Opinion of the Scientific Panel on Biological Hazards on the request from the Commission related to "Risk assessment and mitigation options of *Salmonella* in pig production"[1]

(Question N° EFSA-Q-2005-019)

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SUMMARY

Salmonella spp. is one of the major causes of foodborne illnesses in humans. According to the Community Summary Report on Trends and Sources of Zoonoses[2] a total of 192 703 cases of human salmonellosis were reported by 25 Member States (MS) in 2004. Pork, after eggs and poultry meat, is a major source of human foodborne salmonellosis in the European Union (EU), although the participation of pork-associated salmonellosis in foodborne salmonellosis varies between countries or is unclear as, for most MS, data on the true contribution of pig/pork to human foodborne salmonellosis are not available.

Regulation (EC) No 2160/2003 on the control of *Salmonella* and other specified zoonotic agents[3] provides for the setting of Community targets, for reducing the prevalence of *Salmonella* serovars with public health significance in pig herds. According to this Regulation, the targets shall include in particular the maximum time limits within which the targets shall be reached, the definition of epidemiological units, the definition of the testing schemes necessary to verify the achievement of the targets and, where relevant the definition of the *Salmonella* serovars with public health significance. The Regulation states that before proposing such rules on specific control methods, the Commission shall consult the European Food Safety Authority (EFSA).

All *Salmonella* serovars from pork are to be regarded as a hazard for public health. At present the most common serovar at EU level causing human foodborne infections from pork is *S.* Typhimurium, however there have been significant outbreaks caused by other serovars.

Two main options exist for the implementation of monitoring schemes aimed at detecting/evaluating *Salmonella* prevalence and/or previous exposure to *Salmonella* in pig production. These options are based on bacteriological and immunological methods. When used appropriately, for specific purposes, each of these approaches is of benefit. However, for monitoring purposes the results of immunological and bacteriological investigations cannot be compared directly, as they give different information. The choice between immunology and bacteriology, or their use in combination, therefore, will depend on the actual situation and the questions that have to be answered.

Bacteriology can be of use when (a) isolation of the strain is necessary for identification, (b) information about all *Salmonella* infections (all serovars) is required, (c) antimicrobial sensitivity testing is required, (d) the current *Salmonella* status of individual animals is to be determined, (e) a description of the general diversity of infections with different *Salmonella* serovars in a population is the purpose of the investigation, and (f) the evaluation of *Salmonella*-free status of herds is required.

[2] EFSA. (2005). Community Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and Antimicrobial resistance in the European Union in 2004. The EFSA Journal. 130. http://www.efsa.eu.int/science/monitoring_zoonoses/reports/1277_en.html

[3] OJ L 325, 12.12.2003, p. 1

Immunology can be of use for the screening of large numbers of blood and other samples, for example, for monitoring the effectiveness of control programmes in endemic regions or establishing the current immunological status of a population (e.g. herd) and the prevalence of infection.

Risk mitigation options were identified according to three lines of defence formulated by the World Health Organization (WHO): the first line focuses on the control of *Salmonella* in the food producing animal (Pre-harvest control), the second line deals with improvement of hygiene during slaughter and further processing of meat (Harvest control) and the third line concentrates on measures during the final preparation of the food and the education of the industry and the consumer concerning the application of effective hygienic measures (Post-harvest control).

In general, the control of *Salmonella* is based upon the implementation of preventive actions throughout the whole production chain.

More specifically, measures should be addressed to (i) the prevention of introduction of *Salmonella* into the herd, (ii) the prevention of in-herd transmission, and (iii) the increase of the resistance to the infection.

No universal mitigation option capable of eliminating *Salmonella* entirely from the harvest and post-harvest level was identified. A combination of measures aimed at the prevention of vertical and horizontal transmission is likely to be the most effective approach, as is the case with most other foodborne pathogens.

Reduction of the pathogen load in live pigs in each phase of the food chain, including the transport-lairage (TL) phase, can be incrementally achieved by separation of batches, the implementation of Good Hygiene Practices (GHP) and hygiene management and optimisation of transport and lairage time.

Slaughter and dressing has to be performed with a high level of hygiene, according to Hazard Analysis and Critical Control Points (HACCP) principles in association with GHP, and focusing on the avoidance of direct or indirect faecal/intestinal contamination of carcasses.

Logistic slaughter is a further option for reducing the pathogen load on the carcasses of slaughtered pigs.

Meat/carcass decontamination may be considered in specified situations, under the supervision of the competent health authorities. However decontamination should not be regarded as a substitute for any of the above mentioned recommendations.

Risk mitigation during processing requires maintenance of the cold chain and the application of the so-called "hurdle concept" and the implementation of GHP and the principles of HACCP.

At retail and consumer level mitigation includes hygienic handling and proper cooling or heating of pork and pork products. These options and procedures should be communicated to retailers and consumers.

Monitoring at harvest level is of relevance in regard to both process hygiene evaluation purposes and evaluates the current *Salmonella* status of the entire food chain. For human exposure assessment, monitoring requires to be conducted at the pre-consumption level.

Annexed to the Opinion a proposal for a baseline study on the prevalence of *Salmonella* in fattening pigs in the EU has been suggested.

KEYWORDS: *Salmonella*, pig, baseline study, mitigation options

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BACKGROUND

Salmonella spp. is one of the major causes of food borne illnesses in humans. According to the Commission's report on zoonoses[4] a total of around 144 000 cases of human salmonellosis were reported by 15 Member States in 2002. Pork is regarded to be an important source of these human food-borne infections, after eggs and poultry meat.

Pursuant to Council Directive 92/117/EEC concerning protection measures against specified zoonoses and specified zoonotic agents in animals and products of animal origin in order to prevent outbreaks of food-borne infections and intoxications, data have been collected from Member States on occurrence of *Salmonella* in pigs and food derived therefrom, on the basis of national schemes. Certain Member States have in place or are in the process of introducing active monitoring and/or control measures for *Salmonella* in pigs and/or pork. The control programmes from Sweden and Finland were approved upon their accession to the Community. Other Member States may have national programmes or industry initiatives. The measures follow different schemes, using different types of samples and/or analytical methods (e.g. bacteriology and/or serology), targeting different *Salmonella* types.

Pursuant to Directive 2003/99/EC on the monitoring of zoonoses and zoonotic agents[5], detailed rules for harmonised monitoring throughout the Community may be established.

Regulation (EC) No 2160/2003 on the control of *Salmonella* and other specified zoonotic agents[6] provides for the setting of Community targets, for reducing the prevalence of *Salmonella* serotypes with public health significance in pig herds. According to this Regulation, the targets shall include in particular the maximum time limits within which the targets shall be reached, the definition of epidemiological units, the definition of the testing schemes necessary to verify the achievement of the targets and, where relevant the definition of the *Salmonella* serotypes with public health significance (whose specific criteria are established in Annex III of the Regulation). Within 18 months following the setting of the targets, Member States shall prepare and submit national control programmes and the Commission shall approve them. The timetable for setting targets for pig production is December 2007 for breeding pigs and December 2008 for slaughter pigs. During the inter-institutional discussions on the draft Regulation, it was agreed that the order may be reversed if this is felt to be more appropriate based on the scientific data available. When defining Community targets for pig production, the Commission shall provide an analysis of the expected costs and benefits, taking into account in particular certain criteria laid down in the Regulation. Before proposing targets, comparable data on *Salmonella* prevalence within the Community shall be available.

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4 European Commission : Trends and sources of zoonotic infections in animals, feedingstuffs, food and man in the European Union and Norway in 2002

5 O.J. L 325, 12.12.2003, p. 31

6 OJ L 325, 12.12.2003, p. 1

In addition, according to the Regulation, it may be decided to establish rules concerning the use of specific control methods, such as vaccines, anti-microbials or substances influencing the porcine intestinal flora environment, in the context of the control programmes. The Regulation lays down that before proposing such rules on specific control methods, the Commission shall consult the European Food Safety Authority.

Finally, the Community legislation allows establishment of control measures at stages of the food-chain after primary production.

TERMS OF REFERENCE

The European Food Safety Authority is asked to provide an opinion on the following issues:

- Estimation of the contribution of pig/pork to food-borne salmonellosis,
- Prioritise *Salmonella* serotypes related to pigs according to their current significance for public health and where relevant for this scientific consultation, animal health,
- Identify and assess options for monitoring schemes aimed at detecting/evaluating *Salmonella* prevalence and/or previous exposure to *Salmonella* in pig production, at individual and herd level, indicating their respective advantages and disadvantages, including a comparison between protocols using immunological and bacteriological methods,
- Assess the appropriateness of a progressive approach to reduce the risk to human health from *Salmonella* in different types of pig herds, starting with breeding pigs or with slaughter pigs,
- Identify the advantages and disadvantages of various specific methods at primary production aimed at reducing the risk to human health from the presence of *Salmonella* in pigs,
- Identify options for monitoring and for risk mitigation of *Salmonella* in pork and products there from at different stages of the food chain after primary production.

ASSESSMENT

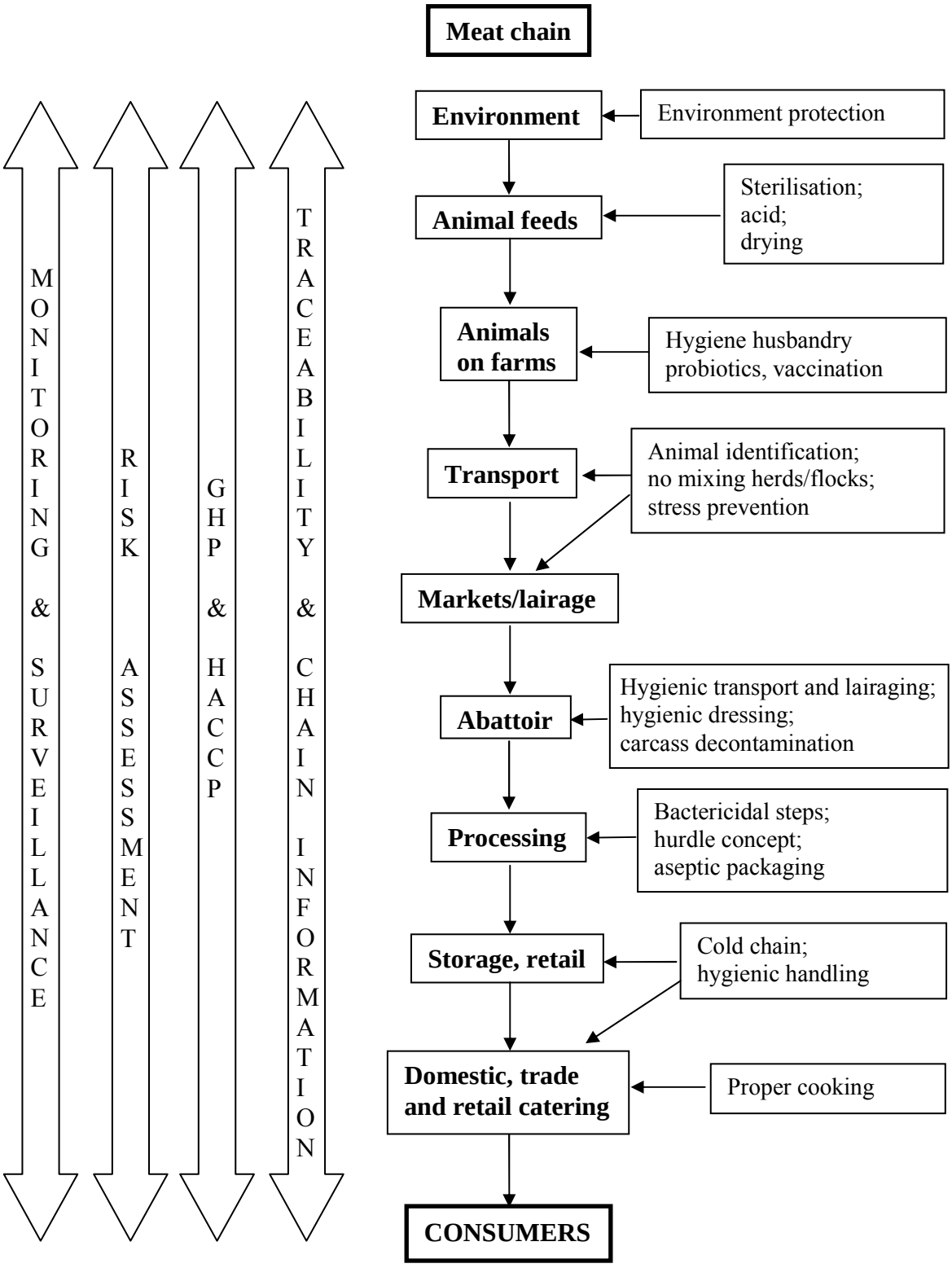
1. INTRODUCTION

Pork is one of the main sources for human salmonellosis (Wegener and Baggesen, 1996; Berends *et al.,* 1998; Fedorka-Cray *et al.,* 2000) being the source of approximately 20% (5-30%) of the human cases (Steinbach and Hartung, 1999; Hald and Wegener, 1999). Therefore, reduction of *Salmonella* risks associated with pork can significantly contribute to the protection of human health.

Globally, the basis of modern longitudinal and integrated food safety assurance (LISA) is a generally accepted novel approach designed to address potential food safety problems before they actually appear, and by intervening at points of the food chain where they are expected to appear (Buncic, 2006). Health hazards (harmful agents) enter the food chain at different, sometimes multiple, points; they have to be dealt with at each of those points. However, because events at one point have consequential effects on later points of the chain, control on the index point cannot be effective if applied in isolation and without remedial actions at subsequent points in the food chain. That is, hazards have to be controlled at relevant, multiple points in a coordinated way. Where they cannot be totally eliminated, public health risks can be reduced and it is possible to achieve a "summation effect" of risk reductions in such a longitudinal and integrated system that results in an ultimate risk reduction (i.e. at the point of food consumption) that would be unachievable using other methods. Understandably, because participants in the food chain are numerous, and diverse in profiles and activities, the development and application of this "farm-to-fork" system requires to be both multidisciplinary and science-based.

The main elements of the meat chain and related control tools and measures for dealing with health hazards, which as a generic illustration also apply to the pork chain and *Salmonella*, are indicated in Figure 1.

Figure 1. Operative aspects of the longitudinal and integrated food safety assurance (LISA) concept: example of the meat chain (Buncic, 2006).



2. PIG/PORK PRODUCTION AND CONSUMPTION

The contribution of pork to the global meat production remained fairly stable over more than a decade at about 38%. Nevertheless regional patterns of production and the trade flows have changed considerably. Several countries which were not to be found among the leading countries a decade ago have been able to develop a very effective swine industry and to become important trade partners. On the other hand, some countries that were ranked among the top pork producers have not been able to hold this position.

Since organisational and managerial conditions of pig and pork production determine to a high degree the occurrence of *Salmonella* in pigs and pork, pork consumption (quantity and eating habits) determines to a high degree human exposure to *Salmonella*. In the following sections (a) the European Union (EU) pig and pork production (with special consideration the variations of the production structure in the EU-25 Member States (MS)) is described and the further development is tentatively predicted, and (b) an overview on the pork consumption with its variations within the EU-25 is given.

2.1. Pork production in the EU in a global perspective

Analysis of the regional contribution to the world's pork production reveals that Europe was until 1980 the leading pork production region in the world. The fast growth of pork production in Asia in the last three decades (the relative increase was 534%) has pushed Europe to the second position in terms of yearly produced tonnes (t) of pork. The position of Europe's pork production (here, the geographic area of Europe is meant, not the European Union) and its development from 1970 to 2003 is shown in Table 1.

A detailed analysis on the basis of the ten leading countries in pork production in 1990 and 2003 shows a regional concentration process. In 2003 the top ranked countries contributed 76.8% to the global production volume; China alone counted for 47.6%. While the high growth rates in Asia are mainly due to the dynamic growth in China, but Vietnam also ranks among the ten leading countries. Japan and the Netherlands have not been able to hold their position among the leading states, on the other hand, Brazil now ranks as number 6 and Spain as number 4. It is remarkable that among the ten leading pork producing countries, 4 are members of the EU-15 and one (Poland) is a new member of the EU-25 (Table 2).

Pork production shows a great variety of organisational structures and farm size patterns. The organisational pattern ranges from small independent farmers who mainly produce for home consumption and local markets, to vertically integrated agribusiness companies which sell their products on national and international markets. A detailed analysis of the regional pattern shows that the centres of pig production are in most cases closely linked to large and very large pig farms. In addition, the availability of feed, either from domestic production or from imports plays an important role in the development of regions with intensive pig production.

2.2. Pork production in the EU-15- and EU-25

A closer look at the development of pork production in the EU-15 between 1970 and 2003 shows considerable differences between the MS (Table 3).

Following the EU enlargement on May 1st, 2004, there were about 151 million pigs in the EU-25 based on figures from December 2004. Germany with 17.4% has the largest share, followed by Spain, with 16.8%, Poland with 11.5%, France with 10.0% and Denmark with 8.8%.

After China, the EU is the second largest pork producing region in the world. Its pork production in 2005 amounts to about 21 million tonnes, with 17.8 from the EU-15 States (Table 3) and 3.2 million tonnes from the new MS.

Of the new EU members, Poland has by far the largest pork production, with about 2 million tonnes of pork per year, whereas Hungary produces about 0.48 million tonnes, and the Czech Republic about 0.43 million tonnes.

A detailed analysis of the shares of the EU-25 MS reveals the high regional concentration (Table 4).

Germany and Spain contribute 33% to the pig stocks in the EU. The four leading countries have a share of almost 55% of the pig population. Of the new MS, Poland ranks as number 3 in pig stocks. A comparison of the share of the new EU MS shows that they amount for nearly 21% of the pig stocks of the enlarged EU. The high share of the pig stocks is mainly due to the large pig population in Poland. Because of foreseeable foreign investments a rapid increase of pig stocks is expected within the coming years. This will stabilise the position of Poland as one of the major pig producers in Europe. However, other aspects have to be considered. Genetics, feed quality, housing systems, meat quality and safety as well as traceability in the new MS have not yet reached the standards of the leading countries in Central and Western Europe.

Not only pig stocks and the contribution to pork production differ considerably between the MS but also the organisation of pork production. There is a wide range, from independently operating pig farmers via co-operatives to vertically integrated agribusiness companies. This aspect is very important with respect to:

a) the quality of the meat produced and traded,
b) the documentation of the production process,
c) the traceability of the product, and as a consequence,
d) the design and implementation of *Salmonella* monitoring and reduction programmes.

2.3. Exports of pork from the EU

The EU-15 has been, and the EU-25 now is, the largest pork exporter in the world. In 2004, the EU exported about 1.7 million tonnes, an increase compared to 2003, with 1.4 million tonnes. Denmark plays the most remarkable role due to the well developed structure and organisation of its national pork production system. In 2004, Denmark has exported more than 600 000 tonnes of pork to non-EU countries and leads by far the export activities of the EU. Germany ranks second with 250 000 tonnes of exported pork. France and The Netherlands are the next ranking export countries.

The European exports are targeted at two geographical areas: a) neighbouring countries such as Russia, Bulgaria and Romania, and b) Southeast Asia with Japan, South Korea, Hong Kong and China being the leading importing countries. Japan is not the main importing country in quantitative terms, but it is in monetary terms, since its demands for quality and safety (e.g. *Salmonella* control programmes) are very high so that only a few EU MS have access to the Japanese pork market.

2.4. Pork consumption in the EU-25

According to estimations conducted by the German Central Market and Price Reporting System (ZMP), the average per capita pork consumption in the EU-25 was 44.3 kg in 2003. The EU per capita consumption can be described according to the amount of pork consumed by different groups:

a) countries with the highest per capita pork consumption in the EU-25 (more than 50.0 kg): Spain with 70.0 kg, Denmark with 56.7 kg, Austria with 56.3 kg, Germany with 55.1 kg;

b) countries with the lowest per capita pork consumption in the EU-25 (less than 30.0 kg): Lithuania with 21.9 kg, the United Kingdom (UK) with 22.1 kg, Greece with 27.1 kg, Estonia with 29.4 kg;

c) countries with a per capita pork consumption between 30.0 and 50.0 kg:
   - 30.0 to 39.9 kg: Finland, Italy, France, Ireland, Sweden, Malta, Slovakia and Slovenia,
   - 40.0 to 49.9 kg: Belgium, The Netherlands, Portugal, Poland, Czech Republic and Hungary.

Additional to the variations in the per capita pork consumption, there is an even more distinct variation in the pork self sufficiency rates (% ratio: produced pork versus consumed pork) of the MS. For instance, Denmark self sufficiency rate is 600%, that of The Netherlands and of Belgium is 223%. In contrast to these high rates, Greece produces only 44% of its pork consumption and the UK with 53% has a very low self sufficiency rate. Due to these differences both in the production quantities and the consumption habits, there is a considerable amount of pig and pork trading between the EU-25 Member States. Major "exporting" countries (that is, EU-internal trade and not true export) are Denmark, The Netherlands, Belgium, France, Germany and increasingly Spain; major "importing" countries are Greece, the UK, Italy and the new MS other than Hungary, Poland and Estonia.

About 20 to 30% of the pork in the EU is purchased fresh by households, restaurants and catering establishments; 70 to 80% is sold as processed products by retailers and butchers.

The major exposure of consumers to health hazards is likely associated with fresh pork; either directly through consuming raw or undercooked pork, or indirectly through cross-contamination of other food items during meal preparation. Of particular concern are the food safety implications of the direct consumption of raw pork (e.g. spiced raw minced pork in Germany and Denmark) and sausages and other delicatesses that consist of raw pork (e.g. salted and smoked without cooking), which are relatively popular in a number of countries.

2.5. Conclusions

The main results of this analysis can be summarised as follows:

- The MS of the EU play an important role in global pig production although due to the dynamic development in Asia and South America, their share has decreased continuously.
- In the EU-25, the regional concentration of pig stocks and pork production is very high. Since joining the EU-15 in 2004, the new MS of the EU have contributed nearly 21% to the EU's pig stocks and 16.4% to pork production. Pig production systems differ considerably from high-input, intensive and large scale husbandry systems to low-input, extensive, back yard production among the MS.
- The EU continues to dominate global pork exports, but in recent years, most of the trade is between MS, as only about 20% of exports are shipped to third countries. The main exporting countries of the EU (e.g. Denmark and The Netherlands) are confronted with a growing competition of Brazil, Canada, and the United States of America (USA) on the world market for pork.
- Compared to other regions of the world, the EU has a relatively high rate of pork consumption with an average of 44 to 45 kg per capita. Among the countries worldwide with the highest per capita consumption of pork, there are "old" MS such as Spain, Denmark, Austria and Germany, but also "new" MS such as Poland, Czech Republic and Hungary. In terms of the potential exposure of consumers to *Salmonella* spp. from pork, both the amount of pork consumed and eating habits are of importance. Therefore, it is necessary to take into account that in some MS such as Denmark and Germany minced pork is consumed raw and that in France many "delicatesses" are made from raw pork. The consumption of these non or minimally processed pork theoretically increases the *Salmonella* risk due to pork.

The changing demands of the consumers in the EU and in the main pork importing countries will have decisive impacts on the organisation and production goals of the swine industry in the EU and the implementation of *Salmonella* monitoring and control programmes in all EU MS that are more or less harmonised. These measures will have a significant positive effect on the acceptance of pork produced in the EU by its own consumers and the competitiveness of EU pork in the global market.

3. *SALMONELLA* IN PORK AND THE HEALTH RISK TO HUMANS

Salmonella spp. are Gram-negative, facultative anaerobe, motile and rod shaped bacteria belonging to the family *Enterobacteriaceae*. At least 2 500 different serovars of *Salmonella* spp. are known and have been placed in two species; *S. enterica* and *S. bongori*. *S. enterica* is divided into six subspecies: *enterica, salamae, arizonae, diarizonae, houtenae* and *indica*. Names for *Salmonella* serovars (e.g. *S. enterica* subsp. *enterica* serovar Enteritidis is abbreviated to *Salmonella* Enteritidis) are only maintained for the subspecies *enterica* serovars, which account for most of the *Salmonella* strains isolated from poultry and humans (see Brenner *et al.*, 2000 for the *Salmonella* nomenclature).

S. Typhi and most *S.* Paratyphi (A, B and C) cause serious systemic infections in humans. Most of these serovars are specific human pathogens, and are transmitted directly or indirectly from humans to humans. Thus, animals are not a reservoir for these pathogens.

3.1. Serovars involved in human salmonellosis

Any serovar that is not animal host-adapted is considered capable of causing gastro-intestinal illness of varying severity in humans. However, even serovars that are considered host-adapted, like e.g. *S.* Dublin, can occasionally cause severe human salmonellosis. *S.* Enteritidis and *S.* Typhimurium were the most frequently reported serovars involved in outbreaks of salmonellosis in Europe in the period 1993-1998, being responsible for 77.1% of the outbreaks recorded and occurring in a ratio of approximately 3:1 (WHO, 2001). Also in 2003 *S.* Enteritidis and *S.* Typhimurium where the most frequent reported serovars, accounting for 78.3% of all reported outbreaks and laboratory confirmed cases.

The serovars most frequently reported in humans in EU from 1993 to 2003 from various sources are presented in Tables 5 and 6.

In 2003, the next serovars ranking three to five in more than one country are *S.* Agona, *S.* Virchow, *S.* Newport, *S.* Brandenburg, *S.* Derby (4th in Belgium, 5th in Germany) and *S.* Braendrup. In 2003, *S.* Virchow was the third most frequent serovar isolated from human cases.

3.2. Epidemiology of non-typhoid salmonellosis in humans in EU

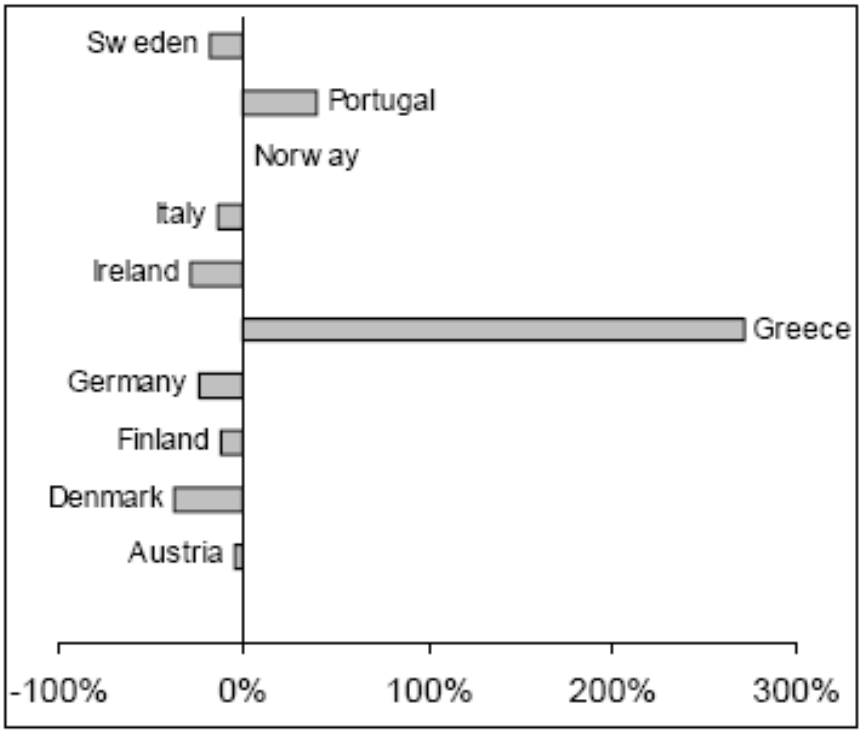
The zoonotic *Salmonella* spp. causes the so-called non-typhoid salmonellosis that in humans usually presents as a localized enterocolitis. The syndrome usually lasts for 2 to 7 days. Systemic infections sometimes occur, and usually involve the very young, the elderly or the immuno-compromised. A fatal outcome is rare. The excreta of infected persons will contain large numbers of *Salmonella* spp. at the time of onset of illness. Those numbers decrease with the passing of time. Some patients excrete non-typhi *Salmonella* spp. for up three months or longer. Non-typhoid salmonellosis can later give rise to chronic diseases including localized infections in specific tissues or organs, reactive arthritis as well as neurological and neuromuscular illnesses.

In 2004, all MS (except Luxemburg) reported cases of human salmonellosis. Altogether, there were 192 703 reported human cases of salmonellosis in all MS and Norway in 2004. These numbers underestimate the magnitude of the problem, as many cases of salmonellosis are not reported because the ill person either does not visit a physician, no specimen is obtained for laboratory tests, or the laboratory findings are not communicated. Sentinel and population studies carried out in The Netherlands, revealed that the true incidence rate varies from 300 – 400 / 100 000 population (de Wit *et al.,* 2000; Hoogenboom-Verdegaal *et al.,* 1994). Taking into account the degree of under-reporting, the Centres for Disease Control and Prevention (CDC) estimates the annual number of non-typhoidal salmonellosis cases in the USA to be approximately 1.4 million (Mead *et al.,* 1999) which corresponds to approximately 560 cases per 100 000 inhabitants (see also paragraph 3.4.2.).

In individual countries, the situation is different. In 2004, in EU-25 the incidence ranged from 6.6 to 300.9 per 100 000 inhabitants (EFSA, 2005b). On average 42.2 cases per 100 000 population were reported in 2004, an increase of 22% compared with EU-15 in 2003. This increase is attributed to a higher incidence of salmonellosis in the new MS.

In 9 MS, together with Norway, where salmonellosis is notifiable, data available for the last five years show that the incidence had decreased in 7 States, increased in 2 States and remained steady in 1 (Figure 2).

Figure 2. Percentage change in number of cases of reported human salmonellosis in countries with available data and where salmonellosis is notifiable. Reported number of cases in 2004 compared to a five-year mean (1999-2003) (EFSA, 2005b).



Except for Sweden, Norway and Finland, where most cases are associated with imported products, or foreign travels, most reported cases were of domestic origin.

Based on data from 23 MS, *S.* Enteritidis was the most commonly reported serovar (76%), ranging from 32% to 100%. This serovar is commonly associated with undercooked eggs and poultry meat. *S.* Typhimurium was identified in 14% of all serotyped isolates. This serovar is associated with the consumption of contaminated animal products particularly pig, poultry and bovine meat. In Sweden and Finland, *S.* Typhimurium was the most common cause of human cases.

Humans can acquire *Salmonella* spp. infections through the consumption of contaminated foods as well as contaminated drinking water. The Scientific Committee on Veterinary Measures relating to Public Health (SCVMPH) concluded that the food categories possibly posing the greatest hazard to public health include raw meat and some meat products intended to be eaten raw, raw or undercooked products of poultry meat, eggs and products containing raw eggs, unpasteurised milk and some products thereof. Sprouted seeds, unpasteurised fruit juices as well as home-made mayonnaise, are also of major concern (SCVMPH, 2003).

The overall importance of the prevalence of *Salmonella* contamination of the food of animal origin as a main source for human cases of salmonellosis is exemplified in the low prevalence countries Finland, Norway and Sweden (see below). In these countries more than three quarters of the total number of registered human case of salmonellosis are attributed to visits abroad. This is in contrast to the situation in e.g. Denmark and the Netherlands, where roughly the opposite situation exists, as described in Chapter 3.4.2.

3.3. Types of food involved

The contribution of the various food categories to the occurrence of domestically acquired human salmonellosis varies between countries and depends on the prevalence of different *Salmonella* serovars in various food production chains, as well as consumption patterns and food preparation practices. Moreover, this picture will also change with time.

According to the World Health Organization (WHO) (Tirado and Schmidt, 2000), in Europe in the period 1993 – 1998, the incriminated food was identified in 1 409 outbreaks caused by *S.* Enteritidis and in 188 outbreaks caused by *S.* Typhimurium.

Several foods have frequently been responsible for outbreaks caused by *S.* Typhimurium including egg or egg products, meat and meat products (33%) – predominantly pork meat - and poultry meat products (10%) (Table 7). In industrialised countries, between 5 and 30% of all cases of foodborne salmonellosis had pork incriminated as the actual source (Baird-Parker, 1994).

3.4. Exposure of humans to *Salmonella* through pork

3.4.1. Outbreak data

The role of pork and pork products in *Salmonella* outbreaks has also been established by several case-control studies, and by studies where molecular typing has been used in epidemiological investigations for identifying relations between patients and infection source (Table 7).

In the period 1992 – 1999, in England and Wales, 73 (32%) of 228 meat related outbreaks of foodborne diseases were associated with pig meat. Of these, 35 (15%) were caused by *Salmonella*. The most important serotypes involved were *S.* Typhimurium (13), *S*. Enteritidis (13) and other *Salmonella* serotypes (9) (Smerdon *et al.,* 2001).

In the same period, pig meat-related outbreaks decreased from 13 per year in 1992 to 4 per year in 1999. The data on reported outbreaks or case-control studies alone are used to identify, but not to quantify, the contribution of the various sources to human salmonellosis.

