3. Review of available scientific information on control of *Salmonella* and *Campylobacter:* occurrence and challenges, and state of the science

3.1 Primary production

The apparent absence of peer-reviewed scientific publications on the efficacy of specific interventions in commercial poultry flocks in terms of food safety of broiler meat needs to be seen in context. Such interventions have been widely used in many countries as part of national control programmes for *Salmonella* and, over a period of time, have been associated with significant reductions in prevalence of pathogens at the pre-harvest stage of broiler production. The countries include Finland, Sweden, Denmark and The Netherlands, and the effectiveness of their respective control strategies is described in peer-reviewed scientific publications and in national reports that include surveillance data for *Salmonella* in poultry. See, for example, Wegener et al., 2003; Maijala et al., 2005; Van der Fels-Klerx et al.*,* 2008.

3.1.1 *Salmonella*

In primary production, control of *Salmonella* within broiler flocks relies on knowledge of the source of infection (FAO/WHO, 2002). Possible sources include water, feed, litter, farm staff and the environment, both inside and outside the broiler house (Davies, 2005). Furthermore, hatcheries are possible sources of infection, as is vertical transmission (FAO/WHO, 2002). Data on the number of *Salmonella* organisms in feed, litter, etc., and the numbers of the organism to which the bird has been exposed, are still limited or unknown. Therefore many of the current risk assessment models today start at the point of estimating the prevalence of contaminated *Salmonella*-positive birds as the birds enter the slaughterhouses, and this means that on-farm control strategies are very poorly investigated at the present time (FAO/WHO, 2002). In relation to this meeting, a call for data was sent out, asking *inter alia* for data regarding prevalence and effect of on-farm control measures. This call for data did not reveal any new information on the effect of on-farm interventions as no quantitative information was presented for this step of the chicken production chain. Enumeration of *Salmonella* is laborious and time consuming, and is rarely carried out in practice.

3.1.2 *Campylobacter*

The principal reservoir of pathogenic *Campylobacter* spp. is the alimentary tract of wild and domesticated mammals and birds. Several countries have monitoring programmes to determine the prevalence of *Campylobacter* in food producing animals and birds. A seasonality of broiler flock colonization has been shown in some countries, leading to a peak in the flock prevalence during the warm summer months (Newell and Davidson, 2003; Kapperud et al., 1993; Jacobs-Reitsma, Bolder and Mulder, 1994; Rosenquist et al., 2009). However, studies in other parts of the world (for instance the United Kingdom and North America) have not shown any evidence of seasonality (Nadeau, Messier and Quessy, 2002). It is believed that the observed influence of season may be associated with the increased ventilation of houses and the increased numbers of insects during the warm summer and autumn months. If large volumes of air are introduced, it is conceivable that flies with *Campylobacter* from the outside are introduced into the flock. In Denmark and Iceland, studies have investigated the effect of using fly-screens to prevent the introduction of *Campylobacter* in the flock. This has shown promising results in lowering the prevalence of *Campylobacter* (Hald, Sommer and Skovgard, 2007). However, more intervention studies must be conducted in order to measure the effect on prevalence and level of contamination, using also control farms. The efficacy of fly-screens also needs to be tested in countries with climatic conditions different from those in the Nordic countries.

Campylobacter shed in faeces from the gastrointestinal tract are able to survive for considerable periods in the environment, but are not known to grow under those conditions. Survival is enhanced by cool, but not freezing, moist and dark environments. As many mammals and birds (wild and domestic) are known hosts for *Campylobacter*, which can be asymptomatically excreted in significant numbers, then the environment (soil, water, pasture, etc.) must be frequently contaminated with this organism. A conventional poultry house that is modern and well maintained and with limited access should be considered a biosecure premise. Passive transgressions of the biosecurity perimeter in such a house may be by essential commodities like water, feed and air. Active transgressions require the carriage of *Campylobacter* from the external environment, which may occur by vectors such as vermin or flying and crawling insects, but the most visible vehicles are humans (Ridley et al., 2008).

It is widely assumed that thinning or partial depopulation is a significant risk factor for flock colonization. The risks include the passive transfer of organisms from previously-visited farms or the processing plant on clothes, boots, crates and vehicles on to the farm, and subsequently into the broiler house during catching. Thinning may result in infection of the remaining birds with *Campylobacter* within 2 to 6 days due to the temporary breakdown in biosecurity (Allen et al., 2007).

3.2 Processing

3.2.1 *Salmonella*

Differences in prevalence resulting from different practices are considered in several studies. In particular, these studies have focused on differences in water-immersion scalding and chilling (with and without chemical additives). Those concerned with the effect of chemical additives generally report a reduction in the prevalence (FAO/WHO, 2002). Data on prevalence and numbers of organisms are available for individual production steps, but most often using these data to estimate level of reduction requires additional assumptions since there are differences in the way the data are obtained. Conducting a baseline study would provide a more certain estimation (FAO/WHO, 2002). The call for data in support of this meeting provided additional data on this production step, but, as is the case for previous studies, the data from different studies are difficult to compare, due to differences in sampling and methods of analysis. Therefore estimates based on these data sources will also contain a certain level of uncertainty. Whereas data on the prevalence of *Salmonella* on poultry meat at the end of processing or at retail were available, very few surveys have been undertaken where the number of organisms has been quantified (Anon., 2005). Data provided by Libya in response to the data call describe the effect of radiation and storage temperature upon growth of *Salmonella* in fresh chicken carcasses, but, as is the case with the previously mentioned investigations, more work needs to be done in order to standardize these studies in a way that renders them comparable among countries. As a consequence, it is very difficult to combine the existing data in a risk assessment model to be used when developing the Web-based decision tool.

