MO1028

CLEANING AND DISINFECTION OF LAIRAGE-TO-STUNNING AREAS IN ABATTOIRS

Final Technical Report

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1 Executive summary

Recent FSA-funded studies conducted at Bristol University, as well as recent studies abroad, have indicated that significant environment-to-animal microbial cross contamination takes place in the lairage-to-stunning areas in abattoirs. The results also indicate that routine cleaning regimes in commercial abattoirs are very variable and often appear inadequate to reduce/prevent cross-contamination.

Relatively high prevalence of foodborne pathogens (particularly *Escherichia coli* O157) on animal coats post-stunning has been demonstrated, and a high risk of coat-to-carcass transfer of these pathogens during dressing exists. Therefore the aim of this project was to identify, and validate, the best "lairage-to-stunning" practices to reduce cross-contamination of animal coats during that phase and to assess the general status of the lairage hygiene and lairage cleaning effectiveness in UK abattoirs.

A comprehensive review of relevant information from previous studies, published papers and other sources was conducted on various pre-lairage factors potentially affecting contamination of lairages. This provided the basic, UK-wide, information needed for optimising, and the rational design, of the experimental and validation work in subsequent objectives.

A survey of a large number of UK abattoirs was conducted via a questionnaire designed to obtain information on:

1. Throughput and species slaughtered.
2. Construction materials used.
3. Use and type of bedding.
4. Details of cleaning/sanitation regimes.

A representative group of abattoirs were selected on the basis of the responses to the questionnaire. The lairage at these plants was investigated through enumeration of generic *E. coli*, as an indicator of the risk of pathogenic bacteria, remaining after routine cleansing operations. The results of these visits showed that generic *E. coli* were not completely removed from abattoir lairages by standard cleaning practices. Thus lairages may allow a risk of transfer of contamination from one processing day to the next. Potentially, bacteria such as salmonella may be transferred to the outer surfaces of animals held in the lairage facilities, and the skin or hide is a significant source of microbial contamination on the red meat carcasses subsequently produced.

Based on the results of the abattoir survey, an experimental study was conducted to evaluate the efficacy of different cleaning regimes. Concrete tiles were artificially contaminated with field strains of *E. coli* and *Salmonella Kedougou*, with and without the presence of bovine faecal matter. This simulated visually clean and visually dirty surfaces respectively. They were then cleaned using a specially designed mechanical rig. Cleaning was carried out using 1) water at mains pressure, 2) water under pressure, 3) water under pressure with a proprietary sanitising agent, 4) steam under pressure and combinations of 5) mains water followed by steam under pressure or 6) water under pressure followed by steam under pressure. Thirty replicates of each of visually clean and visually dirty concrete surfaces were cleaned using each method.

Where there was no faecal matter, the use of a proprietary sanitiser at the maximum recommended concentration, or the application of steam under pressure gave greater reductions in microbial contamination than the use of mains or a pressure wash. Where the

surface was visually contaminated with the faecal material, the use of a pressure wash followed by immediate steam application gave reductions in microbial contamination comparable with the use of a proprietary sanitiser at maximum recommended concentration. The use of steam alone on a visually dirty surface was not an effective means of reducing microbial contamination. A small pilot trial under commercial conditions ranked the efficacy of cleaning treatments as follows:

1. Pressure washing followed immediately by steam application.
2. Use of a sanitising agent at the greatest concentration recommended by the manufacturer, and then by pressure washing alone.
3. Pressure washing followed by a delayed steam application appeared to give a poor final result on the surface.

Further work is required to explore the interactions between angle of application, pressure of jet, and temperature of cleaning fluid, all of which may impact upon the effectiveness of the cleaning procedure. Similarly, alternative proprietary chemical cleaning agents may have effects dissimilar from the Janitol sanitiser used in this study. There may be a significant impact of climatic or environmental conditions on the change in microbial contamination of a surface during the drying phase.