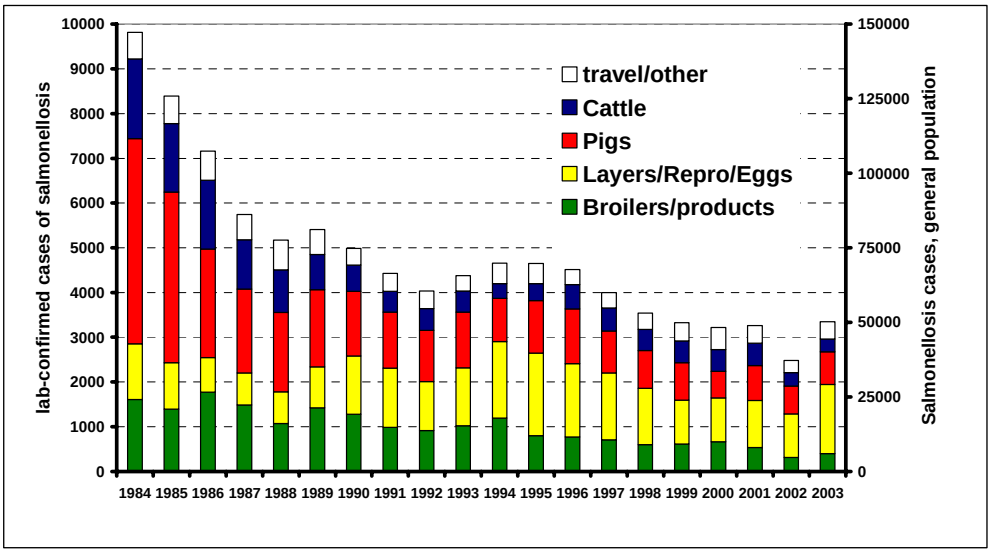
3.4.2. Data based on laboratory surveillance data

In The Netherlands the estimated contribution of travel, farm animals, including pigs and their products to human salmonellosis was presented in the annual report for 2003 of the Dutch Food and Consumer Product Safety Authority.

Using laboratory surveillance typing data of isolates of *Salmonella* spp. the fraction of cases of human salmonellosis that could be attributed to each category of farm animal and their products, or which fraction was of unknown origin including travel, was estimated (Figure 3). Retrospective data were used of isolates derived from humans and farm animals that were routinely sent to the National Reference Laboratory (NRL), at the National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu – RIVM) for serotyping and phagetyping. The estimate exploits the relative host-specificity of *Salmonella* serotypes and phagetypes. In addition to typing data from human isolates, data were used from isolates sent in from broilers (droppings from farms, caeca and meat products), layers (including raw materials for egg products, consumption eggs and materials from farms and hatcheries such as inlay leaflets, fluff, etc.), pigs (both adults, piglets, healthy and sick animals) and cattle (mainly dairy cattle and veal calves, healthy and sick animals). These data allow to trace the most probable origin of the human isolates.

In 2003 the assessed total number of human salmonellosis amounted 50 000 cases (308 case/100 000 population). Of these cases, 22% were associated with consumption of pork; this is equal to 68 human cases per 100 000 inhabitants, which in turn translates to 4 or 5 reported cases per 100 000 inhabitants attributable to the consumption of pork.

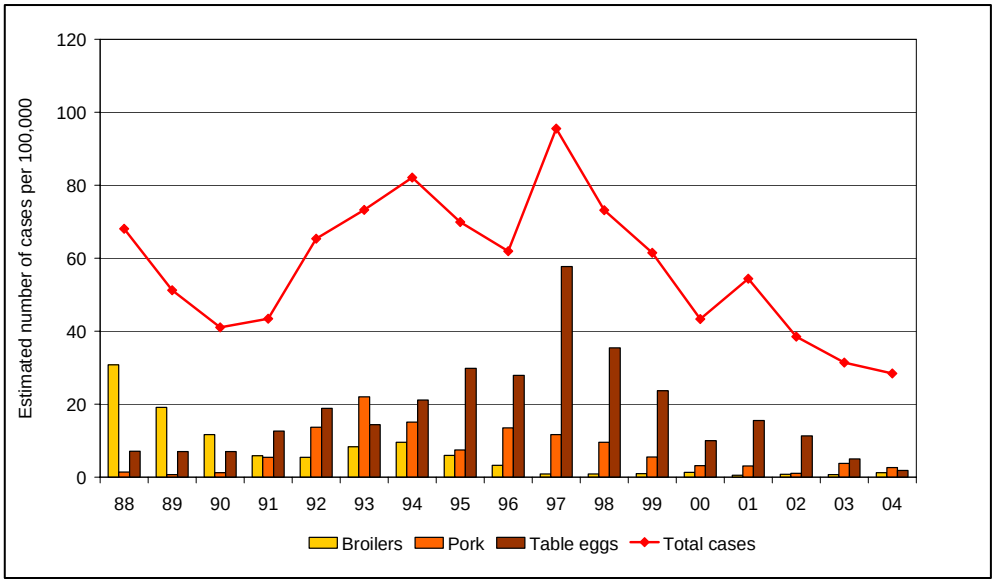
Figure 3. Estimated contribution of travel, farm animals and their products to laboratory-confirmed human salmonellosis and estimated *Salmonella* infection cases in the general population of The Netherlands (Laboratory surveillance, RIVM).



In Denmark, Hald *et al*. (2004) developed a mathematical model to calculate the number of domestic and sporadic cases caused by different *Salmonella* serovars and phage types. In 2003 the most important food sources were table eggs and domestically produced pork comprising 47.1% (95% CI: 43.3–50.8%) and 9% (95% CI: 7.8–10.4%) of the cases, respectively.

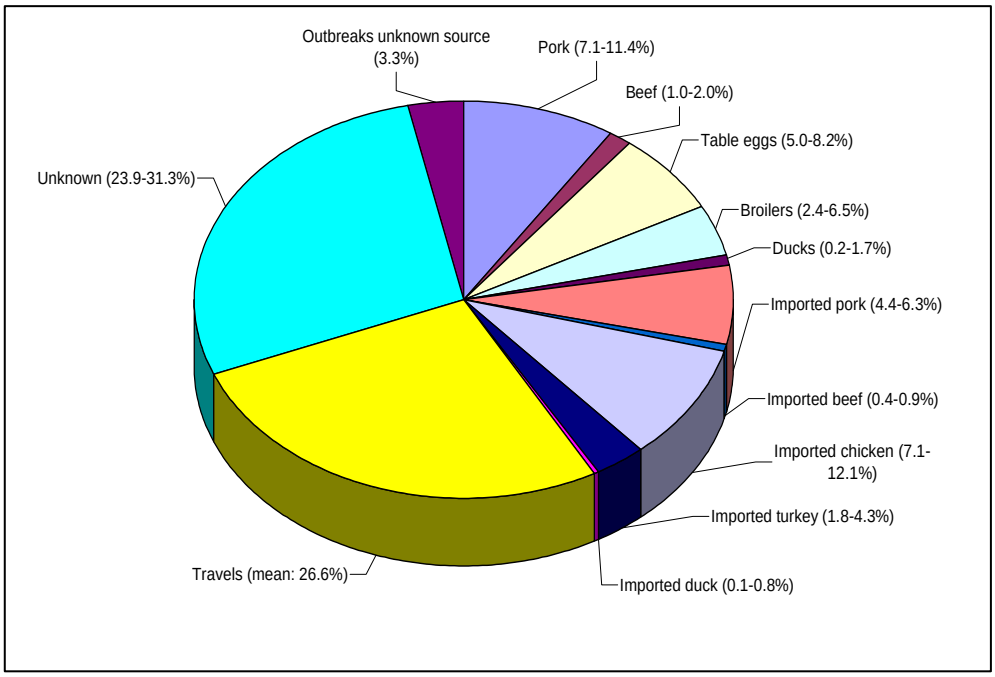
The estimated mean number of human cases (per 100 000 inhabitants) that could be attributed to various sources in Denmark in the period 1988 to 2004 is presented in Figure 4.

Figure 4. Estimated contribution of broilers, pork and table eggs in *Salmonella* infections in the general population (cases per 100 000) in Denmark in the period 1988 – 2004.



In 2004, the relative contribution of the various sources to human salmonellosis in Denmark is presented in Figure 5.

Figure 5. Estimated sources of 1 538 cases of human salmonellosis in Denmark, 2004.



The domestically produced pork was responsible for 9% (95% CI: 7.1–11.4%) of the cases of human salmonellosis. Imported pork was responsible for 5% (95% CI: 4.4 6.3%) of cases.

3.5. Conclusions

- Based on the available statistics, pork is a significant source of human foodborne salmonellosis in EU.
- The most common serovar causing human foodborne infections from pork is *S.* Typhimurium, although many other serovars are involved as well.
- The participation of pork-associated salmonellosis in foodborne salmonellosis varies between countries.
- All *Salmonella* serovars are to be regarded as a hazard for public health.
- Overall, the proportion of *Salmonella* cases in humans of domestic origin reflects the efficiency of the *Salmonella* control. In low prevalence areas (Finland, Sweden) less than one quarter of human cases is of domestic origin, whereas in medium and high prevalence countries roughly the opposite situation exists.

4. *SALMONELLA* SEROVARS DISTRIBUTION IN FEED, PIGS AND PORK IN EU AND NORWAY

Monitoring programmes are in place in several MS, such as, for example surveillance based on swab samples of carcasses (see Annex II). Although figures are not directly comparable as methods are not fully harmonized in these countries, the prevalence ranged from 0% (Sweden, Norway), 0.1% (Finland), 0.8% (Denmark) to 12.3% (Belgium) in 2004 (EFSA, 2005b). Twenty-one MS reported data on *Salmonella* prevalence collected at different stages of production. Denmark, Finland, Sweden, Germany, Hungary, Latvia and Poland reported less than 1.5% of sample positive at slaughter, while Italy reported less than 5%, Spain, Portugal, Belgium between 10 and 20% and Malta 32.8% of positive samples (EFSA, 2005b).

Data on herd prevalence showed that 29.4% of fattening pig herds tested in The Netherlands and 25.4% of batches of fattening pigs tested in Italy were *Salmonella* infected (EFSA, 2005b). In Belgium 92% of pig herds were found positive (Cook *et al.,* 2005), while in the UK it has been estimated that about 50% of herds are *Salmonella* infected and in Denmark 11% of slaughter pig herds were found infected (Christensen *et al.,* 2002). In low prevalence countries the situation is more favourable; for example, in Sweden no *Salmonella* infected pig herd was found in 2004 (EFSA, 2005b).

In 2004, in animal and vegetable derived feed material between 0-7.5% and 0-7.6% respectively of samples were positive in EU-25 (EFSA, 2005b). Figures are not comparable between countries and it can only be concluded that *Salmonella* is not an uncommon finding in feed raw material. In compound feedingstuffs *Salmonella* contamination in pig feed ranged from 0-1.9%, showing that at present contaminated feed is a means of introducing *Salmonella* in pig herds.

Several different serovars are detected in the final product reflecting deficiencies in *Salmonella* control in feed and feed mills. Although no conclusion can be drawn about the frequency of the different serovars, it can be seen that the most common serovars in pig production (*S*. Typhimurium and *S*. Derby) are not the most commonly occurring serovars found in feed (Table 8).

Overall, at the EU level, *S*. Typhimurium and *S*. Derby were the most commonly reported serovars in pigs during 2000-2004 (European Commission, 2002, 2003, 2004, 2005; EFSA, 2005b), and account for approximately 50-60% and 6-20% respectively of all reported serovars in pigs. Many other serovars are reported, however, none of which account for more that 5% of all isolates (Table 9). However in individual countries the situation may be different and may vary significantly from year to year.

S. Typhimurium and *S*. Derby were the most commonly serovars reported in pork in EU Member States during 2001-2004 (European Commission, 2002, 2003, 2004, 2005; EFSA, 2005b), and account for approximately 35-55% and 15-20% respectively of all serovars reported. Many other serovars are reported, however, none of these account for more that 5% of all isolates (Table 10). Meanwhile, in individual

countries the situation may be different and the distribution of serovars in individual countries may also vary significantly from year to year.

4.1. Conclusions

- The data available are too limited to permit a true comparison between MS, so an in depth evaluation for all MS could not be made. However, it is clear that the prevalence of *Salmonella* in pigs and pork differs considerably between MS.
- Overall at the EU-level, *S.* Enteritidis is the most common serovar found in human foodborne infections along with *S*. Typhimurium, to a lesser extent.
- *S.* Derby plays a minor role in human infections, although it is the second most common serovar found in pig and pork.
- Overall at the EU-level, at present, *S.* Typhimurium and *S.* Derby are by far the most common serovars in pigs. These serovars are also the most common serovars in pork. However, serovar distribution is variable over time and the situation in individual MS may, therefore, vary.
- A wide range of other serovars occurs sporadically in pigs and in pork, and these serovars can occasionally cause foodborne salmonellosis in humans.

5. DETECTION METHODS AND METHODS FOR SURVEILLANCE OF *SALMONELLA*

5.1. Bacteriological methods - Current methodology

Isolation of *Salmonella* from the pork production chain is a prerequisite for the estimation of the prevalence of infection at primary production and the frequency of contamination of pork products. Isolation can only be performed by the use of bacteriological examination. Isolation of *Salmonella* is also necessary for the characterisation of the different serovars involved, for assessing the extent of antimicrobial resistance, for tracing of infections, e.g. in outbreaks, and for risk assessment, e.g. of different types of products. The result of the isolation and subsequent studies and estimations will, however, be influenced by the bacteriological method applied, as no diagnostic method has a sensitivity of 100%.

Salmonella can be readily isolated from samples originating from pigs or pig herds showing clinical signs of salmonellosis. In such cases, the pigs excrete high numbers of bacteria in their faeces; these can be detected directly, without any enrichment, by plating on selective agars. However, clinical infection in pigs is rare compared to the occurrence of subclinical infection. The latter is characterised by animals being infected without showing any signs of illness and these animals may be presented for slaughter, becoming a source of contamination for the slaughter plant and products. Subclinically infected animals typically exhibit intermittent excretion of low numbers of *Salmonella* in their faeces; this challenges methods of bacteriological isolation. *Salmonella* can, however, be isolated from intestinal lymph nodes, reflecting a localised intestinal infection, a previous exposure to *Salmonella* or, possibly, spread from internal organs as a consequence of generalised infection.

The sensitivity of the bacteriological methods depends on both the isolation media used and the matrix of the samples (type and amount) that are investigated.

Enrichment media should allow resuscitation and multiplication of low numbers of microorganisms. Furthermore, the media must have a composition that favours the growth of *Salmonella* and suppresses the growth of the strong competing bacterial flora also found in faeces. Compared to faeces, lymph nodes and meat have a lower level of competitive flora, and *Salmonella* will, even when present in low numbers, be more readily isolated from such materials. Several studies describe a variety of methods for detection of *Salmonella* from different materials (Busse, 1995; Dam-Deisz *et al.,* 2003; Korver *et al.,* 2003; Korver *et al.,* 2004; Mooijman, 2004; Voogt *et al.,* 2001). Their results cannot be readily compared, as study designs are not consistent and therefore, it is not possible to identify a single method as the most sensitive in all cases. There is a need for harmonisation, standardisation and quality assurance of the methods applied as well as the nature and the quantity of the materials to be analysed.

Standard methods for the isolation of *Salmonella,* e.g. ISO 6579 (ISO, 2002), have been developed and evaluated in relation to the analysis of food and feed. As the matrix has considerable influence on the performance of the method due to e.g. levels of competitive flora, methods developed for analysis of food cannot be assumed to be appropriate for analysis of materials from primary animal production, e.g. faeces. In recent years, efforts have been made to develop and evaluate a standard bacteriological method for the isolation of *Salmonella* from samples from primary animal production. These studies have resulted in the addition of an annex to the established ISO-method[7].

The method for the analysis of material from primary animal production has been evaluated in the network of CRL-*Salmonella* in a comparative study among the National Reference Laboratories (NRLs) of the MS (Korver *et al.,* 2003; Korver *et al.,* 2004). Thus, the method has been harmonised amongst the NRLs and every MS now has experience in the use of this method.

The method is a horizontal qualitative method, which provides results as *Salmonella* is detected or not. The background for this is that the method includes several enrichment steps and consequently, the number of colonies at the final stage does not correspond directly to the number of bacteria in the initial sample. Such results can be used for prevalence studies, surveillance and control programmes. In relation to risk assessment and consumer protection, quantitative methods that state the actual number of bacteria present are also desirable. Enumerations of *Salmonella* are at present very laborious and have to be performed by Most Probable Number (MPN) techniques.

The significance of the choice of matrix for bacteriological examination is demonstrated by comparing the sensitivity of isolation from different matrices. In

[7] www.iso.org/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=42109&scopelist=PROGRAMME

subclinically infected herds, slaughter pigs present chronic infections with only intermittent excretion, with a low level of salmonellae in faeces (Wilcock and Schwartz, 1992). Therefore, the examination of individual faecal samples from pigs has a poor sensitivity. For faecal samples the sensitivity has been reported to vary between 9% (swabs) and 78% (25g faeces) (Funk *et al.,* 2000) and 10-80% (Hurd *et al.,* 2001a). However, when used on a herd basis, where all animals are included in the examination, as done in the Nordic control programmes (excl. Denmark), the herd sensitivity increases, especially when repeatedly applied. In such cases negative faecal culture of the whole herd (individual samples on adult pigs and pooled pen samples on young pigs/finishers), performed twice, with one month interval, will ensure, with a higher confidence, that all animals are free from *Salmonella*.

A positive correlation has been reported between the prevalence of *Salmonella* in faecal samples collected on farm and in ileocaecal lymph node samples, suggesting that the prevalence of *Salmonella* spp. at slaughter can be predicted from pre-slaughter on-farm sampling and *vice versa* (Bahnson *et al.,* 2005). However, Nollet *et al.* (2004) considered that the prevalence of infected lymph nodes reflected the *Salmonella* status on the farm only if cross-contamination with animals from other farms had not occurred between transport of pigs from the farm to slaughterhouse or it was negligible.

The number of caecal/intestinal lymph nodes analysed can be expected to influence the sensitivity of the analysis. In an investigation by Sorensen *et al*. (2004), only one caecal lymph node was analysed, whereas in the surveillance at Swedish slaughterhouses at least five lymph nodes from the same animal are pooled in one sample. The latter procedure can be expected to be more sensitive, since more lymph nodes are investigated altogether.

It has been suggested that environmental sampling using e.g. a pair of socks, in pig farms, as used in broiler flocks (Skov *et al.,* 1999), could likewise have a higher sensitivity compared to pooled individual faecal samples (Beloeil *et al.,* 2004a, Korsak *et al.,* 2003). The use of such sampling method could be further evaluated as a simpler and more sensitive alternative to faecal samples, for example, when used to establish the true *Salmonella* status of pens or batches of finishing pigs immediately prior to slaughter (as done with poultry). An additional option is sampling of manure in the lorry at the time of unloading. Fractioned sampling during unloading represents a large number of pigs at the same time increasing sensitivity considerably. In the UK, it was found that the use of pooled pen floor faeces gave a useful measure of herd prevalence (Arnold *et al.,* 2005). In that study the highest sensitivity (67%) was achieved when the maximum (20) number of individual pigs contributed to a pool of 25g, assuming the within-pen prevalence was 25%.

5.2. Immunological methods

5.2.1. Basic Principles

Enzyme-Linked Immunosorbent Assay (ELISA) tests detect antibodies against *Salmonella* and are therefore indirect tests that measure previous exposure to *Salmonella*. Therefore, an animal that is ELISA positive may no longer be infected, in

contrast to a pig that is bacteriologically positive. Likewise, ELISA negative animals can be recently infected if testing is performed before detectable levels of antibodies have been produced. These facts have important consequences for the interpretation of test results which are described in Chapter 5.2.2.

All available ELISAs are based on Lipo-Poly-Saccharide (LPS) antigens. LPS-antigens are a part of the cell wall of many bacteria but are very specific for each kind of bacteria. In the case of *Salmonella* the LPS is specific for each serogroup. LPS is very immunogenic and therefore, pigs may react to infection with *Salmonella* by producing specific antibodies. Usually several serogroup-antigens are included in an ELISA, so called mix-ELISA. A microbiological survey of the pig population of interest should be conducted before an ELISA test is developed or applied so that the serogroups that are present are known and their prevalence is established. This approach ensures that the design of the test is optimised.

Harmonisation of methods, by agreement on methodology and calibration, of ELISA tests is a prerequisite if the results of surveillance are to be comparable between countries (van der Heijden, 2001; van der Wolf *et al.,* 2001a). Studies have shown that results of different commercial ELISA kits may not be interchangeable (Meija *et al.,* 2003). It has also been suggested that international reference samples should be made available to ensure a minimum level of sensitivity (van der Heijden, 2001) and specificity.

5.2.2. Test characteristics

Test characteristics depend on several factors such as:

5.2.2.1. Technical design

The ELISA test can be designed with a focus on specific serogroups that occur in a region (e.g. *Salmonella* Typhimurium and therefore serogroup B) or which are of interest for other reasons. The inclusion of LPS from different serogroups may influence the sensitivity of the test. In principal, antibodies against serogroups (O-antigens) that have not contributed LPS to the test cannot be demonstrated by the test. However, some cross-reactivity might occur (e.g. between serogroups B and D1). In Denmark, the ELISA was estimated to detect antibodies against 90-95% of the serovars found in the field; in The Netherlands this figure was 89% (Baggesen *et al.,* 1996; van der Wolf *et al.,* 1999). Changes in serovar distribution in the field resulting in a change of serogroup representation will affect the sensitivity of the ELISA and will require repeated bacteriological investigations.

5.2.2.2. Cut-off

In the original publication of the method applied in Denmark by Nielsen *et al*. (1995) a scientific cut-off of OD%>10 was established. However, another cut-off was adopted by the Danish National monitoring scheme (Mousing *et al.,* 1997). Changing the cut-off will affect both the sensitivity and specificity. When the cut-off is increased from the scientific cut-off of OD%>10 to OD%>20 or even OD%>40, as in the Danish *Salmonella* Monitoring System (Alban *et al.,* 2002b), the sensitivity drops dramatically. With an increase in the cut-off from OD%>10 to OD%>40 the apparent

prevalence in finishers decreases to about 45% of that estimated using the OD%>10 cut-off (23.7 to 10.4 and 24.5 to 11.1) (van der Wolf *et al.,* 2001a). In sows, the effect is even more dramatic, when the cut-off is set at OD%>40 the number of sows found positive is only 16 – 17% of the number found positive at an OD%>10 (60.4 to 9.9)(van der Wolf *et al.,* 2001a). Comparable results were found by Nollet *et al.* (2005) in Belgium.

5.2.2.3. Stage of infection

The interval between the peak of the bacteriological and serological response ranges from one to a few weeks for experimental infections (Lo Fo Wong *et al.,* 2004; van Winsen *et al.,* 2001) up to approximately two months under natural conditions (Kranker *et al.,* 2003). This means that in the early stages of an infection, pigs will be seronegative, while positive bacteriological results may be obtained. In later stages of infection when pigs may have cleared themselves of *Salmonella*, antibodies may still be present, classifying the pigs as seropositive. Therefore serological testing provides a measure of historical exposure that may not correlate closely to microbiological findings at the time of sampling. However, latent carriers and intermittent shedders that are difficult to detect bacteriologically can be identified immunologically (Lo Fo Wong *et al.,* 2004).

5.2.2.4. Serovar

The stimulation of the immune system varies for different serovars and results in different antibody responses (van Winsen *et al.,* 2001). Seropositivity tends to be related to the presence of *S.* Typhimurium (Stege *et al.,* 2000). Van Winsen *et al.* (2001) concluded that in general *S.* Typhimurium will give a clear response, whereas for *S.* Panama or *S.* Goldcoast the antibody responses were poor or not detected. However, exhaustive testing for all serovars found in pigs has not been conducted.

5.2.2.5. Passive immunity

Under field conditions, piglets ingest colostrum from their dam who might be seropositive, thus resulting in passive immunity in these piglets. These maternal antibodies persist for about 8 to 10 weeks, and so, for practical purposes, the ELISA is not used to determine whether piglets under the age of 10 weeks are or have been infected with *Salmonella*. However, this issue requires further investigation (Kranker *et al.,* 2003; van der Heijden *et al.,* 1998).

5.2.2.6. Failure of seroconversion

Some individuals who are unable to react immunologically to the infection will not seroconvert even though they are truly infected with a serovar that normally would lead to a raised antibody level (van Winsen *et al.,* 2001). Part of the explanation for this is genetic resistance to infection in some pigs (van Diemen *et al.,* 2002). This phenomenon may occur in 1 or 2 % of pigs (Nielsen *et al.,* 1995); however, this percentage is hard to establish.

5.2.3. Sensitivity

The sensitivity of the ELISA test is its ability to detect antibodies against a defined range of *Salmonella* serogroups, indicating prior exposure.

The sensitivity at individual level has been reported to be 80-90% (Nielsen *et al.*, 1995; Chow *et al.*, 2004), but depends on many factors, as described above. In reality the sensitivity may, however, be lower. For example, for modelling purposes, the minimum sensitivity of the Danish mix-ELISA was assumed to be as low as 50% (Alban *et al.*, 2002b).

Serology can be used as a screening test to determine herd status at a point in time and for continuous monitoring by repeated sampling. The interpretation of immunological results is not always straightforward, and, furthermore, bacteriological and immunological results will often not correspond at either herd or individual level. However, given that the specificity of the ELISA is high (with the exception of pigs tested in Sweden where specificity was shown to be lower, as may also be the case in other low prevalence areas), a positive immunological result will most likely reflect an infection with *Salmonella*, past or present, in an individual pig (Lo Fo Wong *et al.*, 2004).

The general conclusion of several studies (Nielsen *et al.*, 1995; Stege *et al.*, 1997; Christensen *et al.*, 1999; Sorensen *et al.*, 2000) is that immunological assessment was reliable mainly at herd level and was especially well suited for identifying high-prevalence herds (Alban *et al.*, 2002a; Casey *et al.*, 2004). In high-prevalence herds there was usually a long-term problem present and the herd status was anticipated to be relatively stable over time (Chaunchom, 2003; Nielsen *et al.*, 1995).

In low-prevalence herds, major infection incidents may occur and consequently changes in the *Salmonella* status of such herds can be anticipated (van der Wolf *et al.*, 2001b). Using immunology in such herds will have the drawback of not identifying such changes rapidly because of the time lag between infection and seroconversion. Van der Wolf *et al.* (2003) pointed out the importance of examining recently collected serological samples to confirm the continuing low prevalence of infection in herds. Several authors have shown that the *Salmonella* status changes frequently both within herds as well as in groups within herds over time (Rajic *et al.*, 2005; Carlson and Blaha, 2001). However, in order to identify *Salmonella*-free herds, bacteriological examination is necessary in addition to serological testing (van der Wolf *et al.*, 2003).

5.2.4. Specificity

In the case of the ELISA, the purpose of the test is to detect antibodies that indicate current or previous infection with the *Salmonella* serogroups that are incorporated into the test. Thus, the specificity of the ELISA test is defined as its ability to correctly identify as negative, i.e. not infected, those pigs that do not have antibodies against the *Salmonella* serogroups incorporated in the test.

The specificity of an ELISA test has been evaluated by looking at the results of sera from Specific Pathogen Free (SPF) herds, longitudinal studies in seronegative herds (van der Wolf *et al.*, 2001b) and the results of the ring trial for *Salmonella* ELISAs (van der Heijden, 2001). It can be assumed that the specificity of the *Salmonella*-ELISAs is high at the scientific cut-off (van der Heijden, 2001).

An exception was found in Sweden where 4% (122 out of 3050) of finishing pigs tested using the Danish mix-ELISA were found to be positive (OD% 20-70) (Lo Fo Wong and Hald, 2000). As Sweden has a long standing intensive surveillance and control program for *Salmonella* in swine, the animals which tested positive could be considered to be *Salmonella*-free; however, the origin of these antibodies could not be established (Wiuff *et al.,* 2002). This result shows that care is required when implementing an existing immunological test in a new geographical area without prior investigation of possible background problems and of the general bacteriological profile (i.e. bacteriological survey) of a larger number of animals in that region (Wiuff *et al.,* 2002; Davies *et al.,* 2003; Hamilton *et al.,* 2003). At present the ELISA is not sufficiently evaluated for use in low prevalence areas.

5.3. Choosing bacteriological versus immunological methods: concluding remarks

In the previous sections the principles and the advantages and disadvantages of bacteriological and immunological analysis methods have been described. The elements are summarised in Table 11. The two approaches are very different and the choice of method to be used will depend on the actual situation and the questions that are required to be answered. However, the following conclusions can be drawn:

- the bacteriological methods express the actual infection status of the animal, including transmission or recent contamination. It detects all serovars. The actual infectious agent or agents will be isolated, which makes further characterisation of e.g. serovar and antimicrobial resistance profiles possible. However, the analytical procedure is laborious.
- The immunological methods express a previous exposure to the infectious agent by detecting specific antibodies against *Salmonella*. The method can identify carriers or animals already cleared of infection. It detects only those serogroups included in the test and therefore newly emerging serovars may not be detected. The method can be automated, and it is less laborious.

Both methods require to be defined and harmonised. Quality assurance has to be applied in order to produce results that can be compared with confidence between laboratories/countries. Results obtained using bacteriological methods and immunological methods, for the reasons stated above, cannot be compared directly.

5.3.1. Alternative methods (future perspective)

Conventional bacteriological isolation methods are costly and time consuming, as can be seen from the flow chart of the ISO methods (Table 12). Therefore, much effort has been made to develop rapid methods for the detection of *Salmonella*. In general, the principle of such alternative methods is to enable a rapid screening of all samples by which means the suspect positive samples can be identified. The screening performed in these alternative methods can be either immunologically based or Polymerase Chain Reaction (PCR) based. In the former test only certain serovars will be detected, while in the latter all serovars will be detected. An automated PCR-test system is available to monitor *Salmonella* in pig herds, allowing the investigation of

thousands of faeces samples for *Salmonella* spp. or specified strains in a period as short as a day or earlier in the future (Malorny and Hoorfar, 2005). Before use, however, alternative methods have to be formally validated in relation to the specific material to be sampled and tested in the course of investigations/surveillance.

In the near future, diagnostic DNA microarray-based methods potentially address questions for family, genus, species, subspecies, strain identification, and genotypic characterisation, as well as the presence of several crucial genetic markers such as for antibiotic resistance and virulence. The diagnostic potential of microarrays has been reviewed (Ye *et al.,* 2001; Bodrossy and Sessitsch, 2004; Stöver *et al.,* 2004). This approach is now poised for introduction into diagnostic laboratories.

5.4. Methods for surveillance

The purpose of surveillance is to provide information to be used by decision makers. It is vital to think through the objectives and also put them into writing before designing a surveillance program. Periodical evaluations shall be done and provision for such evaluation included in a surveillance system (Toma *et al.,* 1999).

Surveys and surveillance can describe and quantify a disease status at a given moment or its behaviour over time and in space in a given population. When designing surveillance it is important that the sample is representative of the target population. The design and especially the sampling strategy are defined by the objectives of the survey. A key question is the unit of concern, e.g. individual carcass, animal, herds/certain types of herds or maybe region (Toma *et al.,* 1999). The level of detail of a disease spatial distribution will also affect sampling design; for instance, is it sufficient with an overall estimate of disease frequency in a country or herd or should smaller units with different prevalences be identified (Toma *et al.,* 1999)? For example, it has been shown that separate slaughter of seronegative pig herds can lead to a decrease in the prevalence of *Salmonella*-contaminated pork after slaughter (Swanenburg *et al.,* 2001b). In such cases, surveillance of the end product (carcasses) could preferably be done on a slaughterhouse basis or stratified using separate slaughter batches. When a study includes disease information over time the level of detail required will affect the frequency of sampling, for example when seasonal, annual or other temporal changes require to be identified (Toma *et al.,* 1999). *Salmonella* prevalence can change rapidly over a short period, as has been shown in low-seroprevalence countries/herds. In endemic regions, it can be expected that *Salmonella* infections will occur regularly as long as salmonellae are present in the animal environment, in feed and in animals that are brought into the herd. If such changes are to be detected rapidly, then such herds have to be sampled frequently (van der Wolf *et al.,* 2001b).

If certain (usually small) herds are not included in the programme, this has to be considered. If such pigs are slaughtered at the same slaughterhouses they may still be a risk of contamination. Husbandry systems where pigs are kept outside total confinement (pasture, free range etc.) are at an increased risk of getting infected with *Salmonella* (van der Wolf *et al.,* 2001a). Any population prevalence estimate should

be stratified in order to monitor these kinds of herds separately from total confined housing.

Understanding the characteristics of the test is essential. When estimating the sensitivity and specificity of a test, it is essential that the study population is representative of the target population (e.g. those animals to which the test will be applied in the future). This representativeness refers to attributes of animal being tested; for example age, breed and also environmental factors that might affect the sensitivity or specificity of the test (Dohoo *et al.,* 2003).

When establishing the sample size needed, it is important that the sensitivity of the test at individual and herd level is taken into account. This is especially true for *Salmonella* where the sensitivity of tests is not high. Failure to consider an imperfect sensitivity of a test will lead to an underestimation of prevalence and reduced power to detect *Salmonella* infected herds. The expected within herd prevalence should also be taken into account. It can be expected that, as risk management actions are taken, the within herd prevalence decreases and consequently a larger sample size is needed to identify an infected herd.

