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World Health
Organization



***Joint FAO/WHO Expert Consultation on Risk
Assessment of Microbiological Hazards in Foods***

**Risk characterization of *Salmonella* spp. in eggs and broiler
chickens and *Listeria monocytogenes* in ready-to-eat foods**

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Acknowledgements

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The documents on which this report was based will undergo a further scientific peer review. Therefore the information made available through this report and other sources is subject to revision until the risk assessments have been finalized and published by FAO and WHO. FAO and WHO declines any responsibility for errors and omissions in the information and data provided.

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1. INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) convened an expert consultation on Risk Assessment of Microbiological Hazards in Foods in FAO Headquarters, Rome, Italy on 30 April - 4 May 2001. The list of participants is presented in Annex 1.

Mr Hartwig de Haen, Assistant Director-General, Economic and Social Department in FAO opened the consultation on behalf of the two sponsoring organizations. In welcoming the participants Mr de Haen stated that the assessment of risk associated with microbiological hazards presents unique features due to the nature of these hazards. Microbiological hazards in foods are currently one of the most significant challenges internationally and therefore, must be assessed scientifically in order to provide appropriate information for decision-making both at the national and international levels. He emphasized that FAO and WHO are committed to providing a neutral international forum to address microbiological risk assessment as well as providing assistance to their member countries in this area.

He noted the importance of the work of the Codex Alimentarius Commission (CAC) and the FAO/WHO risk assessment programme in relation to the World Trade Organizations' (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS). Mr de Haen also informed the expert consultation of some of the forthcoming FAO and WHO activities to which this work can contribute, such as the Global Forum for Food Safety Regulators that will take place in October this year and the Pan-European Conference on Food Safety and Quality that will be convened in 2002.

In concluding, Mr de Haen expressed the appreciation of FAO and WHO to the experts who were members of the drafting groups and who had worked for many months in the preparation of the documents for the consultation. He expressed the wish that the sound scientific basis which they had created would be further built on during the expert consultation to produce a useful product for FAO and WHO member countries and for the CAC.

The consultation elected Prof Jean-Louis Jouve (France) as Chairperson of the expert consultation and Dr Michael Doyle (United States) as Vice-Chairperson. Dr Lone Gram (Denmark) was elected as Rapporteur. The consultation also appointed a chairperson and rapporteur for each of the working groups. Prof Jean-Louis Jouve and Dr Olivier Cerf (France) were nominated as Chairperson and Rapporteur, respectively, for the working group on *Listeria monocytogenes* in ready-to-eat foods. Dr Michael Doyle and Dr David Jordan (Australia) were nominated as Chairperson and Rapporteur, respectively, for the working group on *Salmonella* spp. in eggs and broiler chickens.

2. BACKGROUND

Risk assessment of microbiological hazards in foods has been identified as a priority area of work for the CAC. At its 32nd session the Codex Committee on Food Hygiene (CCFH) identified a list of pathogen-commodity combinations for which it requires expert risk assessment advice. In response to this and the needs of their member countries, FAO and WHO jointly launched a programme of work with the objective of providing expert advice on risk assessment of microbiological hazards in foods (Annex 2).

Ms Maria de Lourdes Costarrica, Senior Officer, Food Quality Liaison Group, FAO and Dr Allan Hogue, Food Safety Programme, WHO provided the participants with a history of the FAO, WHO, and Codex activities on microbiological risk assessment. In their presentation they also highlighted the objectives of the current meeting.

The FAO/WHO programme of activities on microbiological risk assessment aims to serve two customers - the CAC and FAO and WHO member countries. The CAC, and in particular its subsidiary committee the CCFH, has requested sound scientific advice as a basis for the development of guidelines and recommendations for the management of risks posed by microbiological hazards in foods and have identified 21 pathogen-commodity combinations of concern (ALINORM 01/13). Member countries on the other hand need adaptable risk assessments to use in conducting their own assessments and, if possible, some modules that can be directly applicable to their national situation. Taking these needs into account FAO and WHO subsequently selected and initiated work on three pathogen-commodity combinations - *Salmonella* Enteritidis in eggs, *Salmonella* spp. in broiler chickens and *L. monocytogenes* in ready-to-eat foods. Problems such as the lack of a clear-cut risk management question at the outset and limitations in the usefulness of a global risk estimate were recognized in the course of the work.

The risk assessments on *Salmonella* spp. in eggs and broiler chickens and *L. monocytogenes* in ready-to-eat foods began in January 2000. In July 2000 an expert consultation was convened to review the hazard identification, exposure assessment and hazard characterization components of the risk assessments (FAO Food and Nutrition Paper 71 *Joint FAO/WHO Expert Consultation on Risk Assessment of Microbiological Hazards in Foods*, 2000). That expert consultation made recommendations for the improvement of the preliminary documents, identified knowledge gaps and information requirements needed to complete the risk assessment work, and developed a list of issues to be brought to the attention of the CCFH. The report of that consultation was presented to the 33rd session of the CCFH for further guidance on the future direction of the work. In the discussion that followed, the CCFH put forward a number of specific risk management questions related to these pathogen-commodity combinations (ALINORM 01/13A). These issues were subsequently addressed by the joint FAO/WHO expert drafting groups.

This expert consultation was the second in a two-year programme of work on risk assessment of these pathogen-commodity combinations. Through this work FAO and WHO are illustrating how to use a tool recommended by Codex in their "Principles and Guidelines for the Conduct of Microbiological Risk Assessment" (CAC/GL-30/1999). Model risk assessments that can be adapted to a country's needs are being developed. The CCFH is being provided with scientific advice to assist it in its activities aimed at protecting the health of consumers and ensuring fair practices in food trade.

This purpose of this report is to present a summary of the risk characterizations reviewed during the expert consultation, preliminary answers to the questions posed by the CCFH, and recommendations for the adaptation of these risk assessments by member countries. It will be presented to the 34th session of the CCFH in October 2001. Following a peer review and a public review, FAO and WHO will publish the complete risk assessment documents as well as their interpretative summaries for use by their member countries and the CAC.

3. OBJECTIVES OF THE CONSULTATION

The consultation examined the technical documents provided by the expert drafting groups on risk characterization of *Salmonella* spp. in eggs and broiler chickens and *L. monocytogenes* in ready-to-eat foods with the following objectives:

- To critically review the risk assessments giving particular attention to the assumptions on which the risk assessments were based.
- To use the risk assessments of *Salmonella* spp. in eggs and broiler chickens and *L. monocytogenes* in ready-to-eat foods to provide a science based response to the specific risk management questions posed by the 33rd session of the CCFH and guidance on how these results may be used by the CCFH.
- To provide advice and guidance on how these FAO/WHO risk assessments could be adapted by FAO and WHO member countries to their national situations.

4. SUMMARY OF THE PROCEDURES AND GENERAL DISCUSSIONS

The drafting groups presented overviews of the risk assessments on *Salmonella* spp. in eggs and broiler chickens and *L. monocytogenes* in ready-to-eat foods to the expert consultation. A summary of these risk assessments and a response to the specific questions posed by the CCFH are included in sections five and six of this report. The complete risk assessment documentation will be available on the FAO and WHO websites at the end of 2001.

The expert consultation acknowledged and expressed their appreciation for the body of work that had been carried out by the expert drafting groups and the quality of the material presented.

The expert consultation noted that due to the nature and status of the documents presented, it was not possible for every expert to address both documents equally. The experts worked in two groups as outlined in the following tables. It was recommended that in future expert consultations more time should be devoted to the exercise or the two risk assessments should be addressed in separate consultations.

Salmonella spp. in eggs and broiler chickens

Independent Experts	Expert members of the drafting groups	Resource personnel
Michael Doyle, United States David Jordan, Australia Susumu Kumugai, Japan George Nasinyama, Uganda Son Radu, Malaysia Dulce Maria Tocchetto Schuch, Brazil Helene Wahlström, Sweden	Eric Ebel, United States Aamir Fazil, Canada Fumiko Kasuga, Japan Anna Lammerding, Canada	Carol Maczka, United States Charles Yoe, United States

Listeria monocytogenes in ready-to-eat foods

Independent Experts	Expert members of the drafting groups	Resource personnel
Olivier Cerf, France Lone Gram, Denmark Inocencio Higuera, Mexico Andrew Hudson, New Zealand Jean-Louis Jouve, France Bruce Tompkin, United States	Robert Buchanan, United States Roland Lindqvist, Sweden Thomas Ross, Australia Ewen Todd, Canada Richard Whiting, United States	Jeronimas Maskeliunas, Codex Secretariat Greg Paoli, Canada Suzanne van Gerwin, Netherlands Kaye Wachsmuth, Chairperson, CCFH

The advantages and disadvantages of a farm-to-table approach were discussed. The 32nd session of the CCFH recommended that “the *ad hoc* expert consultation evaluate the risk reduction potential of relevant risk management options from farm-to-table continuum”(ALINORM 01/13). The consultation, however, recognized that the components of the food chain to be modelled were dependent on the risk management question addressed to the risk assessors and the available information. The expert consultation was of the view that if a component was not modelled, the reasons for this should be clearly documented and the resulting limitations clearly described. *L. monocytogenes* in ready-to-eat foods (milk, ice cream, soft mould-ripened cheese, minimally processed vegetables, semi-fermented meats) was modelled from retail to consumer. *Salmonella* spp. in broiler chickens was modelled from the end of commercial processing to consumption and *Salmonella* Enteritidis in eggs was modelled from production to consumption.

The expert consultation noted that the work on both *L. monocytogenes* and *Salmonella* spp. relied to a large extent on the availability of risk assessments conducted at the national level. In the case of *Salmonella* spp. in broiler chickens, no national risk assessment has been carried out and the expert consultation therefore noted that this work had focussed more on the provision of guidelines for the types of information and approach that might be used to develop a processing to consumer risk model. An individual processing operation, country or region could use their data as parameters to produce a risk estimate.

The expert consultation recognized that a clear definition of the risk management question was essential in order to ensure that the risk assessment was correctly targeted. In order to achieve this, interaction between the risk assessors and the risk managers was necessary from an early stage in the process.

Apart from the contribution that they make towards quantitative microbiological risk assessment, the expert consultation discussed the usefulness of the documents prepared by the expert drafting groups on *Salmonella* and *Listeria* in a broader context. It was noted that the documents provide a good review of the two microorganisms and their occurrence and behaviour and therefore also serve as a reference document for individuals, institutions, industry etc. with an interest in these particular microorganisms.

5. RISK ASSESSMENT OF *SALMONELLA* SPP. IN BROILER CHICKENS AND EGGS

5.1 INTRODUCTION

Salmonellosis is a leading cause of foodborne illness in many countries with eggs and poultry being important vehicles of transmission. During the past two decades *Salmonella* Enteritidis has become a leading serovar causing human infections, with hen eggs being a principal source of the pathogen. The emergence of *Salmonella* Enteritidis as the leading cause of human salmonellosis in many countries was attributed to this serovars unusual ability to colonise the ovarian tissue of hens and be present within the contents of intact shell eggs.

Broiler chicken is the main type of chicken consumed as poultry in many countries. A large percentage are colonised by salmonellae during grow-out and the skin and meat of carcasses are frequently contaminated by the pathogen during slaughter and processing.

Considering the major role eggs and poultry have as vehicles of transmission in human cases of salmonellosis, an assessment of different factors affecting the prevalence, growth, and transmission of *Salmonella* in eggs and on broiler chicken carcasses on the risk of human illness would be useful to risk managers in identifying the intervention strategies that would have the greatest impact on reducing human infections.

A risk characterization study attempting to quantify the human-health risk attributable to *Salmonella* Enteritidis in eggs and *Salmonella* spp. in broiler chickens was described in the working documents provided to the expert consultation. The risk characterizations involved amalgamating earlier work commissioned by FAO and WHO (Hazard Identification and Hazard Characterization of *Salmonellae* in Broilers and Eggs - FAO/WHO MRA 00/03, Exposure Assessment of *Salmonella* Enteritidis in Eggs - FAO/WHO MRA 00/04, and Exposure Assessment of *Salmonella* spp. in Broilers - FAO/WHO MRA 00/05) with new material developed since the preceding consultation. To enable the characterization of risk, both the *Salmonella* in eggs and *Salmonella* in broiler chickens expert drafting groups represented elements of the food production and consumption system as computer-based models. Outputs from these models were obtained using Monte Carlo¹ simulation to enable uncertainty and variability in input variables to be expressed as probability distributions, with the uncertainty and variability propagated through the model at each iteration and finally reflected in the predicted incidence of human disease.

5.2 SCOPE OF THE RISK ASSESSMENT

The risk characterizations initially set out to understand how the incidence of human salmonellosis is influenced by various factors during the agricultural phase of chicken meat and egg production, marketing, processing, distribution, retail storage, consumer storage, meal preparation and finally consumption. Such models are appealing because they enable the study of the broadest range of intervention strategies. However, as the work progressed it became evident that the quantity and quality of information available from all sources was not sufficient to allow the construction of a full and expansive model. Thus, the final scope of the two *Salmonella* risk characterizations, and the components of the food production and consumption continuum that they each consider can now be described as follows:

- A. *Salmonella* Enteritidis in eggs. This risk characterization estimates the probability of human illness due to *Salmonella* Enteritidis following the ingestion of a single food serving of internally contaminated shell eggs either consumed as whole eggs, egg meals, or as ingredients in more complex food (e.g. cake). This work addressed selected aspects of egg production on farms, further processing of eggs into egg products, retail and consumer egg handling and meal preparation practices.
- B. *Salmonella* spp. in broiler chickens. This risk characterization estimates the probability of illness in a year due to the ingestion of *Salmonella* spp. on fresh whole broiler chicken carcasses with the skin intact and which are cooked in the domestic kitchen for immediate consumption. This work commenced at the conclusion of slaughterhouse processing and considers in-home handling and cooking practices. The effects of pre-slaughter interventions and the slaughter process are not presently included in this model.

¹ **Monte Carlo:** In Monte Carlo methods, the computer uses random number simulation techniques to mimic a statistical population. For each Monte Carlo replication, the computer: simulates a random sample from the population, analyzes the sample, and stores the result. After many replications, the stored results will mimic the sampling distribution of the statistic.

In conducting the above risk assessments a common hazard characterization module was used. Within the hazard characterization step the objectives were to produce one or more curves describing the probability that an individual becomes ill due to *Salmonella* versus the dose of *Salmonella* ingested within food.

