Chemical Decontamination Methods

A. Lactic acid, Hydrogen Peroxide and Buffered Lactate

The effect of lactic acid and hydrogen peroxide on survival of *Salmonella typhimurium* inoculated on broiler carcasses has been studied. Both compounds are natural products which do not readily produce toxic residues on carcasses and therefore have potential for use in the future. The bactericidal or bacteriostatic action of lactic acid originates mainly from a lowering of the pH of the substrate, which in turn inhibits bacterial growth. The mechanism of action of hydrogen peroxide on bacteria is not clear, but it has been reported that it affects DNA.

Treatment of carcasses for a 10-minute period with 1% lactic acid or 0.5% hydrogen peroxide resulted in a two-log cycle reduction in numbers of *S. typhimurium* (Mulder *et al.*, 1978). This suggests that the treatment may result in *Salmonella*-free products, as *Salmonella* numbers in poultry are usually lower than 100/g. However, side effects such as a change of colour of the meat or a slight, reversible bleaching and bloating of carcass skin make commercial application of these compound questionable.

The effectiveness of lactic acid, of a mixture of polyphosphates, organic acids and oligosaccharides, and of trisodium phosphate (TSP) on poultry carcass decontamination has been compared. Acid and alkaline substances are both effective. As treatment of carcasses with lactic acid always resulted in slightly discoloured products, Zeitoun and Debevere (1990,1991), and Zeitoun *et al.* (1994) tested the effectiveness of buffered lactic acid. Treatment of carcasses with a buffered lactic acid system decreased numbers of *Enterobacteriaceae* and, especially in combination with modified atmosphere packaging of the products, gave prolonged shelf-life under refrigeration. These effects were attributed to an increase in the concentration of undissociated acid molecules and not to pH. These authors obtained best results against *Listeria monocytogenes* on poultry by the combined use of 10% lactic acid/sodium lactate buffer (pH 3.0) and modified-atmosphere packaging.

Conner and Hall (1996) investigated the effect of several food additives and storage temperatures on *Escherichia coli* O157:H7 in chicken meat. They reported that at 37° C, NaCl and sodium lactate reduced growth of *E. coli*, whereas polyphosphate had no effect. At 10° C, NaCl did not permit *E. coli* growth, and sodium lactate reduced it. At 4° C, populations of *E. coli* steadily declined during storage in untreated samples and after polyphosphate and NaCl treatments, but after 5 weeks at 4° C, *E. coli* began to grow again in the presence of sodium lactate. The results suggested that sodium lactate and NaCl may enhance survival of *E. coli* O157:H7 at refrigeration temperatures.

B. Phosphates and Mixtures

Trisodium phosphate (TSP) alone, in alkaline phosphate mixtures, and in combination with several halogen compounds and hydrogen peroxide are new products, of which TSP has been approved by the United States Department of Agriculture (USDA) as a post-chill decontaminating agent of poultry.

Lillard (1994a) found that dipping chicken carcasses in a 10% TSP solution for 15 minutes reduced *Salmonella* levels by 2 $\log_{10}$ cycles, but *Salmonella* was still recovered from skin and carcasses inoculated with 108 or 102 cfu/g when a water rinse followed TSP treatment and buffered peptone was used for bacterial recovery.

Jeong-Weon-Kim *et al.*, (1994) investigated the effect of 10% TSP on *S. typhimurium* attached to chicken skin. Control samples had concentrations of up to 106 cfu/cm^2, whereas treated skins showed less than 104 cfu/cm^2. The authors suggested that one of the major mechanisms of action of trisodium phosphate on *Salmonella* reduction is detachment of bacterial cells from the poultry skin surface. The bactericidal effect of TSP is considered to be caused by its high pH (12), and by effects on cell wall and on adherence factors, as well as direct killing effects (Bender and Brotsky, 1991; Federighi *et al.*, 1995; Hwang and Beuchat, 1995). The effects of tripotassium- (TPP) and trisodium-phosphate on *Salmonella* are presented in Table 26, which indicates that TSP is more active than TPP (Gudmunsdottir *et al.*, 1993).