To assess the infection dynamics in a *Salmonella* infected herd, repeated sampling in different cohorts (clusters) of animals is required. Point estimates of pre-harvest prevalence in subclinically infected herds are not reliable as variations occur in *Salmonella* prevalence between cohorts within systems and over time (Funk *et al.,* 2001; Beloeil *et al.,* 2003; Kranker *et al.,* 2003).

Surveillance can also, apart from quantifying disease, be aimed at detecting disease as soon as possible, by sampling at critical control points. When disease prevalence becomes very low such sampling may be more appropriate than to quantify disease occurrence. An example of such surveillance is the *Salmonella* control in feed where it is crucial to rapidly identify and eliminate the risk of any *Salmonella* contaminated *batch* (Häggblom, 1994a). However, results of such surveillance are difficult to compare between countries/regions.

Movement of live animals, carcasses and meat between countries may interfere with surveillance results and it is preferable that knowledge about such exists. Finally, the cost and what sampling procedures and analysis are practically possible should be considered when designing surveillance.

Recent modelling studies have shown that focusing control on high prevalence herds (level 2 and 3[8]) may not be the optimal strategy. The greatest public health benefit was obtained from modest improvements in all farms rather than large improvements in farms with only a high prevalence (Alban and Stark, 2005; Cook *et al.,* 2005). Funk *et al.* (2005) concluded that further evaluation of the impact of *Salmonella* serovar present on farms on seroprevalence and the relationship of on-farm seroprevalence with food safety risk are needed prior to utilising serology for pre-harvest *Salmonella*

[8] according to the methods applied in Denmark

diagnostics in the USA swine herd (Funk *et al.*, 2005). It should also be emphasized that immunological surveillance regularly has to be supplemented by bacteriological culture method in order to detect possibly emerging serovars, which might not be included in the ELISA and therefore not captured in the surveillance.

5.5. Conclusions on detection methods and methods for surveillance for *Salmonella*

Different applications for bacteriology and immunology can be distinguished:

- Bacteriology can be used where:
  - isolation of the strain is necessary for identification;
  - information about all *Salmonella* infections (all serovars) is needed;
  - antimicrobial resistance testing is needed;
  - the present *Salmonella* status of individual animals is needed;
  - description on the general diversity of infections with different serovars in a population is the aim of the investigation;
  - the evaluation of *Salmonella*-free status of herds is required.
- Immunology can be of use for the screening of large numbers of blood and other samples, for example for monitoring the effectiveness of control programmes in endemic regions or establishing the current immunological status of a population (e.g. herd) and the prevalence of infection with particular serovars.

Sustained compliance with detailed procedures is required in order to harmonize the collection, processing and reporting of comparable data from MS.

6. RISK MITIGATION OPTIONS FOR *SALMONELLA*

6.1. General options

6.1.1. Strategic approach

Most periodically have seen dramatic and often a continuously ongoing increase in human outbreaks of salmonellosis originating from infections in animals. Therefore attention has been increasingly focused on the prevention and control of *Salmonella* in animal production, by bodies such as WHO (WHO, 1993a), World Organization for Animal Health (Office International des Epizooties – OIE) (Wierup, 1994) and the EU (Dir 92/117/EEC). The need for global cooperation in the control of salmonellosis was also emphasized (Bögel, 1991). Primarily, attention was concentrated on the poultry production. Today the need to control *Salmonella* also in swine production is increasingly focused.

In 1980, WHO formulated three lines of defence for the control of *Salmonella* which are still valid (WHO, 1980):

a) the first line focuses on the control of *Salmonella* in the food producing animal (Pre-harvest control),

b) the second line deals with improvement of hygiene during slaughter and further processing of meat (Harvest control),

c) the third line concentrates on the final preparation of the food by education of the industry and consumer to obtain application of correct hygienic principles at consumer level (Post-harvest control).

In this report the mitigations options are considered according to that strategic approach formulated by the WHO. The definition of harvest for the purpose of this report covers the part of the food chain beginning with the transport of the slaughter animals from the farm gate, the lairage phase, slaughtering itself, up to the cooling of the carcasses. The farmer usually can influence the status of the slaughter animals only up to the point of transport to the slaughterhouse. Therefore harvest is separated from pre-harvest at this stage. The post-harvest level includes cutting and processing, production of raw, fermented or "safe products" (in respect to *Salmonella* contamination) up to retail and consumer levels.

A successful prevention of food borne salmonellosis originating from pork has to involve all those three lines. Today it also seems to be generally accepted that, both from an economic and an epidemiological point of view, it is necessary to focus on the control at the production level. The previously often supported strategy that it is possible to control *Salmonella* only at consumer level, i.e. only the third line of defence, have been abandoned (Wierup, 1995).

Also outside the EU, the control of *Salmonella* at farm level has long been considered as an important part of the pre-harvest pathogen reduction schemes that increasingly have been introduced to supplement traditional meat inspection which cannot of itself, control contamination by *Salmonella* (USDA, 1993).

6.1.2. Serovars to be controlled

Historically, the control of *Salmonella* was firstly directed to those serovars causing diseases and economic losses in animals. The swine-adapted serovar, *Salmonella* Choleraesuis, has therefore been the subject of special focus and may be the reason why the relative prevalence of that serovar has decreased significantly and why to-day it is only rarely isolated in many MS in contrast to the situation in USA (Chiu *et al.*, 2004). However, those *Salmonella* strains that cause disease in animals cannot be strictly limited to specific serovars and any serovar, including those that infect swine or colonize their intestine, is a potential hazard to human health (Chapter 3). This means that actions taken to prevent foodborne salmonellosis in humans originating from swine principally have to direct against all serovars of *Salmonella*. However, a strategy on preventive measures that is limited to a few selected serovars can be expected to have a preventive effect also on most other serovars because most serovars of *Salmonella* have major epidemiological elements in common. If such a strategy is applied, supporting surveillance is needed to detect, and prevent an increase in the prevalence in the production chain, of serovars that are not the particular subject of focus. In the absence of intervention, the latter serovars may later become widely spread throughout the food chain and reach epidemic proportions (Chapter 5). Experience has shown that the pattern of the annual incidence of the most

frequently isolated serovars varies considerably and that substantial changes can occur.

6.2. Pre-harvest control

6.2.1. General risk mitigation options

There have been numerous scientific publications and internationally based workshops, consultations and recommendations on farming under microbiological control and *Salmonella* reduction schemes (e.g. WHO, 1983; CEC, 1984; WHO, 1989; WHO, 1992; WHO, 1993a; WHO, 1993b).

In a review for OIE (Wierup, 1994) on the knowledge and experiences on the prevention of salmonellosis in livestock farms, it was concluded that the control of *Salmonella* can follow general rules that have been successfully applied to the control of other infectious diseases (Wierup, 2002). Of fundamental importance is the fact that monitoring programmes require to be set up by which means *Salmonella*-infected herds and animals are identified and procedures laid down in order to find and remove the sources of infection and prevent its further spread. The ultimate objective is to produce *Salmonella*-free animals. It is emphasized that *Salmonella* is a pathogen and not a ubiquitous bacterium or a normal inhabitant of the intestinal flora of domestic animals, as has previously been claimed.

In contrast to the relatively uniform concept for surveillance and control of *Salmonella* in poultry production, no specific guidelines for corresponding actions appear to have been formulated for swine production. However, the same principles are applicable and so the principles presented here are of particular relevance.

6.2.2. Specific aspects

6.2.2.1. Source of infection

The primary and main source of *Salmonella* infection in swine production, and also in the whole food production chain, is the *Salmonella*-infected food-producing animal. Excreted bacteria infect neighbouring animals on the farm and a contamination of the environment takes place with infections transmitted to rodents and other animals of the wild fauna. When moved, the *Salmonella*-infected animals are an effective introducer of the infection to new holdings.

During the acute phase of the disease, pigs will shed up to 10^6 - 10^7 *Salmonella* bacteria per gram of faeces (Smith and Jones, 1967; Gutzman *et al.,* 1976) and the disease-producing dose is of a magnitude of 10^8 to 10^{11} cells (Schwartz, 1999). Wilcock and Schwartz (1992) concluded that in most instances *Salmonella* establish clinically inapparent infection of unknown duration which is of significance as a potential zoonosis, but usually not to the hosting pig. Under conditions of stress the usual non-pathogenic serovars may cause disease, but normally disease results only from infections with *S.* Choleraesuis or *S.* Typhimurium.

The environment may also act as a source of infection, but even if *Salmonella* bacteria can survive for long periods in the environment, no significant multiplication usually

occurs. Furthermore, *Salmonella* infections in e.g. rodents and wild fauna, are generally secondary to the infection of the farm animals, even though infection cycles may continue independent of a continuous input of *Salmonella* bacteria from the farm animals. In a review on the survival of *Salmonella* in the environment, Murray (1991) concludes that control of *Salmonella* must start with a significant decrease in the number of organisms that are discharged into the environment.

6.2.2.2. Live animals

In order to combat the source of infection, the primary action is to identify the *Salmonella*-infected animals or group of animals at the livestock farm. Methods for this are available and have been summarized in a WHO consultation (WHO, 1994) for the poultry production. Corresponding guidelines have not been worked out for the pig production but have since long successfully been applied in the Scandinavian countries. The current status of knowledge is presented in Chapter 5.

Animals found to be infected may be temporarily raised under isolation and controlled conditions but finally all infected animals must be sent to slaughter followed by appropriate inspection.

Consequently, bringing infected pigs into the herd is likely to be the most common means of introduction of *Salmonella.* To prevent this risk it is necessary to have access to certified *Salmonella*-free herds or pigs. Today this is possible when buying SPF-animals where *Salmonella* is part of the definition of SPF, which is exceptional and in the EU primarily limited to Denmark in addition to Sweden and Finland where the whole swine production have reached a virtually *Salmonella*-free status.

In the absence of "guaranteed *Salmonella*-free replacement animals" other ways have to be used to limit the risk of introducing *Salmonella* by incoming animals. Generally pigs should be introduced only from herds of the same or higher health status. Integrated production limits the need for introducing animals from other herds and thereby the risk of introducing *Salmonella* infected animals. Networking between producers is found to be an effective way to prevent respiratory and enteric infections should be a suitable way also for limiting the risk of introducing *Salmonella* by incoming animals. From research in the UK it became clear that sow herds that do not buy replacement gilts have a lower risk of being infected with *Salmonella* than herds that do buy replacement gilts. Isolation of incoming animals is an additional step to decrease the risk that *Salmonella* shed by subclinically infected animals following the transport is introduced to the new herd (Chapter 6.3.1).

There is undoubtedly a strong genetic association with resistance to salmonellosis in a number of economically important domestic species. However, as yet, selective breeding for resistance traits is not utilized in control of disease or the carriage of *Salmonella* in any of these species (Wigley, 2004).

6.2.2.3. Hygiene and husbandry

Optimal hygiene and management routines are of major importance for the ability of animals to withstand exposure to *Salmonella* and to minimise a possible subsequent

spread of the agent within a farm. Improvement of the hygienic and management procedures must be implemented as a natural part of the control of *Salmonella*. Guidelines and recommendations have been presented by, e.g. WHO (1983), Blood and Radostits (1989) and Schwartz (1999) as well as on vector control (WHO 1993b). Generally such actions, as exemplified below, are cost effective, considering their preventive effects also toward other infectious diseases.

All-in/all-out systems with thorough cleaning and disinfection between batches effectively prevent spread of infections. In the EU Salinpork project, the risk of testing seropositive for *Salmonella* infection at slaughter was found to be twice as high in herds with a continuous production system compared to herds with batch production (Lo Fo Wong and Hald, 2000). Raising of pigs without mixing of animals from different sources or ages, e.g. through group farrowing and subsequent raising of piglets up to slaughter without mixing of animals from other sources, has proved to be a good health supporting measure resulting in increased growth rate (Wierup, 2000). It is also found possible to rear growers and finishers free from *Salmonella* that come from sow herds that are infected with *Salmonella* (Dahl *et al.,* 1997), when using all-in/all-out and thorough cleaning and disinfection procedures. Closed pen separation prevents transmission of faeces from one pen to another and, therefore, it reduces spread of *Salmonella* through a herd. The importance of providing good herd and pen hygiene in the swine production, especially by decreasing the faecal oral transmission route, is emphasized in a recent report by EFSA (2005a).

The occurrence of diseases like *Brachyspira hyodysenteriae*, Aujeszky disease and Porcine Reproductive and Respiratory Syndrome (PRRS) are stressing factors that increase the susceptibility of swine to *Salmonella* exposure, and their control thus also contributes to the prevention or control of *Salmonella* infection in exposed herds.

The importance of hygienic management of animal effluents, including manure, is evident, especially when considering the increasing number of pigs kept on farms in some MS. Jones (1992) reviewed questions related to *Salmonella* in animal wastes and presented recommendations for storage and spread of animal manure and slurry.

As visitors can introduce *Salmonella* to a holding, basic requirements, such as a change of foot ware coveralls before entering a herd, are necessary (van der Wolf *et al.,* 2001c). Equally important is that tools or machinery are thoroughly cleaned and disinfected before being brought into the herd.

Animals like rodents, birds, foxes, cats, dogs as well as other farm animals can be or get contaminated and infected with *Salmonella* and spread the agent e.g. to pigs. Biosecurity prevents these animals to come into the herd and pigs should be kept separate from other species of farm animals. Continuous and effective rodent control is also a natural part of *Salmonella* control. Rodents can easily maintain *Salmonella* infection on a farm (Henzler and Opitz, 1992).

Husbandry systems where pigs are kept outside total confinement (pasture, free range etc.) are at an increased risk to become infected with *Salmonella* (van der Wolf *et al.*,)

2001a; Wingstrand *et al.,* 1999). Control under these circumstances will be very difficult as a result of the continuous exposure (Jensen *et al.,* 2006).

6.2.2.4. Feed control

The control of *Salmonella* contamination of feed is essential and is an integrated part of the pre-harvest control of *Salmonella*. Good Hygiene Practices (GMP) and Hazard Analysis Critical Control Points (HACCP) guidelines are available for feed manufacturers. In all countries there is most likely a constant but varying risk for animals to be exposed to *Salmonella* through their feed (Edel *et al.,* 1974; Fedorka-Cray *et al.,* 1997).

The documentation of the significance of this risk can be difficult to establish in countries with a relatively high prevalence of *Salmonella* without in deep epidemiological studies. Under such circumstances it can be difficult to exclude other sources than feed as the source of infections. In countries with low prevalence of *Salmonella*, feed is considered as a major source of *Salmonella* infections in swine, in particular because the great potential for spread to a large number of farms. Recently, an outbreak in swine caused by *S.* Cubana was documented in Sweden as a result of contamination in a feed plant. Forty-nine out of 77 pig farms having received potentially contaminated feed were infected (Österberg *et al.,* 2005). Currently (2006) a similar outbreak so far involving 140 farms are under investigations (www.sjv.se).

Considerable efforts are required to limit exposure of *Salmonella* from this source to an absolute minimum. Feed control can follow the procedure described by Häggblom (1994a, 1994b). These are based upon more than 50 years of experience in Sweden. Similar measures for the control of *Salmonella* have later been successfully introduced in other countries (Nielsen, 1992); these include the following basic elements:

1) import control to screen feed raw materials, the feed industry shall only produce feed from raw materials that are monitored for *Salmonella* and found negative.
2) Heat treatment. As shown by Edel *et al.* (1970) pelleting is a possibility to strongly reduce *Salmonella* contamination of the finished feed. Feed should therefore undergo such treatment (80°C during 30-45 seconds currently applied in Sweden). However, heat treatment may result in a risk for condensation (free water) due to inefficient cooling of the products in the cooler or transportation equipment or storage bins, creating suitable environment for *Salmonella* growth. Recontamination of heat treated feed may occur in the cooler from infected cooling air or by direct contact with untreated mash. It is therefore extremely important to avoid *Salmonella* contamination in the feed mill. A main objective for control at feed mills is further to provide thorough separation between raw material and finished feed and to avoid recontamination after heat treatment during cooling, transport or storage at farm level. The use of separated transportation systems for mash and pelleted feed is an important measure for preventing such recontamination of formerly heat treated feed. Efficient aspiration of the transportation systems and storage bins is important to remove moisture and dust.

3) It should be emphasized that the control cannot rely upon control of the finished feed from which *Salmonella* seldom can be detected unless it is heavily contaminated. Instead the concept should be to detect *Salmonella* as early as possible. An HACCP-based process control in the feed mill where the idea behind the control is to make sure that the production line is *Salmonella* negative using critical control points. A zero tolerance is adopted for *Salmonella* contamination.
4) Relevant action has to be taken immediately in case of finding of *Salmonella* in the feed mill. The development of an efficient procedure for cleaning and disinfection can ensure that *Salmonella* is eliminated (Stenberg Lewerin *et al.*, 2005).

6.2.2.5. Feed composition

Decades ago the effect of pelleting pig feed was recommended to reduce the introduction of *Salmonella* through the feed (Edel *et al.,* 1967; Edel *et al.,* 1970; Edel *et al.,* 1974)**.** This procedure has successfully been applied in the poultry industry.

However, in recent studies it was shown that feeding pelleted feed was associated with an increased risk of seropositivity for *Salmonella* at slaughter compared to feeding non pelleted feed and that wet feed and the use of whey were associated with reduced risk for seropositivity (Lo Fo Wong and Hald, 2000).

In Denmark a wide range of research is dedicated to meal feeding (Danish Bacon and Meat Council, 1999a; Danish Bacon and Meat Council, 1999b). Meal feed is supposed to enhance the gastric barrier for *Salmonella* and feeding meal is widely advised in Denmark as a method to control *Salmonella* in pigs. However, as feed ingredients like soy meal are frequently contaminated with *Salmonella,* this method using non heat treated feed is currently not recommend in low prevalence countries like Sweden. Methods are now also available for heat treatment of feed without pelleting. Fermenting feed or using fermented feed components (fermented liquid feed - FLF) used as a wet feeding system is found to have a *Salmonella* reducing effect (Brooks *et al.,* 2003; van der Wolf *et al.,* 1999; van der Wolf *et al.,* 2000; van der Wolf *et al.,* 2001b). Adding organic acid (e.g. formic-, acetic- or lactic acid) to feed can also have a *Salmonella* reducing effect (Dahl *et al.,* 1996b; Easter, 1988; Gedek *et al.,* 1992).

6.2.2.6. Drinking water

A draw back of the use of FLF is that it requires a large investment. For smaller herds that are not able to feed FLF it is possible to add organic acids to feed and/or drinking water of pigs. Although the effect is not as strong as with FLF, *Salmonella* can be reduced by adding organic acids to drinking water in low doses (van der Wolf *et al.,* 2001e). A further study combining improved hygiene management and acidification of drinking water showed a significant reduction of the *Salmonella* seroprevalence (van der Heijden *et al.,* 2005).

6.2.2.7. Antimicrobials

The use of antimicrobials to prevent suffering and economic losses in individual animals and herds can be justified but should always be combined with other

Salmonella reduction actions. Antibiotics have sometimes also been used to prevent shedding of *Salmonella* (Laval *et al.,* 1992), but the use of antibiotics in pigs with enterocolitis has not been found to reduce the prevalence, magnitude or duration of *Salmonella* in shedding by sick or recovered animals (Wilcock and Schwartz, 1992). Preventive treatment of carrier pigs with enrofloxacin was not able to eliminate the infection (Dahl *et al.,* 1996a).

It should also be considered that the use of antimicrobials for therapy or growth promoting also disrupt the gut flora which often increase the susceptibility of pigs for *Salmonella* infection (van der Wolf *et al.,* 2001d). The use of antibiotics may thus act as a trigger for the spread of a *Salmonella* infection within a herd which would not have occurred if the animals were untreated. EFSA recently also gave an opinion on the use of antimicrobials for control of *Salmonella* in poultry (EFSA, 2004b). It can be concluded as early also was recommended by WHO (1992) that control of *Salmonella* infection should not be based on the use of antimicrobials and the emergence of antimicrobial resistance is an additional serious reason why they should be used with great care as exemplified by the emergence of the multi-resistant *S.* Typhimurium DT 104 (Threlfall, 2002). Therefore, the use of antimicrobials for *Salmonella* control in pigs should be discouraged due to public health risks associated with development, selection and spread of antimicrobial resistance. Their use should be limited and subjected to the approval of competent authority in defined conditions that would minimize the risk for the public health.

Since 1 of January 2006 the use of antimicrobial growth promoters is prohibited in the EU.

6.2.2.8. Vaccines

Vaccines for the control of *Salmonella* infections are in use all over the world, inactivated vaccine being mainly used. In recent years increasing numbers of live vaccines have been developed but most of them are not yet authorised. However, experience has shown that *Salmonella* vaccines, especially live vaccines, in association with other measures related to improvement of veterinary hygiene and good management can perform outstandingly in the control of salmonellosis. Vaccination could thus very well play an important role in the intervention of *Salmonella* in high prevalence herds (Lumsden and Wilkie, 1992; Ortmann, 1999; Springer *et al.,* 2001; Haesebrouck *et al.* 2004).

Today an oral attenuated live vaccine based on *Salmonella* Typhimurium is available in Germany. Experiences with this vaccine are limited and the vaccine is not available in all EU countries at this moment (Selbitz *et al.,* 2003). Vaccination at an early stage of live (after weaning) would not interfere with serological detection of antibodies against *Salmonella* for monitoring purposes at the end of the finishing period. A special serological test has been developed to distinguish between vaccinated and naturally infected animals. Disadvantage of such vaccines is that they are serovar specific and offer probably only limited cross protection to infection with *Salmonella* from the same serogroup and provide limited protection against infection with *Salmonella* belonging to other serogroups.

Vaccination alone cannot eliminate *Salmonella* spp. from a herd, and whether vaccination is a suitable option in a control programme or not, depends on the aim of control programme (reduction or eradication), prevalence of *Salmonella*, serovars involved, detection methods used and cost-benefit.

6.2.2.9. Competitive exclusion

The use of competitive exclusion is a valuable part of *Salmonella* control in poultry. Competitive exclusion cultures have been used and tested in different countries as reviewed by e.g. Schneitz and Mead (2000). Positive results from the use of competitive exclusion are also reported from pigs (e.g. Genovese *et al.,* 2003). To be maximally effective, competitive exclusion should be administered before a potential exposure to *Salmonella* spp..

Wider studies are needed to fully quantify the effects of competitive exclusion in preventing *Salmonella* infections in pigs.

6.2.3. Current strategies for intervention, at pre-harvest level

The control measures described above are likely to have the effect of preventing or limiting *Salmonella* infection in pig herds. However, an effective intervention requires (i) a performance target to be specified, (ii) a strategy for application to be formulated and (iii) a strategy to be applied when the level of infection with *Salmonella* approaches or exceeds the target formulated for intervention. Optional strategies for the implementation of a control programme for *Salmonella* have been formulated (e.g. Wierup, 1994; Wierup, 1997).

An intervention strategy requires taking into account the situation in each MS and of the current control measures applied in some typical MS, such as those measures presented in Annex II. The following observations provide a scientific basis for intervention in the EU.

There are two different situations regarding the pig industry in the EU-25 in relation to prevalence and control of *Salmonella*, both generally and in the swine production, *viz*. MS with a low prevalence status and those with a medium or higher prevalence status. In Sweden, Finland (and Norway), a zero tolerance policy for *Salmonella* has resulted in a virtually *Salmonella*-free system of pork production. In other MS a higher *Salmonella* herd prevalence exists; of these, Denmark has the most advanced control.

6.2.3.1. Low prevalence status

In Finland and Sweden a strict intervention strategy was implemented since 1950-ies. The long term and consequent use of that strategy has resulted in a very low prevalence of *Salmonella* in the pork production which from a control point of view today can be considered as *Salmonella*-free. This is also the case for other major food producing animals in those countries. The objective of the current interventions is to maintain this status by applying a zero tolerance policy for *Salmonella* contamination in the whole production chain.

Due to the wide spread occurrence of *Salmonella*, re-introduction into *Salmonella*-free herds is a considerable risk. The control is therefore based on controls at critical control points (CCP) to detect occurring contamination or reintroduction of *Salmonella* in all parts of the production chain. Any finding of *Salmonella* in feed, animals, food and humans is notifiable. When *Salmonella* is isolated, subsequent intervention is undertaken immediately. An infected herd will be embargoed, and monitoring and cleaning up procedures are applied. If necessary, ultimately slaughter of all infected animals is carried out, irrespectively of serovar or whether animals are clinically affected or not. Cleaning and disinfection procedures follow and embargo is not lifted until no *Salmonella* is isolated from repeated sampling. The embargo includes up and downstream epidemiological tracing and testing to detect and eliminate possible source and spread of the infection by the use of the same strategy.

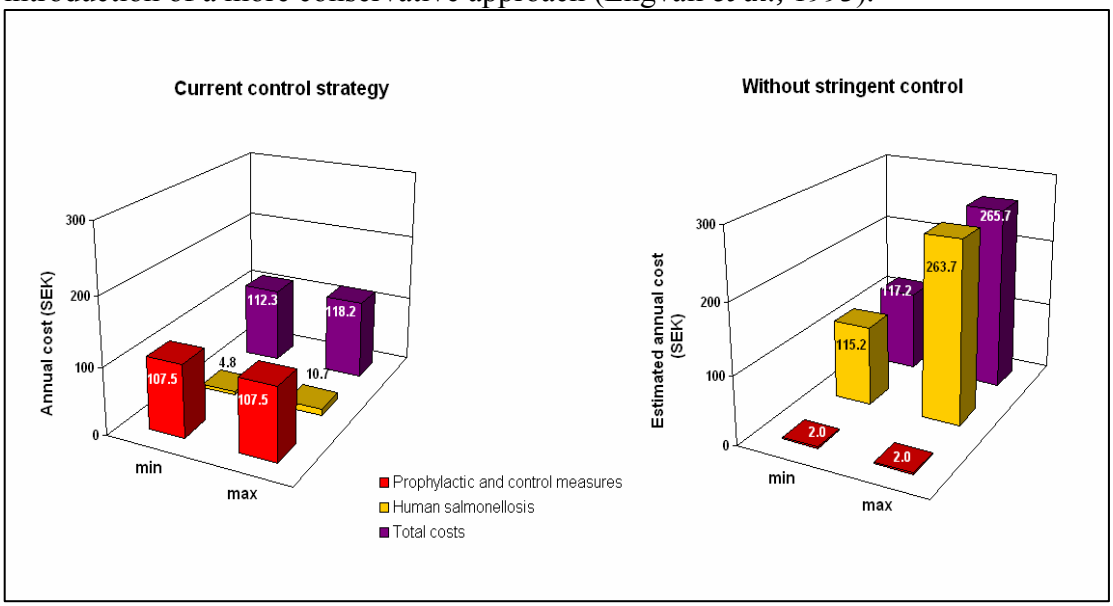
As a necessary complement, imported as well as nationally produced feed is under a continuous control for *Salmonella*. When *Salmonella* is detected in any of the samples in the monitoring programme of feed mills, adapted corrective actions, depending on the location of the positive sample, will take place immediately in the processing line.

Monitoring and interventions are based on detection and identifying *Salmonella* by the use of bacteriological methods. Both control and surveillance follow specific EU approved regulations to enable these countries to maintain their *Salmonella* status when they entered the EU in 1995. In addition industry based complementary actions are also in place. A similar situation exists in Norway.

A cost benefit analysis of the current strategy applied in Sweden has demonstrated its advantages both economically and in public health terms, in relation to a more conservative approach (Figure 6) (Engvall *et al.,* 1993).

The national *Salmonella* monitoring and control programme of Sweden is described in Annex II, as an example of the approach in low prevalence countries.

Figure 6. Result from cost benefit analysis of a more stringent control for *Salmonella* as applied in animal production in Sweden in comparison to the estimated result of the introduction of a more conservative approach (Engvall *et al.*, 1993).



6.2.3.2. Medium and higher prevalence status

In the remaining MS control and surveillance follow different strategies. As a result, it is not possible to compare the prevalence of *Salmonella* in swine production or pork between individual MS with that in the low prevalence countries (Chapter 6.2.3.1). In this group of MS, Denmark has the lowest *Salmonella* prevalence in pork. A plausible reason for this is that Denmark started a strategic *Salmonella* monitoring and control programme in pigs and pork several years before the other MS in the group had implemented any systematic measurement.

The national *Salmonella* monitoring and control programmes of Denmark, United Kingdom, Ireland, Germany and The Netherlands are described in Annex II.

6.2.4. Strategies for intervention in the pre-harvest phase in the EU

To-date, results from *Salmonella* reduction schemes in swine production in Denmark and elsewhere have indicated a decrease in prevalence similar to that attributed to such schemes in operation in the poultry industry (Christensen *et al.*, 2002). However, due to the more complex situation of the swine production, the achievement of positive results of interventions on a national basis will need a more long term application covering all steps of the production chain (Kaesbohrer, 1999). A stepwise approach to the introduction of possible targeted interventions is advisable, however.

6.2.4.1. Feed

An initial and logic approach is to ensure a high level of *Salmonella* control in feed based on GMP-HACCP and not on endpoint control.

6.2.4.2. Hygiene and management routines

Efforts to achieve a good hygienic status and optimal management routines require to be undertaken in all infected herds as a natural part of other specific measures for the control of *Salmonella* (6.2.2.3). These include day to day management procedures like all-in/all-out systems with cleaning and disinfection between batches, supply of clean drinking water, fly and rodent control, no access of pets and birds, visitor hygiene as part of biosecurity, no close contact to other production animals, etc. On the other hand, they include housing strategies like percentage slatted floors, pen separations, pig flow through the herd, feeding troughs and drinking bowls, feeding systems (wet or dry feed, pelleted or meal feed), herd biosecurity, introduction of new animals out-door access and multiple site production systems.

6.2.4.3. Feed interventions

In addition to Point 6.2.4.1 above, feed and water can be used to help control *Salmonella* infections by switching to meal feed or wet feed or fermented liquid feed. Acidifying the feed and/or drinking water are other options.

6.2.4.4. Depopulation and *Salmonella* free replacement animals.

In countries in an advanced stage of *Salmonella* intervention, such as the Nordic Countries, as described in 6.2.3.1 above, total or targeted depopulation and repopulation of entire herds is an option. The establishment of a pool of *Salmonella*-negative herds for replacement animals is a prerequisite for the application of that strategy. The herds at the top of the breeding pyramid need special attention and should be free from *Salmonella*.

A depopulation policy is successfully applied in low prevalence countries (Chapter 6.2.3.1). However, when applied in populations with a medium or higher prevalence of *Salmonella* (Chapter 6.2.3.2) as in Denmark, 52% of 349 herds were in one study found to be re-contaminated (checked by serology) within a few months (Dahl, 1999). The experience of that study was that depopulation always should be combined with the strict applications of other methods for reduction of *Salmonella* contamination. This was also supported when in the same country a higher success rate of eradication policy was applied for *Salmonella* Typhimurium DT 104 when stricter biosecurity was applied (Møgelmose *et al.,* 1999).

However, these options are not advisable in the present situation in the medium and higher prevalence countries. Interventions should instead initially focus on the reduction of the within-herd prevalence (Chapter 6.2.2). When designing a control programme, recent modelling studies that have shown that focusing control on high prevalence herds (as level 2 and 3 in the Danish control programme, see Annex II) may not be the optimal strategy (Alban and Stark, 2005), require consideration. The greatest public health benefit is likely to be obtained from modest improvements on all farms rather than from large improvements on farms with only a high prevalence alone (Alban and Stark, 2005; Cook *et al.,* 2005).

6.2.4.5. Serovars to be the subject of focus

There is no scientific basis to focus intervention on certain serovars to the exclusion of others. Regarding intervention for *Salmonella* in pigs and pork, the same advice can be given in the case of any of the serovars.

6.2.4.6. Monitoring

Monitoring by the use of bacteriological methods is required in order to obtain a true picture of the *Salmonella* status. Serological methods are applicable especially in medium and high prevalence MS as they are fast and suitable for large scale usage at a low cost. However, their limitations have to be considered, as discussed in Chapter 5; furthermore, they require to be supplemented by a strategic use of bacteriological methods (Table 11) to ensure that emerging serovars, that might not have been included in the ELISA, can be detected. On the other hand, in the low prevalence MS the bacteriological methods currently used for detecting *Salmonella* in surveillance and intervention schemes may be supplemented, but may not be replaced, by indirect serological methods, for reasons presented in Chapter 5.

6.2.5. Breeding or finisher

Due to the complexity and diversity of the swine production industry, the achievement of positive results of interventions on a national basis will require a long term action plan covering all phases of the production chain (Kaesbohrer, 1999). If an intervention were to be initiated in any of these phases, it is important to consider that the production steps mentioned here can be run in an integrated way on the same farm (integrated production) or at different locations (specialized production). Further information on the outline of the different steps of the production chain is given in previous EFSA opinions.

In order to respond to the question in the Terms of Reference (ToR) on whether or not to commence interventions in breeding or finishing herds, the following observations are of relevance.