5.3 APPROACH TAKEN

5.3.1 Hazard identification and hazard characterization

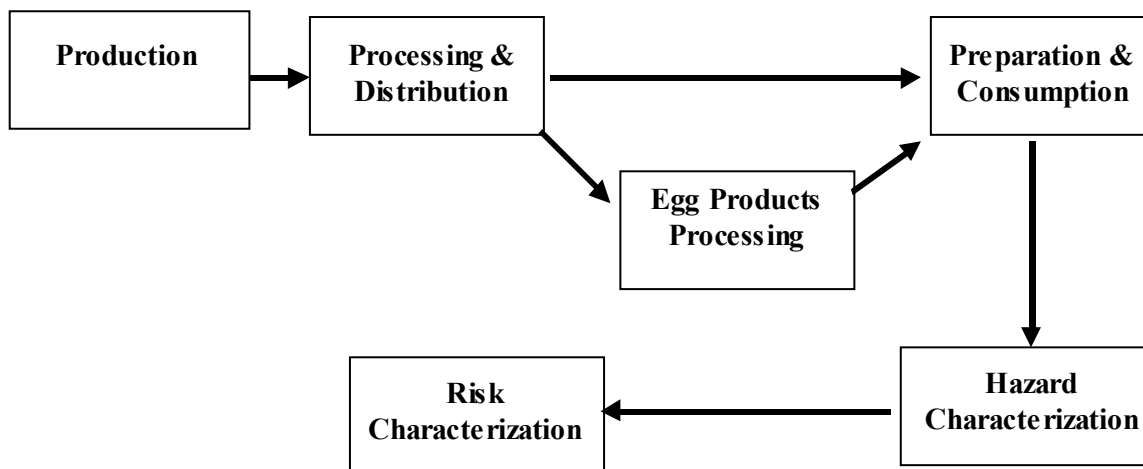
Information was compiled from published literature and from unpublished data submitted to FAO and WHO by various interested parties. Initially this was used to provide a description of the public health outcomes, pathogen characteristics, host characteristics, and food-related factors that may affect the survival of *Salmonella* through the stomach. The hazard characterization then presented a review of information on relevant dose-response models describing the mathematical relationship between an ingested dose of *Salmonella* and the probability of human illness. An extensive review of available outbreak data was also conducted. From these data a new dose-response model was derived using a re-sampling approach and this was used in both risk characterizations in preference to models defined in earlier work (Food Safety Inspection Service (FSIS) - United States Department of Agriculture (USDA) / Food and Drug Administration (FDA) *Salmonella* Enteritidis model, Health Canada *Salmonella* Enteritidis model, and the model produced by Fazil from human feeding trials). Finally, an attempt was made to discern whether separate dose-response curves could be justified for different sub-populations defined on the basis of age and ‘susceptibility’ and whether *Salmonella* Enteritidis had a dose-response distinguishable from other *Salmonella* spp..

5.3.2 Risk characterization for *Salmonella* Enteritidis in eggs

The model developed for this risk characterization combines the FSIS-USDA/FDA and Health Canada models. Generally, where input types were similar, the Health Canada parameters were used. If an input type was missing in one model, then the other model’s parameters were used (e.g., the Health Canada model did not consider cooling constants, so these were specified by the FSIS-USDA/FDA model). The model structure was generally based on the FSIS-USDA/FDA model.

The exposure assessment comprises a production module, a module for the processing and distribution of shell eggs, a module for the processing of egg products, and a module for preparation and consumption. The production module predicts the probability of a *Salmonella* Enteritidis-contaminated egg occurring. The shell egg processing and distribution, and preparation and consumption modules predict the probability of human exposures to various doses of *Salmonella* Enteritidis from contaminated eggs. As the diagram below shows (Figure 5.1), the output of the exposure assessment, in general, feeds into the hazard characterization to produce the risk characterization output. This output is the probability of human illness per serving of an egg-containing meal.

FIGURE 5.1 Schematic diagram of the *Salmonella* Enteritidis in eggs risk assessment



5.3.3 Risk characterization of *Salmonella* spp. in broiler chickens

The exposure assessment component of the risk characterization mimics the movement of *Salmonella*-contaminated chickens through the food chain commencing at the point of completion of the slaughter process. For each iteration of the model a chicken carcass was randomly allocated an infection status and those carcasses identified as contaminated were randomly assigned a number of *Salmonella* organisms. From this point until consumption, changes in the size of the *Salmonella* population on each contaminated chicken were modelled using equations for growth and death. The growth of *Salmonella* was predicted using random inputs for storage time at retail stores, transport time, storage time in homes, and the temperatures the carcass was exposed to during each of these periods. Death of *Salmonella* during cooking was predicted using random inputs describing the probability that a carcass was not adequately cooked, the proportion of *Salmonella* organisms attached to areas of the carcass that were protected from heat, the temperature of exposure of protected bacteria and the time for which such exposure occurs. The number of *Salmonella* consumed were then derived using a random input defining the weight of chicken meat consumed per serving and the numbers of *Salmonella* cells in meat as defined from the various growth and death processes. Finally, in the risk characterization the probability of illness was derived by combining the number of organisms ingested (from the exposure assessment) with information on the dose-response relationship (hazard characterization).

5.4 KEY FINDINGS OF THE RISK ASSESSMENT

5.4.1 Hazard characterization for *Salmonella*

- Existing dose-response models for *Salmonella* Enteritidis and *Salmonella* spp. were found to inadequately characterize the dose-response relationship observed in the outbreak data.
- The expert consultation agreed that the new dose-response model (Figure 5.2) derived from this outbreak data was the most appropriate estimate for the probability of illness upon ingestion of a dose of *Salmonella*. The model was based on observed real world data, and as such was not subject to some of the flaws inherent in using purely experimental data. Nevertheless, the current outbreak data also have uncertainties associated with them and some of the outbreak data points required assumptions to be made. The outbreak data are also from a limited number of developed countries and may not be applicable to other regions.
- From the outbreak data used to examine the dose-response relationship, it could not be concluded that *Salmonella* Enteritidis had a different likelihood of producing illness than other serovars.
- Comparing the attack rates of *Salmonella* for children under five years of age, against those for the rest of the population in the outbreak database, did not reveal an overall trend of increased risk for this sub-population. The database of outbreak information however, may lack the power to reveal the existence of true differences that might exist. Some indication for a difference in attack rates for the two populations was noted in two of the outbreaks examined. However, taking into account the overall trend across the entire database, and until more information becomes available, the dose-response relationship for members of the population across all age groups was considered to be similar.

5.4.2 Risk characterization for *Salmonella* Enteritidis in eggs

- The exposure assessment included consideration of yolk-contaminated eggs and growth of *Salmonella* Enteritidis in eggs prior to processing for egg products. These issues have not been previously addressed by exposure assessments of *Salmonella* Enteritidis in eggs. Yolk-contaminated eggs might allow for more rapid growth of *Salmonella* Enteritidis inside such eggs when compared to eggs that are not yolk-contaminated.
- The estimated risk of human illness from *Salmonella* Enteritidis in eggs varied according to the different input assumptions in the model. The predicted risk of illness per egg serving for five flock prevalence levels are as shown in Table 5.1. Flock² prevalence describes the proportion of all flocks that contain one or more infected hens. The risk of illness per serving increased as flock prevalence increased. Yet, uncertainty regarding the predicted risk also increased as flock prevalence increased. Furthermore, this uncertainty only reflects the influence of within-flock prevalence, egg contamination frequency, fraction of eggs that were yolk-contaminated, and dose-response model parameters. Among the uncertainties not considered in this analysis were those regarding *Salmonella* Enteritidis growth functions, storage times and temperatures, and pathway probabilities.

² A flock is a group of hens of similar age that are managed and housed together.

FIGURE 5.2 Dose-response curve derived from outbreak data based on re-sampling from uncertainty distributions for outbreak variables.

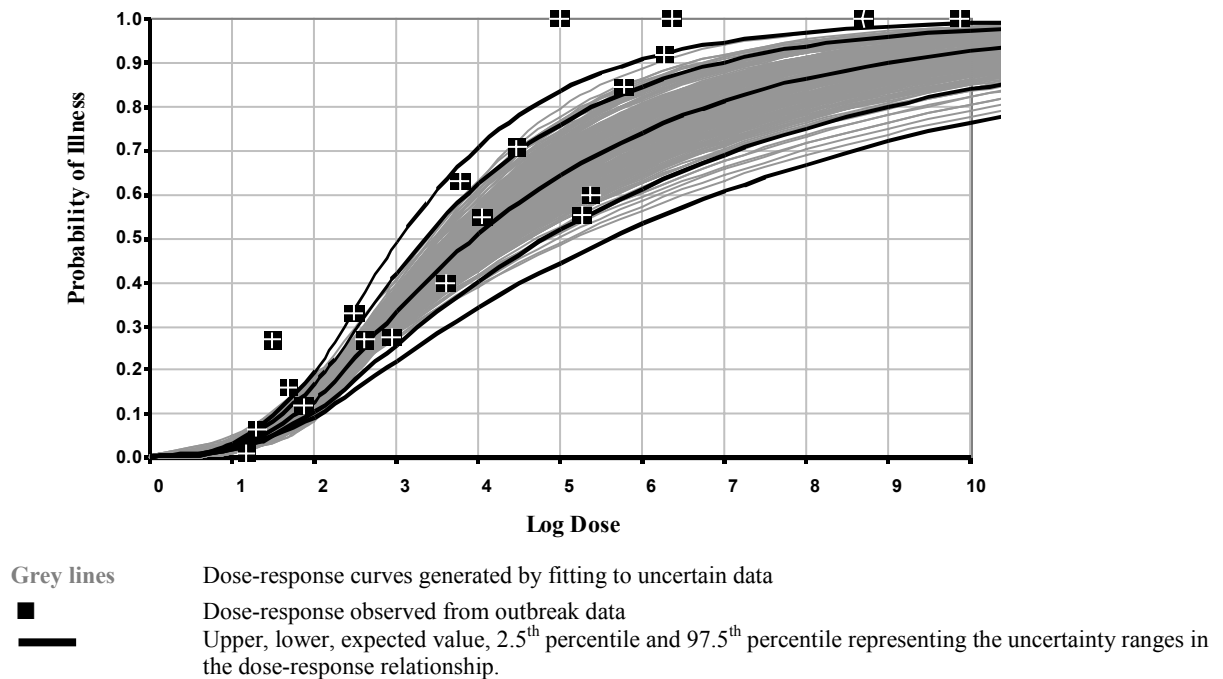


TABLE 5.1 Predicted probabilities of illness per egg serving for different flock prevalence settings, and assuming the baseline egg storage time and temperature scenario. 5th and 95th percentiles of the uncertainty distribution about the risk of illness per egg serving are also shown.

Flock prevalence	Mean	5 th	95 th
0.01%	0.00000005%	0.00000002%	0.00000009%
0.10%	0.00000050%	0.00000020%	0.00000090%
5.0%	0.00002%	0.00001%	0.00004%
25.0%	0.00010%	0.00005%	0.00020%
50.0%	0.00020%	0.00010%	0.00040%

- Reducing flock prevalence resulted in a directly proportional reduction in human health risk. For example, reducing flock prevalence from 50% to 25% resulted in a halving of the mean probability of illness per serving. Another example was that a reduction in prevalence to 0.10%, which may be achievable by pre-slaughter risk management interventions, reduced the estimated mean risk to 5 illnesses per billion servings.
- Reducing prevalence within infected flocks resulted in a directly proportional reduction in human health risk. Within-flock prevalence refers to the proportion of hens that were infected with *Salmonella* Enteritidis in a flock. For example, risk of illness per serving generated from eggs produced by a flock with 1% within-flock prevalence was one-tenth that of a flock with 10% within-flock prevalence.
- Adjusting both egg storage time and temperature profiles for eggs from farm-to-table was associated with large effects on the predicted risk of human illness. For example, when all baseline time and temperature (in degrees Fahrenheit) inputs to the model were increased each by 10%, the resulting risk per serving increased by nearly 90%.

- The risk of human illness per serving appeared to be insensitive to the number of *Salmonella* Enteritidis in contaminated eggs across the range considered at the time of lay. For example, whether it was assumed that all contaminated eggs had an initial number of 10 or 100 *Salmonella* Enteritidis organisms, the predicted risk of illness per serving was similar. This may be because the effect of *Salmonella* Enteritidis growth is greater than the initial contamination level in eggs.

5.4.3 Risk characterization of *Salmonella* spp. in broiler chickens

- The risk assessment model was defined in terms of a number of parameters that describe the processes of broiler chicken carcass distribution and storage, preparation, cooking and consumption. Some of these parameters can be considered general in that they can be used to describe the situation in many countries. On the other hand, some parameters are country specific, for example the prevalence of carcasses contaminated with *Salmonella* at the completion of processing. Predictions of risk for a particular country are best obtained from data relevant to that country.
- The model parameters can be modified to evaluate the efficacy of risk mitigation strategies that target those parameters. For example, the parameter describing prevalence of *Salmonella*-contaminated broiler chickens exiting processing can be modified to evaluate the effectiveness of a processing measure such as chlorination of the chilling water to reduce the prevalence of *Salmonella*-contaminated carcasses.
- Reduction in the prevalence of *Salmonella*-contaminated chicken was associated with a reduction in the risk of illness. A one-to-one relationship was estimated, with a percentage change in prevalence, assuming everything else remains constant, reducing the expected risk by a similar percentage. For instance, a 50% reduction in the prevalence of contaminated poultry (20% to 10%) produced a 50% reduction in the expected risk of illness per serving. Similarly, a large reduction in prevalence (20% to 0.05%) would produce a 99.75% reduction in the expected risk of illness, a risk reduction that perhaps may be obtained by pre-slaughter risk management actions.
- If management strategies that impact the level of contamination, i.e., the numbers of *Salmonella* spp. on chickens were implemented, the relationship to risk of illness was estimated to be greater than a one to one relationship. A shift of the distribution of *Salmonella* cell numbers on broiler chickens exiting the chill tank at the end of processing, such that the mean number of cells was reduced by 40% on the non-log scale reduces the expected risk of illness per serving by approximately 65%.
- A small reduction in the frequency of undercooking and the magnitude of the undercooking event resulted in a marked reduction of the expected risk of illness per serving. The important caveat here is that altering cooking practices does not address the risk of illness through the cross-contamination pathway. The strategy to change the consumers cooking practices needs to be tempered by the fact that cross-contamination may in fact be the predominant source of risk of illness and the nature of cross-contamination in the home is still a highly uncertain phenomenon.

In addition the report highlighted that:

- Although extensive, the literature relating to *Salmonella* spp. in poultry rearing and slaughter operations during processing have several limitations for use in quantitative risk assessment. Few investigations enumerate *Salmonella* or measure changes in cell numbers during processing. Furthermore, in both enumerative and detect/non-detect (prevalence) studies, different investigators employ a wide range of different conditions of sampling (sample type, site, size, unit, etc.) and laboratory testing methods. Other confounding factors are introduced by the original purposes of the studies and experimental design.
- Published results indicate that chlorine addition in the chill tank may not have an effect on the number of *Salmonella* on the carcass but may prevent an increase in the prevalence of contaminated chickens exiting processing, by reducing the potential for carcass-to-carcass cross-contamination in the chill-tank.
- The cross-contamination pathway in the home was recognized as having the potential to induce a risk many times greater than the risk arising from the consumption of undercooked chicken.