TABLE 26

Effect of Tri-Potassium Phosphate (TPP) and Tri-Sodium Phosphate (TSP) on *Salmonella* on Poultry Neck Skin ($\log_{10}$ cfu/g)

	TPP		TSP	
	Contact time (minutes)			
Molarity	0	10	0	10
control	8.48	8.35	8.24	8.25
0.21	7.52	6.54	6.73	2.83
0.30	6.81	4.29	2.44	0.05

(Source: Gudmunsdottir et al., 1993)

Somers *et al.* (1994) reported that *E. coli* O157:H7 (10^5 cfu/cm^2 of biofilm cells) was eliminated by a 30-second treatment with 1% TSP. *Campylobacter jejuni* was slightly less sensitive and *Listeria monocytogenes* was the most resistant, requiring exposure to 8% TSP for 10 minutes to reduce biofilm bacteria by at least 1 $\log_{10}$ cycle.

The effect of a 10% TSP dip on the incidence and level of *Campylobacter* on post-chill chicken carcasses was studied by Slavik *et al.* (1994). *Campylobacter* levels were reduced by 1.5 and 1.2 $\log_{10}$ after 1 and 6 days, respectively.

Rodriguez de Ledesma *et al.* (1996) reported that a combined 10% TSP and hot water treatment of chicken skin was effective in reducing counts of *S. typhimurium*, *S. aureus*, and *L. monocytogenes* by 95 to 99.7%, 84 to 97% and 79 to 95%, respectively.

The effects of chemicals on bacteria present on broiler skin can be studied using several sampling techniques. Attachment of microorganisms to the skin has always influenced the effectiveness of chemical or physical treatments (Notermans and Kampelmacher, 1974, 1975).

In order to avoid adverse environmental effects, special arrangments need to be made for the disposal of chemicals used for decontamination. The industrial equipment for application of TSP treatments, for example, includes a recirculation process. Adverse effects on product quality with these products are minimal, so commercial application is not hampered by this aspect of the treatment, although the cost of the industrial equipment is high.

C. Ozone

Ozone is a powerful oxidizing agent that has been used as a disinfectant in several areas of the food industry. Its use as disinfectant in poultry chiller water with the aim of reducing the microbial load of the carcasses treated with this water has mostly been studied in the US. Table 27 presents results on reduction of numbers of *Salmonella* in an experiment in which carcasses were treated with ozonated water (3.0 - 4.5 ppm aqueous ozone concentration).

TABLE 27

Salmonella Counts on Poultry Carcasses Treated with Ozone

Treatment	*Salmonella* ($\log_{10}$ cfu/g)
Control (no rinse)	1.36
Water	1.08
Ozonated water	0.64

(Source: Sheldon and Brown, 1986).

Ozone treatment also extends the shelf-life of poultry products and does not result in changes in colour or flavour. Negative aspects of the treatment are considered to be the corrosiveness of ozone and the difficulty of installing and operating this type of equipment in poultry abattoirs in terms of workers' safety.

D. Chlorine

Chlorine has been used traditionally in water chilling systems for poultry carcasses (Thomson *et al.*, 1976). The effect of chlorine on pathogenic microorganisms, however, is limited. Dougherty (1974) reported the results of studies indicating that the use of chlorine at concentrations less than 8 ppm in chill water did not reduce the levels of *Salmonella* on the surface of processed chicken carcasses. At concentrations above about 50 ppm free chlorine numbers of bacteria in the chill water, including *Salmonella*, are reduced, although the effect seems to be confined to bacteria in the water and not those attached to the carcasses. The beneficial effect of chlorine in the chill water is to reduce cross-contamination (e.g. with *Salmonella*) from one carcass to another (Mead, 1989; Corry and Mead, 1996). Due to the lack of effect of chlorine on bacteria attached to skin, research was later directed more towards combined treatments, such as chlorination and sonication.

The effects of combined treatment consisting of 30 minutes in 0.5 ppm free residual chlorine plus 15-3-minutes sonication on numbers of *S. typhimurium* inoculated on poultry carcasses were studied (Lillard, 1993,1994b). The results suggested that attached salmonellae were not readily accessible to chlorine and thus were reduced in numbers by less than 1 $\log_{10}$ by chlorine alone. Sonication detached bacterial cells, reducing cell counts by 1-1.5 $\log_{10}$. Sonication with chlorine was the most effective treatment, reducing cell counts by 2.4-3.9 $\log_{10}$. However, it remains to be seen whether this process will ever become industrially feasible.