6.2.5.1. Breeding production

Pigs are generally most susceptible to *Salmonella* exposure during the growing period when the circulation of pathogenic agents usually is most pronounced. This is the critical point to be considered and have to involve also the *Salmonella* status of the breeding animals and piglets earlier in the production chain. However, piglets delivered from units where the *Salmonella* prevalence is successfully reduced will readily be infected and colonized following transfer to the finishing herds if mixed with pigs from herds of a lower *Salmonella* status or by residual infection in the finishing herds. An intervention for *Salmonella* control focused only on the piglet producing breeding and grower herds can therefore not be recommended.

6.2.5.2. Finisher production

The main exposure of the human population is the consequence of *Salmonella* presence in finishing pigs. Therefore it is reasonable to focus the interventions initially on finishing pigs because this would have a more direct influence on the subsequent steps of the food chain (harvest and post-harvest level) and on public

health. Experience shows that an emphasis on control measures in the finisher phase leads to a larger and more rapid reduction in *Salmonella* prevalence in pigs and pork than emphasis on the sow/breeding level.

An advantage of starting with interventions in finisher production is that it would present incentives for *Salmonella* reduction earlier in the production chain including the feed. Due to the "ripple effect", multipliers and breeders would then be asked to supply *Salmonella*-free growers and breeding gilts respectively and compound feed manufacturers would be asked to supply *Salmonella*-free feed, thereby resulting in an involvement of the entire production chain. Research has shown that it is possible to produce *Salmonella*-free growers and finishers without the sows being *Salmonella*-free (Dahl *et al.*, 1997).

6.2.6. Conclusions on risk mitigation options at pre-harvest level

In general, the control has to focus on the implementation of preventive actions in each phase of the entire production chain because there is no "silver bullet" through which the level of *Salmonella* contamination can be reduced.

The control of *Salmonella* can follow those general rules that have been successfully applied to the control of other infectious diseases.

More specifically, the following measures required to be followed:

- Prevention of introduction of *Salmonella* into the herd:
  - by infected animals, being the primary and major source of infection,
  - by feed, being a continuous risk for new introduction to herds in all MS,
  - from a contaminated environment (e.g. rodents) and by equipment and visitors.
- Prevention of in-herd transmission:
  - implementation of optimal hygienic and management routines; e.g. all-in-all-out systems, batch production with through cleaning and disinfection between batches,
  - identification and removal or isolation of *Salmonella* infected animals or group of animals,
  - control of vectors such as rodents and birds.
- Increase resistance to infection:
  - support good health and good management e.g. by reducing predisposing factors like the occurrence of other infectious diseases, e.g. dysentery (*Brachyspira hyodysenteriae*), Aujeszky´s disease and PRRS and worm infections,
  - the use of vaccine is a suitable option in a control programme depending on several factors, e.g. aim of the control plan (reduction or eradication),

prevalence of *Salmonella*, etc. However, vaccination alone cannot eliminate *Salmonella* spp. from a herd,

- the use of antimicrobials for *Salmonella* control in pigs should be discouraged due to public health risks associated with development, selection and spread of resistance. Their use should be limited and subjected to the approval of competent authority in defined conditions that would minimize the risk for the public health,
- the use of fermented liquid feed and acidifying compounds in feed and drinking water generally is found to have a *Salmonella* reducing effect.

- Strategies for interventions:
  - an initial monitoring is required in order to establish a basis, the true picture of the current situation from a public health point of view,
  - focus intervention for the control and elimination of all certain serovars associated with pigs and pork, as there is no scientific basis for focusing on certain serovars,
  - in medium and high prevalence countries (Chapter 6.2.3.2) interventions required to be based on a successive implementation of those *Salmonella* reducing steps specified in Chapter 6.2. The results to be achieved require to be assessed based upon a long term perspective,
  - at regularly controlled intervals the interventions required to be evaluated to ensure compliance and efficacy and necessary modifications undertaken. It is considered that while these interventions will considerably reduce the *Salmonella* prevalence at pre-harvest level, it remains to be seen if this strategy alone can result in a relatively *Salmonella*-free primary production system comparable to those systems that currently exist in the low prevalence countries,
  - low prevalence countries (Chapter 6.2.3.1) require to ensure that the favourable *Salmonella* situation achieved to-date is maintained by the continuous use and, where possible, cost effective improvement of current monitoring and intervention strategies,
  - for all MS a supporting monitoring programme is required to be in place and modified so as to meet the objectives and to apply appropriate strategies consistent with the status of the MS or region under consideration, as described above (Chapter 5.3).
- Intervention in breeding or finisher production:
  - a holistic approach from breeding to slaughter and processing is required in order to reduce the risk to human health from *Salmonella* in pigs and pork. An emphasis on the measures taken at the finisher phase has been shown to result in a greater and more rapid reduction in *Salmonella* prevalence in pigs and pork than emphasis on measures taken at the sow level.

6.3. Risk mitigation options for *Salmonella* at harvest level

As indicated in 6.1.1, the definition of "harvest" for the purpose of this opinion will cover the part of the food chain beginning with the transport of the slaughter animals from the farm gate, the lairage phase, slaughtering itself, up to the cooling of the carcasses.

6.3.1. Transport and Lairage

6.3.1.1. Effect of transport and lairage

In medium and high prevalence countries transport-lairage (TL) phase increases the *Salmonella* occurrence and/or levels of *Salmonella* in pigs in proportions varying approximately from 20 to 40% (Berends *et al.,* 1996; Fravalo *et al.,* 1999). However, any comparison of the status pre- and post-TL may be affected by the sampling methods used to evaluate the status (e.g. faecal *versus* caecal contents). Concerning the evolution of the level of contamination between the farm and slaughtering, the work of Hurd *et al.* (2002) is the highly relevant. The TL step was associated with an increase in the percentage of contaminated pigs, at each sampling site examined (*viz.* caecum, mesenteric lymph nodes and faecal). In another study, 5% of the pigs were positive at the end of the fattening period at the farm; when examined at the slaughterhouse nearly 40% were positive. The group of pigs found to be shedding salmonellae in the slaughterhouse was comprised of (i) newly contaminated pigs and (ii) the initially infected pigs in which latent infection had been reactivated and pigs that were already shedding (Berends *et al.,* 1996). The authors considered that half of the increase was due to new contaminations.

The likelihood and the risk of contamination during transport and lairage may vary both regionally and between countries (Hald *et al.,* 2003; Gebreyes *et al.,* 2004a; 2004b). The excretion or re-excretion risk was estimated with OR 2.6 for a TL phase from 2 to 6 hours (Berends et el., 1996). However, such an estimation should be considered as associated with the particular production system used and may also be influenced according to the *Salmonella* status of the herd and the duration in transit (Beloeil *et al.,* 2003; Stärk *et al.,* 2002). Provided that efforts made to eliminate infection in the earlier production steps are effective, cross contamination with *Salmonella* at slaughterhouses should not be relevant (Thorberg and Engvall, 2001).

6.3.1.2. Duration and conditions of transport

The effect of transport on *Salmonella* shedding depends on various factors, *viz.* the mixing of animals of different origins, the duration of transportation and the general conditions of transport and their effect on animal welfare.

6.3.1.3. Stress

Stress during transport is common and is regularly reported as a risk factor for *Salmonella* contamination (Berends *et al.,* 1996; Marg *et al.,* 2001). However, stress characterisation and quantification is poorly documented. Furthermore, it is difficult both to distinguish between the stress caused by transportation and that which arises during lairage and to characterize the effect of that stress (Marg *et al.,* 2001; Stabel and Fedorka-Cray, 2004).

6.3.1.4. Lairaging conditions

Lairages can act as reservoirs for pathogenic bacteria and there is evidence that longer holding times in lairage increase the risk of cross-contamination (Beloeil *et al.,* 2003; Warriss, 2003). Rapid contamination of pigs can occur in pigs while held in lairage (Hurd *et al.,* 2001a; Hurd *et al.,* 2001b).

Contamination of unloading-race and holding pens. The unloading area (McLaren and Wray, 1991) and the race and restrainer are likely to be highly contaminated (Larsen *et al.,* 2004; Schmidt *et al.,* 2004). Some studies have shown that environmental contamination ranges from 0 to 80% of swabs taken from the holding pens (McLaren and Wray, 1991; Williams and Newell, 1968; Larsen *et al.,* 2004; Schmidt *et al.,* 2004).

Contamination of water troughs. Williams and Newell (1968) showed that the water troughs were highly contaminated, and that pigs readily acquired a range of *Salmonella* serovars present in the troughs.

Contamination of environmental surfaces. In an EU-wide study (Lo Fo Wong and Hald, 2000), *Salmonella* was not isolated from any slaughterhouse in all but one MS. In the remaining MS, *Salmonella* was isolated from 13.8% of the 3 576 environmental samples (ranging from 6.3% to 28.3% between slaughterhouses). In these slaughterhouses, while *Salmonella* could be isolated from the environment before onset of slaughter, the prevalence was generally higher in samples taken during the later sampling rounds.

Duration in lairage. Some studies showed that lairaging duration and *Salmonella* occurrence are directly correlated, i.e. the isolation rate from pigs increases significantly with increasing time spent in the lairage for periods of less than 24 hours (Morgan *et al.,* 1987). Beloeil *et al.* (2004b) showed that two variables, viz. "status of the batch according to that of the herd" (as determined by serology or bacteriology) and "the length of lairage at the slaughterhouse", are associated with the presence of *Salmonella* in the caecum. Independently of any other variables related to herds, these authors concluded that it is the lairage duration that increased the risk of caecal contamination.

After oral or nasal uptake of *Salmonella* during co-mingling, during transport and/or holding, dissemination through the entire body may occur within two to three hours and results in shedding of *Salmonella* (Hurd *et al.,* 2001b; Fedorka-Cray *et al.,* 1995). Consequently many more pigs may be found to have acquired contamination with *Salmonella* e.g. on their skin, in their nasopharynx and in their alimentary tracts when examined at the moment of slaughter compared to when they left the farm (Beloeil *et al.,* 2004a, 2004b; Craven and Hurst, 1982; Davies *et al.,* 1999; Hurd *et al.,* 2001b; Letellier *et al.,* 1999; Morgan *et al.,* 1987; Quirke *et al.,* 2001).

6.3.1.5. Current mitigation options in transport-lairage phase

6.3.1.5.1. Transport

While it is difficult to differentiate the transport phase from the lairage phase of TL, specific options to limit or prevent re-excretion or cross contamination include:

- cleaning and disinfection of the trucks,
- avoiding mixing batches of pigs from different herds in the same trucks (Schwanneburg *et al.*, 2001a),
- optimising the transport logistic so as to reduce the duration of transport (Beloeil *et al.*, 2004b),
- promoting transport under less stressful conditions, and in accordance with the Opinion adopted by the EFSA Panel on animal health and welfare (AHAW) related to the welfare of animals during transport (EFSA, 2004a).

Moreover, it is recognized that feed withdrawal limits the effects of other factors in giving rise to stress (transport) and facilitates technically the performance of evisceration and thereby limits the risk of carcass contamination at this latter "at risk" step.

6.3.1.5.2. Lairage

In one study conducted by Fravalo *et al.* (2002), contamination of the lairage floor was found to be distributed homogeneously, with contaminations not exceeding 1 *Salmonella* per cm^2 of ground. Control of the contamination of the pens floor is necessary as the level of contamination present may determine the extent to which the pigs may acquire infection (Loynachan and Harris, 2005). Control can be achieved through the implementation of plant-specific *Salmonella* minimising strategies (Kühnel and Blaha, 2005). Identification of lairage-specific mitigation options includes two basic objectives, namely:

- to limit the duration of the lairage period in accordance with welfare needs and meat quality considerations (Warriss, 2003),
- to limit the ground contamination by avoiding accumulation: improve cleaning and disinfecting protocols (Kühnel and Blaha, 2005) or the adaptation of ground structure to promote fecal elimination.

6.3.1.6. Further developments

Adaptation of the cleaning and disinfection procedures in the lairage phase is required. Boes *et al.* (2001) confirmed that washing without disinfecting is not efficient to removing *Salmonella* from the lairage pens. In fact, the protocols examined failed to eliminate *Salmonella* inform the lairage (Schmidt *et al.*, 2004; Kühnel and Blaha, 2005). Development of the materials to be used in lairages to prevent contact with fecal matter (slatted floor) and to facilitate cleaning and disinfection, requires to be taken into consideration to limit exposure during this phase.

6.3.2. Slaughter and carcass dressing phase

Slaughter pigs carrying *Salmonella* are known to be a considerable risk for a contamination of the ultimate meat and meat products (Berends *et al.,* 1997; Botteldoorn *et al.,* 2003; Chaunchom, 2003). Within groups of slaughter pigs, there is a strong correlation between the proportion of animals carrying *Salmonella* in the faeces and the proportion of contaminated carcasses (Oosterom *et al.,* 1985; Morgan *et al.,* 1987; Davies *et al.,* 1999; Giovannacci *et al.,* 2001). Pigs with *Salmonella* spp. in their faeces are 3 to 4 times more likely to give rise to a positive carcass than non-carrier animals (Brekelmans *et al.,* 1980).

It should be kept in mind that herd prevalence of *Salmonella* in pigs has been reported to vary widely e.g. 2.8% (Letellier *et al.,* 1999) or 36% (Jones and Hall, 1975). Within-herd prevalence can be as high as 50% or more (Letellier *et al.,* 1999). At individual pig level at slaughter, some investigations showed that prevalence of healthy faecal carriers to be 18% (Mafu *et al.,* 1989), 23% (Davies *et al.,* 2000) or even as high as 75% (Chau *et al.,* 1977).

In the EU study (Lo Fo Wong and Hald, 2000), the extent of cross-contamination in the slaughterhouse was estimated by first investigating pigs slaughtered from one or more *Salmonella* positive herds and then investigating pigs from one or more *Salmonella* negative herds. By sampling the carcasses at several point during the slaughter process, the contamination of the carcasses from the negative herds, when measured, provided information on the degree of cross-contamination brought about by manual handling and processing. The results showed that not all pigs from the *Salmonella* negative herds remained *Salmonella*-negative during and after slaughter. The source of contamination may have been the lairage, since it was possible for faecal matter to pass between the pens holding the positive and the negative pigs. Another source of contamination of the carcasses was considered to be the slaughter equipment, especially the carcass splitter. Carcasses of pigs may be cross-contaminated from either *Salmonella*-positive pigs slaughtered previously on the same day, or from contaminated slaughter equipment. Such equipment can also be contaminated from *Salmonella* positive pigs slaughtered on the same day, but the results strongly suggested, that residual and/or persistent contamination of the equipment is also an important source.

Botteldoorn *et al.* (2003) considered that contamination of 30% of positive carcasses arose from cross-contamination from other infected pigs, and that up to 70% by cross-contamination from the carrier animals themselves (Morgan *et al.,* 1987; Berends *et al.,* 1997). These figures will, however, vary depending on the *Salmonella* prevalence in different batches of slaughtered pigs. Therefore, the epidemiology of *Salmonella* at slaughterhouse level is considered likely to be primarily due to direct or indirect faecal contamination of live pigs or carcasses (D'Aoust, 1989).

6.3.2.1. Effects of slaughter and carcass dressing

Scalding. Scalding usually reduces the number of *Salmonella* spp. on the carcass surface. However, if the water temperature drops below the recommended 62^{o}C

and/or the amount of organic material may be sufficient to protect the bacteria against the heat, the probability of bacteria surviving this process is increased.

Singeing. Some authors report that after singeing the surface of most slaughter pigs can be considered free of *Enterobacteriaceae* (Gerats, 1990; Snijders, 1992; Bolton *et al.,* 2002). Other authors have shown that the number of carcasses positive for *Salmonella* spp. before scalding and dehairing was reduced by from 30 to 70% by these procedures (Chau *et al.,* 1977). In the case of *Salmonella*, the bacterial load *Salmonella* was reduced by approximately 4.5 $\log_{10}$ cfu cm^{-2} (Bolton *et al.,* 2002).

Polishing. Immediately after singeing, a consistent increase in *Enterobacteriaceae* due to polishing and evisceration has been observed (Gerats; 1990, Snijders, 1992, Bolton *et al.,* 2002). Berends *et al.* (1997) estimated that 5 to 15% of all carcass contamination occurred during polishing, 55 to 90% during evisceration and 5 to 35% during further carcass dressing including dressing, splitting etc. Risk factors with high odd ratios for *Enterobacteriaceae* contamination are dirty polishing equipment as well as faulty techniques and inadequate hygiene measures during evisceration (Gerats, 1990). However, in samples collected from properly used and cleaned polishing equipment, *Salmonella* was only found in 2% of the samples (Swanenburg *et al.,* 2001a). However, even if of polishing machines are found to be *Salmonella*-positive, this has only a minor impact on the proportion of positive carcasses (Van der Palen *et al.,* 1992), thus indicating differences between cross-contamination of *Enterobacteriaceae* as described by Gerats (1990) and *Salmonella*.

Evisceration. Faulty evisceration can be the cause for up to 90% of the number of carcasses contaminated with *Enterobacteriaceae* as well as of up to 90% of the loading with these microorganisms (Gerats, 1990). In the evisceration environment of the slaughter line a high number of *Salmonella* positive samples can be found (Giovannacci *et al.,* 2001; von Altrock *et al.,* 2001). Extra careful evisceration can reduce the bacterial load. Besides, the human factor is important for the proper implementation of cleaning and disinfection procedures for e.g. hands and knives (Gerats, 1990; Van der Palen *et al.,* 1992). However, hands of most slaughterhouse personnel as well as the knives are only sporadically contaminated with *Salmonella* spp. (Hald *et al.,* 2003). Handling due to meat inspection has also to be considered, as there is a potential for spread of carcass contamination to other areas of the carcass or to other carcasses in the course of such inspection (Berends *et al.,* 1993).

Slaughterline environment. The hygienic condition of the slaughterhouse walls, the floors, and the ceilings as well as dripping condensation water and the air are usually rather secondary factors with regard to carcass contamination with *Salmonella* in the slaughter routine (Grau, 1989; Van der Palen *et al.,* 1992; Berends *et al.,* 1995) even though high levels of contamination can be found in samples of water outlets (Hald *et al.,* 2003; von Altrock *et al.,* 2001). An average of 25% of overshoe samples taken at two different slaughter lines before the start of slaughter process were found positive (Botteldoorn *et al.,* 2003) as were approximately 5 to 50% of all environmental samples (Giovannacci *et al.,* 2001; Hald *et al.,* 2003). However, all samples from all

of the slaughterhouses investigated in one MS were found to be negative (Hald *et al.*, 2003).

Final washing of the carcasses increases the bacterial counts to between 3.6 to 3.8 $\log_{10}$ cfu cm^{-2} while, at chilling, the amount of bacteria significantly rises to about 4.6 $\log_{10}$ cfu cm^{-2} (Bolton *et al.,* 2002). However, Bauvet *et al.* (2002) described a decrease in the number of *Salmonella*-positive pig carcasses when sampled from the bleeding stage to chilling.

6.3.2.2. Current mitigation options of slaughter and carcass dressing

6.3.2.2.1. Hygiene of slaughtering

The most important mitigation option is to ensure that slaughter and carcass dressing are performed in an efficient manner so as to ensure that fecal contamination of the carcass and offals is not a common event. In addition, specified action requires to be taken when visible fecal contamination is seen. Guidelines for hygienic slaughter are available at both national and international level; these comprise recommendations on the hygienic design of establishments and facilities including their equipment, process control systems including GHP as well as HACCP based systems and codes of personal hygiene (Codex Alimentarius, 2005). Finally, regular monitoring and auditing of all phases of the hygiene programmes for slaughter and carcass dressing including microbiological testing afford the means of ensuring effective control of carcass and offal contamination with *Salmonella* during this phase.

6.3.2.2.2. Cooling

The initial carcass temperature after slaughter is 39-42°C, and not 37°C, as a result of anaerobic glycolysis and technological processes (Beutling, 1992). Temperatures below 10°C can be reached after few hours; however certain commercial systems of cooling can be applied and in which case temperatures below 30°C are reached by 6 hours and below 10°C after approximately 19-20 hours. Pork carcasses are required to reach 7°C after 24 h or before being moved (Beutling, 1992; Savell *et al.,* 2004). Chilling pork to internal temperatures of 20 to 25°C within 2 to 3 hours post-slaughter can reduce the incidence and severity of the condition, Pale Soft Exudative (PSE) meat; however, muscle should not be chilled below 10°C in the first 5 hours post-slaughter (Savell *et al.,* 2004). Under commercial conditions a range of cooling systems are employed in which the time needed to reach a core carcass temperature of 7° C ranges from 12 hours with fast cooling systems to 1.5 hours with shock cooling / intensive cooling systems (Ortner, 1988; Beutling, 1992). The behaviour and survival patterns of *Salmonella* serovars under these conditions requires further study.

6.3.2.2.3. Logistic slaughtering

Separate slaughtering of *Salmonella*-negative herds or slaughtering negative herds before positive herds has a positive impact on the incidence and extent of *Salmonella* contamination of pig carcasses in the slaughterhouse according to Swanenburg *et al.* (2001b). Better results can be obtained if batches from different herds are also separated during transport, lairage and, later, carcass cooling (Swanenburg *et al.*, 2001b). The most efficient means of achieving separation is by slaughtering

Salmonella-negative herds in different slaughterhouses than *Salmonella*-positive herds.

6.3.2.3. Further developments

6.3.2.3.1. Modifications of the slaughterline operations

While technical aspects of individual operations of pig slaughterline may vary considerably between abattoirs, the order in which these operations are carried out is less variable and is generally as follows: slaughter – scalding – dehairing – singeing – polishing – evisceration – splitting – chilling.

Each of these operations carries different microbial risks and contributes differently to the final microbial load of the carcass (Gill and Bryant 1993; James and James, 1995; Gill *et al.,* 1995; Gill *et al.,* 1997; James *et al.,* 1999; James, 2002).

Therefore, when considering possible modifications of these operations aimed at improving microbial status of pork carcasses, the most effective modifications would be those targeting the microbiologically key operations. These would include following:

- tank scalding can lead to cross-contamination: replacing submersion-scalding with spray-scalding would be beneficial,
- faeces-voidage-mediated contamination occurs in dehairing machines: related technical modifications would be beneficial,
- "good" singeing can produce 1.5-3 log microbial reduction, but these effects can be largely negated by common re-contamination during subsequent polishing step: avoiding of polishing step, or inversing of the singeing-polishing order, or repeating of the singeing step, could prevent such a negation,
- high speed of pig slaughterlines leaves short time for laborious but contamination-risky operations such as evisceration: the speed at such points could be slowed down through "branching" the line so to achieve multiple evisceration stations,
- inclusion of a final carcass decontamination step, alone or in combination, e.g. a post-evisceration hot wash could reduce the microbial load on final carcasses (more details in 6.3.1.1.2).

Overall, improving pig abattoir process hygiene and hence microbial status of pork carcasses through re-thinking of the traditional slaughterline design appears promising. It appears that general design of the individual operations, and their order, in industrial high-throughput pig abattoirs have not changed significantly (apart from individual machinery) for decades. The present design/order is dictated primarily by a desire for ever higher speed/throughput, but their actual microbiological effects may appear as a "secondary" criterion. Therefore, further research on hygiene-led re-designing of pig slaughterline and related cost-meat safety benefit analysis is necessary.

6.3.2.3.2. Carcass decontamination treatments

The reason for considering meat decontamination is the fact that certain level of microbial contamination of fresh meat surfaces (i.e. carcasses) inadvertently but regularly occurs during the slaughter and dressing of animals. Presently and under commercial conditions, this risk cannot be fully eliminated only by process hygiene means no matter how carefully the various procedures are carried out. Scientifically, the EU approach to meat decontamination has been based on the SCVMPH Report on the "Benefits and limitations of antimicrobial treatment for poultry carcasses" (SCVMPH, 1998). The report concluded that there is a need to reduce the burden of foodborne disease but that meat decontamination "should not be used as the primary pathogen reduction measure". The report recommended that meat decontamination: a) should not be used as the primary pathogen reduction measure; and b) could be used, but only as part of an overall meat safety strategy and authorised use should be subject to a range of controls, including a full risk assessment covering aspects such as efficacy, consumer perception, microflora changes, environmental impact and others. Consequently, current legislation does not allow for carcass decontamination treatments apart from using water. Literature on various meat decontamination treatments is very voluminous, and only the main types of treatments applicable to pork carcasses will be briefly mentioned here. Based on their nature, the treatments can be divided into following:

- *Heat treatments.* For heat treatment (80-85^{o}C) of carcasses, either hot water or steam can be used (James *et al.,* 1997; James *et al.,* 1999). The total microbial reductions reported in different studies conducted under differing conditions and different meat species vary, and normally are within a 2.5-3.7 logs range for vegetative forms of the main foodborne pathogens (*Salmonella, L. monocytogenes, E. coli* O157).
- *Irradiation treatments.* Doses of 1-3 kGy are used for non-carcass meats in some non-EU countries (Farkas, 1998). Generally, the microbial reduction rates achieved are within a 2-3 logs range for vegetative forms of the main foodborne pathogens (e.g. *Salmonella*), but not with viruses or microbial toxins.
- *Chemical treatments.* A range of low-molecule organic acids (e.g. lactic, acetic, citric, fumaric) are used commercially for meat decontamination in some countries (Smulders and Greer, 1998; van der Marel *et al.* 1988). Generally, the microbial reductions achieved are within a 2-3 logs range for vegetative forms of the main foodborne pathogens (e.g. *Salmonella, L. monocytogenes*). Other chemicals used for pig meat decontamination include chlorine and trisodium phosphate and, generally, the microbial reductions of vegetative forms of main foodborne pathogens (e.g. *Salmonella*, *E. coli* O157) achieved are 1-1.5 logs (Sofos and Smith, 1998; Ellerbroek *et al.,* 1998).
- *Other treatments*. A variety of other decontamination treatments have been published (e.g. high voltage pulsed field, high pressure, etc) but not for carcasses.

Advantages and disadvantages of meat decontamination. Accurate evaluation of overall effects of meat decontamination treatments is difficult, as most efficacy data result from laboratory studies but extrapolation to commercial practice is not

warranted (Smulders and Greer, 1998). Due to variable initial microbial loads and limited microbial reductions by the treatments available, it is not likely that meat decontamination would enable reliable production of hazard-free carcasses. General considerations are summarised here in following way:

a) advantages include improved meat safety through reduction of prevalences/levels of microbial hazards on meat, provision for inclusion of a hazard-eliminating CCP into HACCP, and reduction of overall pathogens populations being passed into the meat processing/distribution stages,

b) disadvantages include potential problems with disproportionate reliance on decontamination step and consequent reduction of the process hygiene, limited reduction rates achievable enabling positive selection for surviving resistant strains, stress-mediated increase of virulence of the surviving strains, subsequent enhanced growth of surviving pathogens due to elimination of background meat microflora, environmental pressure of the treatment chemicals, occupational health aspects, cost-benefit variability, labelling and potential consumer reactions.

6.3.2.4. Microbiological monitoring of carcasses and surfaces

6.3.2.4.1. Main aims of microbiological testing of carcasses

Historically, microbiological testing of carcasses has been used with the following main aims:

A. *Monitoring/surveillance of pathogens in pigs on-farm via testing of resulting carcasses at abattoir*. Due to animal-animal and/or environment-animal cross-contamination taking place at abattoir during unloading-lairaging events (see Chapter 6.3.1.), as well as cross-contamination occurring during slaughter-dressing events (see Chapter 6.3.2.), no direct correlation between *Salmonella* in pigs on-farm and *Salmonella* present on resulting carcasses at-abattoir is to be expected. Therefore, as previously explained, microbiological sampling at abattoirs conducted for the on-farm monitoring of *Salmonella* purpose need to be based on caecal lymph nodes, rather than carcasses. In some countries, carcass samples (meat juice) are immunologically tested to determine on-farm *Salmonella* status (see Chapter 5.2.).

B. *Monitoring/surveillance of pathogens in foods via carcass testing at abattoir*. Although data on pathogens on carcasses can be useful towards human exposure assessment, there are problems with direct interpretation of related data due to non-homogenous distribution on carcasses and because human exposure is affected by the interference of the meat processing-distribution events (see Chapter 6.4.). Nevertheless, carcass testing for pathogens reflects the proportion of carcasses contaminated with *Salmonella* and it is conducted in some countries as a part of global pathogen reduction programmes.

C. Microbiological carcass testing in the context of HACCP verification i.e. for the process hygiene assessment purpose.

6.3.2.4.2. Methods for microbiological sampling of carcasses

Methods for microbiological sampling of meat and/or carcasses described in the literature can be generally divided into two main groups: tissue excision-based and surface swabbing-based. Numerous published studies evaluated the performance of different sampling methods i.e. bacterial recoveries achievable, but the results are difficult to compare directly due to numerous experimental differences that exist between studies with respect to:

a) types of microflora targeted (e.g. total viable count, coliforms, *E. coli*, pathogens),

b) whether the microflora was natural or artificially inoculated,

c) types of meat surface sampled (e.g. joints/cuts vs. carcass, meat vs. skin, lean vs. fat, fresh vs. chilled),

d) types of swab materials (e.g. cotton, sponge, gauze),

e) sizes of surface area sampled (e.g. 10, 100 cm^2),

f) other variables.

Generally, in spite of significant extent of disagreement existing between different studies, an opinion that, under identical conditions, excision methods are less variable and enable higher bacterial recoveries than swabbing methods - have been prevailing (Ingham and Roberts, 1976; Eisel *et al.,* 1997; Unterman *et al.,* 1997; Gill and Jones, 2000; Ransom *et al.,* 2002; Capita *et al.,* 2004; Hutchison *et al.,* 2005). However, it should be kept in mind that direct comparison of excision and swabbing methods - i.e. by sampling the same surface area (having the same microflora) simultaneously by excision and swabbing - is very difficult to achieve due to technical problems. Actually, all the published comparative studies produced results by sampling one set of samples by one method and other set of samples by another, and then compared the two sets of the results. In such a case, inevitably, a number of variable factors, that can affect different sampling methods differently, can affect the resulting conclusions. Apart from carcass- and microflora-related factors, other main factors contributing to variability of the results achieved by different methods can be summarised as shown in Table 13.

With respect to swabbing methods, it seems that abrasiveness of the swab material plays a particularly important role. Cotton-bud swabs have been found to produce significantly lower bacterial recoveries than excision method (Pepperrell *et al.,* 2005; Hutchison *et al.,* 2005). However, some other studies indicated that swabbing of larger surface areas (e.g. 100 or 1000 cm^2) by sponge/gauze can produce recoveries that are statistically comparable to recoveries achieved by excision of smaller areas (e.g. 10 cm^2) (Gill and Jones, 2000; Gill *et al.,* 2001). In both of the latter two studies, this conclusion applied to recoveries of aerobic plate counts; whilst recoveries of coliforms and *E. coli* were lower (Gill *et al.,* 2001).

Overall, it seems that the choice of the carcass sampling method depends on the aim and the design of the microbiological examination to be conducted. A practical aspect to be considered is that excision but not swabbing will cause damage to the carcass.

Whichever method is chosen, for carcass monitoring/surveillance purposes, it is important:

a) to use the same method in repeated examinations the results of which need to be compared,

b) to standardize technical aspects of the sampling procedure/method as much as possible, and

c) to compare only what is comparable i.e. the only results obtained under comparable conditions can be compared.

6.3.2.4.3. Testing of pathogens on carcasses as a part of global pathogen reduction programmes

Carcass testing for *Salmonella* is used in the USA (FSIS, 1996) within a pathogen reduction programme and as a performance standard for abattoirs. US Food Safety and Inspection Service (FSIS) believes that the degree of protection by HACCP systems in abattoirs must be evaluated. Testing for *Salmonella* was selected because it is a major pathogen of concern, is present on virtually all classes of raw food products in numbers large enough to detect, and related methods are available. FSIS expects that reducing the percentage of carcasses with *Salmonella* will lead to a reduction in other pathogens as well. The standard is calculated from the baseline percent positive and is expressed as the number of samples to test (n) and the number of positives to allow from among those samples (c). Standards are calculated to provide an 80% probability of passing when the establishment is operating at the national baseline prevalence of positive *Salmonella* results. FSIS requires corrective action when establishments are not meeting the standards; it is intended to revise the performance standards for *Salmonella* periodically, as new data become available, to further reduce the risk of foodborne illness. Based on the new EU-Food Hygiene regulations 2006, microbiological testing of carcasses for *Salmonella* will be introduced also in the EU.

6.3.2.4.4. Testing of indicator bacteria on carcasses for process hygiene verification purposes

In keeping with decisions taken previously by regulatory authorities in the USA, Australia and New Zealand, EU Commission Decision 2001/471/EC[9] introduced mandatory HACCP-based system in slaughterhouses in the EU in June 2003. For HACCP verification purpose, carcasses are tested for counts of indicator bacteria: a) total viable bacterial counts (TVC) and *Enterobacteriaceae* in the EU; or b) generic *E. coli* in New Zealand and USA. According to the above EU Directive, weekly bacterial mean log trends are used to verify that HACCP-based process hygiene is controlled.