5.5 LIMITATIONS AND CAVEATS INCLUDING UNCERTAINTY AND VARIABILITY

The expert consultation strived to identify features of the work that have an impact on the acceptability of findings and the appropriateness of extrapolating findings to scenarios not explicitly investigated in the risk assessments. They are listed here together for the attention of readers to facilitate interpretation of the documents.

5.5.1 Hazard characterization for *Salmonella* spp.

The hazard characterization did not attempt to quantify secondary transmission (person-to-person), or the impact of chronic or severe outcomes resulting from humans being infected with *Salmonella*.

The available data did not make it possible to discern age-dependent dose-response relationships or separate dose-response relationships for those individuals that might be expected to be more susceptible to illness.

The impact of the food matrix was not incorporated into the hazard characterization due to limitations of available data.

Severity of illness as a function of patient age, *Salmonella* serovar or pathogen dose was not evaluated. Severity could potentially be influenced by any or all these factors. However, the current database of information was insufficient to derive a quantitative estimate of these factors.

Variations in the virulence of different *Salmonella* biotypes were not explicitly incorporated into the hazard characterization steps.

The data used to develop the dose-response model was based on outbreak data from a few developed countries. Application of the dose-response model in regions of the world where the population is believed to be distinct may not predict appropriately the probability of illness upon exposure to a dose of *Salmonella*.

The hazard characterization assumes that the beta-Poisson dose-response function, which has been shown in the literature to provide a good representation of the dose-response relationship for most bacterial pathogens and has low dose linearity properties as recommended in the draft *WHO/FAO Guidelines on Hazard Characterization for Pathogens in Food and Water*, is the appropriate mathematical form of the dose-response relationship.

There was some uncertainty associated with the outbreak data used to develop the dose-response relationship. It was necessary to introduce assumptions to use these data.

5.5.2 Risk characterization of *Salmonella* Enteritidis in eggs

This risk characterization for *Salmonella* Enteritidis in eggs was intentionally developed so as to not be representative of any specific country or region. Yet, within-flock prevalence and other model inputs were based on United States and/or Canadian evidence or assumptions. Therefore, caution is required when extrapolating from this model to countries other than the United States and Canada. At a minimum, data that is representative of a specific country should be used to determine model inputs prior to using the model to predict risk for that country.

A number of assumptions were made concerning the epidemiology of *Salmonella* Enteritidis. These include the assumptions that; infected hens produce contaminated eggs at a constant frequency regardless of hen strain, bacterial strain or environmental factors; the laying hen population is homogenous with respect to flock size, management factors and environmental factors; and within flock prevalence is random and not affected by factors such as age, the presence of an alternative host, bacterial strain and environment effects. Further investigation of the biology of *Salmonella* Enteritidis may enable these assumptions to be refined and to understand whether or not they introduce any limitations in the interpretation of findings.

The *Salmonella* Enteritidis risk characterization was in part based on estimates of the concentration of the organism in contaminated eggs. Evidence regarding enumeration of the organism was based on only 63 *Salmonella* Enteritidis-contaminated eggs. Of these eggs, only 32 contaminated eggs were from naturally infected hens (the remainder coming from experimentally infected hens). These data were used to describe the initial numbers of *Salmonella* Enteritidis in contaminated eggs. Also, these data were used to estimate the frequency of contaminated eggs that contain *Salmonella* Enteritidis organisms in the yolk at the time of lay. Nevertheless, it is difficult to represent uncertainty and variability with such limited data.

Much uncertainty attends the effectiveness of various management interventions for controlling *Salmonella* Enteritidis. The magnitudes of uncertainty regarding test sensitivity, effectiveness of cleaning and disinfecting, and vaccination efficacy have not been measured. Some data were available to describe these inputs, but the data may not be relevant to all regions or countries where such interventions might be applied.

Statistical or model uncertainty was not fully explored in this risk characterization. For example, alternative distributions to the lognormal for within-flock prevalence were not considered. Also, the predictive microbiology used in this model was dependent on very limited data pertaining to *Salmonella* Enteritidis growth inside eggs. Alternative functional specifications for *Salmonella* Enteritidis growth equations were not pursued in this analysis.

5.5.3 Risk characterization of *Salmonella* spp. in broiler chickens

The risk assessment of *Salmonella* in broiler chickens risk assessment did not consider all parts of the farm-to-fork continuum and this limits the range of control options that can be assessed. For example, if the model extended as far back as the pre-harvest stage, then risk management control options at the early stages of the chain could be appropriately evaluated. However, it was acknowledged by the expert consultation that national data exist in some countries that were not made available to the drafting group during the conduct of the work and undoubtedly more will still come to the attention of FAO and WHO upon distribution and discussion of this report. Thus, the opportunity exists to continue to expand upon the work presented in this document.

A 'hypothetical' baseline scenario was constructed to evaluate the relative merit of control strategies for *Salmonella* spp in broiler chickens. This scenario consists of a composite of input assumptions derived from a range of countries. The findings from the baseline scenario should not be used to draw inferences about a particular nation or region. To make specific inferences it would be necessary to collect inputs that were directly relevant to the particular population of interest.

It was not possible to provide a perfect representation of growth of *Salmonella* spp. in raw poultry. For example, it was assumed that no growth occurs below 10°C (although in reality a small amount of growth can be expected), and growth was predicted using average temperatures which may be less accurate than predictions of growth based on time-temperature data. Seasonal variations in ambient temperature were not accounted for. The model adopted also assumed ambient temperature had no impact on the rate of change for storage temperatures used for predicting growth and this is intuitively inappropriate in some circumstances.

Similarly, limitations were present in the way the model predicts the death of *Salmonella* spp. in broiler chicken carcasses during the cooking process. For example, it was not possible to account for the fact that varying locations on the carcass experience a different amount of heat during cooking. Further, assumptions on the duration of cooking of broiler chickens in domestic kitchens were not based on extensive and reliable data, and time-temperature data were not used for these predictions.

At several steps reliance was placed on expert opinion to estimate the value of model inputs. The consultation acknowledged that expert opinion was often easily accessible and sometimes sufficiently accurate for this purpose (for instance information from an Irish retailer was used to estimate retail storage times). However, on some occasions expert opinion might reduce transparency and introduce an unacceptable bias that may not be detected by the risk assessors. This remark is of a general nature and does not only apply to the *Salmonella* risk assessment.

Surveillance data from some countries often show a marked seasonality in the number of notifications of human salmonellosis with peak incidence occurring in the warmer months. The current model cannot account for or explain this important phenomenon as there is no facility for including time-dependent climatic effects which arise because the biological basis of seasonal effects is presently too uncertain to enable it to be represented in a model.

The consultation agreed that a lack of detailed understanding of all aspects of cross-contamination in the home hampered the ability of the drafting group to address this process. Thus, the drafting group could only consider a limited number of pathways by which cross-contamination could occur, and these required assumptions having a questionable basis. Nevertheless, the consultation agreed that it was necessary for cross-contamination to be represented in the model because it is considered important in the epidemiology of foodborne salmonellosis in humans and because it provides a basis for future improvement of the models.

Although the uncertainty associated with several parameters in the consumption portion of the risk assessment was accounted for, a full analysis of statistical and model uncertainty was not performed. For instance, the influence of uncertainty in the cross contamination pathway was not explored.

5.6 GAPS IN THE DATA

5.6.1 Hazard characterization

- Outbreak and epidemiological data, specifically indicating: cell number in the implicated food, amount of food consumed, accurate estimates of the size of ill and exposed populations, accurate characterization of the population including age profiles, medical status, sex and other potential susceptibility factors.
- Characterization and quantification of the impact of the food matrix effects, host-pathogen interactions and virulence factors and their effect on the probability of infection and/or illness.
- New dose-response models that improve the ability to estimate the probability of illness.

- Quantitative information to facilitate estimating the probability of developing sequelae following illness.

5.6.2 Exposure assessment of *Salmonella* Enteritidis in eggs

- Data relating to the biology of *Salmonella* Enteritidis in eggs. This need is seemingly universal in its application to previous and future exposure assessments.
- Additional studies on the numbers, and factors that influence the survival and growth of *Salmonella* Enteritidis in naturally (yolk) contaminated intact shell eggs (information is currently available for 63 intact shell eggs) and enumeration data of *Salmonella* Enteritidis in raw liquid egg.
- More data on the prevalence of *Salmonella* Enteritidis in breeder and pullet flocks and the environment, as well as in feedstuffs is needed to adequately assess the benefit of pre-harvest interventions. In particular, associations between the occurrence of *Salmonella* Enteritidis in these pre-harvest steps and its occurrence in commercial layers should be quantified.
- Better data on time and temperature, specifically in relation to egg storage would serve to build confidence in the modelling results. The importance of time and temperature distributions in predicting growth of *Salmonella* Enteritidis in eggs – combined with the lack of reliable data to describe these distributions – highlights the need for these data.
- New studies on the relationship between cooking time, cooking method and cooking temperature on the death of *Salmonella* Enteritidis.
- Additional data concerning the numbers of *Salmonella* Enteritidis in raw liquid egg before pasteurization in order to reliably predict the effectiveness of a regulatory standard concerning egg products.
- More studies on the survival and growth of *Salmonella* Enteritidis in eggs, particularly as a function of egg composition, and the attributes of infecting strains of organism (e.g. heat sensitivity).

5.6.3 Exposure assessment of *Salmonella* spp. in broiler chickens

- Prevalence data of *Salmonella* in broiler chickens during production and at slaughter, and on carcasses post processing and information on study design for many regions of the world.
- Microbial ecology studies to determine sources and numbers of the pathogen.
- Studies on the correlation between within-flock prevalence levels and the number of *Salmonella* cells shed in faeces and/or on birds.
- Precise estimates of the numbers of organisms per bird for all stages of the exposure pathway and improvements in the sensitivity and availability of cost effective methods to enumerate small populations of *Salmonella*.
- Between-bird (bird-to-bird) cross-contamination data suitable for modelling this phenomenon at the pre-harvest, transport, and processing stages.
- Data on the survival of *Salmonella* spp. under chilling and freezing conditions. This information will improve the predictive microbiology component of exposure assessments relevant to the international trade of poultry products.
- Specific consumption data and information about food preparation practices for most geographical locations preferably presented as portion size and frequency of consumption rather than average consumption per day.
- Information on the distribution of time and temperature for storage and cooking in domestic kitchens in a variety of national environments.
- Data on the magnitude of cross-contamination in the domestic kitchen and the pathways for cross-contamination.

If an attempt were made to extend the risk assessment to more fully assess pre-slaughter interventions then more data would be required on the prevalence of *Salmonella* in feed and replacement stock and fasting prior to slaughter. Data on the effect of scalding, de-feathering, evisceration, washing and chilling processes as well as other decontamination treatments are needed to effectively model the benefits of control interventions at the level of processing.

5.7 RESPONSE TO THE SPECIFIC RISK MANAGEMENT QUESTIONS POSED BY THE CODEX COMMITTEE ON FOOD HYGIENE.

The 33rd session of the CCFH discussed the preliminary report of the *Joint FAO/WHO Expert Consultation on Risk Assessment of Microbiological Hazards in Foods* (17 - 21 July 2000), which addressed hazard characterization and exposure assessment of *Salmonella* spp in broiler chickens and eggs and *L. monocytogenes* in ready-to-eat foods. Through that discussion the Committee identified a number of risk management questions to be addressed by the joint FAO/WHO *ad hoc* expert consultations. These questions were listed in the report of the session (ALINORM 01/13A) and are outlined below.

Risk management questions for *Salmonella* Enteritidis in eggs

- Estimate the risk from *Salmonella* Enteritidis in eggs in the general population and in the various susceptible populations (e.g. elderly, children, immunocompromised patients) at various prevalence and concentration levels of *Salmonella* Enteritidis in contaminated eggs.
- Estimate the change in risk likely to occur from each of the interventions below including their efficacy.
 - Reduce the prevalence of positive flocks
 - Destroy positive breeding and/or laying flocks
 - Vaccinate egg-laying flocks for *Salmonella* Enteritidis
 - Competitive exclusion
 - Reduce the prevalence of *Salmonella* Enteritidis-positive eggs
 - Test and divert eggs from positive flocks to pasteurization
 - Reduce the number of *Salmonella* Enteritidis organisms in eggs
 - Heat treatment of egg products
 - Refrigeration of eggs after lay and during distribution
 - Require a specific shelf-life for eggs stored at ambient temperatures

Risk management questions for *Salmonella* spp. in chicken (broilers)

- Estimate the risk from pathogenic *Salmonella* spp. in chicken (broilers) consequential to a range of levels in raw poultry for the general population and for various susceptible population groups (elderly, children, and immunocompromised patients).
- Estimate the change in risk likely to occur for each of the interventions under consideration including their efficacy.
 - Reduce the prevalence of positive flocks
 - Destruction of positive breeder and chicken (broiler) flocks
 - Vaccination of breeding flocks
 - Competitive exclusion (e.g. with *Salmonella sofia*)
 - Reduce the prevalence of positive birds at the end of slaughter and processing
 - Use of chlorine in water chilling of chicken (broilers)
 - Water chilling vs. air chilling for chicken (broilers)
 - Evaluate the importance of various routes for introduction of pathogenic *Salmonella* into flocks including feed, replacement birds, vectors, and hygiene

The response to these questions as outlined below is based on the risk assessment documents prepared by the expert drafting group and the discussions that took place during the expert consultation.

5.7.1 Estimation of the risk from pathogenic *Salmonella* spp. consequential to a range of levels for the general population and for various susceptible population groups. (elderly, children, immunocompromised patients).

The hazard characterization component of the risk assessment was used as the basis for addressing this question. While the risk from different levels of *Salmonella* was considered using reported outbreak data, there were insufficient data to limit the analysis to that from outbreaks associated with eggs and broiler chickens only.

A relationship between doses (numbers) of *Salmonella* ingested by people and the probability of developing symptoms of gastrointestinal illness was estimated using data from 34 outbreak investigations. For each outbreak the data described the magnitude of the ingested dose, the number of people consuming the contaminated food and the number who developed illness as a result. The outbreak data came from Japan, United States, Canada and Europe and included water- and food-related outbreaks.