Loncarevic *et al.*, (1994) examined samples of neck skins from 1615 broilers for the presence of *Listeria* spp. Free available chlorine in the chilling water varied from 2 to 15 ppm. *Listeria* was isolated at a lower level post-chilling than pre-chilling. However, irrespective of chlorine level, *Listeria* on chicken was not eliminated.

6.1.6.2 Physical Decontamination Methods

A. Irradiation

Another possibility of protecting the consumer against *Salmonella*, *Campylobacter* and other microbial hazards in poultry is the use of ionizing radiation. Irradiation is the use of ionizing radiation either emitted by radionuclides such as ^{60}cobalt and ^{137}cesium or generated by machines that produce electron beams or x-rays.

The biological effects of ionizing radiation on cells can be due to direct interaction with critical cell components and to indirect action on these critical targets by molecular entities (notably free radicals and peroxides) formed from water. As with other antimicrobial agents, the response of a microbial cell and hence its resistance to ionizing radiation depends on the nature and amount of direct damage, the amount of reactive chemical entities formed, and the ability of the cell to repair damage. Ionizing radiation is capable of causing a variety of chemical changes in microorganisms. DNA in living cells is the most critical target of ionizing radiation, to the extent that direct inactivation of microorganisms by ionizing radiation is mainly a result of damage to the DNA.

The major extracellular environmental factors that influence the survival of irradiated cells (Grecz *et al.*, 1983) are temperature, gaseous environment, water activity, pH and chemical composition of the food. These conditions presumably can modify the physical and chemical consequences of intracellular deposition of energy. Bacterial spores appear to be less susceptible to modifying factors than vegetative cells because of their structure and particularly because spores contain very little water. Since part of the effect of ionizing radiation on a microorganism is due to indirect action mediated through free radicals, the nature of the medium or menstruum (e.g., food) in which the microorganisms are irradiated plays an important role in determining the dose required for a given antimicrobial effect. The more complex the medium, the greater is the competition by its components for the free radicals formed by irradiation outside the cell, thus protecting the microorganisms by absorbing free radicals. Therefore, care should be taken in comparing radiation resistance in laboratory media and in food. Generally, microorganisms are more resistant to irradiation in food than in laboratory media.

It is now well-established that microorganisms that survive radiation treatment, as is the case with heat-damaged cells, tend to be more sensitive to subsequent adverse environmental conditions such as heat, pH, inhibitors, etc., than are untreated cells (Welch and Maxcy, 1979). This fact could be used to advantage in combination treatments of food involving irradiation and other preserving factor(s) (e.g., food additives, low temperatures, mild heat, vacuum packaging, etc.).

Radiation resistance varies widely among different microorganisms. There can be differences in inherent resistance from species to species, and even among strains of the same species. Differences in radiation sensitivity within groups of similar organisms are related to differences in their structure, as well as to their ability to recover from radiation injury.

Analogous to the situation with heat, the radiation dose required to preserve or decontaminate a food depends on the initial level of the contaminating microorganisms. Thus, it requires a larger dose to inactivate a large number of microorganisms than to inactivate a small number. This parallels the situation in heat inactivation of microorganisms, in which the time necessary to inactivate a microbial population also depends on the initial concentration of microorganisms. Radiation survival can be represented by the logarithm of the number of surviving organisms plotted against radiation dose. Similar to heat resistance, the response of a microbial population to radiation exposure can be expressed by the decimal reduction dose, or D_{10} value, which is the radiation dose necessary to reduce the number of viable cells of a microorganism by 90%. Table 30 lists D_{10} values under non-frozen and frozen conditions of important non-sporing bacterial pathogens potentially present in poultry.

The safety and wholesomeness of irradiated foods in general, including their microbiological safety, was confirmed by an FAO/WHO/IAEA Joint Expert Committee on Food Irradiation (JECFI) in 1980 (WHO, 1981). As a result, the FAO/WHO Codex Alimentarius Commission issued a Codex General Standard for Irradiated Food in 1984 and an associated Code Of Practice for the Operation of Irradiation Facilities Used to Treat Food (FAO, 1984). A code of good irradiation practice for poultry was published in 1991 by the International

Consultative Group on Food Irradiation (ICGFI, 1991), and a comprehensive review of the safety of irradiated food was published by WHO (1994). A total of 21 countries have so far approved irradiation of fresh or frozen chicken (or poultry as a group) for pathogen control (ICGFI, 1999).