Overall, the study has shown that at present microbial contamination, including Salmonella, often remains in UK lairage holding pens after routine cleaning operations. It would appear that there are significant differences in the effectiveness of lairage cleaning programmes at commercial abattoirs, and that the stun-box-roll-out areas are often cleaned to a better standard than the holding areas. As a result, there is a possible the risk of foodborne pathogens persisting in the environment and potentially contaminating animals and carcasses processed on subsequent days. Slaughterhouse operators should take steps to reduce the level of contamination both in their premises and on their carcasses. Pressure washing followed immediately by steam application appears the best method of cleaning a holding pen floor, followed by use of a sanitising agent at the greatest concentration recommended by the manufacturer.

The results of this work provide the Food Standards Agency with a scientific base to derive best practice information for the meat industry, which will ultimately contribute to improved meat safety.

Contents

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2 Introduction

Recent FSA-funded studies conducted at Bristol University, as well as recent studies abroad, have indicated that significant environment-to-animal microbial cross contamination takes place in the lairage-to-stunning areas in abattoirs. The results also indicate that routine cleaning regimes in commercial abattoirs are very variable and often appear inadequate to reduce/prevent that cross-contamination. Relatively high prevalence of foodborne pathogens (particularly *Escherichia coli* O157) on animal coats post-stunning has been demonstrated, and a high risk of coat-to-carcass transfer of these pathogens during dressing exists. Consequently the aim of this project was to identify, and validate, the best "lairage-to-stunning" practices to reduce cross-contamination of animal coats during that phase.

2.1 Scientific background

2.1.1 General scope of the problem

Healthy cattle can be a reservoir for the major foodborne pathogens *E. coli* O157, *Salmonella* spp., and *Campylobacter* spp. (8, 10, 38), and these organisms can be transferred from hides to meat during slaughter and dressing of the carcasses (31, 45, 46, 49, 50). The coats of animals destined for slaughter are a significant source of contamination of resultant carcasses (6, 45). Consequently, visual assessment of animal cleanliness at ante-mortem inspection, via a scoring system, is being used to prevent grossly contaminated animals entering the slaughter line (28, 39). The lairaging of animals prior to slaughter can result in cross-contamination with foodborne pathogens, both animal-to-animal and animal-environment-animal (2, 44, 52), due to their potential persistence in the environment in spite of routine cleaning procedures (15, 44, 47). The excretion of, and contamination of animals with, foodborne pathogens can increase as lairage time increases (1, 36, 43). Slaughterhouse lairages are designed primarily to facilitate animal handling and welfare, and are constructed of materials that are durable and relatively easy to clean, thus reducing the risk of build-up of pathogens (12, 17, 18, 19, 24, 26). Depending on the species held and the length of holding time straw bedding may be provided, and this may transfer contamination to the coats of animals (26, 32). However, there is little systematic information on lairage operation and cleaning regimes under commercial conditions and/or their effectiveness in preventing the accumulation of, and cross-contamination with, foodborne pathogens just before slaughter. Numerous published studies showed that pathogenic bacteria can survive in farm-related environments for very extended periods of time (5, 22), e.g. *Salmonella* Dublin survived on faecally contaminated surfaces (non-woven polyester, rubber and concrete) for almost six years (41), and *E. coli* O157 survived in bovine and ovine manure for several months (30). Comparably, there is little information on pathogens' persistence specifically in the immediate pre-slaughter environment and on the hides of slaughter cattle (7, 27, 48). The hygienic status of surfaces, floors and walls in lairage holding pens can significantly affect visible dirtiness and pathogen loads on animal coats and feet (16). Floors in both lairage pens and stunning boxes are particularly important because they are often contaminated with major foodborne pathogens (44) and many animals lie down during lairaging (12, 25, 29).

2.1.2 Lairage operations at commercial abattoirs in the UK

There is very little published information on commercial lairage practices in the UK, or other, countries. In a previous study conducted at Bristol University, basic information on design, construction materials, use of bedding and cleaning regimes in lairages was gathered via a questionnaire from twenty-one commercial abattoirs (17 slaughtering both cattle and sheep, 2 slaughtering cattle only, and 2 slaughtering sheep only) in the South-West of England. The information was validated through subsequent visits paid to most of participating abattoirs.