Comparing the outbreak attack rates for children under five years of age, against those for the rest of the population, there was no overall trend of increased risk of illness for this sub-population. The limited database of outbreak information, however, lacks the power to reveal the existence of any true differences that may exist. There was some indication in two outbreaks for the existence of a different attack rate for the two populations. However, considering the overall trend, and until more information is made available, the dose-response relationship for members of the population across all age groups was assumed to be the same.

There were no outbreak data available that would allow a more comprehensive assessment of other susceptibility factors.

The expert consultation agreed that this was an appropriate response.

5.7.2 The effect of specific management interventions on the risk posed by *Salmonella* Enteritidis in eggs.

A. Reducing the prevalence of infected flocks and destroying breeding or laying flocks

The model is capable of examining the effect of changing flock prevalence on the probability of illness per serving. For example, if flock prevalence was reduced by an amount, say $x\%$, by the application of some intervention, then risk of human illness would also be reduced by $x\%$ (assuming all other model inputs remain constant).

Although the model did not explicitly include breeder flocks, it was expected that reducing infection in breeder flocks would reduce the prevalence of infected commercial flocks. If data were available that explain the contribution of breeder flocks to commercial flock prevalence, the change in risk per serving could be estimated using this model.

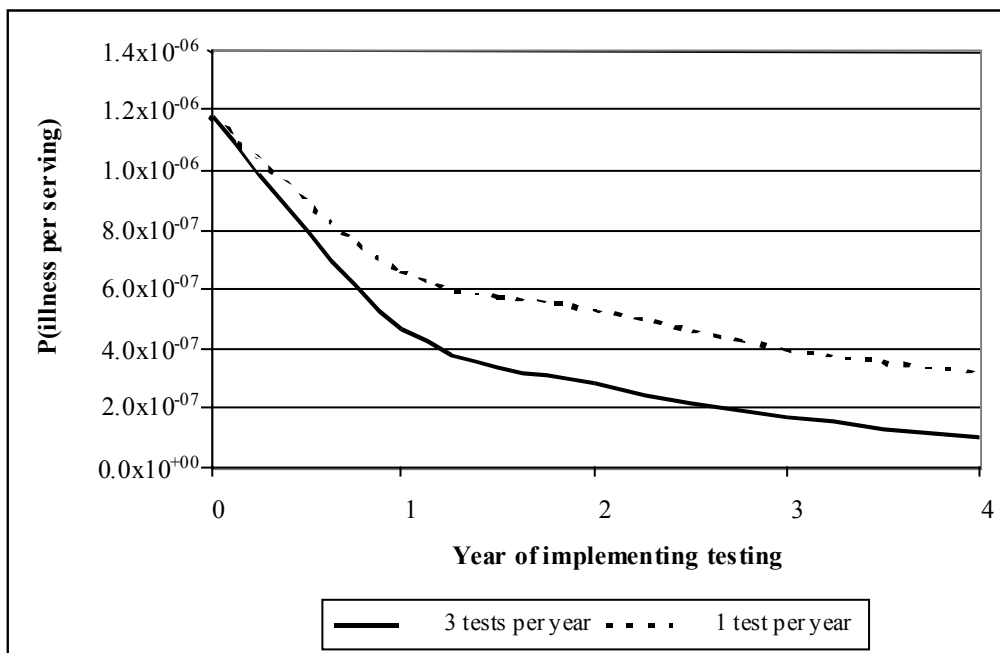
B. Reducing the prevalence of *Salmonella* Enteritidis positive eggs via testing of flocks and diversion of their eggs to pasteurization (including the effect of pasteurization)

Given a baseline scenario with flock prevalence of 25%, the effects of two test and diversion protocols were evaluated using the model. In one protocol, a single test was administered to all commercial flocks at the beginning of their egg production. In the other protocol three tests were administered to commercial flocks throughout the life of each flock. A single test was assumed to detect 44% of flocks. In the model, flocks that test positive for *Salmonella* Enteritidis were required to divert eggs to pasteurization, and to clean and disinfect the environment following depopulation (50% effective).

The probability of illness per shell egg serving for each year was calculated for each protocol (Figure 5.3). Testing three times per year reduced the risk of human illness from shell eggs by nearly 90% across four years.

While egg diversion from positive flocks reduces the public health risk from shell eggs, it might be expected that there is some increased risk from egg products. Mandatory diversion causes more contaminated eggs to be sent to pasteurization. Nevertheless, in this model the average number of *Salmonella* Enteritidis in pasteurized liquid whole eggs was reduced by diversion. This is because diverted eggs are stored for shorter periods than those not diverted and this reduces the opportunity for growth of the pathogen within those eggs that are contaminated.

FIGURE 5.3 Predicted probability of illness per serving from shell eggs per year following the implementation of two testing protocols. It was assumed that all flocks in the region were tested each time. Initial flock prevalence was assumed to be 25%. The baseline egg storage time and temperature scenario was used for the four years.



C. Vaccination of flocks against *Salmonella* Enteritidis and the use of competitive exclusion.

A single test for *Salmonella* Enteritidis, or two tests four months apart, of 90 faecal samples per test were used to evaluate the effect of vaccination against *Salmonella* Enteritidis. The vaccine was assumed to be capable of reducing the frequency of contaminated eggs by approximately 75%, based on data discussed in the source document (MRA 01/02).

Assuming 25% flock prevalence and the baseline egg storage time and temperature scenario, the probability of illness per serving for a single faecal test for *Salmonella* Enteritidis and vaccination protocol is about 70% of a non-vaccination protocol (Figure 5.4). Risk of illness was reduced to 60% of the non-vaccination protocol if two faecal tests for *Salmonella* Enteritidis were applied. Nevertheless, the actual reduction in risk of illness would depend on the prevalence of *Salmonella* Enteritidis within flocks and other input values.

Given data concerning competitive exclusion efficacy on infected flocks, an approach similar to that used for vaccination could be used in the model to estimate the effect on the risk of human illness.

D. Refrigeration of eggs after lay and during distribution or requirement of a specific storage time at retail for eggs at ambient temperatures.

The effect of mandatory retail storage times and temperatures was evaluated using baseline assumptions for a country that does not have egg refrigeration requirements.

Truncating retail storage time to <7 or <14 days simulated a shelf-life restriction scenario. Truncating the retail storage temperature to 7°C (<45°F) simulated a refrigeration requirement. The results are summarized in Figure 5.5. Shelf-life restrictions at retail within 14 days reduced risk of illness per serving very little. The refrigeration requirement reduced risk of illness per serving by about 58%. If shelf-life at retail was limited to 7 days, an effect comparable to that of refrigeration was noted. The actual reduction in risk will depend, however, on the prevalence of *Salmonella* Enteritidis within flocks and other input values.

FIGURE 5.4 Comparison of predicted probability of illness per serving between scenarios where no vaccination was used, where one faecal test for *Salmonella* Enteritidis was applied at the beginning of production and positive flocks were all vaccinated, and where a second faecal test for *Salmonella* Enteritidis was applied four months after the first test and additional test-positive flocks were vaccinated. The prevalence was assumed to be 25%, and the baseline egg storage time and temperature scenario was used. 1.4×10^{-6}

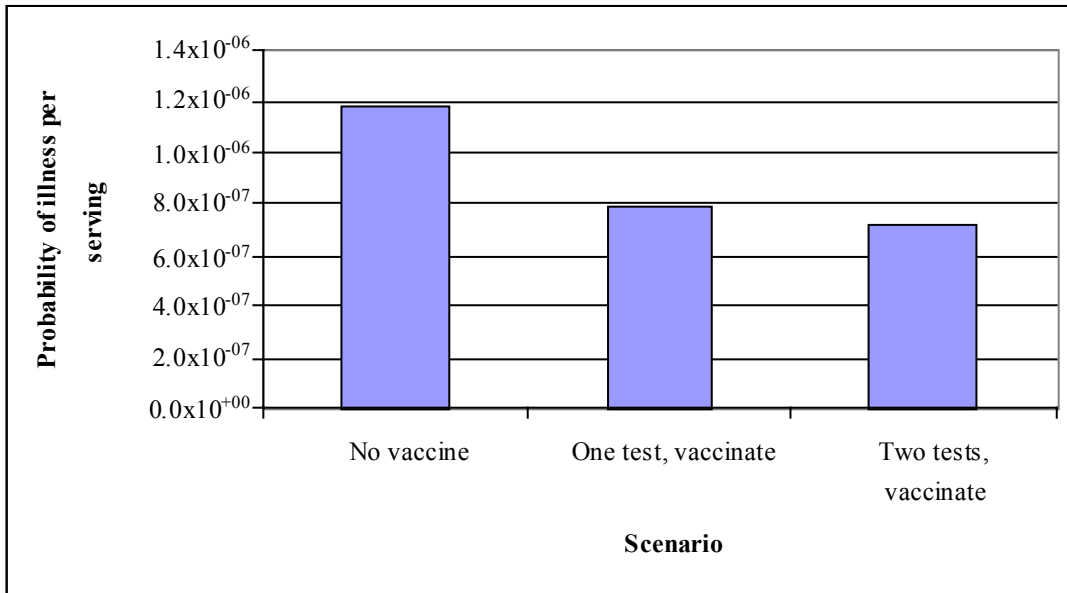
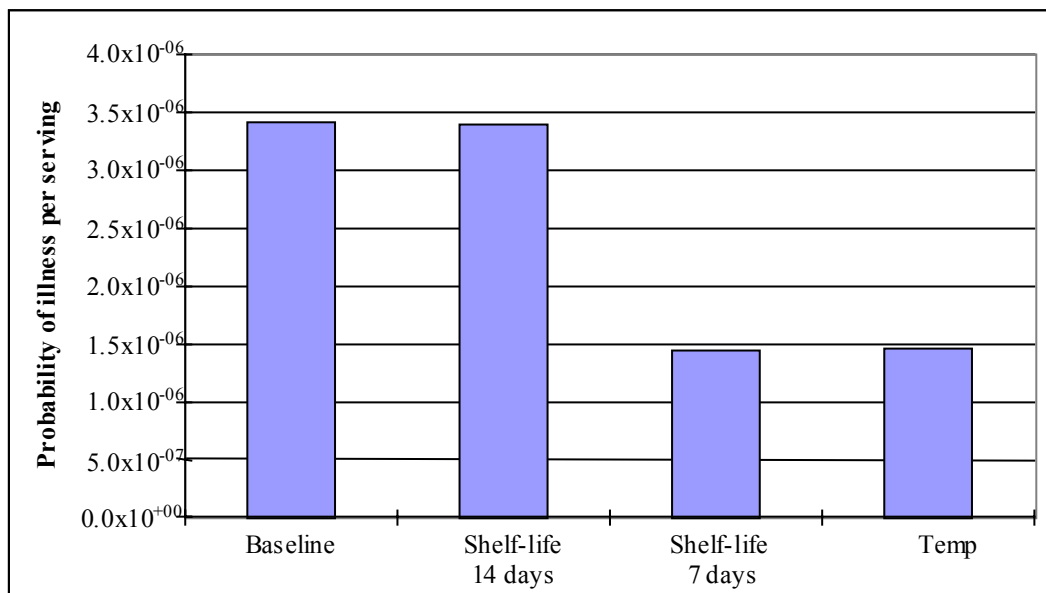


FIGURE 5.5 Probability of illness per serving of shell eggs having a mandatory shelf-life of <7 or <14 days at retail, or a mandatory retail storage temperature of 7°C (<45°F)



5.7.3 The effect of specific management interventions on the risk posed by *Salmonella* spp. in broiler chickens.

A. On-farm and processing interventions

The approach taken for the risk assessment was to develop a model that uses prevalence and numbers of *Salmonella* spp. on broiler chickens at the end of processing as the starting point. A baseline model was established in order to provide a means to compare the effects on risk when prevalence and cell numbers were changed. In this way, a reduction in prevalence or cell numbers of *Salmonella* on raw poultry carcasses could be evaluated by the

measure of change in the risk estimate compared to the baseline risk assessment. Farm or process interventions could be evaluated, provided the effect that the interventions have on the prevalence or cell numbers at the end of processing can be estimated.

Specific on-farm interventions, such as those mentioned in the question from CCFH, were not evaluated in the risk assessment model because of a lack of representative data to analyse how much change in either the prevalence and/or level of *Salmonella* in poultry could be attributable to any specific treatment or action. It is acknowledged that destruction of *Salmonella* positive flocks will influence public health outcomes. However, without information about the extent to which this practice translates to fewer infected birds at the completion of processing or fewer *Salmonella* cells per infected bird the magnitude of risk reduction could not be estimated

In addition, while there are many studies reporting the prevalence of *Salmonella* infection in birds, very few report the numbers of *Salmonella* that might be found on-farm and in live poultry. The studies providing enumeration data that were reviewed were substantially different with respect to sample sizes, experimental approach, testing methods, test accuracy, and spatial and temporal factors.

If management strategies that impact on the level of contamination, i.e., the numbers of *Salmonella* spp. on chickens are implemented, the relationship to risk is estimated to be greater than a one-to-one relationship. A shift of the cell number distribution on broiler chickens exiting the chill tank at the end of processing, such that the mean cell number from the baseline scenario is reduced by 40% on the non-log scale, reduces the expected risk of illness per serving by approximately 65%.

A change in the prevalence of contaminated raw product changes the estimated risk of illness to the consumer by altering the frequency of exposure to risk events i.e. exposure to the pathogen. The change in risk of illness as a result of a change in the prevalence of *Salmonella*-contaminated broiler chicken carcasses was estimated by simulating the model for a range of prevalence that are representative of data reported in various studies and countries (reviewed in Exposure Assessment MRA 00/05). If the prevalence of contaminated chickens leaving processing is altered, through some management practice either at the farm level or at the processing level, the expected risk of illness per serving is altered. The magnitude of the changes in risk of illness per serving and risk of illness per cross-contamination event as a result of changes in prevalence are summarized in Table 5.2.

TABLE 5.2 Change in risk of illnesses a result of decreasing or increasing the prevalence of *Salmonella*-contaminated broiler carcasses, relative to a baseline prevalence of 20% *Salmonella*-contamination used in the risk model.

Prevalence of contaminated carcasses exiting processing	Percent change in prevalence relative to assumed baseline	Per serving risk (estimated from model)	Percent change in per serving risk relative to assumed baseline
0.05%	-99.8%	4.80×10^{-8}	-99.7%
1%	-95%	1.20×10^{-6}	-93%
5%	-75%	4.68×10^{-6}	-72%
10%	-50%	7.95×10^{-6}	-52%
20% (assumed baseline)	NA	1.66×10^{-5}	NA
50%	+150%	3.99×10^{-5}	+140%
90%	+350%	7.40×10^{-5}	+346%

The change in risk of illness associated with a change in prevalence of *Salmonella* spp. was estimated to be a one-to-one relationship, assuming everything else remains constant. If the prevalence of *Salmonella* spp. on contaminated carcasses at the end of slaughter and processing is reduced by a specific percentage, the expected risk is reduced by a similar percentage. For example, reducing prevalence by 50% (e.g. from 20 to 10%) produces a 52% reduction in the expected risk of illness per serving (Table 5.3). Similarly, a larger reduction in prevalence (e.g., from 20% to 0.05%) was estimated to produce a 99.7% reduction in the expected risk of illness.