In recent studies simultaneously using the two official EU sampling methods (McEvoy *et al.,* 2004; Pepperell *et al.,* 2005; Hutchison *et al.,* 2005), no significant

9 European Commission. (2001). Commission Decision (2001/471/EC) of 8 June 2001 laying down rules for the regular checks on the general hygiene carried out by the operators in establishments according to Directive 64/433/EEC on health conditions for the production and marketing of fresh meat and Directive 71/118/EEC on health problems affecting the production and placing on the market of fresh poultry meat. Official Journal L 165, 21/06/2001, 48-53.

linear relationships between bacterial counts (TVC or *Enterobacteriaceae*) on carcasses between swabbing and excision was found. The above authors suggested that a simple mean log trend (used in EU) may not be an appropriate tool for HACCP verification purposes. In addition, it should be kept in mind that there is no direct, quantitative correlation between the indicators and pathogens (e.g. *Salmonella*) on carcasses. Nevertheless, at general level, the higher the faecal indicator levels, the worse process hygiene so the higher meat safety risks, could be expected.

6.3.3. Conclusions on risk mitigation options at harvest level

Because the slaughter and dressing of infected and/or contaminated pigs is the main risk factor, the provision of pigs that are virtually "*Salmonella*-free" is a significant litigatory factor. Therefore, it is essential to establish measures to prevent/reduce meat contamination at pig slaughterhouses based on GHP- and HACCP-principles including limitation of the level of contamination of the animals or their intensity of excretion of salmonellae at the end of the fattening phase.

The objective is to decrease the pathogen load on slaughtered pigs as follows:

- if *Salmonella* infection is eliminated or reduced to very low levels, contamination at TL will also be reduced or even eliminated (Thorberg and Engvall, 2001). Best results will be obtained if *Salmonella* negative herds are slaughtered in different slaughterhouses than *Salmonella* positive herds (thereby separated during transport, lairage and cooling) (Swanenburg *et al.*, 2001b),
- transport in cleaned and disinfected trucks,
- effective controls during transport-lairaging phase including separation of batches and cleaning-disinfection of the lairage between batches of pigs,
- shorter lairage duration decreases the risk of caecal contamination,
- application of frequent cleanings and disinfections in the piggeries at the slaughterhouse (about 2 to 3h),
- ensure hygienic procedures for the personnel, the equipment and the environment of the room, including cleaning and disinfection procedures, temperature control of the room and of the products, are operated and by applying HACCP concept,
- decrease pathogen contamination of carcasses, slaughter/dressing technology by ensuring:
  - that slaughter is performed according to HACCP principles in association with GHP focusing on avoiding faecal and oral contamination of carcasses,
  - slaughter of pigs from *Salmonella*-free batches/herds before pigs from *Salmonella*-positive batches/herds,
  - an effective feed withdrawal,
  - increased sanitation after slaughter of high risk herds,
  - prevention/reduction of negative microbiological effects of critical operations on slaughterline, especially carcass polishing,

- sterilisation between carcasses of slaughterline equipment in contact with edible tissues, and all equipment thoroughly cleaned and disinfected preferably several times during a slaughter day,
- rapid cooling to temperatures of 7°C or below avoids the multiplication of *Salmonella*,
- meat/carcass decontamination could be considered in special situations, under the supervision of the competent health authorities. However decontamination should not be a substitute for above mentioned recommendations (6.3.2.3.2),

- monitoring, including corrective actions, of the hygiene of the slaughter process, effectiveness of cleaning/sanitation and of other process hygiene controls by suitable methods should take place,
- certain modifications of the conventional pig slaughterline technology could result in reduction of microbial loads on carcasses including *Salmonella* (Chapter 6.3.2.3.1).

6.4. Risk mitigation options for *Salmonella* at post-harvest

6.4.1. Effects and mitigation options of cutting, deboning and meat preparations

6.4.1.1. Fresh meat

After slaughtering and dressing, carcasses are chilled in different conditions and then cut in different parts. These products (half carcasses, quarter, meat…) can be sold as fresh or frozen.

These products could be contaminated by *Salmonella* serovars and outbreaks can occur. During these operations, microbial contamination can occur, especially by using utensils (knives saws, etc.), and by prior handling of contaminated products. In a study conducted in two pork slaughter and cutting plants, Giovanacci *et al.* (2001) found that in most cases, serovars or genotypes of *Salmonella* found in the cutting room has earlier been identified at the supplying slaughter plant. These cross contaminations in the cutting plant can be contribute to an increasing in the prevalence of positive *Salmonella* spp.

Furthermore, cutting and deboning operations can themselves be a source of contamination of the meat, by spraying bacteria from the surface of the carcasses to the internal part (muscle). The resulting presence of *Salmonella* serovars in the exposed core of the meat thus exposed could be an important risk factor. For example, the consumption of undercooked roast pork internally contaminated by *Salmonella* Typhimurium was associated with a salmonellosis outbreak in Australia (Delpech *et al.*, 1998).

The risk of *Salmonella* contamination is mainly in relation with the initial contamination of the surface carcasses and with the hygienic quality of these operations.

In some cases the final products is mechanically deboned meat or minced meat. Again, the process used re-distributes microorganisms present on meat surfaces throughout the product (Concerted Action CT94-1456, 1997). Due to the structure of the meat, these products are very sensitive to microbial contamination. In this way, the presence of *Salmonella* serovars on the carcass before deboning is an important risk factor.

The risk of *Salmonella* contamination is mainly associated with the level of the initial contamination of the surface carcasses and with the standards of hygienic practices of these operations. The likelihood of salmonellae being present in fresh meat including pork can be high, especially when originating from carcasses with a high prevalence of salmonellae (SCVMPH, 2003).

6.4.1.2. Meat preparations

Meat preparations consist of raw ground (minced) meat for different animal products (beef, pork, chicken, turkey) with added compounds (salts, spices). These products are not preserved by means of reduced water activity a_w or pH. Although such meat preparations may be cooked, they are commonly eaten raw. The probability of salmonellae occurring in "meat preparations" is high, especially in products originating from raw material with a high prevalence. If the product is eaten raw, the risk of contracting salmonellosis is consequently higher (SCVMPH, 2003).

6.4.1.3. Edible offals

Heart, lungs, liver, kidney, are used for human consumption. However, edible offals are generally consumed after heating, which lowers the risk of transmission of salmonellae and may also be lethal for heat-sensitive salmonellae (SCVMPH, 2003).

6.4.1.4. Mitigation options

During all these operations it is important to control the risk of microbial contamination by ensuring that hygienic procedures for the personnel, the equipment and the environment of the room, including cleaning and disinfection procedures, temperature control of the room and of the products, are operated and by applying HACCP concept. However, the processing of contaminated carcasses is the main risk factor. Consequently the provision of carcasses that are virtually "*Salmonella*-free" is recognized as a significant litigatory factor; this status can be attained by using methods described in earlier chapters.

6.4.2. Effects and mitigations options of processing

The initial objective of further processing of meat is to extend keeping quality during the storage time. More recently, other processes have been introduced in order to increase the value of the final product.

All edible parts of the carcass may be used including muscle, with or without bone, heart, liver kidney, fat, blood, etc.

6.4.2.1. Curing

This technique involves the addition of some additives (e.g. sodium chloride, sodium nitrite, potassium nitrate or their combination) to a raw meat, in dry or aqueous solution form. The addition of salts mainly reduces the a_w of the product and then has a role to inhibit the growth of microorganisms (bacteriostatic). However, curing does not eliminate microbial hazards and some bacteria such as *Salmonella* spp. can survive for a considerable time (weeks) in immersion brines and thus spread to uncontaminated meat during curing.

Furthermore, due to the consumers' demand, the level of salts used is more and more low, decreasing the bacteriostatic effect of this compound. In that way it's necessary to combine this process with another one such as fermentation or to keep these products under chill conditions to minimize potential hazards.

6.4.2.2. Fermentation

This process results of the fermentation of lactic acid bacteria (Lactic acid bacteria and Gram positive cocci) present into the raw meat and frequently by addition of starter cultures mainly to decrease the process time of fermentation. The role of these bacteria is to decrease the pH of the meat under 4.6-5.0.

Usually finished fermented meat products do not support the growth of pathogenic microorganisms and could be considered as low risk products. Nevertheless some pathogens such as *Salmonella* may survive particularly if the ultimate pH value is not sufficiently low, and outbreaks due to contaminated "natural" or "no-fermented" sausages have been described (Prencipe *et al.*, 2000).

There is a very wide range of fermentation procedures. Some of them, for example "Frische Mettwurst" are marketed within 3 or 5 days of production as a fresh fermented sausage (SCVMPH, 2003). Schmidt (1985) recovered salmonellae from these kind of products in 4.3% of samples tested. Inefficient fermentation has been associated with the presence of *Salmonella* spp. in sausages (ICMSF, 1998).

6.4.2.3. Drying

Drying inhibits microbial growth by depriving microorganisms of moisture. The inhibition is determined not so much by the water content of the meat, but rather by the availability of the water (a_w).

For many products, drying is applied in combination with fermentation for example to produce sausages, or as the final phase of production for cured ham.

6.4.2.4. Smoking

Smoking can be achieved by contact with smoke aerosol or by treatment with a liquid smoke. These products contain a variety of organic compounds active against Gram negative bacteria and other microorganisms.

6.4.2.5. Mitigation options

There is a wide range of processed products using pork meat (sausages, ham, salamis, etc.). These products could be contaminated by *Salmonella* spp. mainly following the presence of these bacteria into the raw meat. Nevertheless processes used, (curing, fermentation, drying), sometimes in combination, allow to stop the growth of pathogenic bacteria, but some traditional salting, drying and smoking of raw pork meat are not effective enough against some serovars and can be the source of human outbreaks (Mertens *et al.,* 1999).

Some of these products should be considered as "Ready To Eat" (RTE) products. In that way, the level of contamination by *Salmonella* spp. should be as low as possible to prevent human outbreaks. Applying GHP during the process, and using low contaminated raw meat and ingredients, are the most important tools to prevent the presence of *Salmonella* spp. in the final product.

Furthermore, packaging using vacuum or modified atmosphere could be used to control the level of contamination.

6.4.3. Effects and mitigations options for retail and food preparation

6.4.3.1. Retail

At retail level, in some EU countries, the observed level of *Salmonella* contamination ranged between 1.2% (The Netherlands, pig meat) and 12.7% (Belgium, minced meat) (EFSA, 2005b). A study in Irish retail pork sausages showed a prevalence of between 1.7 and 4.4 %, depending the sampling period (Boughton *et al.,* 2004).

At butcher shops, some products can be deboned and or minced. This process can be a critical point for cross contamination. The application of specific codes of good hygienic practices, including maintaining the cold chain, is necessary to avoid cross contamination and increase of level of *Salmonella* spp. and other pathogenic bacteria into the meat presented to the consumer.

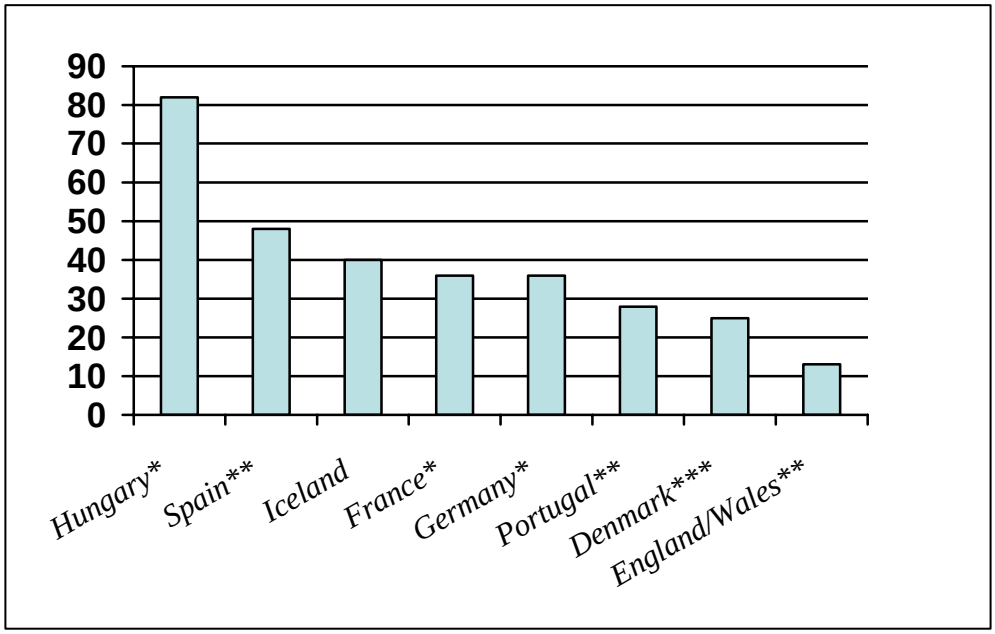
At the retail level, in some countries and shops, some processed meat such as ham, sausages, pâtés, could be sliced into individual parts. This process could also be a critical point, mainly due to the contamination of the side from the surface. Again application of codes of good hygienic practices and control of the temperature are the best options to control spread of *Salmonella* spp. and other pathogenic bacteria.

6.4.3.2. In private homes

Over the past two decades a substantial amount of valuable information about consumer food safety has been collected.

Epidemiological data from Europe, North America, Australia, and New Zealand indicate that substantial proportions of foodborne-disease can be attributed to food preparation practices used in the domestic environment. In Figure 7 data are presented on the incidence of foodborne disease outbreaks associated with private homes in Europe (Tirado and Schmidt, 2000).

Figure 7. Incidence of foodborne disease outbreaks (%) in some European countries associated with private homes (Tirado and Schmidt, 2000).



* Outbreaks of foodborne disease caused by food eaten or contaminated in private homes
** Outbreaks of foodborne disease for which food was eaten or acquired in private homes
*** Outbreaks of foodborne disease for which food was prepared or contaminated in private homes

Historically, the largest proportions of reported foodborne disease outbreaks associated with private homes have been caused by *Salmonella* (Tirado and Schmidt, 2000). Epidemiological studies have indicated that sporadic cases or small outbreaks in homes account for the majority of food poisoning incidents (Worsfold and Griffith, 1997).

In an overview of Redmond and Griffith (2003) of observational studies a number of inadequate food-handling practices (risk factors) were indicated. Their results are summarised in Table 14.

In a study of among others Anderson *et al.* (2002) it reveals that the consumer's intention to perform a food safety procedure does not always result in the implementation of that procedure. For example, although 85% of consumers indicated that they intended to wash their hands before food preparation, only 45% attempted to wash their hands before beginning to prepare food. The same applied for using a food thermometer: 30% reported owning a food thermometer; however 5% used a food thermometer to determine the internal temperature of their meat during cooking. Identical results were obtained from a UK study carried out by Griffith *et al.* (2001). They observed that 100% of the inquired persons were aware about hand washing after handling raw foods. Actually none of them practised hand washing.

6.4.3.3. Conclusion

The length of the pig/pork chain production is probably the longest in the agro-industry. This means that during the each of the different steps, contamination can occurred and it is necessary to address this successive potential risk by implementing new options. This strategy based on a "hurdle concept" (Leistner and Gorris, 1995) should be applied along the pig/pork chain production to maintain at a minimum the level of contamination by *Salmonella* spp. The conclusions of a Danish risk assessment study, concerning human salmonellosis due to multi-resistant *Salmonella* Typhimurium DT 104 from consumption of dry-cured pork sausages, show that normally *Salmonella* spp., when present in raw pork, is usually in low numbers and during processing, the level of contamination could be reduced around 2 to 3 logs units (Alban *et al.,* 2002b). During storage, *Salmonella* spp. can survive in these products and their destruction by frying or grilling is not always effective (Mattick *et al.,* 2002).

6.4.4. Monitoring at post-harvest

The recent European Regulation no. 852/2004 on the hygiene of foodstuffs lays down general rules for food business operators which are to be applied at all stages of production, processing and distribution of food. In particular food business operators shall comply with the general hygiene requirements and put in place, implement and maintain a permanent procedure based on the HACCP principles. Furthermore they shall comply with temperature control requirements for foodstuffs and maintain the cold chain. In addition food business operators are to comply with microbiological criteria established by the Commission Regulation (EC) 2073/2005. Concerning *Salmonella* spp., minced meat, meat preparations, mechanically separated meat and meat products intended to be eaten raw should be tested for food safety criteria; these criteria define the acceptability of a product or a batch of foodstuff applicable to products placed on the market, and unsatisfactory results shall induce the withdrawn or recall of these products. In addition, some "process hygiene criterion", indicating the acceptable functioning of the production process, concerns the presence of *Salmonella* spp. and the pork production (carcasses). The application of these criteria in the HACCP procedures will contribute to produce "*Salmonella*-free or low contaminated" carcasses and consequently to reduce the prevalence of contaminated raw material entering the processing plant.

6.4.5. Further developments at post-harvest

The microbial stability and safety of both traditional and novel meat products are frequently based on combination of several principles, sometimes called "hurdles", which prevent microorganisms growing in or on meat (Concerted Action CT94-1456, 1996). This concept of "hurdle" technology (Leistner and Gorris, 1995) requires to be further improved not only to prevent the growth of *Salmonella* spp. and other pathogenic bacteria during processing and storage of processed meat, but also to reduce the number of these microorganisms present. For example, use of food packaging materials inhibitory to microorganisms, so-called "active" packaging, appears to be one of promising novel approaches not only to keep down the total microbial level but also to have a bactericidal effect on spoilage and pathogenic bacteria, including *Salmonella* serovars.

6.4.6. Conclusions on risk mitigation options at post-harvest

The processing of contaminated carcasses is the main risk factor. Consequently the provision of carcasses that are virtually "*Salmonella*-free" is recognized as a significant litigatory factor.

In order to reduce the consumers' exposure to *Salmonella*, some mitigation options should be considered:

- ensure hygienic procedures for the personnel, the equipment and the environment of the room, including cleaning and disinfection procedures, temperature control of the room and of the products, are operated and by applying HACCP concept,
- application of a further developed hurdle technology in the production and preservation of raw and processed meat (pork) products,
- classification of a range of processed meat products containing pork and other meats as RTE products and subjecting these to compliance with specifications requiring the level of contamination by *Salmonella* spp. to be as low as possible to prevent human outbreaks,
- applying GHP during the process, and using low contaminated raw meat and ingredients, are the most important tools to prevent the presence of *Salmonella* spp. in the final product.

7. OVERALL CONCLUSIONS (based upon answers relating to the TOR)

7.1 Estimation of the contribution of pig/pork to food-borne salmonellosis.

- Based on the available statistics, pork is a significant source of human foodborne salmonellosis in Europe.
- The contribution of pork-associated salmonellosis to foodborne salmonellosis varies between countries. For most countries there are no data.
- Available data indicate that pork-associated human salmonellosis accounts for 5 to 30% of reported cases.

7.2 Prioritise *Salmonella* serotypes related to pigs according to their current significance for public health and where relevant for this scientific consultation, animal health.

- All *Salmonella* serovars isolated from pigs and pork are to be regarded as a hazard for Public Health.
- At present the most common serovar at EU level causing human foodborne infections from pork is *S.* Typhimurium; however there have been significant outbreaks due to other serovars.
- Presently, there is no scientific basis for serovar prioritization because serovar occurrence/distribution varies between countries and is changeable within a given country, in addition to infectivity-related uncertainties.

7.3 Identify and assess options for monitoring schemes aimed at detecting/evaluating *Salmonella* prevalence and/or previous exposure to *Salmonella* in pig production, at individual and herd level, indicating their respective advantages and disadvantages, including a comparison between protocols using immunological and bacteriological methods.

- There are two main options for monitoring schemes namely, those based on bacteriological methods and those based on immunological methods. When used appropriately for specific purposes, each of these approaches is of benefit.
- For monitoring purposes the results of immunological and bacteriological investigations cannot be compared directly, as they give different information.
- The choice between immunology and bacteriology, and their use in combination, will depend on the actual situation and the questions that require to be answered.
- Different applications for bacteriology and immunology can be distinguished. Bacteriology can be used when:
  - isolation of the strain is necessary for identification;
  - information about all *Salmonella* infections (all serovars) is required;
  - antimicrobial sensitivity testing is required;
  - the current *Salmonella* status of individual animals requires to be determined;
  - a description of the general diversity of infections with different serovars in a population is the purpose of the investigation;
  - the evaluation of *Salmonella*-free status of herds is required.

Immunology can be used for screening large numbers of blood and other samples, for example, for monitoring the effectiveness of control programmes in endemic regions or to establish the immunological status of a population (e.g. herd) and the prevalence of infection.

- Sustained compliance with detailed procedures is required in order to harmonize the collection, processing and reporting of comparable data from MS.

7.4 Assess the appropriateness of a progressive approach to reduce the risk to human health from *Salmonella* in different types of pig herds, starting with breeding pigs or with slaughter pigs.

- A holistic approach from breeding to slaughter and processing is required in order to reduce the risk to human health from *Salmonella* in pigs and pork. An emphasis on the measures taken at the finisher phase has been shown to result in a greater and more rapid reduction in *Salmonella* prevalence in pigs and pork than emphasis on measures taken at the sow level.

7.5 Identify the advantages and disadvantages of various specific methods at primary production aimed at reducing the risk to human health from the presence of *Salmonella* in pigs.

- In general, the control has to focus on the implementation of preventive actions in each phase of the entire production chain because there is no "silver bullet" through which the level of *Salmonella* contamination can be reduced.
- The control of *Salmonella* can follow those general rules that have been successfully applied to the control of other infectious diseases.

More specifically, the following measures are required to be followed:

- Prevention of introduction of *Salmonella* into the herd:
  - by infected animals, being the primary and major source of infection,
  - by feed, being a continuous risk for new introduction to herds in all MS,
  - from a contaminated environment (e.g. rodents) and by equipment and visitors.
- Prevention of in-herd transmission:
  - Implementation of optimal hygienic and management routines; e.g. all-in-all-out systems, batch production with through cleaning and disinfection between batches,
  - identification and removal or isolation of *Salmonella* infected animals or group of animals,
  - control of vectors such as rodents and birds.
- Increase resistance to infection:
  - Support good health and good management e.g. by reducing predisposing factors like the occurrence of other infectious diseases, e.g. dysentery (*Brachyspira hyodysenteriae*), Aujeszky´s disease and PRRS and worm infections,
  - the use of vaccine is a suitable option in a control programme depending on several factors, e.g. aim of the control plan (reduction or eradication), prevalence of *Salmonella*, etc. However, vaccination alone cannot eliminate *Salmonella* spp. from a herd,
  - the use of antimicrobials for *Salmonella* control in pigs should be discouraged due to public health risks associated with development, selection and spread of resistance. Their use should be limited to animal health/welfare purposes, subject to the approval of competent authority and under defined conditions that would minimize the risk for the public health,
  - the use of fermented liquid feed and acidifying compounds in feed and drinking water generally is found to have a *Salmonella* reducing effect.

- Strategies for interventions:
  - an initial monitoring is required in order to establish a basis, the true picture of the current situation from a public health point of view,
  - focus intervention for the control and elimination of all certain serovars associated with pigs and pork, as there is no scientific basis for focusing on certain serovars,
  - in medium and high prevalence countries (Chapter 6.2.3.2) interventions required to be based on a successive implementation of those *Salmonella* reducing steps specified in Chapter 6.2. The results to be achieved require to be assessed based upon a long term perspective,
  - at regularly controlled intervals the interventions required to be evaluated to ensure compliance and efficacy and necessary modifications undertaken. It is considered that while these interventions will considerably reduce the *Salmonella* prevalence at pre-harvest level, it remains to be seen if this strategy alone can result in a relatively *Salmonella*-free primary production system comparable to those systems that currently exist in the low prevalence countries,
  - low prevalence countries (Chapter 6.2.3.1) require to ensure that the favourable *Salmonella* situation achieved to-date is maintained by the continuous use and, where possible, cost effective improvement of current monitoring and intervention strategies,
  - for all MS a supporting monitoring programme is required to be in place and modified so as to meet the objectives and to apply appropriate strategies consistent with the status of the MS or region under consideration, as described above (Chapter 5.3).

7.6 Identify options for monitoring and for risk mitigation of *Salmonella* in pork and products there from at different stages of the food chain after primary production.

- After primary production available risk mitigation options can relate to the harvest level or the post-harvest level. The definition of harvest for the purpose of this report covers that part of the food chain beginning with the transport of the slaughter animals from the farm gate, the lairage phase, slaughtering itself, up to the cooling of the carcasses. The post-harvest level includes meat cutting and processing resulting in products that can be raw, fermented or subjected to bactericidal treatments (e.g. cooked), as well as storage, handling and preparation at retail and consumer levels.
- There is no universal mitigation option that could eliminate *Salmonella* spp. entirely from the harvest and post-harvest level. A combination of measures is most effective and in general is applicable to other foodborne pathogens. However, if *Salmonella* infection is eliminated or reduced to very low levels at the pre-harvest level, the risk of contamination at harvest and post-harvest level will also be reduced or even eliminated.

- Reduction of the pathogen load in live pigs requires measures to produce slaughter pigs with as low a *Salmonella* prevalence as possible both at the pre-harvest level and also to maintain this low prevalence during the transport-lairage phase through the separation of batches, GHP and hygiene management and optimisation of transport and lairage time.
- Assurance that slaughter is performed at a high level of hygiene and performed according to HACCP principles in association with GHP, focusing on the avoidance of faecal/intestinal contamination of carcasses.
- Reduction of the pathogen load on the carcasses and offals of slaughtered pigs by the practice of GHP, the application of HACCP principles and where appropriate, logistic slaughtering.
- Risk mitigation options during processing include the improvement of the bacterial quality of raw material (e.g. carcasses) used, process hygiene based on GHP and HACCP principles in accordance with the new European Regulation, maintenance of the cold chain, and the application of "hurdle" concept. At retail and consumer level, mitigation includes hygienic handling and proper cooling or heating of pork and pork products. These options and procedures require to be effectively communicated to retailers and consumers.
- Meat/carcass decontamination may be considered in special situations, under the supervision of the competent authorities. However, decontamination should be regarded as an addition to, and not a substitute for, above mentioned recommendations.
- Monitoring at harvest level is of relevance in regard to both process hygiene evaluation purposes and the evaluation of the *Salmonella* status of product throughout the entire food chain. For human exposure assessment, monitoring requires to be conducted at the pre-consumption level.

8. RECOMMENDATIONS

8.1. Risk mitigation options for *Salmonella* at pre-harvest level

- A panel of reference sera for the evaluation and harmonization of immunological tests and to be used for ring-trials should be established.
- New information to be gathered through zoonosis monitoring based on Directive 2003/99/EC could be used also for further scientifically based considerations whether or not is possible to prioritize *Salmonella* serovars in the future.
- The effectiveness of intervention "packages" (combinations of e.g. all-in/all-out and cleaning, disinfection with acidifying feed and or drinking water, vaccination, use of competitive exclusion) in improving the *Salmonella*-status of infected herds should be evaluated.
- Methods used for the prevention of *Salmonella* infection in swine from *Salmonella* contaminated feed should be further scientifically assessed. This includes particular methods for detection, decontamination and traceability along the feed chain.

- More scientifically documented knowledge on how to reduce *Salmonella* prevalence at herd level is needed. In advance of and, in particular, during the implementation of the EU interventions, studies to evaluate the effectiveness of different strategies are required.
- Sampling and testing methods for pigs, pork and faecal material (e.g. ISO-methods) should be harmonized.
- More scientifically based information on the role of weaned piglets as source of *Salmonella* for fattening farms is needed.
- The relation between other (enteric) pig diseases and the occurrence of *Salmonella* in pigs need to be clarified.
- Reproducible sub-clinical infection model for *Salmonella* in swine, to be able to analyze and compare the effectiveness of different intervention strategies, should be developed.
- There is a need to investigate whether differences in applicability/efficacy of risk mitigation options between different pig production systems (e.g. organic versus industrial) exist.

8.2. Risk mitigation options for *Salmonella* at harvest level

- The effectiveness of possible modifications in the conventional pig slaughterline technology in reducing the *Salmonella* loads on carcasses and offals should be investigated. Such modifications should aim primarily at improving hygiene parameters.
- Overall positive and negative effects of meat decontamination treatments should be accurately evaluated through laboratory-based studies and application under commercial conditions.

8.3. Risk mitigation options for *Salmonella* at post-harvest level

- Further work focused on efficacy optimization of "hurdle" technology, as well as on development of novel approaches aimed at *Salmonella* reduction, during processing-storage stages, should be encouraged.

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11. REFERENCES

Alban L., Stege H., Dahl J. (2002a). The new classification system for slaughter-pig herds in the Danish *Salmonella* surveillance-and-control program. Prev.Vet. Med. 53: 133-146.

Alban L., Olsen A-M., Nielsen B., Sørensen R. and Jessen B. (2002b). Qualitative and quantitative risk assessment for human salmonellosis due to multi-resistant *Salmonella* Typhimurium DT 104 from consumption of Danish dry-cured pork sausages. Prev.Vet.Med., 52, 251-265.

Alban L. and Stark K. D. (2005). Where should the effort be put to reduce the *Salmonella* prevalence in the slaughtered swine carcass effectively? Prev. Vet. Med. 68:63-79.

Anderson J. B., Shuster T. A., Gee E., Hansen K., Mendenhall V. T. (2000). A camera's view of consumer food safety practices. Personal communication. Cited by Redmond E. C. and Griffith C. J. (2003).

Arnold M.E., Cook A.J.C. and Davies R.H. (2005). A modelling approach to estimate the sensitivity of pooled faecal samples for isolation of *Salmonella* in pigs. Journal of the Royal Society Interface 2: 365-372.

Baggesen D.L., Wegener H.C., Bager F., Stege H., Christensen J. (1996). Herd prevalence of *Salmonella enterica* infections in Danish slaughter pigs determined by microbiological testing, Prev. Vet. Med. 26: 201-213.

Bahnson P.B., Kim J.Y., Weigel R.M., Miller G.Y., Troutt H.F. (2005). Associations between on-farm and slaughter plant detection of *Salmonella* in market-weight pigs. J. Food Prot. 68, 246-250.

Baird-Parker C.A. (1994). Food and microbiological risks. Microbiology. 140, 687-695.

Bauvet J., Bavai C., Rossel R., Le Roux A., Montet M.P., Lavenir R., Ray-Gueniot S., Mazuy-Cruchaudet C., Vernozy-Rozand C. (2002). Effects of slaughter and cutting processes on pig carcass and pork meat contamination by *Salmonella* spp.. In: International Symposium on *Salmonella* and Salmonellosis, St. Brieuc, France. Proc., Session 3, pp. 355-356.

Beloeil P.A., Chauvin C., Proux K., Rose N., Queguiner S., Eveno E., Houdayer C., Rose V., Fravalo P., Madec F. (2003). Longitudinal serological responses to *Salmonella enterica* of growing pigs in a subclinically infected herd. Prev. Vet. Med. 60:207-226.

Beloeil P.A., Chauvin C., Proux K., Madec F., Fravalo P., Alioum A. (2004a). Impact of the *Salmonella* status of market-age pigs and the pre-slaughter process on *Salmonella* caecal contamination at slaughter. Vet. Res. 2004, Sep-Oct. 35(5): 513-30.

Beloeil P.A., Fravalo P., Fablet C., Jolly J.P., Eveno E., Hascoet Y., Chauvin C., Salvat G., Madec F. (2004b). Risk factors for *Salmonella enterica* subsp. enterica shedding by market-age pigs in French farrow-to-finish herds. Prev. Vet. Med. 63:103-120.

Berends B.R., Snijders J.M.A., Van Logtestijn J.G. (1993). Efficacy of current EC meat inspection procedures and some proposed revisions with respect to microbiological safety: A critical review. Vet. Rec. 133, 411-415.

Berends B.R., Burt S.A., Snijders J.M.A. (1995). Critical control points in relation to breaking *Salmonella* and *Listeria* cycles in pork production. In: Burt, S.A, Bauer, F. (edts.): New Challenges in Meat Hygiene: Specific Problems in Cleaning and Disinfection. European Consortium for the Continuing Education in Advanced Meat Science and Technology (ECCEAMST). Utrecht. The Netherlands, pp. 11-17.

Berends B.R., Urling H.A.P., Snijders J.M.A. and Van Knapen F., (1996). Identification and quantification of risk factors in animal management and transport regarding *Salmonella* spp. in pigs. Int. J. Food Microbiol. 30, 37-53.

Berends B.R., van Knapen F., Snijders J.M.A., Mossel D.A.A. (1997). Identification and quantification of risk factors regarding *Salmonella* spp. on pork carcasses. Int. J. Food Microbiol. 36, 199-206.

Berends B.R., Van Knapen F., Mossel D.A.A., Burt S.A., Snijders J.M.A., (1998). Impact on human health of *Salmonella* spp. on pork in the Netherlands and the anticipated effects of some currently proposed control strategies. Int. J. Food Microbiol. 44, 219-229.

Beutling D. (1992) Fleisch. In: Fehlhaber, K., Janetschke, P. (Ed.): Veterinärmedizinische Lebensmittelhygiene. Gustav Fischer Verlag Jena, pp. 191-241

Blood D.C. and Radostits O.M. (1989). Veterinary Medicine. Seventh edition, Balhiere Tindall, London, 643-657.

Bodrossy L. and Sessitsch A. (2004). Oligonucleotide microarrays in microbial diagnostics. Curr.Opin.Microbiol. 7:245-254.