3.2.2 *Campylobacter*

Since *Campylobacter* is a common inhabitant of the intestinal tract of warm-blooded animals, the organism can be expected to contaminate meat during slaughter and evisceration as a result of faecal contamination (FAO, 2003). Therefore, the main goal in controlling *Campylobacter* contamination of chicken carcasses during processing is to minimize the spread of faecal material. The process operations that have been considered in risk assessments are: scalding, de-feathering, evisceration, washing and chilling (FAO, 2003; Nauta et al., 2009). A study performed in Denmark on the numbers of *Campylobacter* during specific slaughter operations has revealed that the evisceration operation may lead to increased *Campylobacter* concentrations on the carcasses, whereas air- and water-chilling can lead to reductions of 0.8–1.0 $\log_{10}$ cfu/g. Furthermore, it has been shown that freezing causes an additional reduction of 1.4 $\log_{10}$ cfu/g before further frozen storage (Rosenquist et al., 2006). Because scalding washes much of the dirt and faeces off the carcass exterior, more microorganisms can be removed during scalding than during any other process step (USDA-FSIS, 2008; Cason and Hinton, 2006; Hinton et al 2004a, 2004b). The scald process cannot eliminate excessively high numbers of microorganisms entering the process, and the effect of scalding is very dependent on the method used, since immersion scalding has been shown to increase the level of contamination in cases where the operating conditions are poor. This was probably caused by an accumulation of dirt and faeces in the scald water due to an inadequate flow of fresh water into the tank, making the scald tank a source of cross-contamination for subsequent carcasses (USDA-FSIS, 2008; Cason and Hinton, 2006; Hinton et al 2004a, 2004b). The scalding process is a major site of cross-contamination for *Salmonella,* but is less important in this respect for *Campylobacter* because prevalence and numbers of the organism tend to be much higher in positive flocks.

3.3 Distribution, handling and preparation

3.3.1 *Salmonella*

Most often, interventions at these stages are assessed using growth models that take account of levels of contamination when carcasses leave the processing plant, thereafter using inputs for storage time in retail stores, transport time, storage times in homes, and the temperatures carcasses were exposed to during each of these periods. The presence and level of *Salmonella* in this step is very much country specific, since the level of infection when leaving the processing step will vary between the countries in relation to the methods used at the processing plant. Therefore national data must be used when estimating levels of contamination (FAO/WHO, 2002).

The call for data sent out in conjunction with the Technical Meeting revealed that many of the contributors do investigate the prevalence of *Salmonella* in the chicken meat, but often this is not done for the level of contamination. Furthermore, the analyses are not done in a standardized manner and the results will be very hard to use for comparison between countries, and even within regions of the same country.

3.3.2 *Campylobacter*

Reports from the European Union (EU), as well as other countries, reveal that fresh poultry meat is the food vehicle most frequently contaminated with *Campylobacter*. In some EU member states in 2007 the prevalence in retail products was as high as 83%. In Iran, a prevalence of 63% has been reported, and in Japan 45.8% of retail poultry was contaminated with *Campylobacter* (FAO, 2003). A study performed in Denmark uses simulations designed to predict the effect of different mitigation strategies, which showed that the incidence of campylobacteriosis associated with consumption of chicken meals could be reduced 30 times by achieving a 2 Log reduction in the number of *Campylobacter* on the chicken carcasses. To obtain a similar reduction of the incidence, the flock prevalence should be reduced approximately 30 times, or the kitchen hygiene improved approximately 30-fold (Rosenquist et al., 2003). A study from Germany investigated the transfer of *Campylobacter,* using simulations of some typical situations in kitchens and quantification of the *Campylobacter* transfer from naturally contaminated chicken parts most commonly used in Germany. One scenario simulated the seasoning of five chicken legs and the re-use of the same plate for cooked meat. In another, five chicken breast fillets were cut into small slices on a wooden board where, without intermediate cleaning, a cucumber was sliced. Average transfer rates from hands or kitchen utensils to ready-to-eat foods ranged from 2.9 to 27.5% (Luber et al., 2006). It is generally believed that cross-contamination, not undercooking, is the dominant route of exposure to humans (Nauta et al., 2009). However, in some special, minimally processed meat products, this may be otherwise. Exposure is a consequence of insufficient food hygiene by the person preparing the food. The vast majority of consumers in a study in the Netherlands have been shown to be unable to prevent cross-contamination; the effect of consumer information on the prevention of cross-contamination as a control measure is very small (Nauta et al., 2008).