TABLE 5.3 Reported data from different studies on the effects of chlorine vs. no-chlorine in immersion water chilling on the prevalence of *Salmonella* on broiler chicken carcasses.

With Chlorine								
Study No.	Amount	Prevalence before chilling			Prevalence after Chilling			Ratio After / Before)
		Total	Positive	Prevalence	Total	Positive	Prevalence	
1	20-50ppm (tank)	48	48	100%	103	60	58%	0.6
2	4-9ppm (overflow)	50	21	42%	50	23	46%	1.1
3	1-5ppm (overflow)	90	18	20%	90	17	19%	0.9
4	15-50ppm (tank)	48	4	8%	96	7	7%	0.9
AVERAGE								0.9
Without Chlorine								
		Prevalence before chilling			Prevalence after Chilling			Ratio (After / Before)
		Total	Positive	Prevalence	Total	Positive	Prevalence	
1		160	77	48%	158	114	72%	1.5
2		99	28	28%	49	24	49%	1.7
3		40	5	13%	40	11	28%	2.2
4		40	4	10%	40	15	38%	3.8
5		84	12	14%	84	31	37%	2.6
6		60	2	3%	120	18	15%	4.5
7		AVERAGE						2.7

There are very few data on the effect of air chilling vs. water chilling on the prevalence or numbers of *Salmonella* spp. on processed carcasses. Regarding the use of chlorine in water chilling of broilers, it is difficult to objectively evaluate because of differences in the literature on the level of chlorine used, and the location at which chlorine was measured. There is little information on the effect of chlorine addition at levels of 50 ppm or less on the numbers of the pathogen attached to the skin of poultry carcasses. On the other hand, studies reporting changes in prevalence seem to indicate that the effect of chlorine might be to simply prevent an increase in prevalence (i.e. reduce the extent of cross-contamination in the chill tank) as compared with before and after data where chlorine was not used (Table 5.3). However, the reported effectiveness of chlorine ranged from only a small increase in prevalence, to no change, to a decrease, and was not necessarily consistent with the concentration of chlorine.

B. The importance of various routes for introduction of pathogenic *Salmonella* spp. into flocks

In relation to the importance of various routes for introduction of pathogenic *Salmonella* spp. into flocks including feed, replacement birds, vectors, and hygiene, the available data were inconclusive. Interpretations of existing studies and results are confounded because of the number of different sampling protocols, specimen types, and laboratory methods, as well as the nature of poultry-rearing operations (e.g., very large vs. very small premises, types of waterers, feeders, etc.). For these reasons, it was not possible to evaluate the importance of on-farm routes of introduction of *Salmonella* spp., and this stage was not incorporated into the risk assessment.

5.8. CONCLUSIONS AND RECOMMENDATIONS

The consultation expressed its appreciation for the quality and extent of information found in the risk characterization document. It was felt that the work represented a substantial advance in the application of scientific knowledge to improve the objective basis for managing *Salmonella* spp. in the food chain. The consultation further commended the extent of transparency achieved in the documents and for the pro-active manner in which limitations of the work were highlighted.

The consultation concluded that the new dose-response model derived from outbreak data represents the best available method for estimating probability of illness upon ingestion of a dose of *Salmonella*. However, with respect to the hazard characterization it was recommended that future analyses of data attempt to quantify the extent to which other factors effect the form of the dose-response relationship

There is a need to increase the understanding of cross-contamination processes (on-farm, during transport, during processing, during storage and food preparation in the home and food service establishments) so that these can be modelled. The consultation recommended that additional data to improve these aspects of the model should be collected.

Special emphasis should also be placed on improvement of the survival and growth modules, for example modelling survival and growth of *Salmonella* spp. below 10°C. In relation to *Salmonella* spp. in broiler chickens the consultation recommended that when technically possible the model be extended to include the whole production chain, from farm to fork. The consultation was informed that some data are available in this respect; occurrence of *Salmonella* in the environment and feed flock-prevalence of *Salmonella* in replacement birds, layers and broilers; prevalence in broiler chickens after slaughter; and data showing a recent decrease of cases of *Salmonella* spp. in humans due to preharvest risk management actions (actions taken in broiler chicken production). In relation to data generation the expert consultation also noted that current enumeration methods vary in sensitivity. The most sensitive method (MPN) is labour intensive and expensive. Improvements are needed to overcome these difficulties and develop cost effective methods to enumerate small populations of *Salmonella*.

It was also recommended that a sensitivity analysis of the model be performed aimed at identifying the parameters that have the most impact on the predictions of probability of human illness.

The consultation recommended that the model, and in particular the data inputs to the model, are evaluated prior to their use by member countries. If possible, user-friendly versions of the models should be made available to member countries provided the new versions could be made to accurately reflect the behaviour of the models reviewed in this expert consultation.

6. RISK ASSESSMENT OF *LISTERIA MONOCYTOGENES* IN READY-TO-EAT FOODS

6.1 INTRODUCTION

Foodborne listeriosis represents a relatively rare but clinically serious disease, with high case-fatality rates (20-30%) that largely affects specific segments of the population with increased susceptibility. The microorganism is widely dispersed in the environment and foods. Despite the fact that a wide variety of foods may be contaminated with *L. monocytogenes*, outbreaks and sporadic cases of listeriosis appear to be predominately associated with ready-to-eat (RTE) products. RTE food is a large, heterogeneous category of foodstuffs and can be subdivided in many different ways. According to the Codex definition (CAC/GL 22-1997), ready-to-eat food includes any food (including beverages) which is normally consumed in its raw state or any food handled, processed, mixed, cooked, or otherwise prepared into a form in which it is normally consumed without further processing. Furthermore, RTE foods differ in different countries according to local eating habits, availability and the integrity of the chill chain and regulations regarding, for example, the maximum temperature at retail level.

6.2 SCOPE OF THE RISK ASSESSMENT

The current risk assessment was undertaken in part to determine how previously developed risk assessments done at a national level could be adapted or expanded to address concerns related to *L. monocytogenes* in ready-to-eat foods at an international level. In addition, after initiation of the risk assessment, the risk assessors were asked by the 33rd session of the CCFH, through FAO and WHO, to consider three specific questions related to ready-to-eat foods in general. These questions were:

- Estimate the risk for consumers in different susceptible population groups (elderly, infants, pregnant women, and immunocompromised patients) relative to the general population.
- Estimate the risk from *L. monocytogenes* in foods that support growth and foods that do not support growth under specific storage and shelf-life conditions.
- Estimate the risk from *L. monocytogenes* in food when the number of organisms ranges from absence in 25 grams to 1000 colony forming units (CFU) per gram, or does not exceed specified levels at the point of consumption.

Considering the resources available and the time constraints placed on the risk assessors, it was impossible to consider all ready-to-eat foods that could be contaminated with *L. monocytogenes*. Accordingly, it was decided to limit the risk assessment to a finite range of ready-to-eat foods that have been selected to represent various classes of product characteristics, in order to determine if the risk of these foods serving as a vehicle for human foodborne listeriosis can be estimated. These foods were selected to provide examples of how microbiological risk assessment techniques can be used to answer food safety questions at an international level³. This educational component is a stated goal of the FAO/WHO microbiological risk assessment programme.

It was also decided to limit the scope of the risk assessment to foods at retail and their subsequent public health impact at time of consumption. This was done for two reasons. Firstly, such a scope was sufficient to address the charge provided by the CCFH within the time frame and resources made available to the risk assessors. Secondly, most of the exposure data for *L. monocytogenes* that is currently available relates to the frequency and extent of contamination at the retail level. More detailed examination of factors contributing to the levels of *L. monocytogenes* found at retail as a result of manufacturing parameters would have required that a much smaller range of foods be evaluated or that a substantially greater amount of resources and data be made available. Accordingly, the assessment did not evaluate the risks associated with different means of manufacturing these products. However, the risk assessment does consider several post retail factors that could influence the consumers' risk of acquiring foodborne listeriosis, such as the temperature and duration of refrigerated storage. In addition to invasive listeriosis, *L. monocytogenes* can also cause mild febrile gastroenteritis in otherwise healthy individuals. The public health significance of this type of listeriosis is uncertain at this time and was not considered in the current risk assessment.

In its request to FAO and WHO in 1999 for expert risk assessment advice (ALINORM 01/13), the CCFH indicated that a farm-to-table risk assessment would provide the broadest range of risk management options. However, the expert drafting group considered only the retail to consumer part of the food chain for the reasons explained above. The expert consultation agreed that there may be a need for CCFH and national risk managers to commission new risk assessments for specific foods or product categories if pre-retail considerations are to be addressed.

6.3 APPROACH TAKEN

The drafting group split into two working subgroups addressing the hazard characterization and the exposure assessment components. The exposure assessment subgroup further split into two subgroups. This appears to be reflected in both the writing styles within the document provided to the consultation and the multiple approaches used in the exposure assessment.

While it was recognized that the exposure assessment and hazard characterization components were part of a complete risk assessment, the expert consultation recommended that these sections be written in a manner that would allow their use as stand alone documents. In particular, it would be beneficial if the hazard characterization could be written in a manner that would allow it to be used as a stand-alone training document. The expert drafting group was made aware of this and will further amend the document.

Stochastic approach

The stochastic approach, as opposed to the deterministic approach, was used for the risk assessment. Stochastic means that inputs for a model are obtained by sampling from probability distributions. This allows uncertainty (which can be reduced if more data are gathered) and variability (a pervasive feature of biological data) to be propagated through the model and reflected in the model output. Other approaches, such as point estimates, interval modelling, etc. have their own value but are less versatile and often less adequate for demonstrating the impact of uncertainty and variability. Point estimates are useful to provide a quick estimate of the magnitude of risk.

The expert consultation agreed with this approach but encouraged the incorporation of an appropriate general reference to other potential methodologies in the final report of the risk assessment.

6.3.1 Hazard identification

L. monocytogenes is widely distributed in the environment and has been isolated from a variety of sources including soil, vegetation, silage, faecal material, sewage and water. There is evidence to suggest that it is a

³ The limitations of the international character of microbiological risk assessment were recognised by the expert consultation and are discussed in section 7.3.

transitory resident of the intestinal tract in humans, with 2 to 10 % of the general population being carriers of the organism without any apparent adverse health consequences. The bacterium can grow at refrigerator temperatures. It is more resistant to various environmental conditions than most other non-spore-forming, foodborne pathogenic bacteria, allowing it to survive longer under adverse conditions. Most cases of human listeriosis are sporadic and the source and route of infection are usually unknown, however, contaminated food is considered to be the principal route of transmission. Foods most often associated with human listeriosis are ready-to-eat products that support growth of *L. monocytogenes*. Typically, these foods have long refrigerated shelf lives, and are consumed without further listericidal treatments (e.g., cooking).

Invasive listeriosis (i.e., severe *L. monocytogenes* infections) is a relatively rare but often severe disease with incidence rates typically of about 4 to 8 cases per 1,000,000 individuals and fatality rates of 20 to 30 % among hospitalized patients.

Most strains of *L. monocytogenes* appear to be pathogenic but their virulence, as defined in animal studies, varies substantially. Listeriosis is an opportunistic infection that most often affects those with severe underlying disease (e.g. immunosuppressive therapy, AIDS, and chronic conditions, such as cirrhosis, that impair the immune system), pregnant women, unborn or newly delivered infants and the elderly. The bacterium most often affects the bloodstream, the central nervous system or the pregnant uterus. Manifestations of listeriosis include, but are not limited to, bacteremia/septicemia, meningitis, meningo-encephalitis, encephalitis, miscarriage, stillbirth, premature birth, neonatal disease and prodromal illness in pregnant women. Incubation periods range from a few days up to three months.

6.3.2 Exposure assessment

The objective of this phase of the risk assessment was to determine the frequencies and extent of ingestion of *L. monocytogenes* in RTE food meals using examples of food types, and population groups. Initially, existing exposure assessments were reviewed as a background in developing a modelling approach.

Seven examples to be modelled for exposure assessment were selected such that several food related attributes could be considered; different food commodities, lightly processed and highly processed RTE foods, potential for growth or not during long-term storage, cold-chain integrity, potential for inactivation, e.g., pasteurization, post-process contamination, expected high contamination load of final RTE foods, high consumption rates, and use in international trade. Modelling was done from retail to the point of consumption.

The steps taken were:

- estimation of prevalence and cell numbers of *L. monocytogenes* at retail level for each of the selected RTE foods;
- identification of conditions allowing or preventing growth of *L. monocytogenes* between retail and consumption, especially time and temperature of storage of the product;
- estimation of frequency and size of meal servings of the specific RTE foods for both less susceptible and more susceptible populations;
- determination of cell numbers of *L. monocytogenes* in contaminated servings consumed by less susceptible and more susceptible populations.

The influence of climate and season in different regions in the world could not be determined and was not considered.

An influence diagram to compare consumption frequency and amount based on gender, age, and susceptible population was incorporated into the exposure assessment.

The RTE foods chosen were raw and pasteurized milk, ice cream, soft mould-ripened cheese (information related to cheeses made from raw milk and from pasteurized milk were combined), minimally processed fresh vegetables, cold-smoked salmon, and semi-dry fermented meats. The aim of these examples is to illustrate the effect on risk of:

- a) product categories;
- b) low contamination levels in products that do not permit growth of *L. monocytogenes*;
- c) long-term storage on *L. monocytogenes* concentration;
- d) consumption patterns and volumes on dose eaten.

Due to time constraints, the exposure assessment on cold-smoked salmon was not presented and the expert consultation recommended that this example be completed. Specifically, it was pointed out that the processing of hot and cold smoked fish differs and this should, if possible, be reflected in the exposure assessment.

6.3.3 Hazard characterization

As agreed by the experts, severe listeriosis i.e. infected individuals suffering from life-threatening, systemic infections such as perinatal listeriosis, meningitis or septicaemia, was used as the biological endpoint.

No single previously developed dose-response model was fully able to meet the needs of the current risk assessment in relation to the parameters examined and the simplicity of calculations. For these reasons, alternate approaches were developed and evaluated for the current risk assessment. The general approach was to take advantage of the epidemiological data and detailed exposure assessment available in the FDA/USDA-FSIS risk assessment, but simplify the modelling by describing the dose-response relations using an Exponential dose-response model based on epidemiological data with the best estimation of *L. monocytogenes* contents of the foods.