The abattoirs were grouped according to throughput status as per the abattoir licence (14). Fifteen abattoirs were full throughput abattoirs (slaughtering more than 20 livestock units per week), and six were low throughput operating on one or two days per week (slaughtering less than 20 livestock units). One livestock unit corresponds to 1 bovine, or 10 ovines, or 7 porcines).

Concrete was used as a flooring material in all the abattoirs surveyed except one, which had brick flooring. In full throughput abattoirs, the most common types of concrete were roughened (46.6%) or grooved (40%), while in 26.6% the concrete was smooth (some abattoirs had more than one type). Wire grid and concrete slat floorings were each used in one lairage. However, four of these lairages used two types of concrete flooring, in different areas. Generally, grooved and roughened flooring is used to give the animals' feet better grip and prevent falls, thus improving the welfare status, and was present more often in newer abattoirs. On the other hand, in low throughput abattoirs, 66.6% of lairages had smooth concrete, while roughened concrete and brick floorings were each used in one lairage. Generally, good hygiene practice requires that construction materials used in abattoir lairages are both durable and easily cleanable. Concrete and galvanised steel, as used in the surveyed lairages, satisfies these requirements. However, roughened or grooved floor surfaces, used particularly in newer lairages and in newer extensions of older lairages, may hinder cleaning and facilitate persistence of micro-organisms in the environment, as would crumbling edges of deteriorating or broken concrete (47).

Bedding is used in lairage holding pens for animal welfare reasons and to speed up drying of wet animals, particularly sheep (34). The majority of both high- and low throughput abattoirs used bedding in holding pens. In full throughput abattoirs, straw bedding was used in 86.6% of lairages, one used straw bedding for lambs, but no bedding for cattle, another used straw bedding overnight but not during the working day, while two used no bedding at all. The latter two were the lairages utilising wire grid or concrete slats as pen floors. In low throughput abattoirs, straw bedding was used in 83.3% of lairages; the other used no bedding. Sometimes, slatted flooring for sheep and cattle is advocated to prevent animal coat contamination if they lie down (34). The main problem encountered with slatted flooring is the need for a large manure collection pit below the floor, with sufficient clearance for its regular emptying. In this study, only one of 21 abattoirs used slatted flooring for cattle, and one used a wire grid for sheep.

With respect to cleaning of lairages in full throughput abattoirs, bedding was changed daily in 60% of lairages, weekly in 13.3% of lairages or every two months in 6.7%. However, not all these lairages were routinely washed at the time that bedding was changed. Only approximately 1/5 and 1/4 of full throughput lairages were washed after each batch of animals and daily, respectively. In low throughput abattoirs, bedding was changed daily in 50% of lairages, or more rarely on a weekly or monthly basis. None of the surveyed abattoirs used any detergent and/or disinfectant during lairage cleaning, although in all lairages washing was carried out by hosing or using a pressure wash. There is little doubt that lairage cleaning regimes are very important for meat hygiene and safety. Removal of dirty/contaminated bedding and washing out should reduce bacterial loads in the environment and contribute to improved visible cleanliness of animal coats (16). It is believed that holding animals in lairages with insufficient bedding or inadequate drainage could lead to faecal soiling of the coat and skin (20), while improved coat cleanliness would have a positive effect on the microbiological status of the carcasses (6, 21). Nevertheless, routine cleaning of cattle and sheep lairages does not necessarily eliminate *E. coli* O157 or salmonella in the environment (44), and even use of an alkaline chloride cleaning solution did not satisfactorily reduce rates of environmental salmonella contamination in pig lairages

(47). In conclusion, the current lairage cleaning practices in the surveyed abattoirs are unlikely to significantly reduce rates of environmental contamination with pathogens.

2.1.3 Incidence and spread of foodborne pathogens in lairages

To date, only two reports on spread of contamination with pathogens in lairages during unloading-to-stunning phase in UK abattoirs have been published (Small *et al.*, 2002). The studies were funded by the FSA and conducted at Bristol University, and the main aspects are quoted here.