A radiation dose of 2.5 kGy was tested in The Netherlands for elimination of *Salmonella* in poultry carcasses (Mulder, 1982). The results indicated that this dose was too low to guarantee complete absence of *Salmonella* in artificially-contaminated poultry (>10^4 cfu/g). Using chickens that were naturally contaminated with *Salmonella*, Kamat *et al.*, (1991) found that 2 kGy eliminated the *Salmonella* from fresh chicken meat and chicken meat at -40° C. Chicken samples artificially inoculated with 10^8 cells/g *S. senftenberg* and *S. typhimurium* required gamma radiation doses of 4-5 kGy to completely eliminate them. This indicated that a dose of 2 kGy may be adequate for naturally-contaminated chicken. Consequently, radiation doses in the range 1.0-2.5 kGy for refrigerated poultry (Table 29) and >3.0 kGy for frozen poultry are recommended for pathogen control (ICGFI, 1991).

TABLE 28

Radio-Sensitivity of Some Potentially Pathogenic Microorganisms

Microorganism	Range of Radiation D_{10} values (kGy)
Campylobacter jejuni	0.14 - 0.32
Escherichia coli O157:H7	0.25 - 0.35
Listeria monocytogenes	0.40 - 0.60
Salmonella spp.	0.40 - 0.50
Yersinia enterocolitica	0.14 - 0.21

(Source: Murano, 1995)

Thayer *et al.*, (1991) examined the effects of gamma-irradiation preceded or followed by heating at 60° C for 3 minutes on the survival of *S. typhimurium* in chicken meat. Gamma radiation made *Salmonella* much more sensitive to the effects of heat, so that a radiation dose of 0.90 kGy followed by the above heat treatment decreased the number of survivors by 8.9-$\log_{10}$ units.

As *Campylobacter* is very radiation sensitive in comparison to *Salmonella*, the doses that destroy *Salmonella* also eliminate *Campylobacter*, although the latter is said to occur in larger numbers on poultry carcasses than *Salmonella*. Patterson (1995) investigated the sensitivity of *Campylobacter jejuni*, *C. coli*, *C. fetus* and *C. lari* to irradiation in poultry meat. The D_{10} values ranged from 0.12 to 0.25 kGy, and there was a significant difference in the radiation sensitivity between different *Campylobacter* species and between strains of the same species. The values, however, confirmed that *Campylobacter* spp. are more radiation sensitive than *Salmonella* spp. In addition, Patterson (1989) demonstrated that radiation doses suggested to eliminate salmonellae from poultry would also be sufficient to remove *Listeria monocytogenes*.

Decontamination of poultry carcasses by chemical and other physical methods (Section 6.1.6) do not completely eliminate pathogens and, because they are applied to the product before packaging, do not get rid of possible post-processing contamination. In contrast irradiation lends itself well to the treatment of packaged broiler carcasses, cuts, or mechanically deboned or ground meat, thereby providing the essential critical control point under the HACCP plan before the product reaches the consumer. And, as a critical control point during the processing operation, irradiation is a treatment that is easy to monitor, with quantifiable parametres which are scientifically based and identified after many years of world wide research.

The effects of radiation treatment on quality characteristics of fresh poultry are very small, and these effects can be further reduced by irradiating carcasses in the chilled and/or frozen condition. Commercial interest in food irradiation is increasing and consumers are beginning to appreciate the benefits of irradiation as a method to ensure the hygienic quality of food. Thousand of tonnes of mechanically deboned poultry meat has been irradiated commercially in France each year since early 1980's for use mainly by the food industry and small volumes of irradiated poultry are being sold in selected retail outlets and some food service establishments in the USA.

B. Ultrasonication

Ultrasounds are vibrations similar to sound waves but at a frequency too high to be noticed by the human ear. These vibrations cause locally high pressures and temperatures, resulting in the disruption of cellular structures. Since product quality is altered by the treatment, this process is mainly suitable for decontamination of scald water to prevent spreading of microorganisms to uncontaminated poultry carcasses. It can also be used to aid cleaning of knives, shackles and steel-mesh gloves.