The Exponential dose-response model was chosen because of its acknowledged applicability for modelling severe listeriosis, its simplicity as a single parameter model, and its log linear nature at the dose ranges of interest. The equation is:

$$P = 1 - e^{-RN}$$

where P is the probability of severe illness, N is the number of *L. monocytogenes* consumed, and R is the parameter that defines the dose-response relation for the population being considered. The Exponential model is a non-threshold model, which implies that there is no “minimum infectious dose.” Instead the model assumes that a single *L. monocytogenes* cell has a small but finite probability of causing illness. The use of the Exponential model meets the recommendations of the draft *WHO/FAO Guidelines on Hazard Characterization for Pathogens in Food and Water* for the selection of dose-response models for infectious microorganisms. A key attribute of the model is its loglinearity (log dose vs. log probability of illness) at low doses. This implies that if the dose is reduced ten-fold, the probability of illness is reduced ten-fold. In addition, it implies that at low doses, a single serving with a specified level of contamination has the same public health impact as ten servings with ten-fold fewer organisms.

Specific R-values were derived in the current risk assessment for both the less susceptible and more susceptible populations. This was achieved using the consolidated food contamination distribution from the FDA/USDA-FSIS model in conjunction with their annual estimated number of listeriosis cases as a percentage of the total population of either more or less susceptible groups within the U.S. population. This provided values for P and N, so that the R-value could be calculated by rearranging the above equation.

The accuracy of the R-value is dependent on the size and definition of the population being considered, the accuracy of the annual disease statistics, and the reliability of data on the frequency and extent of *L. monocytogenes* contamination of foods. The uncertainty based on these parameters was estimated and incorporated into the derived R-values. The effect of maximum levels of *L. monocytogenes* in foods on the calculation of the R-value was evaluated in detail since there is a degree of uncertainty and/or variability related to the actual maximum levels of *L. monocytogenes* observed in foods. Several different means of calculating the R-values were explored in order to examine the impact of basing the calculations on multiple doses or on the highest contamination level only. This was found to have minimal effect. The R-values selected for subsequent use in the risk assessment were $R = 1.06 \times 10^{-12}$ with a 5% to 95% range of 2.47×10^{-13} to 9.32×10^{-12} for the more susceptible population and $R = 2.37 \times 10^{-14}$ with a 5% to 95% range of 3.55×10^{-15} to 2.70×10^{-13} for the less susceptible population.

The consideration of the variability in virulence among *L. monocytogenes* isolates and its impact on the dose-response relations for this microorganism have been addressed in detail within the hazard characterization section of the risk assessment. This includes a discussion of how this is handled in different manners in the risk assessments that have been done previously assuming the presence of the most virulent strain. In selecting the approach used in the current risk assessment’s dose-response model, strain virulence is implicitly considered. The drafting group responded to the expert consultations questions related to the consideration of strain virulence by including both a table from the FDA/USDA-FSIS risk assessment and some additional text which describe how virulence variability is handled by the various risk assessments including the current one (Table 6.1).

Differences in the susceptibility exist among the various subpopulations with increased susceptibility to *L. monocytogenes*. It was decided to consider all persons with increased susceptibility as a single group for the purposes of the subsequent risk characterizations. However, the hazard characterization did consider how the dose-response relations for various subpopulations with increased susceptibility could be modelled individually by using

epidemiologically derived relative susceptibility data. A detailed explanation and examples of this alternative approach is provided in section 6.7 where the response to the question from the CCFH on the risk to consumers in different susceptible population groups is addressed.

6.3.4 Risk characterization

The 33rd session of the CCFH requested an estimation of the risk for consumers in different susceptible population groups (elderly, infants, pregnant women, and immunocompromised patients) relative to the general population. This was addressed by estimating the relative risk of different susceptible subpopulations based on epidemiological data assuming similar consumption patterns in these groups. The estimates of relative susceptibility were then used to estimate dose-response relationships for different susceptible subpopulations using an Exponential model.

Risk characterization was done by combining the dose-response models for the general population and the more susceptible population with the estimated exposure for six of the ready-to-eat products.

TABLE 6.1 Comparison of the characteristics of the dose-response models selected for use in the current risk assessment with the dose-response models developed in other studies.

Study	Empirical Basis	Endpoint	Models Examined	Model Used	Host Susceptibility	Strain Virulence
Farber <i>et al.</i> (1996)	Subjective	Illness (including lethality)	Weibull-Gamma	Weibull-Gamma	Explicit	Unknown
Buchanan <i>et al.</i> (1997)	Epidemiology	Severe illness (including lethality)	Exponential	Exponential	Implicit	Implicit
Haas <i>et al.</i> (1999)	Mouse	Infection	Beta-Poisson, Exponential	Beta-Poisson	Mouse assumed to predict response in humans	Not addressed
Lindquist and Westöo (2000)	Epidemiology	Illness	Exponential and Weibull-Gamma	Exponential	Implicit	Implicit
FDA/FSIS (2001)	Mouse, Epidemiology	Lethality and infection	Multiple	Multiple	Explicit, Epidemiology-based	Explicit based on animal data
FAO/WHO (2001)	Epidemiology	Severe listeriosis (including lethality)	Multiple	Exponential	Explicit, consideration of healthy population and subpopulation with increased susceptibility	Implicit

6.4 KEY FINDINGS OF THE RISK ASSESSMENT

6.4.1 General

The risk assessment document:

- demonstrated that questions pertaining to international food safety issues can be addressed by expanding and/or adapting components of risk assessments done at a national level.
- showed that pre-existing models and data sets can serve as the basis for subsequent quantitative risk assessment efforts. This finding highlights the need to develop archives or clearinghouses where models and data sets can be accessed and used by others.

- identified a number of areas where data gaps exist and clearly demonstrated the need for improved data acquisition for prevalence and growth of *L. monocytogenes* in food and the incidence of foodborne listeriosis on a global basis.
- recognized that using data acquired from around the world has an underlying assumption that there are no regional differences, unless those differences are explicitly considered.

6.4.2 Exposure assessment

- Exposure assessments were developed for six of the RTE foods from initial prevalence and concentration at the retail level to final concentration in contaminated servings.
- The modelling chosen was to determine final concentration of *L. monocytogenes* in contaminated servings based either on a time-temperature distribution or by adding other factors of importance to model growth rates.
- Four home refrigerator temperature distributions were chosen based on studies done in three countries to include in the exposure assessment. These affected the predicted growth rate of *L. monocytogenes* in foods stored for long periods in home refrigerators. These were chosen to demonstrate the importance of different storage temperature distributions in different regions of the world.
- The exposure assessment component of the risk assessment was quite extensive providing an assessment of the exposure to *L. monocytogenes* from six RTE foods. However, due to the identification of an error in the simulation model the expert consultation decided that these findings should not be reported until the models used in assessing exposure have been subjected to a more extensive review and revised if necessary.

6.4.3 Hazard characterization

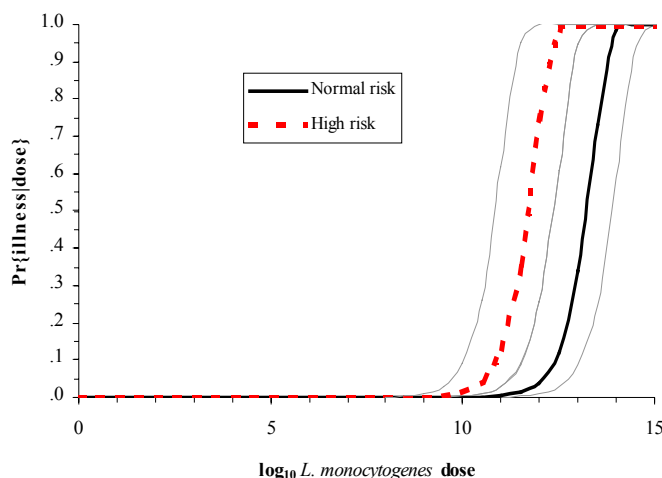
- The document critically reviewed the different data sources and mathematical models that have been used for developing microbial dose-response relations, providing practical advice on the strengths and weaknesses of each.
- Available dose-response models for *L. monocytogenes* were critically reviewed for effectiveness and for fulfilling the criteria established in the draft *WHO/FAO Guidelines on Hazard Characterization for Pathogens in Food and Water*. The strengths and limitations of each model were evaluated. This includes dose-response models developed using (a) expert elicitation, (b) surrogate animal data, (c) epidemiological (annual disease statistics) plus food survey data, and (d) mixed models.
- The current risk assessment developed for the first time dose-response models that were based on the use of outbreak investigation data in conjunction with the Exponential model. This included dose-response models for both severe listeriosis and for listerial gastroenteritis.
- Two simplified models based on the Exponential model and epidemiological data on severe listeriosis, one for the less susceptible population and a second for the population at increased susceptibility, were developed for the current risk assessment (Figure 6.1). These models were then used for the risk characterization phase of the risk assessment. In addition relative susceptibility data from France and the United States were used to develop dose-response curves for specific susceptible subpopulations including transplant patients, AIDS patients, individuals undergoing dialysis, patients with pulmonary and related cancers, patients with bladder cancer and related cancers, patients with gynaecological cancer, individuals suffering from diabetes, hepatitis or alcoholism, elderly (France and United States), and prenatal and neonatal cases. The alternative dose-response approach is discussed in more detail in section 6.7.1 on the risk from *L. monocytogenes* to susceptible population groups compared to the general population.

6.4.4 Risk characterization

- Risk characterizations based on the exposure profile of *L. monocytogenes* at consumption and the dose-response models were used to attempt to estimate predicted cases of listeriosis per serving for each of the six foods. However, the identification of an error in the simulation model precluded the final calculation of risk and further work will be required.
- An alternative, deterministic approach was used on an interim basis to characterize the risk based on the dose-response relations/curve from the current risk assessment and the exposure data from the FDA/USDA-FSIS

model. This approach indicated that eliminating high levels of *L. monocytogenes* contamination from foods at the point of consumption would have a positive public health impact.

FIGURE 6.1 Simulated dose-response functions for susceptible and non-susceptible populations for $\Pr\{\text{illness}|\text{L.monocytogenes dose}\}$.



6.5 LIMITATIONS AND CAVEATS INCLUDING UNCERTAINTY AND VARIABILITY

6.5.1 Modelling

The risk characterization results are subject to uncertainty associated with a modelled representation of reality involving simplification of the relationships among prevalence, cell number, growth consumption characteristics and the adverse response to consumption of some number of *L. monocytogenes* cells. However, modelling is appropriate to quantitatively describe uncertainty and variability related to all kinds of factors.

The risk characterizations attempt to provide estimates of the uncertainty and variability associated with each of the predicted levels of risk. This is one of the strengths of this type (stochastic) of modelling, but also leads to confusion in the interpretation of data. Furthermore, these estimates of uncertainty are themselves uncertain and dependent on the methods and assumptions used to make these calculations. This is often exacerbated by the limited data sets available describing the levels of *L. monocytogenes* and may overestimate the maximum extent of contamination and thus the risk associated with a specific food.

6.5.2 Prevalence and cell number

It was emphasized that the amount of quantitative data available on *L. monocytogenes* contamination was limited and restricted primarily to European foods.

Prevalence was determined by combining results available in the published literature, government surveillance reports and industry reports. Estimates of prevalence were subject to the variability and uncertainty associated with the published results and the methods used here to combine those results into a single distribution.

Cell number distributions were also derived from articles in the published literature. The estimated distributions are subject to uncertainty and variability associated with small sample sizes in many of those articles and assumptions that those separate data sets can be pooled into a single distribution. Moreover there are assumptions on the redistribution of pathogens in products when repackaged that contribute to uncertainty in the distribution of cell numbers.

The data used for prevalence and cell numbers may not reflect changes in certain commodities that have occurred in the food supply during the past ten years.

6.5.3 Consumption characteristics

The consumption characteristics used in the risk assessment were primarily those for Canada or the United States.

6.5.4 Modelling of dose-response

The R-values and their distributions were developed using epidemiological data on the current frequency of *L. monocytogenes* strain diversity that are observed with their associated virulence. If that distribution of virulence were to change (as reflected by new epidemiological data), the R-values would have to be recalculated. There is uncertainty associated with the form of the dose-response function used, and with the parameterization.

It should also be understood that the dose-response section of the hazard characterization is entirely a product of the shape of the distribution of predicted consumed doses in the FDA/USDA-FSIS exposure assessment. Further, since the underlying phenomenon of consumed doses is essentially unmeasurable, the validity of the dose-response model is dependent on the validity of the FDA/USDA-FSIS exposure assessment, which would be very difficult to externally validate. Note that the dependency is not limited to the parameter, r , but includes the choice of the best functional form (i.e., Exponential, beta-Poisson). Changes to the FDA/USDA-FSIS exposure assessment should lead directly to changes in the parameter, R . As a result it may not be possible to validate the exposure assessment and dose-response model as separate entities.

6.5.5 Modelling of microbial growth

Predictive modelling was used to model the growth of *L. monocytogenes* in RTE foods, between the point of retail and the point of consumption. Exposure assessment was based on distributions of the numbers of bacteria derived from those models. It is known that models may overestimate growth in food, as there are examples of foods in which maximum levels are much lower than those predicted by models. Reliance on such a model will result in an overestimation of the risk. An example is cold smoked fish. Another example is frankfurter where the occurrence and extent of growth on the surface is different to that in the core of product. Nevertheless, it has been observed that even in such foods, there were examples of very high levels e.g. 10^{11} per serving (e.g. chocolate milk). Therefore, the approach taken was purposely conservative and all details can be found in the complete risk assessment document, which will be made available on the FAO/WHO webpages. There is uncertainty in the assumed distributions for the growth rates (derived from data sets available in the published literature), storage temperatures (from four published sources), and storage times.

6.6 GAPS IN THE DATA

This section identifies gaps for this and future risk assessments.

- *L. monocytogenes* prevalence in potential environmental sources, including i) agricultural environments, e.g. ground and well water; cultivated soil used for different crops or uncultivated soil for grazing pasture at different times of the year, silage, fresh and composted manure, farm equipment and farm workers; ii) aquatic environments, marine and freshwater where fish or shellfish are harvested including the effects of sewage or agricultural runoffs into water, fishing equipment, and commercial and recreational fishers.
- *L. monocytogenes* prevalence and cell numbers in production including i) primary production: animals, fish, and crops; ii) secondary production, e.g. initial preparation, cleaned carcasses, gutted and stored fish, shucked shellfish, washed produce.
- Prevalence and cell numbers of *L. monocytogenes* in finished packages of RTE foods from around the world on which risk assessment is being or will be undertaken.
- Information on the frequency of naturally occurring very high levels of contamination.
- Product formulation information, e.g. pH, water activity, humectants and preservatives (e.g. nitrite and organic acids, lactic acid bacteria) and their distributions to enable best estimates of microbial growth, survival or death.
- Better knowledge on the growth of *L. monocytogenes* in naturally contaminated food.
- Data for evaluating the validity of predictive models for *L. monocytogenes* in specific products, recognizing the effect of prior history of the culture and potential differences between naturally contaminated products and those deliberately inoculated in challenge tests.
- Identification of virulence markers for *L. monocytogenes* so that exposure to those strains can be assessed specifically.
- Identification of sources and levels of contamination and recontamination, at the point of processing, retail and the consumer are needed, with information on frequency, and microbial load transferred.