In cattle abattoirs, overall prevalence of *E. coli* O157 and *Salmonella* spp. in cattle lairages were very similar, 7.2 and 6.1%, respectively. In the case of *E. coli* O157 in the lairage environment, no major difference in it's overall prevalence between samples collected before work started and samples taken during the production process was observed. This indicates that *E. coli* O157 contamination within the lairage was, in practice, fully carried-over from one day to the next. This was in spite of routine cleaning conducted between days. In contrast, overall prevalence of *Salmonella* spp. in lairages before work was low, but increased ten times during working hours. Generally, the presence of the pathogens within the lairage environment makes their transfer onto hides of at least some cattle during lairaging inevitable. The prevalence of both *E. coli* O157 and *Salmonella* spp. on hides were higher than their respective, overall prevalence in the lairage environment. This fact could mean that a certain proportion of the hide contamination with pathogens probably took place within the lairage environment, but part of it could also have originated from the pre-lairage chain of events (i.e. on-farm, during transport). However, to distinguish exactly the extents of pre-lairage and within-lairage hide contamination with pathogens, the prevalence of pathogens on the hide of animals before their lairaging would have to have been known, but this was not investigated. Also, a proportion of each pathogen population could have been transferred from hide to hide i.e. via direct animal-to-animal physical contact within the lairage but without involvement of the lairage environment itself. With respect to distribution of the pathogens on different hide areas, the mean frequencies of contamination with *E. coli* O157 and *Salmonella* spp. were: brisket (22.2% and 10.0%, respectively), flank (4.4% and 8.8%, respectively) and rump (3.3% and 2.2%). On the other hand, *Campylobacter* spp. were found only rarely in the cattle lairages i.e. 6-7 times less frequently than *E. coli* O157 or *Salmonella* spp., and not at all on hides of slaughtered bovines. The reasons for this phenomenon may be numerous, including the possibility of lower faecal shedding by the cattle and comparably lower survival rates of campylobacter on dry surfaces and/or hide, than those of the other two pathogens.

In sheep abattoirs, relatively low overall prevalence of *E. coli* O157 and *Salmonella* spp. were found in lairage environments, 2.2 and 1.1%, respectively. However, these pathogens were found on pelts of slaughtered lambs with prevalence of roughly two-fold (*E. coli* O157) and seven-fold (*Salmonella* spp.) higher than respective average prevalence found in the lairage environments. These results indicate that part of the pelt contamination could have occurred during lairaging, but other parts could have originated from the pre-lairage period. Also, a certain proportion of each pathogen population on the pelt could be acquired through direct animal-to-animal physical contact, without involvement of the lairage environment itself. With respect to distribution of the pathogens on different pelt areas, the average frequencies of contamination with salmonella and *E. coli* O157 were: brisket (3.3 and 2.2%, respectively), flank (3.3 and 2.2%, respectively) and rump (1.1%, both). In the case of *Campylobacter* spp., it is unclear why the pathogen was not found on the pelt of any lamb examined, although it was present in the sheep lairage environments more frequently than the

other two pathogens. Further research is needed to determine whether campylobacter survival rates differ between the fleece and the floor material.

When considering related differences between abattoirs, prevalence of the pathogens in lairages, as well as on coats of slaughtered animals, varied between individual abattoirs even those slaughtering the same animal species. This probably can be attributed to numerous variables, such as animal origin, lairage design, animal handling, cleaning and disinfection practices, that differed between abattoirs. However, the focus of the present study was primarily on general trends attributable to cattle or sheep abattoirs, and the abattoir-specific factors were not explored in the abattoirs visited. Generally, when comparing cattle and sheep abattoirs, it is important to note that the overall prevalence of *E. coli* O157 in lairage and on hides in the cattle abattoirs were markedly higher than the respective prevalence of this pathogen in lairages and on pelts in the sheep abattoirs. Similar trends, although less marked, were observed with Salmonella spp. In the case of *E. coli* O157, it could be speculated that the higher prevalence in cattle abattoirs was the consequence of higher faecal shedding in cattle, compared to sheep. Some studies (4) have shown that overall shedding of *E. coli* O157 in cattle and sheep was 15.7% and 2.2%, respectively.