Boes J., Dahl J., Nielsen B. and Krog H.H. (2001). Effect of separate transport, lairage, and slaughter on occurrence of *Salmonella* Typhimurium on slaughter carcasses. Berl. Münch. Tierärztl. Wschr., 114, 363-365.

Bögel K. (1991). Global cooperation in the control of salmonellosis. In Proc. Symposium on the Diagnosis and Control of *Salmonella*, San Diego, USA, Oct. 29, 1-5.

Bolton D.J., Pearce R.A., Sheridan J.J., Blair I.S., McDowell D.A., Harrington D. (2002). Washing and chilling as critical control points in pork slaughter hazard analysis and critical control point (HACCP) systems. J. Appl. Microbiol. 92, 893-902.

Botteldoorn N., Heyndrickx M., Rijpens N., Grijspeerdt K., Herman L. (2003). *Salmonella* on pig carcasses: positive pigs and cross contamination in the slaughterhouse. J. Appl. Microbiol. 95:891-903.

Boughton C., Leonard F.C., Egan J., Kelly G., O'Mahony P., Markey B.K., Griffin M. (2004). Prevalence and number of *Salmonella* in irish retail pork sausages. J. Food Prot. 2004 Sep;67(9):1834-9.

Brekelmans A.J.M., Lamers J.C.H., Snijders J.M.A. (1980). The prevalence of *Salmonella* in the faeces, the *Lnn. mesenteriales*, the *Lnn. lumbales aortici* and on the carcass of 100 randomly sampled Dutch slaughter pigs. Memorandum about the

results of a pilot-study (Dutch). Utrecht, The Netherlands, Department of the Science of Food of Animal Origin, Faculty of Veterinary Medicine, Utrecht University.

Brenner F.W., Villar R.G., Angulo F.J., Tauxe R., Swaminathan B. (2000). *Salmonella* nomenclature. J. Clin. Microbiol. 38 (7): 2465-2467.

Brooks P. H., Beal J. D., Demeckova V., Niven S. J. (2003). Fermented Liquid Feed (FLF) can reduce the transfer and incidence of *Salmonella* in pigs. International Symposium On the Epidemiology and Control of Foodborne Pathogens in Pork :21-27.

Buncic S. (2006). Integrated Food Safety and Veterinary Public Health. CABI International Publishing, Oxon (UK), in press.

Busse M. (1995). Media for *Salmonella*..Int. J. Food Microbiology. 26, 117-131.

Capita R., Prieto M., Alonso-Calleja C. (2004). Sampling methods for microbiological analysis of red meat and poultry carcasses. J. Food Prot. 67:1303-1308.

Carlson A. and Blaha T. (2001). In-herd prevalence of *Salmonella* in 25 selected Minesota swine farms. Swine Health Production. 9:1-10.

Casey P.G., Butler D., Gardiner G.E., Tangney M., Simpson P., Lawlor P.G., Stanton C., Ross R.P., Hill C., Fitzgerald G.F. (2004). *Salmonella* carriage in an Irish pig herd: correlation between serological and bacteriological detection methods. J. Food Prot. 67:2797-2800.

CEC, European Communities. (1984). Priority aspects of salmonellosis research. Larsen H.E. Ed. EUR 9197 EN, pp 341.

Chau F.Y., Shortridge K.F., Huang C.T. (1977). *Salmonella* in pig carcasses for human consumption in Hong Kong: a study on the mode of contamination. J. Hyg. Camb. 78, 253-260.

Chaunchom S. (2003). Assessment of *Salmonella* contamination using an antibody-ELISA test and a PCR technique in pigs at slaughter and on farm level. Diss. Vet. Med., University of Veterinary Medicine Hannover, Germany.

Chiu C.H., Su L.H., Chu C. (2004). *Salmonella* enterica Serotype Choleraesuis: Epidemiology, Pathogenesis, Clinical Disease, and Treatment**.** Clin. Microbiol. Rev. 2004 Apr; 17(2): 311-322.

Chow E.Y., Wu J.T., Jauho E.S., Heegaard P.M., Nilsson E., Harris I.T., Manninen K. (2004). Evaluation of a covalent mix-enzyme linked immunosorbent assay for screening of *Salmonella* antibodies in pig serum. Can. J. Vet. Res. 2004 Apr; 68 (2):134-9.

Christensen J., Baggesen D.L., Soerensen V., Svensmark B. (1999). *Salmonella* level of Danish swine herds based on serological examination of meat-juice samples and *Salmonella* occurrence measured by bacteriological follow-up. Prev. Vet. Med. 40:277-292.

Christensen J., Baggesen D.L., Nielsen B., Stryhn H. (2002). Herd prevalence of *Salmonella* spp. in Danish pig herds after implementation of the Danish *Salmonella*

Control Program with reference to a pre-implementation study. Vet. Microbiol. 88:175-188.

Codex Alimentarius Commission. (2005). Code of hygienic practice for meat. CAC/RCP 58-2005.

Cook A. J. C., Miller A., Snow L. and Davies R. H. (2005). Epidemiological studies of *Salmonella* infection in pigs. MedVetNet General Scientific Meeting. Whichester.

Cooksey K. (2005). Effectiveness of antimicrobial food packaging materials. Food Additives and Contaminants, 22(10), 980-987.

Concerted Action CT94-1456. 1997. Microbial control in the meat industry. Vol. 6. Further Processing of Meat. University of Bristol Press, ISBN 0 86292 447 2.

Craven J.A. and Hurst D.B. (1982). The effect of time in lairage on the frequency of *Salmonella* infection in slaughtered pigs. J. Hyg. Camb. 88, 107-111.

D'Aoust J.Y. (1989). *Salmonella*. In: Doyle, M.P. (edt.): Foodborne bacterial pathogens. Marcel Dekker, New York, 327-445.

Dahl J., Wingstrand A., Bager F., Baggesen D.L., Nielsen B., Larsen K. (1996a). Failure to eradicate *Salmonella* Typhimurium by medication and strategic removal of pigs. International Pig Veterinary Society Congress :179.

Dahl J., Wingstrand A., Baggesen, D.L., Nielsen B., Thomsen L.K. (1996b). The effect of a commercial organic acid preparation on seroprevalence and shedding of *Salmonella* in finishing pigs. International Pig Veterinary Society Congress :178.

Dahl J., Wingstrand A., Nielsen B., Baggesen D.L. (1997). Elimination of *Salmonella* Typhimurium infection by the strategic movement of pigs. Vet. Rec. 140:679-681.

Dahl J. (1999). Success- rate for eradication of *Salmonella* by cleaning and restocking pig herds and the use of antemortem- blood samples in herds after restocking. International Symposium on Epidemiology and Control of *Salmonella* in Pork, 1999 ISECSP, 336- 339.

Dam-Deisz W.D.C., Maas H.M.E., Nagelkerke N., van de Giessen A.W. (2003). Comparison of selective enrichment media for the isolation of *Salmonella* spp. from faecal samples from fattening pigs, veal calves and dairy cows. (In Dutch). De Ware(n) chemicus 3, 143-151. [cited by Mooijman, K. A. 2004]

Danish Bacon and Meat Council. (1999a). The effect of feeding non-heat treated, non-pelleted feed compared to feeding pelleted, heat-treated feed on the *Salmonella*-prevalence of finishing pigs. Washington DC, USA.

Danish Bacon and Meat Council. (1999b). The effect of feeding pellets, meal and heat treatment on the *Salmonella*-prevalence in finishing pigs. Washington DC, USA.

Davies R.H., McLaren I.M., Bedford S. (1999). Observations on the distribution of *Salmonella* in a pig abattoir. Vet. Rec. 1999; 145(23):655-661.

Davies R.H., Paiba G.A., Evans S.J., Dalziel B. (2000). Surveys for *Salmonella* in pigs, cattle and sheep at slaughter in Great Britain. Vet Rec. 2000 Dec 9;147(24):695.

Davies R.H., Heath P.J., Coxon S.M., Sayers A.R. (2003). Comparison of two commercial ELISA kits and bacteriology for *Salmonella* monitoring. In: Leontides L, editor. Safe Pork, 5th International Symposium of the Epidemiology and Control of Food Borne Pathogens in Pork. Crete. p 86-89.

Delpech V., McAnulty J and Morgan K. (1998). A salmonellosis outbreak linked to internally contaminated pork meat. Aust. N.Z.J. Public Health, 22(2), 243-246.

de Wit M.A.S., Hoogenboom-Verdegaal A.M.M., Goosen E.S.M., Sprenger M.J.W., Borgdorff M.W. (2000). A population-based longitudinal study on the incidence and disease burden of gastroenteritis and *Campylobacter* and *Salmonella* infection in four regions of the Netherlands. Eur. J. Epidemiol., 16:713-8.

Dohoo I., Martin W., Stryhn H. (2003). Veterinary Epidemiologic Research. Charlottetown: AVC Inc. Pub., pp.573.

Easter R. A. (1988). Acidification of diets for pigs. 61-71.

Edel W., Guinee P. A. M., Van Schothorst M., Kampelmacher E. H. (1967). *Salmonella* infections in pigs fattened with pellets and unpelleted meal. Zentralblatt für Veterinärmedizin 14 (5):393-401.

Edel W., Van Schothorst M., Guinee P.A.M., Kampelmacher E.H. (1970). Effect of feeding pellets on the prevention and sanitation of *Salmonella* infections in fattening pigs. Zentralbl. Veterinärmed. 1970; 17(7):730-738.

Edel W., Van Schothorst M., Guinee P.A.M., Kampelmacher E.H. (1974). *Salmonella* in pigs on farms feeding pellets and on farms feeding meal. Zentralbl. Bakteriol. [Orig A] 1974; 226(3):314-323.

EFSA, European Food Safety Authority. (2004a). Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to the welfare of animals during transport. The EFSA Journal. 44, 1-36, http://www.efsa.eu.int/science/ahaw/ahaw_opinions/424_en.html, accessed on 14 February 2006.

EFSA, European Food Safety Authority. (2004b). Opinion of the Scientific Panel on Biological Hazards on a request from the Commission related to the use of antimicrobials for the control of *Salmonella* in poultry. The EFSA Journal. 115, 1-76. http://www.efsa.eu.int/science/biohaz/biohaz_opinions/723_en.html, accessed on 31 January 2006.

EFSA, European Food Safety Authority. (2005a). Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to welfare of weaners and rearing pigs: effects of different space allowances and floor types. The EFSA Journal. 268, 1-19.
http://www.efsa.eu.int/science/ahaw/ahaw_opinions/1203_en.html, accessed on 31 January 2006.

EFSA. (2005b). Community Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and Antimicrobial resistance in the European Union in 2004. The EFSA Journal. 130
http://www.efsa.eu.int/science/monitoring_zoonoses/reports/1277_en.html, accessed on 31 January 2006.

Eisel W.G., Linton R.H. and Muriana P.M. (1997). A survey of microbial level for incoming raw beef, environmental sources and ground beef in a red meat processing plant. Food Microbiol. 14:273-282.

Ellerbroek L., Okolocha E.M. and Weise E. (1998). Decontamination of poultry meat with trisodium phosphate and lactic acid. Fleischwirtschaft 78 (9) 984-986.

Engvall A., Andersson Y. and Cerenius F. (1993). The economics of the Swedish *Salmonella* control. A cost/benefit analysis. In Proc. Int. Course on *Salmonella* Control in Animal Production and Products. August, -Malmö, Sweden. National Veterinary Institute, Uppsala, Sweden, 221-237.

European Commission. (2002). Trends and Sources of Zoonotic Agents in Animals, Feedstuffs, Food and Man in the European Union and Norway in 2000 to the European Commission in accordance with Article 5 of the Directive 92/117/EEC, prepared by the Community Reference Laboratory on the Epidemiology of Zoonoses, BgVV, Berlin, Germany.

European Commission. (2003). Trends and Sources of Zoonotic Agents in Animals, Feedstuffs, Food and Man in the European Union and Norway in 2001 to the European Commission in accordance with Article 5 of the Directive 92/117/EEC, prepared by the Community Reference Laboratory on the Epidemiology of Zoonoses, BgVV, Berlin, Germany.
http://europa.eu.int/comm/food/food/biosafety/salmonella/zoonoses_reps_2001_en.htm, accessed on 31 January 2006.

European Commission. (2004). Trends and Sources of Zoonotic Agents in Animals, Feedstuffs, Food and Man in the European Union and Norway in 2002 to the European Commission in accordance with Article 5 of the Directive 92/117/EEC, prepared by the Community Reference Laboratory on the Epidemiology of Zoonoses, BgVV, Berlin, Germany.
http://europa.eu.int/comm/food/food/biosafety/salmonella/zoonoses_reps_2002_en.htm, accessed on 31 January 2006.

European Commission. (2005). Trends and Sources of Zoonotic Agents in Animals, Feedstuffs, Food and Man in the European Union and Norway in 2003 to the European Commission in accordance with Article 5 of the Directive 92/117/EEC, prepared by the Community Reference Laboratory on the Epidemiology of Zoonoses, BgVV, Berlin, Germany.
http://europa.eu.int/comm/food/food/biosafety/salmonella/zoonoses_reps_2003_en.htm, accessed on 31 January 2006.

Farkas J. (1998). Irradiation as a method for decontaminating food. A Review. Int. J. Food Microbiol. 44, 189-206.

Fedorka-Cray P.J., Kelley L.C., Stabel Th.J., Gray J.T., Laufer J.A. (1995). Alternate routes of invasion may affect pathogenesis of *Salmonella* typhimurium in swine, Infection and Immunity. 63: 2658-2664.

Fedorka-Cray P.J., Hogg A., Gray J.T., Lorenzen K., Velasquez J., von Behren P. (1997). Feed and feed trucks as sources of *Salmonella* contamination in pigs. Pigs Health Prod. 5 (5):189-193.

Fedorka-Cray R.J., Gray T.J., Wray C. (2000). *Salmonella* infections in pigs. In: Wray, C., Wray, A. (edts.): *Salmonella* in domestic animals. CABI Publishing, Wallingford, UK, pp. 191-207.

FSIS, Food Safety and Inspection Service. (1996). Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems; Final Rule. Federal Register, Vol. 61, No. 144, July 25, 1996. 38806-38989.

Fravalo P., Proux K., Eveno E., Rose V., Humbert F., Salvat G., Madec F. (1999). Bacteriological assessment of the *Salmonella* status of marked-aged pigs. Poster at the 3rd international symposium on epidemiology and control of *Salmonella* in pig. Washington D.C. (USA) : 4-8 August 1999.

Fravalo P., Hascoët Y., Le Fellic M., Quéguiner S. et Salvat G. (2002). Qualification du niveau de contamination par *Salmonella* d'un échantillon par miniaturisation de techniques. 2ème Colloque International Francophone de Bactériologie Vétérinaire, Ploufragan-France, 5-6.

Funk J.A., Davies P.R., Nichols M.A. (2000). The effect of fecal sample weight on detection of *Salmonella enterica* in swine feces. J. Vet. Diagn. Invest. 12:412-418.

Funk J.A., Davies P.R., Nichols M.A. (2001). Longitudinal study of *Salmonella enterica* in growing pigs reared in multiple-site swine production systems. Vet. Microbiol. 83: 45-60.

Funk J.A., Harris I.T. and Davies P.R. (2005). Comparison of fecal culture and Danish Mix-ELISA for determination of *Salmonella enterica* subsp. enterica prevalence in growing swine. Vet. Microbiol. 107(1-2):115-26.

Gebreyes W.A., Davies P.R., Turkson P.K., Morrow W.E., Funk J.A., Altier C., Thakur S. (2004a). Characterization of antimicrobial-resistant phenotypes and genotypes among *Salmonella enterica* recovered from pigs on farms, from transport trucks, and from pigs after slaughter. J. Food Prot. 67(4):698-705.

Gebreyes W.A., Davies P.R., Turkson P.K., Morrow W.E., Funk J.A., Altier C. (2004b). *Salmonella enterica* serovars from pigs on farms and after slaughter and validity of using bacteriologic data to define herd *Salmonella* status. J. Food Prot. 67, 691-697.

Gedek B., Kirchgessner M., Eidelsburger U., Wiehler S., Bott A., Roth F.X. (1992). Zum Einfluss von Ameisensaeure auf die Keimzahlen der Mikroflora und deren Zusammensetzung in verschiedenen Segmenten des Gastrointestinaltraktes. 5. Mitteilung Untersuchungen zur nutritiven Wirksamkeit von organischen Saeuren in der Ferkelaufzucht. Journal for Animal Physiology and Animal Nutrition 67 :206-214.

Genovese K. J., Anderson R. C., Harvey R. B., Callaway T. R., Poole T. L., Edrington T. S., Fedorka-Cray P. J., Nisbet D. J. S. (2003). Competitive exclusion of *Salmonella* from the gut of neonatal and weaned pig. J. Food Prot. Vol. 66, No. 8, pp. 1353-1359.

Gerats G.E.C. (1990). Working towards quality: Aspects of quality control and hygiene in the meat industry. Thesis, Utrecht university, Utrecht, The Netherlands.

Gill C.O. and Bryant J. (1993). The presence of *Escherichia coli*, *Salmonella* and *Campylobacter* in pig carcass dehairing equipment. Food Microbiol. 10, 337-344.

Gill C.O., McGinnis D.S., Bryant J. and Chabot, B. (1995). Decontamination of commercial, polished pig carcasses with hot water. Food Microbiol. 12, 143-149.

Gill C.O., Bedard D. and Jones T. (1997). The decontamination performance of a commercial apparatus for pasteurizing polished pig carcasses. Food Microbiol. 14, 71-79.

Gill C. O. and T. Jones. (2000). Microbiological sampling of carcases by excision and swabbing. J. Food Prot. 63:167-73.

Gill C.O., Badoni M., McGinnis J.C. (2001). Microbiological Sampling of Meat Cuts and Manufacturing Beef by Excision or Swabbing. J. Food Prot. 64:325-334.

Giovannacci I., Queguiner S., Ragimbeau C., Salvat G., Vendeuvre J.L., Carlier V., Ermel G. (2001). Tracing of *Salmonella* spp. in two pork slaughter and cutting plants using serotyping and macrorestriction genotyping. J. Appl. Microbiol. 90, 131-147.

Grau F. (1989). Fresh meats: Bacterial Association. Arch. Lebensmittelhyg. 30, 87-92.

Griffith C. J., Price P., Peters A. C. and Clayton D. A. (2001). An evaluation of food handlers knowledge, belief and attitudes about food safety and its interpretation using social cognition models. Food Standards Agency, London.

Gutzmann F., Layton H., Simiins and Jarolmen H. (1976). Influence of antibiotic-supplemented feed on the occurrence and persistence of *Salmonella* Typhimurium in experimentally infected swine. Am. J. Vet. Res. 37, 649-655.

Haesebrouck F., Pasmans F., Chiers K., Maes D., Ducatelle R., Decostere A. (2004). Efficacy of vaccines against bacterial diseases in pigs: what can we expect? Vet. Microbiol. 100 (3-4):255-268.

Häggblom P. (1994a). Monitoring and control of *Salmonella* in animal feed. In: Öijeberg Bengtsson S, editor. NVI/WHO International course on *Salmonella* control in animal production and products. Malmö: SVA. p 265.

Häggblom P. (1994b). Cleaning of feed-mills. In Proc. Int. Course on *Salmonella* Control in Animal Production and Products. August, -Malmö, Sweden. National Veterinary Institute, Uppsala, Sweden 185-188.

Hald T., Wegener H.C. (1999). Quantitative assessment of the sources of human salmonellosis attributable to pork. In: International Symposium on *Salmonella* and Salmonellosis, Washington, USA. Proc., pp. 200-205.

Hald T., Wingstrand A., Swanenburg M., von Altrock A., Thorberg B.M. (2003). The occurence and epidemiology of *Salmonella* in European pig slaughterhouses. Epidemiol. Infect. 131, 1187-1203.

Hald T., Vose D., Wegener H.C., Koupeev T. (2004). A Bayesian Approach to Quantify the Contribution of Animal-Food Sources to Human Salmonellosis. Risk Analysis 24, 255-269.

Hamilton D.R., Bobbit J., Lester S., Pointon A.M. (2003). Effect of pre-slaughter handling on *Salmonella* in pigs. In: Leontides L, editor. Safe Pork, 5th International

Symposium of the Epidemiology and Control of Food Borne Pathogens in Pork. Crete. p 180-183.

Henzler D.J. and Opitz H.M. (1992). The role of mice in the epizootiology of *Salmonella* enteritidis infection on chicken layer farms. Avian Diseases, 36,625-631.

Hoogenboom-Verdegaal A.M.M., Jong J.C., During M., Hoogenveen R., Hoekstra J.A. (1994). Community-based study of the incidence of gastrointestinal disease in the Netherlands. Epidemiol. Infect., 112:481-7.

Hurd H.S., Stabel T.J., Carlson S. (2001a). Sensitivity of various fecal sample collection techniques for detection of *Salmonella* Typhimurium in finsihing hogs. In: Proceedings of the Third International Symposium for Epidemiology and Control of *Salmonella* in Pork. Washington DC, USA. p 63-64.

Hurd H.S., Gailey J.K., McKean J.D., Rostagno M.H. (2001b). Rapid infection in market-weight swine following exposure to a *Salmonella* Typhimurium-contaminated environment. Am. J. Vet. Res. Aug;62(8):1194-7.

Hurd H.S., McKean J.D., Griffith R.W., Wesley I.V., Rostagno M.H. (2002). *Salmonella enterica* infections in market pigs with and without transport and holding. Appl. Environ. Microbiol. 68(5):2376-2381.

Hutchison L.M., Walters L.D., Avery S.M., Reid C.A., Wilson D., Howell M., Johnston A.M. and Buncic S. (2005). A field comparison of wet-dry swabbing- and excision- sampling methods for microbiological testing of bovine, porcine and ovine carcasses at red meat slaughterhouses. J. Food Prot. 68, 2155-2162.

Ingham S.C. and T.A. Roberts. (1976). The microbiology of the red meat carcases and the slaughterhouse. Royal Soc. Health J. 96:270-276.

ICMSF, International Commission on Microbiological Specifications for Foods. (1998). Microorganisms in Foods. Microbial Ecology of Food Commodities. Roberts T.A. Ed. Blackie Academic and Professional, London.

ISO, International Organisation for Standardisation. (2002). ISO 6579. Microbiology of food and animal feeding stuffs -- Horizontal method for the detection of *Salmonella* spp. Geneva, Switzerland.

James C. and James S.J. (1995). Past and future research into methods of red meat decontamination. Report-MAFF contract MH0211, UK MAFF, London.

James C., Goksoy E.O. and James S.J. (1997). Past present and future methods of meat decontamination. MAFF Fellowship in Food Process Engineering, University of Bristol.

James C., Nicolaon M. and James S.J. (1999). Review of microbial contamination and control measures in abattoirs. FRPERC, University of Bristol, Bristol, ISBN 0-86292-498-7.

James C. (2002). MePOSS: Review of microbial contamination during meat manufacture (WP 1). Report for Work Package 1 of the EU CRAFT project - CRAF-1999-70560: Reduction of health risks and extension of shelf life for meat products by application of oscillating saturated steam (MePOSS).

Jensen A.N., Dalsgaard A., Stockmarr Nielsen E. M. and Baggesen D.L. (2006). Survival and transmission of *Salmonella* Typhimurium in outdoor organic pig farming. Applied and Environmental Microbiology (accepted Dec. 2005).

Jones P.W. and Hall G.A. (1975). Detection of *Salmonella* infection in pig herds by examination of slurry. Vet. Rec. 1975 Nov. 1; 97 (18): 351-2.

Jones P.W. (1992). Salmonellas in animal wastes and hazards for other animals and humans from handling animal wastes. In Int. Symp. on Salmonelia and Salmonellosis, Ploufragan (France), Sept. 15-17, 280-284.

Kaesbohrer A. (1999). Control strategies for *Salmonella* in the pig to pork chain in the European Union. International Symposium on Epidemiology and Control of *Salmonella* in Pork, 1999 ISECSP, 358- 361.

Korsak N., Jacob B., Groven B., Etienne G., China B., Ghafir Y., Daube G. (2003). *Salmonella* contamination of pigs and pork in an integrated pig production system. J. Food Prot. 66:1126-1133.

Korver H., Mooijman K.A., Nagelkerke N.J.D., van de Giessen A.W. and Henken A.M. (2003). EU collaborative study VI (2002) on bacteriological detection of *Salmonella* spp. National Institute for Public Health and the Environment (RIVM), Bilthoven The Netherlands. Report no. 330300 001, 2003.

Korver H., Mooijman K.A., Nagelkerke N.J.D. and van de Giessen A.W. (2004). EU Interlaboratory comparison study VII (2003) on bacteriological detection of *Salmonella* spp. National Institute for Public Health and the Environment (RIVM), Bilthoven The Netherlands. Report no. 330300 004, 2004.

Kranker S., Alban L., Boes J., Dahl J. (2003). Longitudinal study of *Salmonella enterica* aerotype Typhimurium infection in three Danish farrow-to-finish swine herds, J.Clin.Microbiol. 41: 2282-2288.

Kuehnel K. and Blaha T. (2005). Developing plant-specific *Salmonella* minimisation programmes - recommendations for slaughter and processing plants. Fleischwirtschaft, 85, 12, 115 – 118.

Larsen S.T., Hurd H.S., McKean J.D., Griffith R.W., Wesley I.V. (2004). Effect of short-term lairage on the prevalence of *Salmonella* enterica in cull sows. J Food Prot. 2004 Jul;67(7):1489-93.

Laval A., Morvan H., Disperez G. and Corbion B. (1992). Salmonellosis in swine. In Proc. lnt. Symp. on *Salmonella* and Salmonellosis, Sept. 15-17, Ploufragan (France), 164-175.

Leistner L and Gorris L.G.M. (1995). Food preservation by hurdle technology. Trends in Food Science and Technology, 6, 41-46.

Letellier A., Messier S., Quessy S. (1999). Prevalence of *Salmonella* spp. and *Yersinia enterocolitica* in finishing pigs at Canadian abattoirs. J. Food Prot. 62(1):22-25.

Lo Fo Wong D.M.A. and Hald T. (2000). *Salmonella* in Pork (SALINPORK): Pre-harvest and Harvest Control Options based on Epidemiologic, Diagnostic and Economic Research. In: Final Report to the Commission of the European

Communities, Agriculture and Fisheries FAIR1 CT95-0400. Royal Veterinary and Agricultural University, Department of Animal Health and Animal Science and the Danish Veterinary Laboratory, Danish Zoonosis Centre, Copenhagen, pp. 132–155.

Lo Fo Wong D.M.A., Dahl J., Stege H.,. van der Wolf P.J, Leontides L., von Altrock A. and Thorberg B.M. (2004). Herd-level risk factors for subclinical *Salmonella* infection in European finishing-pig herds. Prev. Vet. Med. 2004 Apr 16;62(4):253-66.

Loynachan A.T. and Harris D.L. (2005). Dose determination for acute *Salmonella* infection in pigs.Appl Environ Microbiol. 2005 May;71(5):2753-5.

Lumsden J.S. and Wilkie B.N. (1992). Immune response of pigs to parenteral vaccination with an aromatic- dependent mutant of *Salmonella* Typhimurium. Can. J. Vet. Res. 56(4):296-302.

Mafu A.A., Higgins R., Nadeau M., Cousineau G. (1989). The incidence of *Salmonella*, *Campylobacter*, and *Yersinia enterocolitica* in swine carcasses and the slaughterhouse enviroment. J. Food Prot. 52, 642-645.

Malorny B. and Hoorfar J. (2005). Toward standardization of diagnostic PCR testing of fecal samples: lessons from the detection of salmonellae in pigs. J. Clin. Microbiol. 2005 Jul;43(7):3033-7.

Marg H., Scholz H.C., Arnold T., Rosler U., Hensel A. (2001). Influence of long-time transportation stress on re-activation of *Salmonella* typhimurium DT104 in experimentally infected pigs. Berl Munch Tierarztl Wochenschr. 2001 Sep-Oct;114(9-10):385-8.

Mattick K.L., Bailey R.A, Jørgensen F. and Humphrey T.J. (2002). The prevalence and number of *Salmonella* in sausages and their destruction by frying, grilling or barbecuing. J. Appl. Microbiol., 93, 541-547.

McEvoy J. M., Sheridan J. J., Blair I. S. and McDowell D. A. (2004). Microbial contamination on beef in relation to hygiene assessment based on criteria used in EU Decision 2001/471/EC. Int. J. Food Microbiol. 92:217-225.

McLaren I.M. and Wray C. (1991). Epidemiology of *Salmonella* Typhimurium infection in calves: persistence of *Salmonella* on calf units. Vet. Rec. 129, 461-462.

Mead P.S., Slutsker L., Dietz V., McCaig L.F., Bresee J.S., Shapiro C., Griffin P.M. and Tauxe R.V. (1999). Food-Related Illness and Death in the United States. Emerging Infectious Diseases 5(5): 607-25.

Meija W., Zapata D., Martin M., Casal J., Mateu E. (2003). Comparison of two commersial ELISA for the diagnosis of *Salmonella* in swine. In: Leontides L, editor. Safe Pork, 5th International Symposium of the Epidemiology and Control of Food Borne Pathogens in Pork. Crete. p 269-271.

Mertens P.L., Thissen J.F., Houben A.W. and Sturmans F. (1999). An epidemic of *Salmonella* Typhimurium associated with traditional salted, smoked and dried ham. Ned. Tijdschr. Geneeskd., 143(20), 1046-1049.

Møgelmose V., Nielsen B., Sorensen L.L., Dahl J., Wingstrand A., Johansen M., Pihl K., Nielsen V., Svensmark B., Udesen F., Larsen L.P. and Baggesen D.L. (1999). Eradication of multi – resistant *Salmonella* Typhimurium DT 104 infection in 15

Danish swine herds. International Symposium on Epidemiology and Control of *Salmonella* in Pork, 1999 ISECSP, 367- 369.

Mooijman K.A. (2004). The use of semi-solid media for the detection of *Salmonella* spp. in poultry faeces and other matrices, Working document ISO/TC34 SC9 N681 – annex 1, 17.12.2004.

Morgan I.R., Krautil F.L., Craven J.A. (1987). Effect of time in lairage on caecal and carcass *Salmonella* contamination of slaughter pigs. Epidem. Inf., 98, 323-330.

Mousing J., Jensen P.T., Halgaard C., Bager F., Feld N., Nielsen B., Nielsen J.P., Bech-Nielsen S. (1997). Nation-wide *Salmonella enterica* surveillance and control in Danish slaughter swine herds, Prev. Vet. Med. 29: 247-261.

Murray C.J. (1991). *Salmonella* in the environment. Rev. Sci. Tech. Off Int. Epiz., 10, 765-785.

Mygind J. (2004). The Danish *Salmonella* control programme for the production of table eggs and broiler: an overview, In: Symposium on the Public Danish Plan for control of *Salmonella* in poultry, Danish Veterinary and Food Administration, Copenhagen 23 March 2004.

National Veterinary Institute. Sweden. (2001). Zoonoses in Sweden up to and including 1999. Uppsala, 2001, 48 pp. http://www.sva.se/pdf/zoonosinsweden.pdf (accessed on 26 January 2006).

Nielsen B. (1992). Production of *Salmonella*-free poultry feed. In lut. Symp. on *Salmonella* and Salmonellosis, Ploufragan (France), Sept. 15-17, 436-441.

Nielsen B., Baggesen D., Bager F., Haugegaard J., Lind, P. (1995). The serological response to *Salmonella* serovars Typhimurium and Infantis in experimentally infected pigs. The time course followed with an indirect anti-LPS ELISA and bacteriological examinations. Vet. Microbiol. 47, 205 – 218.

Nollet N., Maes D., De Zutter L., Duchateau L., Houf K., Huysmans K., Imberechts H., Geers R., de Kruif A. and Van Hoof J. (2004). Risk factors for the herd-level bacteriologic prevalence of *Salmonella* in Belgian slaughter pigs. Prev. Vet. Med. 65(1-2):63-75.

Nollet N., Maes D., Duchateau L., Hautekiet V., Houf K., Van Hoof J., De Zuttera L., de Kruif A., Geers R. (2005). Discrepancies between the isolation of *Salmonella* from mesenteric lymph nodes and the results of serological screening in slaughter pigs, Vet. Res. 36: 545-555.

Oosterom J., Dekker R., De Wilde G.J.A., Van Kempen-De Troye F., Engels G.B. (1985). Prevalence of *Campylobacter jejuni* and *Salmonella* during pig slaughtering. Vet. Quart. 7, 31-34.

Ortmann R. (1999). Immunisierungsversuche mit der *Salmonella* Typhimurium-Lebendvakzine Salmoporc R zur Bekämpfung von Salmonellen-Infektionen in Ferkelerzeugerbetrieben. Hannover.

Ortner H. (1988) Einfluß der Kühlung auf die Fleischqualität. Fleischwirtsch. 68, 794-796.

Österberg J., Vågsholm I., Boqvist S. and Sternberg Lewerin S. (2005). Feed-borne outbreak of *Salmonella* Cubana in Swedish pig farms: Risk factors and factors affecting the restriction period in infected farms. In press.

Pepperell R., Reid C.A., Nicolau Solano S., Hutchison M. L., Walters L. D., Johnston A. M. and Buncic S. (2005). Experimental comparison of excision and swabbing microbiological sampling methods for carcasses. J. Food Prot. 68, 2165-2168.