- Impact of microbiota, including spoilage organisms on the growth and survival of *L. monocytogenes* in RTE foods or their ingredients, and on the shelf-life of products.
- Retail and consumer handling practices, in particular, storage time and temperature and including more accurate measurements of home storage conditions including refrigeration temperatures by country or region.
- Specific RTE product consumption data for meal servings and frequency by specific populations of individuals, including in developing countries, and particularly for those who are immunocompromised or otherwise susceptible.
- Epidemiological data that distinguish serious or life threatening (usually systemic) vs. mild disease.
- Data on the degree of compliance to regulations established for control of *L. monocytogenes* cell numbers in food and the influence these regulations have on prevalence and cell numbers. This information will influence estimates of the efficacy of the control programme.
- Data on the capacity to which industry can control the prevalence and numbers of *L. monocytogenes* in foods and meet different tolerance levels (e.g. negative in 25 g, 0.1 g, 0.01g).

6.7 RESPONSE TO THE SPECIFIC RISK MANAGEMENT QUESTIONS POSED BY THE CODEX COMMITTEE ON FOOD HYGIENE

6.7.1 Evaluation of the risk from *Listeria monocytogenes* to susceptible population groups compared to the general population

This question was addressed by inspection of the epidemiological data on the number of cases in more susceptible subgroups. However, in taking this approach it was assumed that consumers in the different subgroups have similar consumption patterns.

If the risk for listeriosis is the same for more susceptible consumers as for the general, or healthy, population the proportion of cases in a specific subgroup should reflect its proportion of the total population. Conversely, if the risk for a subgroup is larger the actual number of cases in the subgroup is a reflection of the increased risk. This risk may be expressed as a relative risk⁴ based on the healthy population or, using the Exponential model derived in the hazard characterization section, as an R for a specific subgroup, e.g. R_{elderly}.

In the present analysis, epidemiological data from France (that do not include perinatal cases) and from the United States were used.

Under the assumption that the Exponential dose-response model is an accurate model to describe the relationship between dose and the probability of illness the relative risks (RR) presented for different subgroups may be used to derive dose-response models for specific susceptible subgroups. The Exponential dose-response model is described by:

$$P = 1 - e^{-R*N}$$

where P is probability of illness and N is the ingested dose. The R-value is a reflection of the host/microorganism interaction probability, and is the probability of the ingested organisms being individually capable of causing an infection to a specific consumer. The relative risk describes the ratio between the probabilities of illness for the subgroup and the healthy population and thus;

$$RR_{\text{subgroup}} = P_{\text{subgroup}}/P_{\text{healthy}} = 1 - e^{(-R_{\text{subgroup}} * N)} / 1 - e^{(-R_{\text{healthy}} * N)}$$

$$R_{\text{subgroup}} = [- \ln(1 - RR + RR * e^{(-R_{\text{healthy}} * N)})] / N$$

From this relationship R_{subgroup} can be estimated since the R-value for the healthy population (derived in the Hazard Characterization section) and the relative risks are known. Since P, the probability of illness and R are related by an Exponential function, the value of R_{subgroup} depends to some extent on both the dose and the magnitude of the relative risk. The influence of dose on the estimated R-values for the different subgroups was investigated by calculating R for a low (1 CFU) and a high dose (the assumed maximum doses). The influence of dose was most significant at higher doses, close to the assumed maximum dose, and when the probabilities of

⁴ The level of risk of listeriosis for the population with an underlying condition relative to the level of risk for the reference population (less than 65 years and no known health conditions).

illness were larger than 0.01. In view of the overall uncertainty the variation with dose was considered insignificant and in Table 6.2 the average of the estimated R's at the two doses are presented for the different subgroups.

It should be remembered that the R-values derived from calibration of the Exponential model to the exposure assessment results and the epidemiological data represents an implicit consideration of the virulence of *L. monocytogenes* strains, the vulnerability of the subgroups, the consumption and exposures etc..

The estimated R-value varied within a particular susceptibility subpopulation depending on assumed maximum dose. Thus for the most susceptible group (transplant patients), the estimated R-values varied from 5.8×10^{-10} (log dose 7.5) to 2.3×10^{-11} (log dose 10.5). In comparison, similar R-value estimates ranged from 2.23×10^{-13} to 7.45×10^{-15} in the healthy population.

Relative susceptibilities for individuals have been estimated from French epidemiology data using the sizes of these groups and the numbers of cases. A similar calculation for perinatal and elderly populations was made using data from the United States. The R-values were then calculated using the healthy population (less than 65 years of age and no known health conditions) for reference.

TABLE 6.2 Relative susceptibilities, R- value, and estimated log dose for immunocompromised and nonimmunocompromised populations

Population	Relative susceptibilities	R-value ^a	Estimated log dose
France			
Organ Transplant ⁵	2584	1.4×10^{-10}	7.5
AIDS	865	4.6×10^{-11}	-
Dialysis	476	2.5×10^{-11}	-
Cancer-Bladder	112	6.0×10^{-12}	-
Cancer-Gynaecological	66	3.5×10^{-12}	-
Elderly - over 65 years old	7.5	4.0×10^{-13}	10.5
Non-immunocompromised	1	-	-
United States			
Elderly - over 60 years old	1.6	8.4×10^{-12}	-
Perinatal	839	4.5×10^{-11}	-
Non-immunocompromised	1	-	-

^a R-value 5.33×10^{-11} from maximum dose at $10^{8.5}$ used for reference population

6.7.2 Risk from *Listeria monocytogenes* in food when the number of organisms does not exceed a specified level at the point of consumption.

There are a number of different means of answering this question using various degrees of sophistication and assumptions e.g. the extent of deviation from a criterion that could be anticipated. However, it is worthwhile considering the simplest form of the answer to this question, that is the best case scenario of what could be anticipated if different criteria were successfully implemented. This best case scenario can be easily estimated by using the dose-response relationship derived in the hazard characterization in conjunction with a “global contamination distribution”. As an example of this type of analysis, the distribution for the total number of contaminated servings of food from the FDA/USDA-FSIS risk assessment was used in conjunction with the R-value (5.85×10^{-12}) from the current risk assessment assuming a maximum dose of $10^{7.5}$ CFU/serving for the susceptible population. This was the most conservative dose-response curve used in the current risk assessment. The total predicted number of cases per year in this example was 2130 (susceptible individuals).

⁵ A transplant patient (with listeriosis) is someone who has had an organ transplant within the last year, and received an immunosuppressive therapy

TABLE 6.3 Baseline number of cases predicted by the dose-response model.

Log dose at consumption (Log CFU/serving)	Number of servings at the specified dose	Number of cases* attributed to a specified dose level
-1.5	5.93 x 10 ¹⁰	0.01
-.5	2.50 x 10 ⁹	0.005
.5	1.22 x 10 ⁹	0.02
1.5	5.84 x 10 ⁸	0.1
2.5	2.78 x 10 ⁸	0.5
3.5	1.32 x 10 ⁸	2.4
4.5	6.23 x 10 ⁷	11.5
5.5	2.94 x 10 ⁷	54.4
6.5	1.39 x 10 ⁷	25.7
7	3.88 x 10 ⁶	228
7.5	2.67 x 10 ⁶	1580
Totals	6.41 x 10 ¹⁰	2130

* the number of cases is predicted based on the dose and the number of servings containing that dose

Using the serving numbers listed above, the upper range of cell numbers were limited to dose values equal to or less than values between 1.5 log and 4.5 log CFU per serving. Then assuming 100% realisation of these limits, the number of cases that would be anticipated was calculated for seven scenarios (Table 6.4). In the scenario calculations the number of servings at dose values higher than that of the criterion being considered were added to the highest dose level. Thus when a dose limit of 4.5 log was considered, the number of servings from the baseline data (Table 6.3) for 5.5, 6.5, and 7.5 log were added to the number of servings for 4.5 log. It is important to note that these values are in terms of CFU per serving. To calculate what this would be in terms of CFU per gram of food, the values in the table below would have to be divided by the serving size in terms of grams.

TABLE 6.4 The number of cases predicted if various criteria for CFU/serving could be realized at 100% effectiveness.

Maximum log dose at consumption (log CFU/serving)	Predicted Number of Cases
Baseline distribution above ^a	2130
4.5	24.9
3.5	5.3
2.5	1.1
1.5	0.2
0.5	0.06
-0.5	0.02
-1.5	0.01

^a. This depicts the current number of predicted cases based on the observed distribution of *L. monocytogenes* depicted in Table 6.3.

It is obvious from the table provided above that eliminating the higher dose levels at the time of consumption has a large impact on the number of predicted cases, i.e., an approximate 99% reduction in cases

could be potentially realised by implementing even the highest criterion. However, it is important to note that this is based on cell numbers at time of consumption. Consideration of cell numbers at time of retail would have to be corrected to take into account the potential increases in *L. monocytogenes* that would occur as a result of growth in those foods that will support replication of *L. monocytogenes*. Likewise, this does not take into account the reality that there would likely be some incidence where the criteria analysed above would not be realized. Consideration of these factors requires a more rigorous evaluation of the risk posed, using more sophisticated modelling techniques. This advanced modelling was not completed in time for the expert consultation, but is anticipated shortly.

6.7.3 Risk from *Listeria monocytogenes* in foods that support growth and do not support growth under specific storage conditions and shelf-life.

The question concerning the relative risk associated with foods that do and do not support growth can also be considered broadly by using the example above. The key consideration is whether a correction factor needs to be applied when comparing levels at time of retail versus at time of consumption. For foods that support growth, increases in *L. monocytogenes* cell numbers between retail and consumption would have to be assumed and there is a significant likelihood that the hypothetical criteria analysed above would be exceeded. However, this would not be the case for foods that do not support growth. Thus, for foods that do not support growth of *L. monocytogenes*, the predicted number of cases in relation to maximum dose level at retail would be the same as those depicted above for doses at time of consumption. Again, more rigorous modelling of other factors that could influence the differential in risk of severe listeriosis between foods that do and do not support the growth of *L. monocytogenes* are currently underway and the results of that activity are expected shortly. However, these are not likely to alter the large differential in risk between food that do and do not support the growth of *L. monocytogenes* to high levels that is suggested by the current “best-case” analysis.

6.8 CONCLUSIONS AND RECOMMENDATIONS

The *L. monocytogenes* risk assessment represents a major achievement and presents novel approaches to solve the problems of dose-response and exposure assessment modelling for *L. monocytogenes*. The expert consultation recognized that this risk assessment will provide a very valuable contribution not only relative to the process in CCFH, but also in general as a resource document for FAO and WHO member countries, academia and other interested parties.

The expert consultation acknowledged the enormous amount of work done but suggested some reorganization of the risk assessment document and an editorial review to make reading easier. It also suggested that the exposure assessment provides further explanation of the different approaches used therein. Furthermore, the expert consultation strongly recommended that the risk assessment, when completed and edited by the drafting group, be sent for an international peer review.

The consultation identified problems related to the statistical basis applied in the exposure assessment of *L. monocytogenes*, specifically in relation to the representation of events with very low probability that could have a very large impact on human health. These problems may limit the ability of models to produce accurate absolute numerical estimates of listeriosis. This is an issue with general implications for modelling in microbiological risk assessment. It was also concluded that there is a wider array of probabilistic techniques available from other disciplines to deal with this issue. In relation to this, the consultation suggested to FAO and WHO that further work be urgently initiated in order to reach agreement on the modelling approach to be taken to finalize the *L. monocytogenes* exposure assessment and risk characterization.

Risk characterization was done by combining the dose-response models for the general population and the more susceptible population with the estimated exposure for six ready-to-eat foods. The expert consultation asked that the drafting group further expand the risk characterization section of the risk assessment document. The drafting group proposed that the risk characterization would be developed for each of the six foods. An additional section to address the questions on the risk from *L. monocytogenes* in foods that do and do not support its growth and the risk from *L. monocytogenes* in foods when the number of organisms does not exceed a specified number at the point of consumption as posed by CCFH would also be included.

Quantitative data on levels of *L. monocytogenes* contamination of foods and prevalence of listeriosis should be obtained in various regions of the world. Similarly, this information should be developed to determine if seasonality and/or regional differences exist and the influence of climate and season in different regions in the world.

The output of any risk assessment depends greatly on the tails of distribution⁶, notably the number of bacterial cells at the time of consumption. Any management options that reduce the uncertainty associated with these tails of distribution would be helpful.

The expert consultation agreed with the statement of CCFH (ALINORM 01/13A) that one of the important future work issues for the joint FAO/WHO programme of activities on microbiological risk assessment would be to estimate the change in risk of listeriosis from food likely to occur when specific interventions are introduced. In doing so it would be important to include in the modelling exercise data from the parts of the production chain going back to and including processing and in some cases the steps before processing.

7. APPLICABILITY OF THE RISK ASSESSMENT WORK

7.1 INTRODUCTION

Quantitative microbiological risk assessment is intended to answer specific questions of importance to public health. For microbiological risk assessment to deliver benefits it needs to be purposefully incorporated into the decision making process. This implies a change in the way nations approach food safety and public health decisions. The novelty of microbiological risk assessment is that it quantifies the hazard throughout the food production chain and directly links this to the probability of foodborne disease. The risk assessments on *L. monocytogenes* and *Salmonella* spp. discussed in this report present powerful examples of the potential of this approach. However, it should also be realized that it would not be necessary in all cases to use such advanced tools to provide an objective basis for decisions in food safety.

7.2 APPLICABILITY: TRAINING AND CAPACITY BUILDING

The increased use of microbiological risk assessment will result in new capacity building needs. The exercise of producing these two risk assessments has been a learning experience and since it is so comprehensive it can also provide a basis for future training efforts and applied research.

An important prerequisite for microbiological risk assessment is the need for an interdisciplinary approach. There is a dual need to develop the capacity for microbiological risk assessment skills and expertise within all the relevant disciplines (microbiology, modelling, epidemiology, etc.) and to ensure that these disciplines become effectively integrated into the risk assessment process. Transparency must be maintained throughout the risk assessment process from the initial stages of building the risk assessment team, to data collection and analysis procedures. General education materials on microbiological risk assessment should be accumulated by FAO and WHO and made freely available for use by member countries.