2.1.4 Relevance of the proposed research from a regulatory perspective

One should keep in mind that abattoir lairages, in addition to livestock markets, are places where, directly or indirectly, mixing of animals from different farms takes place, with potentially negative consequences from the perspective of epidemiology of zoonotic agents. This was investigated, and the results compared with those from other studies from abroad, in the recent FSA-funded published study conducted by the Bristol University (44) and quoted here. Within a given pen, animals from the same group obviously exchange pathogens: cattle do lay down in lairages, 26% of them are lying after three hours, and lairaging sometimes lasts up to 27.5 hours. However, some critical contamination points in abattoir lairages identified in the present study can get in intimate contact with every single animal and, consequently, produce an "indirect mixing" of animals from different groups or farms that consecutively pass through the same premises during any given day. This is particularly case with stunning box/roll-out unit, where every stunned animal falls on the same spot on the floor – likely contaminated from previously stunned animals – so can pick up any pathogens from the floor onto the hide (particularly, brisket). From a microbiological perspective, therefore, "mixing" of different groups may occur via critical contamination points even if different groups are kept physically separately during the whole unloading-to-slaughter period as required by GMP/GHP and animal welfare principles. In addition, the results of this study showed that lairage-mediated exchange of pathogens is possible even between groups of animals slaughtered on different days, as the contamination can be carried-over from one processing day to the next, despite routine washing-down of the lairage overnight. Also, they indicate that the risks of previously pathogen-free animals getting their coats contaminated with pathogens during unloading-to-slaughter chain of events can be high.

The results of this and other recent studies confirm at least qualitatively that contamination of pre-slaughter environment and animal coats are a very relevant meat safety issues, as the contamination rates of animal coats can determine the contamination rates of the carcasses. Further research is required, however, for better understanding of the epidemiology of, and potential control strategies for, zoonotic agents during unloading-to-stunning phase. From meat safety and regulatory perspective, the main aspects of interest include: a) relationship between lairage-to-stunning layout/practices and the environment-to-animal coat cross contamination, and b) control measures to prevent/reduce such microbial cross contamination.

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3 Objective 1: Survey of layouts, practices and cleaning regimes in commercial abattoirs in the UK

The aim of the experimental work in this objective was to provide the basic, UK-wide, information needed for optimising, and rational design, of the experimental and validation work in subsequent objectives.

3.1 Task 1.1 Review of relevant information on pre-lairage factors

There is little doubt that lairage contamination (and consequently difficulties in cleaning) is largely determined by the nature, and the amounts of dirt brought in to the abattoir with animals, both internally as well as externally, which in turn, can be influenced by a number of pre-lairage factors. A comprehensive review of relevant information from previous studies, published papers and other sources was conducted on various pre-lairage factors potentially affecting contamination of lairages including:

- Availability, use, and any related geographical and/or seasonal specifics, of different bedding types;
- Levels and nature of dirt on animals, and any related geographical and/or seasonal specific, as determined by type of farming, breed, diet, husbandry, transport, etc.
- Any animal species-related differences, with respect to the above factors.

The conclusions drawn from this review enabled initial characterisation and ranking by either geographical regions, or abattoir types, or both, with respect to risks from contamination caused directly by animals entering lairages.

3.1.1 Summary

The rise in the occurrence of food-borne illness amongst humans has raised the importance of meat and meat products as a significant source. Animals produced for meat may be reservoirs for human pathogens such as *Escherichia coli* O157, *Salmonella* spp., *Campylobacter* spp. and more indirectly *Listeria monocytogenes* because these organisms occur commonly within animals produced for meat, without causing disease symptoms. These food-borne pathogens may be shed in the faeces of meat-producing animals and contaminate the surrounding environment and resultant carcass. The microbiological contamination transferred to carcasses during slaughter is a function of the types and numbers of bacteria acquired by the animal from farm to abattoir, and the care taken on the slaughter hall floor during the dressing process. Contamination of carcasses in the abattoir is minimised by HACCP plans, and the Clean Livestock Policy provides guidance on acceptable levels of hygiene for animals being presented into the lairage for slaughter, i.e. the visual cleanliness of the hide or fleece. The policy provides guidance for visual cleanliness, but this does not necessarily reflect in the microbial status of the animal; a visually clean animal does not guarantee that it is pathogen-free.