Prencipe V., Conte A., Giovannini A., Marino L., Petrini A., Pomilio F. and Rizzi V. (2000). Quantitative risk assessment of *Salmonella* spp. infection for the consumer of pork products in an Italian region. Proceedings ISVEE Conference, 917-919.

Quirke A.M., Leonard N., Kelly G., Egan J., Lynch P.B., Rowe T., Quinn P.J. (2001). Prevalence of *Salmonella* serotypes on pig carcasses from high- and low-risk herds slaughtered in three abattoirs. Berl Munch Tierarztl Wochenschr. 114(9-10):360-362.

Rajic A, Keenliside J, McFall ME, Deckert AE, Muckle AC, O'Connor BP, Manninen K, Dewey CE, McEwen SA. (2005) Longitudinal study of *Salmonella* species in 90 Alberta swine finishing farms. Vet Microbiol. 2005 Jan 5;105(1):47-56.

Ransom J.R., Belk K.E., Bacon R.T., Sofos J.N., Scanga J.A. and Smith G.C. (2002). Comparison of sampling methods for microbiological testing of beef animal rectal/colon feces, hides, and carcasses. J. Food Prot. 64:621-626.

Redmond E. C. and Griffith C. J. (2003). Consumer food handling in the home: A review of food safety studies. J. Food Prot. 66, 130 – 161.

Savell J. W., Mueller S. L., Baird B. E. (2004). The chilling of carcasses. 50th ICoMST Helsinki, Finland.

Schmidt P.L., O'Connor A.M., McKean J.D., Hurd H.S. (2004). The association between cleaning and disinfection of lairage pens and the prevalence of *Salmonella enterica* in swine at harvest. J. Food Prot. 2004 Jul;67(7):1384-8.

Schmidt, U. (1985). Salmonellen in frischen Mettwürsten. 1. Mitteilung, Vorkommen von Salmonellen in frischen Mettwürsten. Fleischwirtschaft, 65, 1045-1048.

Schneitz C. and Mead G.C. (2000). Competitive exclusion. In C. Wray and A. Wray, *Salmonella* in domestic animals. Oxon, United Kingdom: CABI Publishing, CAB International, pp. 301-322.

Schwartz K.J. (1999). Salmonellosis. In: Diseases of Swine. 8th edition, Blackwell Science, ISBN 0-632-05256-2, pp 535-551.

SCVMPH, Scientific Committee on Veterinary Measures relating to Publick Health. (1998). Benefits and limitations of antimicrobial treatments for poultry carcasses. http://www.europa.eu.int/comm/food/fs/sc/scv/out14_en.pdf, accessed on 26 January 2006.

SCVMPH, Scientific Committee on Veterinary Measures relating to Publick Health. (2003). EU/SANCO. Opinion of the SCVMPH on salmonellae in Foodstuffs. http://www.europa.eu.int/comm/food/fs/sc/scv/out66_en.pdf, accessed on 26 january 2006.

Selbitz H.J., Lindner T. and Springer S. (2003). Immune prophylaxis of *Salmonella* infection in swine. Praktischer Tierartz. 84, 2, 124-130.

Skov M.N., Carstensen B., Tornoe N., Madsen M. (1999). Evaluation of sampling methods for the detection of *Salmonella* in broiler flocks. J. Appl. Microbiol. 86:695-700.

Smerdon W.J., Adak G.K., O'Brien S.J, Gillespie I.A. and Reacher M. (2001). General outbreaks of infectious intestinal disease linked with red meat, England and Wales, 1992 – 1999. Communicable Disease and Public Health, 4, 259 – 267.

Smith R.W. and Jones J.E.T. (1967). Observations on experimental oral infection with *Salmonella* Dublin in calves and *Salmonella* Cholerasuis in pigs. J. Pathol. 93, 141-456.

Smulders F.J.M. and Greer G.G. (1998). Integrating microbial decontamination with organic acids in HACCP programmes for muscle foods: prospects and controversies. Int. J. Food Microbiol. 44 149-169.

Snijders J.M.A. (1992). Beinvloeding van de microbiologische kwaliteit van varkensvlees. In: Den Hartog, L.A., Schumer, O.L., Visser-Reyneveld, M.I. (edts.). Kwaliteitiszorg in de Varkenshouderij – van Voer tot Vlees. PUDOC, Wageningen, The Netherlands.

Sofos J.N. and Smith G.C. (1998). Nonacid meat decontamination technologies: Model studies and commercial applications. Int. J. Food Microbiol. 44, 171-188.

Sorensen L.L., Carstensen B., Dahl J. (2000). Sammanhaeng mellem *Salmonella*-serologi og bacteriologiske undersögelser af blindtarmsinhold, slagtekroppe, svaelg og lymfeknuder fra danske slagtsvin: Niveau 1-2-3 undersögelsen (Association between *Salmonella* serology and bacteriology testing investigation of caecum content, carcasses, throat and lympnodes from Danish finishers: Level 1-2-3 investigation). Danske Slagterier:14.

Sorensen L.L., Alban L., Nielsen B., Dahl J. (2004). The correlation between *Salmonella* serology and isolation of *Salmonella* in Danish pigs at slaughter. Vet. Microbiol. 101:131-141.

Springer S., Lindner T., Steinbach G., Selbitz H.J. (2001). Investigation of the efficacy of a genetically-stabile live *Salmonella* Typhimurium vaccine for use in pigs. Berl Munch Tierarztl Wochenschr. 114 (9-10):342-345.

Stabel T.J. and Fedorka-Cray P.J. (2004). Effect of 2-deoxy-d-glucose induced stress on *Salmonella* choleraesuis shedding and persistence in swine. Res Vet Sci. 2004 Jun;76(3):187-94.

Stärk K.D.C., Wingstrand A., Dahl J., Mogelmose V. and Lo Fo Wong D.M.A. (2002). Differences and similarities among experts' opinions on *Salmonella enterica* dynamics in swine pre-hervest. Prev. Vet. Med. 53, 7-20.

Stege H., Carstensen B., Christensen J., Feld N.C., Baggesen D. (1997). Subclinical *Salmonella* infection in Danish finishing herds-association between serological and bacteriological testing. In: Proceedings of the IInd international Symposium on Epidemiology and Control of *Salmonella* in Pork. Copenhagen, Denmark. p 114-118.

Stege H., Christensen J., Nielsen J.P., Baggesen D.L., Enoe C., Willeberg, P. (2000). Prevalence of subclinical infection in Danish finishing pig herds. Prev. Vet. Med. 44, 175-188.

Steinbach G. Hartung M. (1999). Attempt to estimate the share of human *Salmonella* infections, which are attributable to *Salmonella* originating from swine. Berl Munch Tierarztl Wochenschr. 1999 Aug;112(8):296-300.

Sternberg Lewerin S., Boqvist S., Engström B., Häggblom P. (2005). The effective control of *Salmonella* in Swedish poultry. In: Mead GC, editor. Food safety control in the poultry. Cambridge: Woodhead Publishing Limited. p 544.

Stöver A. G., Jeffery E., Xu J., Persing D. H. (2004). Hybridization array technology, p. 619-639. In D. H. Persing, F. C. Tenover, J. Versalovic, Y.-W. Tang, E. R. Unger, D. A. Relman, and T. J. White (eds.), Molecular Microbiology: Diagnostic principles and practise. ASM Press, Washington, D.C.

Swanenburg M., Berends B.R., Urlings H.A., Snijders J.M., van Knapen F. (2001a). Epidemiological investigations into the sources of *Salmonella* contamination of pork. Berl Munch Tierarztl Wochenschr. 114:356-359.

Swanenburg M., van der Wolf P.J., Urlings H.A., Snijders J.M., van Knapen F. (2001b). *Salmonella* in slaughter pigs: the effect of logistic slaughter procedures of pigs on the prevalence of *Salmonella* in pork. Int. J. Food Microbiol. 70:231-242.

Thorberg B.M. and Engvall A. (2001). Incidence of *Salmonella* in five Swedish slaughterhouses. J. Food Prot. 64(4):542-5.

Threlfall E.J. (2002). Antimicrobial drug resistance in *Salmonella*: problems and perspectives in food- and water-borne infections. FEMS Microbiol. Rev., **26,** 141-148.

Tirado C. and Schmidt K. (ed.). (2000). WHO surveillance programme for control of foodborne infections and intoxications in Europe, 7th report, 1993–1998. BGVV-FAO/WHO Collaborating Centre for Research and Training in Food Hygiene and Zoonoses.

Toma B., Dufour B., Sanaa M., Benet J.J., Moutou F., Louza A., Ellis P., Shaw A. (1999). Applied veterinary epidemiology and the control of disease in populations. AEEMA Ed, Maisons-Alfort, France.

Unterman, F., Stephan R., Dura U., Hofer B., and Hemann P. (1997). Reliability and practicability of bacteriological monitoring of beef carcass contamination and their rating within a hygiene quality control programme of abattoirs. Int. J. Food Microbiol. 35:195-204.

USDA, United States Department of Agriculture. (1993). Proc. World Congress on meat and poultry inspection, Oct. 10-14 1993, College Station, Texas, USA.

van der Heijden H.M. (2001). First international ring trial of ELISAs for *Salmonella*-antibody detection in swine. Berl Munch.Tierarztl.Wochenschr. 114: 389-392.

van der Heijden H.M., Boleij P.H.M., Loeffen W.L.A., Bongers J.H., van der Wolf P.J., Tielen M.J.M. (1998). Development and validation of an indirect ELISA for the

detection of antibodies against *Salmonella* in swine. International Pig Veterinary Society Congress, 69. 1998. Birmingham, England.

van der Heijden M., van Dam H., Niewerth D. and Frankena K. (2005). Effectiveness of *Salmonella* control strategies in fattening pigs. In proceedings of the 6th International symposium on the epidemiology and control of foodborne pathogens in pork, Rohnert Park, California, USA: 145-148.

van der Marel G.M., van Logtestijn J.G. and Mossel D.A.A. (1988). Bacteriological quality of broiler carcasses as affected by in plant lactic acid decontamination. Int. J. Food Microbiol. 6, 31-42.

Van der Palen C.J.N.M., Eelderink-De Grip I., Eggenkamp A.E., Berends B.R., Burt S.A., Snijders J.M.A. (1992). Een orienterend onderzoek naar het voorkomen van *Campylobacter jejuni/coli, Listeria monocytogenes, Salmonella* spp. en *Yersinia enterocolitica* in het schone gedeelte van de varkensslachtlijn. (Dutch). VVDO-Report H9205. Utrecht, The Netherlands, Department of the Science of Food of Animal Origin, Faculty of Veterinary Medicine, Utrecht University.

van der Wolf P.J., Bongers J.H., Elbers A.R.W., Franssen F.M.M.C., Hunneman W.A., Exsel A.C.A., Tielen M.J.M. (1999). *Salmonella* infections in finishing pigs in The Netherlands: bacteriological herd prevalence, serogroup and antibiotic resistance of isolates and risk factors for infection, Vet. Microbiol. 67: 263-275.

van der Wolf P.J., Elbers A.R.W., Wolbers W.B., Koppen J.M.C.C., Lommerse J.R.N., van der Heijden H.M.J.F., van Schie F.W., Hunneman W.A., Tielen M.J.M. (2000). Risk factors for *Salmonella* infections in finishing pigs in The Netherlands. Symposium of the International Society for Animal Hygiene :283-287.

van der Wolf P.J., Elbers A.R., van der Heijden H.M., van Schie F.W., Hunneman W.A., Tielen M.J. (2001a). *Salmonella* seroprevalence at the population and herd level in pigs in The Netherlands. Vet. Microbiol. 80:171-184.

van der Wolf P.J., Lo Fo Wong D.M., Wolbers W.B., Elbers A.R., van der Heijden H.M., van Schie F.W., Hunneman W.A., Willeberg P., Tielen M.J. (2001b). A longitudinal study of *Salmonella enterica* infections in high-and low-seroprevalence finishing swine herds in The Netherlands. Vet.Q. 23:116-121.

van der Wolf P.J., Wolbers W.B., Elbers A.R.W., van der Heijden H.M.J.F., Koppen J.M.C.C., Hunneman W.A., van Schie F.W., Tielen M.J.M. (2001c). Herd level husbandry factors associated with the serological *Salmonella* prevalence in finishing pig herds in The Netherlands, Vet. Microbiol. 78: 205-219.

van der Wolf P.J., Peperkamp N.H.M.T. (2001d). *Salmonella* (sero)types and their resistance patterns isolated from pig faecal and post-mortem samples. Vet. Q. 23(4):175-181.

van der Wolf P.J., van Schie F. W., Elbers A. R., Engel B., van der Heijden H. M., Hunneman W. A., Tielen M. J. (2001e). Administration of acidified drinking water to finishing pigs in order to prevent *Salmonella* infections. Veterinary Quarterly 23 (3):121-125.

van der Wolf P.J., Swanenburg M., Urlings H.A.P., Snijders J.M.A. (2003). Selection of finishing pig herds with a low *Salmonella* prevalence for logistic slaughtering. In:

Leontides L, editor. Safe Pork, 5th International Symposium of the Epidemiology and Control of Food Borne Pathogens in Pork. Crete. p 144-146.

Van Diemen P.M., Kreukniet M.B., Galina L., Brumstead N. and Wallis T.S. (2002). Characterisation of a resource population of pigs screened for resistance to salmonellosis. Vet. Imm. and Immunopath. 88: 183-196.

van Winsen R.L., van Nes A., Keuzenkamp D., Urlings H.A., Lipman L.J., Biesterveld S., Snijders J.M., Verheijden J.H., van Knapen F. (2001). Monitoring of transmission of *Salmonella enterica* serovars in pigs using bacteriological and serological detection methods. Vet. Microbiol. 80:267-274.

Von Altrock A., Schütte A., Hildebrandt G. (2001). Results of the German Investigation in the EU-Project „*Salmonella* in Pork (Salinpork)" – Part 2: Investigations in a slaughterhouse. Berl. Münch. Tierärztl. Wschr. 112, 225-233.

Voogt N., Raes M., Wannet W.J.B., Henken A.M., van de Giessen A.W. (2001). Comparison of selective enrichment media for the detection of *Salmonella* in poultry faeces. Letter in Applied Microbiology, 32, 2001, 89-92.

Warriss P.D. (2003). Optimal lairage times and conditions for slaughter pigs: a review. The Veterinary Record, Vol 153, Issue 6, 170-176.

Wegener H.C., Baggesen D.L. (1996). Investigation of an outbreak of human salmonellosis caused by *Salmonella enterica* ssp. enterica serovar Infantis by use of pulsed field gel electrophoresis. Int. J. Food Microbiol. Volume 32, Number 1, September 1996, pp. 125-131.

WHO, World Health Organization. (1980). Report of the WHO/WAVFH Round Table Conference on the Present Status of the *Salmonella* Problem (Prevention and Control), Bilthoven, the Netherlands, WHO/VPH/81.27.

WHO, World Health Organization. (1983). Guidelines on Prevention and Control of Salmonellosis. Linton A. ed., World Health Organization, Geneva, Switzerland. VPH/83.42.

WHO, World Health Organization. (1989). Report of WHO Consultation on Epidemiological Emergency in Poultry and Egg Salmonellosis, Geneva, 20-23 March.

WHO, World Health Organization. (1992). Report on WHO Consultation on National and Local Schemes of Salmoneila Control in Poultry, Ploufragan, France, 18-19 September, WHO/CDS/VPHJ92. 110.

WHO, World Health Organization. (1993a). Report of the WHO Consultation on Control of *Salmonella* Infections in Animals. Prevention of Food - borne *Salmonella* Infections in Man Jena Germany 21-26 November.

WHO, World Health Organization. (1993b). Guidelines on cleaning, disinfecting and vector control in *Salmonella* infected poultry flocks. WHO/ZOON 94.172.

WHO, World Health Organization. (1994). WHO Consultation for the Development of Strategies for Detecting and Monitoring of *Salmonella* Infected Poultry Flocks with Particular Reference to S. enteritidis. Graz, Austria, 11-15 April.7, 1026-1033.

WHO, World Health Organization. (2001). WHO Surveillance Programme for Control of Foodborne Infections and Intoxications in Europe, Seventh Report 1993-1998 (eds K Schmidt and C Tirado), Federal Institute for Health Protection of Consumers and Veterinary Medicine (BgVV), Berlin, ISBN 3-931675-70-X, ISSN 0948-0307.

Wierup M., Wold-Troell M., Nurmi E. and Häkkinen M. (1988). Epidemiological evaluation of the *Salmonella*-controlling effect of a nationwide use of a competitive exclusion culture in poultry. Poultry Sci. 67,1026-1033.

Wierup M. (1993). Control of *Salmonella* in animal production and products in Sweden. In Proc. NVI/ WHO Int, Course on *Salmonella* Control in Animal Production and Products. Malmö, Sweden, Aug. 21-27. 1993. Ed. National Veterinary Institute, Uppsala (Sweden), pp 7-28.

Wierup M. (1994). Control and prevention of Salmonellosis in livestock farms. In comprehensive report on technical items presented to the International Committee or to Regional Commissions. OlE (ISSN 1022-1050) 1994, pp 249-269.

Wierup M. (1995). Preharvest control of salmonellosis WHO/USAA Consulting andeconomical Implication of foodborne disease and consequences on Animal production food hygiene, Washington. 8-10 June, 1995.

Wierup M. (1997). Principles for integrated surveillance and control of *Salmonella* in swine production. In Second Int. Symp on Epidemiology and Control of *Salmonella* in Pork, Aug. 20-22, 1997, Copenhagen, Denmark, pp 42-49.

Wierup M. (2000). The control of microbial diseases in animals: alternatives to the use of antibiotics. In AFFSSA European Symp on Antibiotic Resistance in Bacteria of Animal Origin, Nov 29-30, Institut Patsteur, Paris, France 1999, Int J of Antimictrobial Agents, 2000, 14, 315-319.

Wierup M. (2002). Strategies for avoiding health problems of farmed animals. Sustainable Animal Production. Proc, Workshop on Sustainable Animal Production, organized by the Institute for Animal Science and Animal Behaviour and Federal Agricultural Research Centre (FAL), Mariensee, 4-5 Sept 2000. Landbauforschung (FAL), Sonderheft 227, editors Ellendorff *et al.*, 2002, ISBN 3-933140-50-1, 103-105.

Wilcock B.P. and Schwartz K.J. (1992). Salmonellosis. In: Leman A, Straw BE, Mengeling WL, D'Allaire S, Taylor DJ, editors. Diseases of Swine. Ames: Iowa State University Press. p 570-583.

Williams L.P. Jr and Newell K.W. (1968). Sources of salmonellas in market swine.J Hyg (Lond). 1968 Jun;66(2):281-93.

Wigley P. (2004). Genetic resistance to *Salmonella* infection in domestic animals. Res.Vet. Sci.76,165-169.

Wingstrand A., Dahl J., Lo Fo Wong D.M.A. (1999). *Salmonella*-prevalences in Danish organic, free-range, conventional and breeding herds. In: Proceedings of the 3rd International Symposium on the Epidemiology and Control of *Salmonella* in Pork, p. 186-189. August 5.-7., 1999, Washington DC, USA.

Wiuff C., Thorberg B.M., Engvall A., Lind P. (2002). Immunochemical analyses of serum antibodies from pig herds in a *Salmonella* non-endemic region. Vet. Microbiol. 85: 69-82.

Worsfold D. and Griffith C. J. (1997). Food safety behaviour in the home. Br. Food J. 99:97–104.

Ye R. W., Wang T., Bedzyk L., Croker K. M. (2001). Applications of DNA microarrays in microbial systems. J. Microbiol. Methods 47:257-272.

12. GLOSSARY

- **Contaminant:** any biological or chemical agent, foreign matter, or other substances not intentionally added to food which may compromise food safety or suitability.[10]
- **Contamination:** the introduction or occurrence of a contaminant in food or food environment.[12]
- **Disease Monitoring:** the ongoing efforts directed at assessing the health and disease status of a given population. This activity necessitates a system for collecting, processing and summarising data and disseminating information to appropriate agents and individuals.[11]
- **Disease Surveillance:** the ongoing, systematic collection and evaluation of data describing the occurrence and spread of disease.[12] It describes a more active system and implies that some form of directed action will be taken if the data indicate a disease level above a certain threshold.[13]
- **Harvest stage or level:** the part of the food chain beginning with the transport of the slaughter animals from the farm gate, the lairage phase, slaughtering itself, up to the cooling of the carcasses.
- **Infection:** the presence of the pathogenic agent in the host.[13]
- **Pre-harvest stage or level:** the part of the food chain which includes the period when the animals are held on the holding or farm up to the point when the pigs leave the farm and are loaded for transportation to the slaughterhouse.
- **Post harvest stage or level:** the part of the food chain which includes cutting and processing, production of raw, fermented or "safe products" up to retail and consumer levels.
- **Primary production[14]:** the production, rearing or growing of primary products including harvesting, milking and farmed animal production prior to slaughter. It also includes hunting and fishing and the harvesting of wild products.

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[10] Codex Alimentarius. (2003). Recommended international code of practice general principles of food hygiene. CAC/RCP 1-1969, Rev. 4 (2003). ftp://ftp.fao.org/codex/Publications/Booklets/Hygiene/FoodHygiene_2003e.pdf

[11] Martin S.W, Meek A.H. and Willeberg P. (1987). In Veterinary Epidemiology: Principles and Methods, pp. 259-282. Ames, Iowa: Iowa Sate University Press.

[12] World Health Organization, WHO. (2002). Methods for Foodborne Disease Surveillance in Selected Sites. Report of a WHO consultation 18-21 March 2002 Leipzig, Germany. http://www.who.int/salmsurv/links/en/Leipzigmeetingreport.pdf

[13] World Organizaton for Animal Health, OIE. (2005). Terrestrial Animal Health Code. 14th Edition, 2005. http://www.oie.int/eng/normes/mcode/en_chapitre_1.1.1.htm

[14] Regulation 178/2002. OJ L31/01.02.2002 p.1

13. ANNEXES

13.1. ANNEX I - Tables

Table 1: The regional development of global pork production between 1970 and 2003, data in 1000 tonnes (t) (Source: FAO database).

Region	1970	1980	1990	2003	Total increase (%)
Africa	261	346	590	739	183
Asia	8452	15810	29568	53505	534
Europe	13516	19299	21641	25381	88
USSR	4453	5184	6655	-	-
North and Central America	7746	10009	9103	12247	58
South America	1306	1741	1900	3373	158
Oceania	239	239	405	534	123
World	35793	52679	69862	95779	168

Table 2: The ten leading countries in global pork production in 1990 and 2003, data in 1000 tonnes (t) (Source: FAO database).

Country	1990		2003	
	Production	Share (%)	Production	Share (%)
China	24016	34.4	45567	47.6
USA	6964	10.0	8931	9.3
USSR	6654	9.5	4123	4.3
Germany	4457	6.4	3200	3.3
Poland	1855	2.6	2350	2.5
Spain	1789	2.6	2145	2.2
France	1726	2.5	2050	2.1
The Netherlands	1661	2.3	1795	1.9
Japan	1555	2.2	1761	1.8
Italy	1333	1.9	1657	1.7
10 countries	52010	74.4	73597	76.8
World	69862	100.0	95779	100.0

Table 3: The development of pork production in the EU-15 between 1970 and 2003, data in 1000 tonnes (Source: FAO database).

Country	1970	1980	1990	2003	Variation between 1970 and 2003(%)
Germany	3399	4418	4457	4123	+ 21
Spain	492	1182	1789	3200	+ 550
France	1375	1803	1726	2350	+ 71
Denmark	717	972	1208	1761	+ 146
Italy	593	1085	1333	1550	+ 161
The Netherlands	701	1125	1661	1420	+ 103
Belgium/Lux.	474	669	784	1062	+ 124
United Kingdom	921	926	946	717	- 22
Austria	333	426	517	650	+ 95
Portugal	94	155	279	330	+ 251
Sweden	236	317	191	284	+ 20
Ireland	144	153	157	215	+ 49
Finland	105	169	187	185	+ 76
Greece	52	144	140	140	+ 169
EU (15)	9636	13547	15476	17986	+ 87

Table 4: Pig stocks and pork production in the EU Member States (2004) (Source FAO-Database).

Country	Pigs (1000 tonnes)	% of total	Pigmeat (1000 tonnes)	% of total
Germany	26495	17.3	4366	20.2
Spain	23990	15.7	3335	15.4
France	15189	9.9	2290	10.6
Poland	18100	11.8	2100	9.7
Denmark	13257	8.7	1762	8.2
Italy	9223	6.0	1618	7.5
The Netherlands	11122	7.3	1245	5.8
Belgium	6366	4.2	1050	4.9
United Kingdom	5038	3.3	675	3.1
Hungary	4913	3.2	600	2.8
Austria	3245	2.1	510	2.4
Czech Rep.	3309	2.2	410	1.9
Portugal	2203	1.4	330	1.5
Sweden	1903	1.2	228	1.0
Ireland	1732	1.1	223	1.0
Finland	1394	0.9	199	0.9
Slovakia	1443	0.9	160	0.7
Greece	948	0.6	135	0.6
Lithuania	1054	0.7	86	0.4
Slovenia	621	0.4	60	0.3
Cyprus	491	0.3	53	0.2
Latvia	440	0.3	38	0.2
Estonia	345	0.2	38	0.2
Luxemburg	76	0.1	11	0.0
Malta	73	0.1	10	0.0
EU (25)	153173	100.0	21592	100.0

Table 5: Most frequently reported *Salmonella* serovars in humans based on laboratory surveillance data (WHO, 2001; EC 2002, EC 2004, EC 2005, EFSA 2005).

Salmonella	**Year**									
serovar	**1993[1]**	**.994[1]**	**1995[1]**	**1996[1]**	**1997[1]**	**1998[1]**	**2000[2]**	**2002[3]**	**2003[4]**	**2004[5]**
S. Enteritidis	74%	77%	77%	79%	80%	84%	59%	67%	61.8%	76.4%
S. Typhimurium	20%	16%	17%	16%	15%	12%	13%	17%	16.5%	13.9%
S. Infantis	1.2%	1.1%	1.3%	0.9%	0.9%	0.6%	0.9%	0.7%	0.5%	0.5%
S. Hadar	0.4%	0.8%	0.8%	1.0%	1.0%	0.9%	1.8%	0.6%	0.5%	0.2%
S. Virchow	1.0%	1.1%	0.9%	0.6%	0.5%	0.4%	1.4%	0.5%	0.6%	0.4%
Other serovars	3.6%	4%	3%	2.5%	2.6%	2.1%	23%	14.2%	20.1%	8.6%

[1] WHO, 2001; [2] EC, 2002; [3] EC 2004, [4] EC 2005, [5] EFSA 2005

Table 6: Distribution of the most common *Salmonella* serovars in humans (source: Reports on Trends and sources of zoonotic agents in animals, feedingstuffs, food and man in the European Union and Norway, 2000-2004).

Countries	n isolates serotyped considered	Serotypes	%	Note
A; B, C; Cz; D; E; F; Fr; G; Gr; H; Ir; La; Li; M; UK; Pl; Sl; Sk; Sp; Sw; Nh	157164	*S.* Enteritidis	76.4	**REPORT 2004**
		S. Typhimurium	13.9	
		S. Group D	2.6	
		S. Newport	0.6	
		S. Infantis	0.5	
		S. Virchow	0.4	
		S. Stanley	0.30	
		S. Group B	0.22	
		S. Hadar	0.2	
		S. Derby	0.12	
A; B; D; F; Fr; G; Gr; Ir; L; Nh; N; P; Sp; Sw; UK	133494	*S.* Enteritidis	61.8	**REPORT 2003**
		S. Typhimurium	16.5	
		S. Virchow	0.6	
		S. Infantis	0.5	
		S. Hadar	0.5	
		S. Group D	0.3	
		S. Group B	0.3	
		S. Newport	0.3	
		S. Agona	0.3	
		S. Derby	0.2	
		S. Branderup	0.2	
		S. Stanley	0.2	
A; B; D; F; Fr; G; Ir; L; Nh; N; P; Sp; Sw; UK	127783	*S.* Enteritidis	67.1	**REPORT 2002**
		S. Typhimurium	17.0	
		S. Infantis	0.7	
		S. Virchow	0.6	
		S. Group D	0.5	
		S. Hadar	0.5	
		S. Group B	0.3	
		S. Agona	0.3	
		S. Brandenburg	0.3	
		S. Derby	0.3	
		S. Newport	0.2	
		S. Branderup	0.2	

Countries	n isolates serotyped considered	Serotypes	%	Note
A; B; D; F; G; Gr; Ir; L; Nh; N; P; Sp; Sw; UK	114253	*S.* Enteritidis	71.0	**REPORT 2001**
		S. Typhimurium	21.2	
		S. Infantis	1.1	
		S. Virchow	1.0	
		S. Hadar	0.9	
		S. Bovismorbificans	0.6	
		S. Agona	0.4	
		S. Derby	0.4	
		S. Oranienburg	0.4	
		S. Newport	0.4	
		S. Brandenburg	0.4	
		S. Branderup	0.4	
A; B; D; UK; F; Ir; N; Sw		*S.* Enteritidis	59.1	**REPORT 2000**
		S. Typhimurium	13.0	
		S. Hadar	1.8	
		S. Virchow	1.4	
		S. Infantis	0.9	
		S. Agona	0.8	
		S. Brandenburg	0.7	
		S. Newport	0.5	
		S. Blockley	0.5	
		S. Branderup	0.4	
		S. Stanley	0.4	
		S. Derby	0.4	

A: Austria; B: Belgium; C: Cyprus; Cz: Czech Republic; E: Estonia; D: Denmark; F: Finland; Fr: France; G: Germany; Gr: Greece; H: Hungary; Ir: Ireland; I: Italy; L: Luxemburg; L: Latvia; Li: Lithuania; M: Malta; Nh: Netherlands; P: Portugal; Pl: Poland; Sp: Spain; Sw: Sweden; N: Norway; NI: North Ireland; UK: United Kingdom; Sk: Slovakia; Sl: Slovenia

Table 7: Pork identified as the contamination source in recent *Salmonella* associated outbreaks.

Year	Reference	Country	*Salmonella* serovar	Infection source
2005	Torpdahl *et al.*, 2006	Denmark	*S.* Typhimurium	Pork
2005	Gilsdorf *et al.*, 2005	Germany	*S.* Bovismorbificans	Raw minced pork
2003	Quinn *et al.*, 2003	Australia	*S.* Typhimurium	Roast pork
2001	Buchholz *et al.*, 2005	Germany	*S.* München	Raw pork meat
2000	Tribe and Walker, 2000	Australia	*S.* Typhimurium	De-boned spiced pork
1997-1998	Mølbak, *et al.*, 1998	Denmark	*S.* Manhattan	Ready-to-eat fillet of pork
1996	Mølbak and Hald, 1997	Denmark	*S.* Typhimurium	Pork
1993	Wegener and Baggesen, 1996	Denmark	*S.* Infantis	Pork

Table 8: Distribution of the most common *Salmonella* serovars in compound feedingstuffs (source: Reports on trends and sources of zoonotic agents in animals, feedingstuffs, food and man in the European Union and Norway, 2000-2004).