The expert consultation suggested that the capacity for microbiological risk assessment could be strengthened through:

- Establishment or designation of centres of modelling expertise.
- Development of regional data collection centres (sentinel sites for active foodborne disease surveillance) with special attention to the quality of data to improve comparability between countries and regions.
- Preparation of regional⁷ risk assessments.

In this effort WHO Collaborating Centres and FAO Centres of Excellence could be involved, in conjunction with other relevant national and international entities. There is an urgent need to direct international and national support to this area. If a country does not have the resources to determine the incidence of human illness attributable to a given foodborne hazard, the use of a sentinel system through FAO and WHO would be one approach to gather the necessary information. Efforts also need to be made to collect data on the prevalence and cell numbers of microorganisms throughout the foodchain.

⁶ The tails of a distribution are the higher and lower values which are less frequent, but exert a major influence on the output of a calculation.

⁷ Regional in this case means areas with similar food production and consumption patterns and can be within a single country or cover similar areas within several countries.

The consultation identified three basic approaches to meeting the microbiological risk assessment software needs of member countries. One option would be for member countries to acquire and use commercially available software. A second option would be to take the models developed for each of these risk assessments and transfer their structure and logic to a stand-alone tool. This might be done by reprogramming the mathematics and logic of the model and embedding it in a user-friendly package. The models could then be made available free of charge to member countries. A third software option would be for an international organization to develop a set of tools that would be most useful to modellers around the world and then to make them available free of charge. This approach is similar to that taken by the United States Centers for Disease Control and Prevention in the development of *Epi Info*. The Monte Carlo capability that is used by popular commercial software can be used, for example, to develop a set of macros that would enable users of spreadsheet software to enter data as a distribution. The software could then do Monte Carlo simulations as used in these assessments.

7.3 APPLICABILITY: UNDERTAKING RISK ASSESSMENTS

The expert consultation recognized these risk assessments as a resource that can be used by many parties including national authorities. Ensuring the applicability and utility of the risk assessments to all regions and all nations should be a priority for future work of national governments and FAO and WHO. This exercise in conducting risk assessment at the international level has underlined the need for data to be acquired from all regions and for the development of countries' capacities to conduct risk assessments. The development of these capacities requires an infrastructure for the surveillance of foodborne illness and the monitoring of microbial hazards in foods throughout the foodchain and the effect of processing and other factors on the microorganism. It also requires human resources with the technical skills needed to conduct microbiological risk assessment.

7.3.1 Adaptability of the exposure assessment component

The models developed by the drafting group are applicable by others on the condition that the mathematical model is validated and the computer programs are made available. If these conditions are met, the model can be used to do risk assessment for these pathogen-commodity combinations at regional or national levels. The data used in the model must reflect the food item, raw material, manufacture, retail conditions, and consumption habits within the region under consideration. The predictive models for growth, survival or decline of microorganisms, once improved and accepted on a global basis, will still have to be used with parameters fitted to the regional or national conditions of interest.

Although some users may find value in the complete risk assessment, it is intended that any and all useful components of the assessments be exploited as fully as is possible among all member countries. While some of the concepts and data presented in these risk assessments are generic and directly adaptable, significant parts of the exposure assessment relate to specific national situations.

Although the exposure assessments are reasonably close to the exposure scenarios in some developed countries they do not truly represent any one country or situation. Therefore, the exposure assessment component should not be used without careful scrutiny of its applicability to the national situation and taking into consideration the exposure pathway in the country. Some results can be used directly as presented in the risk assessments. Some functions must be parameterized and some data must be replaced with data for a specific region or use. Other portions of the model may not be applicable at all in certain national contexts.

The two greatest concerns for adaptability of the exposure assessment are the lack of a standard format for data reporting and how to bridge data gaps. A standard format for data reporting for use in a risk assessment includes methods of collection of data and its use in a risk assessment model. In addition to the well known data collection issues of comparability and differences in methods, quality assurance etc., data collected in traditional food safety control systems are generally not collected in a manner that is well-suited to risk assessment. This would ideally require the removal of bias, accounting for confounding factors and summarizing the data in the form of a probability distribution.

FAO and WHO are in the process of developing guidelines for microbiological exposure assessment. It is anticipated that these will provide further detail on the topic of standardized reporting of data.

7.3.2 Adaptability of the hazard characterization component

The Consultation believed that the hazard characterization portions of these risk assessments offer the most readily adaptable data and models for other users of the assessment. The information there is quite generic and the approach adaptable. In those cases where the information may not be applicable it is believed that the required data can be collected. However, within any human population there are sub-groups characterized by different levels of

susceptibility to infection. The degree of susceptibility and size of these sub-groups have to be defined carefully. It should be noted that collection of these data would be less likely in nations lacking a risk assessment infrastructure. The experts believed that the dose-response curves used in these risk assessments have more general applicability and that they are the best currently available for general use.

7.3.3 Other applications of the FAO/WHO risk assessment documents

The expert consultation concluded that there is a considerable amount of useful information made available through these risk assessments for those planning to undertake a quantitative microbiological risk assessment. For example, the dose-response model based on outbreak data provides meaningful estimates of the probability of illness upon ingestion of a dose of *Salmonella* spp. There is also information on the dose-response relationship for *L. monocytogenes* and an estimation of relative risks for the more susceptible subpopulations.

This *Salmonella* spp. risk assessment provides information that would be useful in determining the impact intervention strategies may have on reducing cases of salmonellosis from contaminated eggs and poultry. In the risk assessment of *Salmonella* spp. in broiler chickens, for example, it was determined that there is a relationship between changing the prevalence of *Salmonella* spp. on the broiler chickens and reducing the risk of illness per serving. In the risk assessment of *Salmonella* Enteritidis in eggs, reducing the prevalence of *Salmonella* Enteritidis in poultry flocks was directly proportional to the reduction in risk to human health. The model can also be used to estimate the change in risk of human illness from changing storage times or temperature of eggs. The *Listeria* risk assessment indicates that measures that reduce the prevalence of food servings containing the highest numbers of *L. monocytogenes* at the point of consumption would contribute greatest to reducing disease incidence.

The reports presented to the expert consultation by the drafting group also provide an example of a format for organizing the available information in a readable way, connecting problems in food with human health outcomes. They explain clearly steps taken to gather the statistics that were used. They also provide scientific advice and analysis that may be useful for establishing regulatory policies for control of foodborne disease in different countries. For example, the *Listeria* report indicates that on a per serving basis foods where growth of *L. monocytogenes* does not occur have a lower relative risk than foods that support growth. These reports can be used to provide the scientific basis for assessing or judging the proposal before the CCFH on microbiological criteria for RTE foods. In addition the risk assessments have identified important data gaps which can be used by societies to prioritise research.

8. OVERALL CONCLUSIONS OF THE EXPERT CONSULTATION

In addition to their specific conclusions on the risk assessments of *Salmonella* spp. in eggs and broiler chickens and *L. monocytogenes* in RTE foods (sections 5.8 and section 6.8), the expert consultation concluded that, overall, the draft risk assessments were comprehensive and of a high quality. Appreciation was expressed for the magnitude of work carried out by the expert drafting groups. The work represented a substantial advance in the application of scientific knowledge to improve the objective basis for managing microbiological hazards in the food chain.

The consultation concluded that the work done by the expert drafting groups should be seen as an exercise, aimed at demonstrating:

- the applicability and usefulness of the available methodology;
- the need for data based on surveys and experimental studies specifically designed to provide information for microbiological risk assessment;
- the need for a better knowledge and understanding of the tails of probability distributions used to describe some input variables (tails provide high or low values, which are less frequent, but can exert a major influence on the predictions of risk);
- the opportunity for performing sensitivity or importance analysis so as to give indications to risk managers on where risk management options can be implemented with the best use of resources.

Furthermore, the consultation concluded that validation of results was a relevant part of any modelling exercise. However, there are currently no data available that allow validation of the models used in the exposure assessment and therefore validation of the final risk estimate was not possible. To perform these validations, data are needed on prevalence of contamination and numbers of cells at the point of consumption and/or data on

listeriosis and salmonellosis attributable to certain food groups. Given the practical difficulties with regard to validation of risk estimates it would be sensible to develop guidelines for judging the quality of risk assessment models.

The consultation also concluded that the FAO/WHO process for undertaking microbiological risk assessment could be improved and identified some of the key areas to be addressed. In order to critically appraise all elements of a model, its documentation and some instruction on its structure and use could be provided to a peer review panel prior to future expert consultations. Training documents, manuals, guidelines, and quality control procedures are needed in this process. In relation to this the consultation concluded that an international peer review was essential for the credibility of the risk assessments.

9. RECOMMENDATIONS

The expert consultation endorsed the recommendations made by the *joint FAO/WHO Expert Consultation on Risk Assessment of Microbiological Hazards in Foods* that took place on 17 - 21 July 2000.

In addition the consultation recommended that:

- Interaction between the risk assessors and the risk managers should begin at an early stage in the risk assessment process. A clear definition of the risk management question is essential in order to ensure that the risk assessment is correctly targeted and interaction is essential to achieving this.

In order to improve data collection and generation for microbiological risk assessment the consultation recommended that:

- FAO and WHO develop a form to be completed by CCFH and member countries when requesting risk assessment advice from the *ad hoc* expert consultations on microbiological risk assessment. The form should request basic elements of a risk profile and a clear question to be addressed in the risk assessment to be carried out.
- FAO and WHO develop guidelines for the collection of data to ensure that the quality of data collected for use in risk assessment is comparable between countries. These guidelines should address sampling strategies and methods of data analysis and generation of microbiological data from food and clinical specimens
- Data required to strengthen risk assessments be obtained from purposefully designed studies that withstand the criticisms of the various scientific disciplines that participate in microbiological risk assessment.
- FAO and WHO facilitate the development of surveillance systems with the view to data generation for quantitative microbiological risk assessment and enhancing the interaction between epidemiologists and the other disciplines involved in risk assessment.
- Member countries promote the collection of high-quality data and optimise their food safety research, surveillance programmes, outbreak investigations, food testing activities and monitoring of microbial hazards throughout the food chain so that the data generated can support national and international microbiological food safety risk assessments
- Research is undertaken so that the importance of factors such as the influence of climate and season in different regions in the world, which could not be determined or considered in the current work, can be addressed in the future.

In order to improve the modelling approaches used in microbiological risk assessment the consultation recommended that:

- Further work is undertaken to illustrate the use of various levels of sophistication in calculations for quantitative risk assessment, and defining specific situations that need a certain level of sophistication. The work should include a description of problems in the modelling of microbial pathogens (and validation of such models) and the development of a means to communicate such problems and their resolution to all parties involved in the development and use of quantitative microbiological risk assessments.
- FAO and WHO co-ordinate research to explain or reconcile the different approaches used in the development of dose-response models.

- That careful consideration be given to the use of expert opinion to estimate the value of model inputs as on some occasions expert opinion might reduce transparency and introduce an unacceptable bias that may not be detected by the risk assessors.

In order to facilitate the use of risk assessment in addressing microbiological food safety issues the consultation recommended that:

- Member countries embrace the risk analysis approach to ensure optimal allocation of resources in foodborne disease and food control programs. As part of this member countries need to develop the capacity and expertise in the various disciplines involved in microbiological risk assessment and also ensure that these disciplines become effectively integrated into the risk assessment process.
- FAO, WHO, their member countries, the scientific community and the food industry strengthen their technical co-operation in order to enhance risk assessment capabilities and capacities at national and international levels. Support by FAO and WHO for training is required to assist in the transfer of technology for microbiological risk assessment especially for developing countries.
- FAO and WHO make educational materials on microbiological risk assessment available for use by member countries.

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ANNEX 2: JOINT FAO/WHO MICROBIOLOGICAL RISK ASSESSMENT ACTIVITIES



ANNEX 3: LIST OF WORKING DOCUMENTS

The documents on which this report is based are currently being revised taking into account the discussions and recommendations of the expert consultation. They will also will undergo a further scientific peer review. Therefore, the information made available through this report and other sources is subject to revision until the risk assessments have been finalized and published by FAO and WHO. FAO and WHO declines any responsibility for errors and omissions in the information and data provided.

Paper no.	Title	Authors
MRA 01/01	Risk assessment of <i>Listeria monocytogenes</i> in ready-to-eat foods	Robert Buchanan, Food and Drug Administration, United States Roland Lindqvist, National Food Administration, Sweden Tom Ross, University of Tasmania, Australia Ewen Todd, Michigan State University Mark Smith, Bureau of Biostatistics and Computer Applications, Health Canada Richard Whiting, Food and Drug Administration, United States
MRA 01/02	Risk characterization of <i>Salmonella</i> in broilers and eggs	Aamir Fazil, Health Canada, Canada Anna M. Lammerding, Microbial Food Safety Risk Assessment, Health Canada, Canada Fumiko Kasuga, National Institute of Infectious Diseases Japan Eric Ebel, United States Department of Agriculture, United States Louise Kelly, Veterinary Laboratories Agency, United Kingdom Wayne Anderson, Food Safety Authority of Ireland Emma Snary, Veterinary Laboratories Agency, United Kingdom
MRA 00/01	Hazard identification and hazard characterization of <i>Listeria monocytogenes</i> in ready-to-eat foods	Robert Buchanan, Food and Drug Administration, United States Roland Lindqvist, National Food Administration, Sweden
MRA 00/02	Exposure assessment of <i>Listeria monocytogenes</i> in ready-to-eat foods	Tom Ross, University of Tasmania, Australia Ewen Todd, The National Food Safety and Toxicology Center, Michigan State University, United States Mark Smith, Bureau of Biostatistics and Computer Applications, Health Canada
MRA 00/03	Hazard identification and hazard characterization of <i>Salmonella</i> in broilers and eggs	Aamir Fazil, Health Canada Roberta A. Morales, Research Triangle Institute, United States Anna M. Lammerding, Microbial Food Safety Risk Assessment, Health Canada Andrea S. Vicari, North Carolina State University, United States Fumiko Kasuga, National Institute of Infectious Diseases Japan
MRA 00/04	Exposure assessment of <i>Salmonella</i> Enteritidis in eggs	Eric Ebel, United States Department of Agriculture Fumiko Kasuga, National Institute of Infectious Diseases Japan Wayne Schlosser, United States Department of Agriculture, United States Shigeki Yamamoto, National Institute of Infectious Diseases Japan
MRA 00/05	Exposure assessment of <i>Salmonella</i> spp. in broilers	Louise Kelly, Veterinary Laboratories Agency, United Kingdom Wayne Anderson, Food Safety Authority of Ireland Emma Snary, Veterinary Laboratories Agency, United Kingdom