C. Steam

The possibility of using steam for end-product decontamination has been reviewed by Corry *et al.* (1995). In the beef industry, Dorsa *et al.*, (1996) have shown the perspectives for this treatment against *Escherichia coli* O157 H7. No recent data are available with respect to treatment of poultry carcasses, but preliminary data using reduced pressure steam, indicate that the appearance of the product is likely to be adversely affected (Corry, 1998, unpublished).

6.1.6.3 Novel Methods - Natural Antimicrobials

Natural antimicrobials include bacteriocins (nisin, colicin and reuterin), primary metabolites (as alcohols and organic acids), secondary metabolites (toxins and antibiotics), and siderophores (iron chelating compounds).

Promising products for use as decontaminating agent include nisin, a protein produced by *Lactobacillus lactis* and consisting of 34 amino acids. It is stable to autoclaving, effectively inhibits growth of Gram-positive foodborne pathogens such as *Listeria monocytogenes* and *Staphylococcus aureus*, and is active also against Gram-negative *Salmonella* spp. and *Escherichia coli*. However, this product has not yet been tested in poultry under actual commercial conditions. Potential problems with these products are their relatively high cost, their narrow spectrum of activity and the possibility of the selection of resistant strains.

Other products under development include magainin peptides, which are extracted from the African clawed frog (*Xenopus laevis*) and have a broad spectrum of inhibitory activity against *Salmonella* and other food poisoning microorganisms. Studies are being conducted to determine the effect of these peptides as endproduct decontamination agents in the poultry industry, but results are not yet available.

6.1.7 Factors Affecting the Application of Poultry Decontamination Treatments

Before new technologies are allowed and accepted for application, there are several factors which have to be considered. Among these, besides the legal aspects, the following should be considered (Farkas, 1996): technical feasibility; technical realities; health impact (in relation to the wholesomeness of the product, occupational safety and environmental friendliness); cost (with special reference to energy aspects); infrastructure requirements; political and social attitudes and conditions, and psychological aspects.

7. CONCLUSIONS

A. Control of infection or contamination with potentially pathogenic microorganisms in the various areas of the poultry production chain, starting with breeding and ending with processing, is a very difficult and complex problem.

B. To minimize faecal contamination of carcasses during processing, appropriate measures must be taken at critical points. Maintenance of hygienic conditions and mandatory good manufacturing practices during catching and transport, scalding, plucking, evisceration and chilling would help in keeping the proportion of contaminated poultry carcasses from increasing. The end-product, however, whether chilled or frozen, may remain contaminated. This situation cannot be accepted any longer.

C. Scientific data are available on several aspects of colonization of poultry by potentially pathogenic microorganisms, as well as on their further spread in poultry products. Industry should be forced, as part of a mandatory HACCP system, to implement known technologies and methods, to monitor the results and after a two-year period, the results should be evaluated. In the meantime, research should continue on genetic resistance aspects; on improving preventive strategies (including vaccines); on improving management control programmes for live animals and processing plants; on detection and identification methods, and, with help from the media, on developing better consumer education programmes. In this respect, the *Salmonella* control programmes already started in several countries and now mandatory at the primary production level (which should be extended to consumer ready products) in the European Union, will be of great help to create better awareness through the entire production chain regarding production of a very high-quality food. It must be remembered, however, that the poultry industry is only a fraction of food production, and that measures taken only in the poultry industry fail completely when the surrounding environment is not cleaned up.

D. As a consequence of the inability to produce pathogen-free live birds at this moment, either in intensive or extensive poultry production, decontamination treatments of end-products must be considered. Addition of preventive substances to poultry carcasses would be helpful, and application of irradiation would solve the problem. Practical implementation of these treatments should not be blocked any more by directives from national or international bodies. Alternatively, production systems would have to change to *Salmonella*-free production (SPF), a very costly way of production, and/or poultry products should not be allowed in the market unless they are pre-cooked. Both of these alternatives should encourage the poultry industry to implement existing technology. The costs for this are relatively low compared to the costs of foodborne disease.

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