COUNTRY	ISOLATED	SEROTYPED	SEROVARS
			YEAR 2000
Austria	2	2	*S.*Montevideo (2)
Belgium	1	1	*S.* Meleagridis (1)
Denmark	4	4	*S.*Tennesse (2); *S.* Derby (1); *S.* Typhimurium (1)
Italy	3	3	*S.* Typhimurium (1); serovars other than *S.* Typhimurium or *S.* Enteritidis (2)
UK (Great Britain)	38	36	*S.* Agona (22); *S.* Anatum (2); *S.* Kedougou (2); *S.* Tennessee (2); *S.* Agama (1); *S.* Cubana (1); *S.* Kiel (1); *S.* Mbandaka (1); *S.* Messina (1); *S.* Montevideo (1); *S.* Poona (1); *S.* Taksony (1)
			YEAR 2001
Belgium	1	1	*S.* Panama (1)
Denmark	1	1	S Agona (1)
The Netherlands	9	1	*S.* Enteritidis (1)
UK (Great Britain)	29	28	*S.*Agama (2); Agona (6); *S.* Ajiobo (1); *S.* Cubana (1); *S.* Lexington (3); *S.* Mbandaka (4); *S.* Montevideo (1); *S.* Newington (4); *S.* Oranienburg (1); *S.*Rissen (1); *S.* Tennessee (2); *S.* Yoruba (1); *S.* Typhimurium (1)
			YEAR 2002
Austria	2	2	*S.* Falkensee (1); *S.* Lille (1)
France	3	1	*S.* Anatum (1)
Spain	10	5	*S.* Abony (5)
The Netherlands	20	4	*S.* Mbandaka (1); *S.* Wortington (1); *S.* Bareily (1); *S.* Carrau (1)
UK (Great Britain)	42	36	*S.* Agama (1); *S.* Agona (6); *S.* Anatum (1); *S.* Cubana (1); *S.* Havana (2); *S.* Kedougou (7); *S.* Kentucky (1); *S.* Lexington (1); *S.* Livingstone (1); *S.* Mbandaka (8); *S.* Montevideo (1); *S.* Newington (1); *S.* Rissen (1); *S.* Senftenberg (1); *S.* Taksony (1); *S.* Worthington (1); *S.* Typhimurium (1)
UK (Northern Ireland)	275	275	*S.* Typhimurium (148); serovars other than *S.* Typhimurium or *S.* Enteritidis (127)
			YEAR 2003
Belgium	2	2	*S.* Thompsom (1); *S.* Brandenburg (1)
Denmark	1	1	*S.* Idikan (1)
Latvia	4	1	*S.* Senftenberg (1)
The Netherlands	18	2	*S.* Typhimurium (2)
UK (Great Britain)	22	22	*S.* Agama (1); *S.* Agona (2); *S.* Anatum (3); *S.* Cubana (1); *S.* Dublin (1); *S.* Ealing (1); *S.* Java (1); *S.* Kedougou (1); *S.* Lexington (1); *S.* Mbandaka (4); *S.* Meleagridis (1); *S.*Oranienburg (1); *S.* Rissen (1); *S.* Senftenberg (1); *S.* Worthington (1); *S.* Typhimurium (1)
			YEAR 2004
Italy	1	1	*S.* Enteritidis (1)
Poland	22	3	*S.* Enteritidis (1); *S.* Typhimurium (2);
Slovenia	1	1	*S.* Enteritidis (1)
Spain	1	1	*S.* Infantis (1)
The Netherlands	18	2	*S.* Typhimurium (2)
UK (Great Britain + Northern Ireland)	12	12	*S.* Typhimurium (2); *S.* Agona (3); *S.* Kedougou (1); *S.* Kentucky (1); *S.* Mbandaka (2); *S.* Memeagridis (1); *S.* Montevideo (1); *S.* Rissen (1)

Table 9: Distribution of the most common *Salmonella* serovars in pigs, in MS that have serotyped at least 25 monitoring isolates. The serovar distribution for each MS was based on the number of serotyped isolates, including nontypeable isolates (source: Reports on Trends and sources of zoonotic agents in animals, feedingstuffs, food and man in the European Union and Norway, 2000-2004).

Countries	n isolates serotyped considered	Serovars	%	Note
Cz; D; G; H; I; UK; Pl; Sl; Nh; B	2551	*S.* Typhimurium	57.9	Distribution of the most common *Salmonella* serotypes in pigs in MS that have serotyped at least 25 monitoring isolates. REPORT 2004
		S. Derby	16.4	
		S. Infantis	3.7	
		S. 4,12:i:-	2.5	
		S. Anatum	2.4	
		S. Rissen	1.3	
		S. Choleraesuis	1.2	
		S. Enteritidis	1.0	
A; B; G; D; F; Fr; Ir; I; L; Nh; N; P; Sp; UK	3930	*S.* Typhimurium	52.44	REPORT 2003
		S. Derby	8.88	
		S. Gr. B-O-orm	3.23	
		S. Golgcoast	2.39	
		S. Livingstone	2.21	
		S. Panama	1.93	
		S. Dublin	1.55	
		S. Infantis	1.27	
		S. Brandenburg	1.27	
A; B; G; D;F; Fr; Ir; I; L; Nh; N; P; Sw; UK	2348	*S.* Typhimurium	57.03	REPORT 2002
		S. Derby	10.43	
		S. Bovismorbificans	3.24	
		S. Infantis	2.90	
		S. Brandenburg	2.00	
		S. London	1.02	
		S. Manhattan	1.02	
		S. Livingstone	0.98	
		S. Goldcoast	0.94	

Countries	n isolates serotyped considered	Serovars	%	Note
A; B; D; F; I, Nh; P, Sp; Sw; UK	2233	*S.* Typhimurium	58.71	REPORT 2001 * data obtained considering the number of isolates typed/positive flocks/positive animals/positive reported by each MS. In some MS, only *S.* Enteritidis and *S.* Typhimurium are covered in the report and these data are not considered.
		S. Derby	5.55	
		S. Newport	3.31	
		S. Brandenburg	2.87	
		S. Infantis	2.42	
		*S.*Livingstone	1.12	
		S. Enteritidis	0.94	
		S. Anatum	0.99	
		S. Panama	0.67	
A; B; F; Ir; I; N; P; Sw; UK	971	*S.* Typhimurium	49.74	REPORT 2000 * data obtained considering the number of isolates typed/positive flocks/positive animals/positive reported by each MS. In some MS, only *S.* Enteritidis and *S.* Typhimurium are covered in the report and these data are not considered.
		S. Derby	19.77	
		S. Kedougou	2.37	
		S. Goldcoast	2.37	
		S. Brandenburg	2.16	
		S. Panama	1.54	
		S. Livingstone	1.34	
		S. 4,5:i:-	1.03	
		S. Enteritidis	0.82	

A: Austria; B: Belgium; C: Cyprus; Cz: Czech Republic; E: Estonia; D: Denmark; F: Finland; Fr: France; G: Germany; Gr: Greece; H: Hungary; Ir: Ireland; I: Italy; L: Luxemburg; L: Latvia; Li: Lithuania; M: Malta; Nh: Netherlands; P: Portugal; Pl: Poland; Sp: Spain; Sw: Sweden; N: Norway; NI: North Ireland; UK: United Kingdom; Sk: Slovakia; Sl: Slovenia

Table 10: Distribution of the most common *Salmonella* serovars in pig meat, in MS that have serotyped at least 25 monitoring isolates. The serovar distribution for each MS was based on the number of serotyped isolates, including nontypeable isolates (source: Reports on Trends and sources of zoonotic agents in animals, feedingstuffs, food and man in the European Union and Norway, 2000-2004).

Countries	N isolates serotyped	Serotypes	%	Note
D; B, G; H; Ir; I	1411	*S.* Typhimurium	35.8	Distribution of the most common *Salmonella* serotypes in pork in MS that have serotyped at least 25 monitoring isolates. REPORT 2004
		S. Derby	20.6	
		S. Infantis	5.0	
		S. London	3.7	
		S. 4,12:i:-	3.0	
		S. Anatum	2.6	
		S. Rissen	2.0	
		S. Bredeney	1.7	
		S. Livingstone	1.5	
A; B; G; D; F; Fr; Gr; Ir; I Nh; P; Sp	1212	*S.* Typhimurium	39.93	REPORT 2003
		S. Derby	20.87	
		S. Infantis	1.65	
		S. Enteritidis	1.32	
		S. Brandenburg	0.74	
		S. London	0.50	
		S. O:5-	0.41	
		S. I-Rauform	0.25	
		S. G. B O-form	0.25	
		S. Livingstone	0.25	

Countries	N isolates serotyped	Serotypes	%	Note
B; D; F, Fr;G; Ir; I; Nh; S	1181	*S.* Typhimurium	36.75	REPORT 2002
		S. Derby	17.53	
		S. Infantis	3.98	
		S. Enteritidis	0.85	
		S. Anatum	0.76	
		S. Brandenburg	0.42	
		S. Orion	0.25	
		S. Panama	0.17	
		S. Derby	15.55	
		S. Infantis	4.36	
		S. Brandenburg	2.47	
		S. Bredney	1.31	
		S. London	1.02	
		S. Enteritidis	0.87	
B; N; P	168	*S.* Typhimurium	29.76	REPORT 2000 * data obtained considering the number of isolates typed/positive flocks/positive animals/positive reported by each MS. In some MS, only *S.* Enteritidis and *S.* Typhimurium are covered in the report and these data are not considered.
		S. Derby	27.98	
		S. Brandenburg	13.10	
		*S.*Livingstone	5.36	
		S. London	3.57	
		S. Goldcoast	3.57	
		S. Bredney	1.79	
		S. Infantis	1.79	
		S. Dublin	1.79	

A: Austria; B: Belgium; C: Cyprus; Cz: Czech Republic; E: Estonia; D: Denmark; F: Finland; Fr: France; G: Germany; Gr: Greece; H: Hungary; Ir: Ireland; I: Italy; L: Luxemburg; L: Latvia; Li: Lithuania; M: Malta; Nh: Netherlands; P: Portugal; Pl: Poland; Sp: Spain; Sw: Sweden; N: Norway; NI: North Ireland; UK: United Kingdom; Sk: Slovakia; Sl: Slovenia

Table 11: Characteristics of methodologies for the isolation by culture of *Salmonella* and the detection of antibodies against *Salmonella*.

Issue	Isolation (culture)	Antibody detection (immunology)
Principal	Direct method, detects the pathogen itself, identifies infection / excretion at present	Indirect method, detects antibodies, identifies previous exposure
Matrix	Faeces, feed, carcasses and many other different sources including environmental samples	Serum, colostrum, meat drip
Isolation of the strain, making identification possible	Yes	No
Antimicrobial resistance testing possible	Yes	No
Quantification of *Salmonella* possible	Yes	No
Covers all serovars	Yes	No
Sensitivity	Depending on 1) infection stage, 2) matrix and 3) amount of analysed material 4) method of analysis	Depending on 1) antigens (serogroups) which are part of the coating, 2) infection stage 3) cut-off, 4) serovar infecting the pig
Sensitivity on herd level	High	High
Specificity	100%	High in endemic areas, may be lower in non-endemic populations
Variation in methods	Large standardization and harmonization of methods needed.	Minor International reference sera needed.
Variation between labs	Minor,	Minor
Interpretation of result	Manual, depends on training of lab technician	Automated reader
Ring trials	Difficult, costly	Not very complicated, International reference sera needed.
Costs per test	High	Low
Automation	Difficult at present	Yes
Window of opportunity to isolate *Salmonella* or antibodies from individual#	Medium (days to weeks, intermittent shedding)	Large (months, continuous)
Window of opportunity to isolate *Salmonella* or antibodies from herds	Large	Large
Response time*	(Very) Short (can be hours)	Long (2 to 3 weeks to 2 months)
Application	Where: 1) Isolation of the bacteria is necessary for identification; 2) Information about all *Salmonella* infections (all serovars) is needed; 3) Antimicrobial resistance testing is needed; 3) the current *Salmonella* status of individual animals is needed; 4) Description of the general diversity of infections with different serovars in a population 5) to declare herds "free from *Salmonella*"	1) screening large numbers of samples for ex Surveillance of effect of control programmes in endemic regions . 2) To establish a herd status.

the time frame in which it is possible to detect the infection in an individual infected animal
* time between infection and the first possible positive test

Table 12: Flow chart of the standard ISO 6579 methods recommended for analysis of samples (ISO, 2002)

Detection of *Salmonella* from food and feed		**Detection of *Salmonella* in animal faeces**	
Buffered peptone water (BPW). Incubation 18 h. at 37°C ±1°C			**PRE-ENRICHMENT**
0,1 ml of culture + 10 ml RVS Incubation for 24 ± 3 h. at 41.5°C ±1°C	1 ml of culture + 10 ml MKTTn Incubation for 24 ± 3 h. at 37°C ± 1°C	0,1 ml of culture onto MSRV Incubation for 24 ± 3 h at 41.5°C ±1°C Additional incubation 24 ± 3h. at 41.5°C ±1°C for negative samples	**SELECTIVE ENRICHMENT**
XLD medium and second agar of choice. Incubation for 24 ± 3 h. at 37°C ± 1°C			**ISOLATION**
From each plate test a characteristic colony. If negative, test four other marked colonies Nutrient agar, incubated for 24 ± 3 h. at 37°C ± 1°C Biochemical and serological confirmation			**CONFIRMATION**

Table 13: Variability of some factors affecting bacterial recoveries by sampling methods

Variable factors	**Affecting excision methods**	**Affecting swabbing methods**
Microbial transfers	Single (meat-diluent)	Double (meat-swab; swab-diluent)
Microbial attachment-detachment to meat surface	Yes	Yes
Microbial attachment-detachment to swab material	No	Yes
Staff-related factors during sampling (e.g. pressure, strokes)	No	Yes
Abrasiveness of the swab material	No	Yes

Table 14: Observed risk factors during consumer meal preparation in the United Kingdom and the United States (Redmond and Griffith, 2003).

Food handling practice (risk factors)	UK consumer home kitchen	U.S. consumer home kitchen
Cooking	15% did not cook foods to an internal temperature of 75°C	18-24% used internal cooking temperatures that were to low
Cooling	100% failed to implement necessary actions for adequate cooling	24-47% implemented improper cooling procedures for leftovers
Storage	57% left cooked chicken salad at room temperature for storage	44% stored leftover meatloaf in the original cooking container with lid or plastic covering
Hand washing and drying	93-100% failed to wash and dry their hands immediately	29-57% neglected hand washing
Actions that increased cross-contamination potential during the preparation of raw meat	52% failed proper hand washing 60% failed to wash and dry chopping board and or knife for cutting meat	84% of cross-contamination actions observed involved transmission from potentially contaminated raw meat 80% did not use separate areas of the kitchen for raw and RTE foods

13.2. ANNEX II - existing national *Salmonella* monitoring and control programmes

13.2.1. Countries with a Low Prevalence Status (Sweden, Finland and Norway)

13.2.1.1. The Control of *Salmonella* in Sweden

Historical background
A general control of *Salmonella* started in the early 1950-ies following severe *Salmonella* epidemics in particular when *Salmonella* was spread from a slaughterhouse in 1953-54 and more than 9 000 people were recorded sick and 90 people died (Lundbeck *et al.,* 1955).

The current control in swine production
The objective of the control is to ensure that all animal products delivered to human consumption are free from *Salmonella*.

Any finding of *Salmonella*, irrespective of serovar, in animals, humans, feed and food is compulsory notifiable, independent of reason for sampling. All primary isolates are sero and phage typed and primary isolates from animals are tested for antibiotic resistance. If a veterinarian suspects that an animal is *Salmonella* infected he/she is obliged to perform further investigations to clarify this. Furthermore all sanitary slaughtered animals are tested for *Salmonella*.

The strategy is to monitor at critical points of the production chain to ensure that no *Salmonella* contamination occurs. When *Salmonella* is isolated, irrespectively of serovar and in case of live animals whether clinical signs are present, actions are taken to eliminate the microbe. Infected farms are e.g. subjected to restrictions which include a ban of movement of animals except for transport to sanitary slaughter. Environment and animals are sampled and tested by bacteriological method for *Salmonella*. *Salmonella* carriers are eventually slaughtered or destroyed followed by careful cleaning and disinfection. Restrictions are lifted following two negative samplings of the whole herd. Up and down streams epidemiological tracing is undertaken and followed up by similar actions. The basic principle of the control is the non acceptance of *Salmonella* contaminated animals, feed and food products.

According to an EU approved scheme additional monitoring for *Salmonella* is done on a statistical basis since 1995. Annually, approximately 6 000 pigs at slaughter (five ileocaecal/intestinal lymph nodes per animal), approximately 6 000 carcasses (1 400cm^2 is swabbed) and 4-5 000 scraping from pork/beef at cutting plants are analysed for the presence of *Salmonella*. In addition, 59 faecal samples from all elite-breeding and multiplier herds are tested annually and sow pools twice a year. Furthermore, in all herds affiliated to a voluntary quality assurance program covering about 60-65% of all slaughtered pigs (approximately 1 300 herds in 2004) 10 faecal samples are collected annually. The testing is paid by the industry and in case of

restrictions different degrees of compensation, governmental or by means of insurance are in place depending on compensatory preventive actions in place.

Furthermore all sanitary slaughtered animals as well as any suspect animal at normal slaughter will be tested. If *Salmonella* is suspected at autopsy or due to clinical signs, samples for *Salmonella* is also collected.

Control of feed

In the Swedish *Salmonella* control programme for food producing animals the control of animal feed is an essential element. Monitoring and control of feed has been carried out by the feed industry since the late 1940´s (Thal *et al.*, 1957). In accordance with the Swedish animal feed legislation feed must be *Salmonella* negative.

The need to control *Salmonella* in feed production became the primary objective for an industry association founded in 1958, comprising most of the Swedish feed companies. Several of the early guidelines on how to control *Salmonella*, were developed as industry recommendations in collaboration with government experts. Since 1991, a Hazard Analysis of Critical Control Point (HACCP) approach has been employed in the control of feed mills, with critical control points being monitored weekly (Sternberg Lewerin *et al.*, 2005) .

The control of *Salmonella* in commercial feed must be based on several different strategies. An important part of the programme is the control and quarantine of contaminated raw materials before ingredients may be incorporated into compounded feed. After a proper heat treatment, care must be taken not to re-contaminate the feed during cooling, transport or storage at the farm level. An important point of the control programme is the HACCP-based process control in the feed mill where the main hazards are identified. The aim is to make sure that the processing line for feed is not contaminated with *Salmonella*. Temperatures above 75°C are used in the feed mills during pelleting for at least 30 seconds. Another important factor is the hygiene of the premises and the need to develop efficient procedures for cleaning and disinfection, particularly of the processing line (Sternberg Lewerin *et al.*, 2005).

Statistics and documentation

The control has continuously been described and statistics and related data on the isolation of *Salmonella* from animals, feed and food products as well as resistance patterns from animals have regularly been published (Anonymous, SVARM, 2004).

Supporting references

Anonymous. (1995-2004). Swedish report to the Commission concerning trends and sources of zoonotic infections recorded in Sweden. National Veterinary Institute, Uppsala, Sweden, www.sva.se

Eld K., Gunnarsson A., Holmberg T., Hurvell B. and Wierup M. (1991). *Salmonella* isolated from animals and feedstuffs in Sweden during 1983- 1987. Acta. Vet. Scand, 32, 261-277.

Engvall A., Andersson Y. and Cerenius F. (1993). The economics of the Swedish *Salmonella* control. A cost/benefit analysis. In Proc. Int. Course on *Salmonella* Control in Animal Production and Products. Aug. 21-27, Malmö, Sweden. Ed. National Veterinary Institute, Uppsala, Sweden, 22 1-237.

Lundbeck H.; Plazikowski U. and Silverstolpe L. (1955). The Swedish *Salmonella* outbreak of 1953, J. Appl. Bact, 18: 535-548NVI/WHO (1993). International Course on *Salmonella* Control in Animal Production and Products. Arranged by the National Veterinary Institute of Sweden and the World Health Organization, August, Malmö Sweden, Aug. 21-27. 1993. Ed. National Veterinary Institute, Uppsala (Sweden), www.sva.se

Sternberg Lewerin S., Boqvist S., Engström B., Häggblom P. (2005). The effective control of *Salmonella* in Swedish poultry. In: Mead GC, editor. Food safety control in the poultry. cambridge: Woodhead Publishing Limited. p 544.SVARM (2004). Swedish Veterinary Antimicrobial Resistance Monitoring. National Veterinary Institute, Uppsala, Sweden, www.sva.se

Thal E., Rutqvist L., Holmqvist H. (1957). *Salmonella* isolated from animals in Sweden during the years1949-1956. Nordisk Veterinaermedicin:822-830.

Wahlström H., Bergström K., Engvall A., Gunnarsson A., Lindqvist H., Berge C. and Wierup M. (1998). The Swedish *Salmonella* Control of Pig and Pork Production. In Proc.No 2, 15th IPVS Conf. Birmingham, England, 5- 9 July 1998, 73

Wahlström H., Eriksson E., Noll B., Plym Forsell L., Wierup M. and Wollin R. (2000). The Swedish control of pig and pork production during 1999, 16 th IPVS Congr.,17-21 Sept. 2000, Melbourne, 215

Wierup M. and B. Nordblom (1984). The *Salmonella* control program in Sweden with special reference to poultry. Proc. Int. Symp. on *Salmonella*, New Orleans, 'USA, Editor C.H. Snoyenbos, pp 84-108.

Wierup M. (1991). The control of *Salmonella* in food producing animals in Sweden. Proc. Symp. On the diagnosis and control of *Salmonella*. San Diego, California, USA, Oct 29, 1991, 65-77.

Wierup M., Engström B., Engvall A. and Wahlström H. (1992). Control of *Salmonella* in food producing animals in Sweden. Int. Symp. *Salmonella* and Salmonellosis, Ploufragan, France, Sept. 15-17,386-398

Wierup M. (1994). Control of *Salmonella* in Animal production and products in Sweden. WHO/Zoon 1994.94, 171, 33-46

Wierup M. (1994). Control of *Salmonella* in animal production in Sweden with special reference to swine. XVII Nord.Vet. Comp, 26-29 July 1994, Reykjavik, Iceland.

Wierup M. (1995). Swedish control of *Salmonella* - III Pigmeat production. Meat: the Law, MLC, Oct. 1995, No 15, 2-8.

13.2.2. Countries with a Medium or Higher Prevalence Status

13.2.2.1. The Danish surveillance program of *Salmonella* in pigs and pork production

In 1995, a serological surveillance programme for detection of *Salmonella* infection in slaughter-pig herds was implemented. The programme has been adjusted over the years and revisions have previously been described in Annual Reports 2000-2002. Originally, the Danish Veterinary and Food Administration (DVFA) was responsible for the administration of the programme. However, since May 2002, the Danish Bacon and Meat Council (DBMC) has carried out the daily administration supervised by the DFVA. All data from the surveillance of *Salmonella* in pigs are registered in the central Zoonosis Register database, which is part of the Central Husbandry Register, administered by the DVFA. Surveillance by serological testing of meat juice (approx. 600 000 meat-juice samples per year) is carried out in herds producing more than 200 slaughter pigs per year. These results are used to assign the herds to one of three levels, based on the proportion of seropositive meat-juice samples collected over the last three months. The sample results are weighted, such that results from the most recent month are weighted more heavily than those from previous months. Level 1 herds are classified as having none or a small proportion of positive samples, Level 2 has a higher proportion of positives, and Level 3 herds have an unacceptably high proportion of positive samples. Pigs from Level 3 herds must be slaughtered under special hygienic precautions. It is mandatory to collect pen-faecal samples from herds placed in level 2 or 3 in order to clarify the distribution and type of the *Salmonella* infection. With a few exceptions, all sow herds supplying piglets to slaughter-pig herds in level 2 or 3 are obligated to collect pen-faecal samples for determining the distribution of *Salmonella* within the herd, and to clarify possible transmission of *Salmonella* from sow herds to slaughter pig herds. Breeding and multiplying herds are monitored monthly through serological testing of blood samples. If the set threshold is exceeded, the herd owner is obliged to collect pen-faecal samples.

Monitoring of *Salmonella* in pork is based on swab samples taken from three designated areas of chilled half-carcasses at the slaughterhouse. Samples from 5 carcasses are pooled, except in slaughterhouses slaughtering 50 pigs or less per month in which case, samples are analysed individually. When determining the prevalence of pooled samples, the loss of sensitivity and the probability of more than one sample being positive in each pool are taken into consideration. A conversion factor has been determined on the basis of comparative studies, as described in the Annual Report 2001. In 2004, 33 890 samples were pooled and the prevalence of *Salmonella* was 1.3%. An additional 148 samples were collected from slaughterhouses with a low production and were analysed individually. Of these, two samples were found positive for *Salmonella.*

Like in previous years, the most common serotypes observed were *S.* Typhimurium, *S.* Derby and *S.* Infantis.

13.2.2.2. The British *Salmonella* monitoring programme, "Zoonoses Action Plan"

The Zoonoses Action Plan *Salmonella* Programme (ZAP) is an industry-owned initiative that began in June 2002 for pigs supplied to quality assured abattoirs in Great Britain (GB) and in January 2003 ZAP was extended to producers in Northern Ireland. To implement ZAP, muscle samples are collected by Meat and Livestock Commission staff from 3 pigs for every Pig Movement Order received at the abattoir with the intent that at least 15 samples are collected every 3 months. Samples are linked to their herd of origin via the registered slap marks. Samples are frozen in containers that facilitate meat juice collection during thawing whilst being transported to the laboratory. An indirect lipopolysaccharide (LPS) mix-*Salmonella* meat-juice Enzyme-Linked Immunosorbent Assay (MJE) which detects antibodies against Group B and C_1 *Salmonella* is conducted by a commercial laboratory. Testing is accredited to the ISO 17025 standard by the UK Accreditation Service (UKAS). Results from individual samples and the positive and negative controls are converted to a Sample to Positive Ratio (S/P Ratio) which is interpreted as negative if it is less than or equal to 0.25 and positive if it is greater than 0.25. From July 2003 all herds where at least 15 samples had been reported in the preceding 3 months were assigned a ZAP level and expected to act as follows:

ZAP level 3 – 85% or more MJE results were positive; an action plan must be developed and implemented to reduce to ZAP level 1 within 11 months.

ZAP level 2 – 65% or more but less than 85% of MJE results were positive; an action plan must be developed and implemented to reduce to ZAP level 1 within 17 months

ZAP level 1 – less than 65% of MJE results were positive; no action required

ZAP level 1 status can only be regained if the prevalence of MJE positive pigs is below 65% after testing a minimum of 15 samples in a three month period. Farms that fail to return to ZAP level 1 will be suspended from Quality Assurance schemes, thus losing access to Quality Assured abattoirs.

ZAP aims to assign ZAP levels to at least 85% of herds delivering >500 pigs a year and to 50% farms delivering between 200-500 pigs per year. In the 3 month period ending in December 2004, 79.9% of 1 533 holdings were allocated to ZAP levels 1-3 and 92% of these farms were in ZAP level 1. In 2004, 22.9% of 153 321 MJ samples were positive in the ZAP programme. The overall aim of ZAP is to reduce the prevalence of *Salmonella* in assured pigs at slaughter by 25% and the GB Food Standards Agency strategy is to reduce *Salmonella* in pigs at slaughter by 50% by 2010.

13.2.2.3. The Irish Pig *Salmonella* legislation

The purpose of the regulations is to reduce any possible risk of public health problems arising from the consumption of pork and pig meat products and thereby to maintain consumer confidence in these products.

The following are the main points of this legislation:

- every pig herd in the country is tested on an ongoing basis for the purpose of establishing its *Salmonella* status,
- sampling takes place at slaughter plants,
- samples are tested at the Central Veterinary Research Laboratory,
- the test results are sent directly to a centralised database,
- the database centre calculates the up-to-date *Salmonella* status of the herd and issues to the herd owner a certificate of categorisation which is valid for five months,
- this certificate indicates whether the herd is Category 1 (i.e. showing the least evidence of exposure to *Salmonella*), Category 2 or Category 3 (the worst status),
- at slaughter, pigs from Category 3 herds are slaughtered separately from other pigs and in a manner that minimises the risk of cross-contamination,
- the head meat and offals of Category 3 pigs may not be sold in the raw state and must be either heat-treated in an approved manner before being passed fit for human consumption or destroyed,
- pigs with no valid category certificate will be treated as Category 3 in slaughter plants.

Pig producers' responsibilities

Producers must ensure that they are in possession of a valid certificate of categorisation for their herd and to make it available on request at pig slaughter plants. Each producer arranges with the plant at which his/her pigs are to be slaughtered to have samples taken and forwarded for testing to the approved laboratory. A set of samples must be taken three times each year at intervals of not less than 3 months and not more than 5 months.

A set of samples consists of samples from 24 pigs from the herd submitted together. If the size of the herd is such that fewer than 24 pigs are presented for slaughter on any individual day, then samples are to be taken from 24 pigs in every 4 month period. If the number of pigs presented for slaughter is below 24 in a 4 month period, then samples are to be taken from all pigs slaughtered in that period.

It is the responsibility of herd owners to ensure that the required level of sampling is undertaken and that a valid certificate of categorisation exists for his/her herd.

Calculation of *Salmonella* category

When a set of samples is tested the result of the test is expressed as the percentage of the samples in the set that tested positive for exposure to *Salmonella* (e.g. if 6 of the 24 samples are positive, the result is 25%). The initial herd categorisation is based on a simple average of the first two test results for the herd (e.g. if the first two test results are 25% and 50%, then the average of these is reported as 37.5%). Thereafter

herd categorisation will be established by calculating a weighted average of the three most recent test results as follows:

Test	Weighting
Most recent	0.5
Second most recent	0.3
Third most recent	0.2

Herds are categorised as:

- category 1, if the result of this averaging is 10% or less,
- category 2, if the average result is more than 10% and not more than 50%,
- category 3, if the average result is more than 50%.

Breeding pigs
It is a requirement of the *Salmonella* legislation that all breeding pigs being introduced into a herd come from Category 1 herds and that producers maintain a record of the origin of their breeding animals.

Guidance note
Producers who have had *Salmonella* diagnosed in their herds should seek the advice of their veterinary practitioner with a view to implementing a *Salmonella* control programme on their holding.

13.2.2.4. The German "QS *Salmonella* Monitoring Programme"

In September 2001, the German food industry (encouraged and promoted by the government) has launched a voluntary quality assurance programme for food producers of all sectors (feed production, animal production, slaughtering, processing, and grocery retail), the so-called "QS-System" (in short: "QS"). As for pork production, so far, about 15 000 pork producers are participating in "QS". This number is low compared to the about 70 000 pig producers in Germany, but these 15 000 represent about 70% to 75% of the German pig production. Those pork producers and slaughter plants (100% of the larger slaughter enterprises) that participate in QS have agreed to participate in the QS *Salmonella* Monitoring Programme, which was started in early 2002.

The programme, like the Danish, the British and the Irish programmes, is targeted at categorising pig herds according to their assessed risk of carrying *Salmonella* into the slaughter plant. Sixty meat juice samples per herd (evenly distributed over one year), taken from slaughter pigs, are serologically tested for antibodies against *Salmonella* spp. The assumption is that herds with many positive pigs pose a higher risk to carry *Salmonella* into the slaughter plant than herds with no or only few positive pigs. The current cut-off for the serological test (based on the Danish mixed-ELISA) is 40% OD. The current "risk categories" are as follows: Category I (= low risk): < 20% positive samples, Category II (= medium risk): 20% - 40% positive samples, and Category III (= high risk): > 40% positive samples.

Since 2002 the number of participating pig producers has steadily increased. By August 2005 about 6 200 pig producers are already categorised. This number is steadily increasing, since more and more producers out of the 15 000 QS-participants have sampled more than a year.

All data are collected in a central database "Qualiproof" and can be analysed for further conclusions for improving the programme.

At present, throughout Germany, about 67 000 samples per month are taken and tested for *Salmonella* antibodies (per year about 800 000).

The present categorisation result is: out of the 6 200 categorised herds, about 80% are Category I, about 15% are Category II and about 5% are Category III.

There are two planned for the *Salmonella* control based on the monitoring results:

- separating Cat. III pigs from Cat. I and II pigs at slaughter,
- supporting pig producers in reducing the *Salmonella* load of their pig herds.

The first has not yet started (there must first be a higher proportion of pig herds that are categorised). The latter, however, is gradually increasing: more and more farmers with Cat. III and even Cat. II are looking for veterinary help in increasing their hygiene and biosecurity standard to either get back into Cat. II and I, or to avoid being categorised into Cat. III.

Results in terms of a measurable reduction of human salmonellosis due to pork can only be expected in the near future, and when the programme becomes mandatory.

The German Ministry for Agriculture, Nutrition and Consumer Protection is working on a regulation that will oblige all pork producers and slaughter plants to take part in a nation-wide *Salmonella* monitoring and control programme – the regulation will be issued in 2006.

13.2.2.5. The Dutch National *Salmonella* Control Plan

In The Netherlands, a nation-wide *Salmonella* Monitoring Programme was started on February 1, 2005. Although the programme is not a governmental program, it is mandatory for every finishing pig owner and every slaughterhouse, since it is run by the Product Board for Live stock and Meat (the "PVV"), which has the authority to oblige all pig owners and slaughterhouses to participate in the programme. The principle of the programme is the categorisation of finishing pig herds by means of testing randomly selected serum samples from every herd. Samples are to be collected from finishers within 3 weeks before marketing or at slaughter. Thirty six samples per year (12 samples per trimester) are the basis for the categorisation and the cut-off value (measured in OD%) is 40%. The category thresholds for assigning the pig herds to three categories (low, medium and high risk of introducing *Salmonella* species into the slaughter plant) are as follows:

- category 1: ≤ 20% samples with > OD40,

- category 2: >20% and < 40% samples with > OD40,
- category 3: ≥ 40% samples with > OD40.

Slaughterhouses producing more than 10 000 pigs per year are monitored using swab samples as described by USDA/FSIS and in EU regulation 2001/471/EC, swabbing 300 cm^2 or a destructive method. Slaughterhouses slaughtering less than 150 000 pigs / year sample ten carcasses every 14 days and all samples are investigated separately. Slaughterhouses slaughtering more than 150 000 pigs / year sample five carcasses every day which will be investigated as one pooled sample. Both schemes result in 10 *Salmonella* cultures every two weeks for every slaughterhouse.

Further measures with regard to interventions and incentives have not been decided upon yet.

13.2.2.6. *Salmonella* control in pigs in the other EU Member States

In Austria, regional programmes (e.g. in Styria) have been implemented, which are a good basis for the planned national programme.

In all other EU Member States, *Salmonella* control programmes are either lacking (the new Member States and most southern EU countries) or sporadic and limited to scientific and/or pilot studies (e.g. Belgium and France).

13.3. ANNEX III – Proposal of Baseline Study on the Prevalence of *Salmonella* in Fattening Pigs in the EU

This annex is published at
www.efsa.eu.int/science/biohaz/biohaz_opinions/opinion_annexes/1433_en.html