Research to date has demonstrated that several factors influence both the visible and microbial cleanliness of animals presented at slaughter and these include; diet and feed withdrawal prior to slaughter (often considered one the most important factors); the age and breed of the animal; season of year; husbandry on farm handling and through to lairage; transport to market and lairage; livestock marketing and the lairaging environment. Within these categories interaction between animals and between animals and the environment, including wildlife such as rodents and birds, are critical in the acquisition and spread of pathogens. Each of these processes could be included in a HACCP type plan for production, to reduce the risk of food-borne illness.

Lairage, including the race and stunning area, is the final step in the production chain of the live animal before it is slaughtered, and is considered by many to be a prominent and important site for cross contamination of food-borne pathogens both between animals and via animal-environment-animal spread. It is therefore important that measures are taken to reduce the risk of carcass contamination by addressing microbial carriage and contamination on animals and providing a suitable environment to achieve this.

3.1.2 Background

It is well known that food animals (cattle, sheep and pigs) may harbour organisms such as *Salmonella* spp. *Campylobacter* spp. and *E. coli* O157, associated with human food-borne illness. The predominant organisms associated with food-borne illness are salmonella and campylobacter, which are thought to account for 90% of all reported cases of bacteria-related food poisoning (Thorns, 2000). The delivery of animals for slaughter infected with these bacteria provides a potential source of infection for the consumer if they are transferred to meat surfaces. Poultry has been implicated in the majority of food-borne illness, as a result of the higher level of meat consumption and increased rate of contamination of carcasses; however other livestock such as pigs, sheep and cattle are also sources of food-borne pathogens (Thorns, 2000). Any reduction of these pathogens at any stage in the production chain can be viewed as potentially additive; the overall effect is one of a greater reduction in risk. This is because the risk of certain food-borne illness cannot be eliminated at processing, retailing or at the consumer level. The greatest risk of transmission of contamination to humans is the contamination of raw/uncooked products or recontamination of cooked products (Stanley & Jones, 2003). Therefore, the primary production stage through to slaughter requires significant intervention to minimise the primary risks.

Studies, such as that of Oosterom & Notermans (1983), have shown that it is very difficult in practice to obtain pathogen-free animals. They found it impossible to obtain salmonella-free pigs, mainly because of problems in obtaining uncontaminated feed and isolating the pigs from sources of contamination, and vectors such as mice. Nonetheless, they did substantially reduce the incidence of salmonella by reducing initial incidence of infection in the live animals, and this was found to reduce the incidence of salmonella on the subsequent carcasses. Cattle are the main risk for *E. coli* O157:H7 and if the prevalence of this organism on in-coming cattle to the abattoir could be reduced this would be expected to reduce contamination levels further along the food chain (Besser *et al.,* 1999). Colonisation of *E. coli* O157 in cattle is typically of short duration (1-2 months) and behaves as a transient commensal in the gut and does not cause overt disease symptoms. Recurrent infections and re-infection with new strains can occur, and this means that *E. coli* O157 can be carried to the slaughter environment following exposure as calves or older animals (Besser *et al.,* 1999). It is important to recognise that it is impossible to completely eradicate these organisms as many are ubiquitous in animals and widespread in the natural environment, and wildlife reservoirs including birds, deer and small mammals (Besser *et al.,* 1999). Skovgaard (1996) reports that, although hitherto considered impossible, *Yersinia* organisms may be eliminated on the farm, but this may be considered doubtful in a commercial situation.

Berends *et al.* (1996), with specific reference to salmonella in pig production, recommended a programme to reduce the risk of primary infection using the following controls. Firstly, they insisted on very strict and consistent farm hygiene, together with the promotion of the colonisation resistance of animals kept, and the avoidance of unnecessary use of broad-spectrum antibiotics. Secondly, they advised on simultaneous execution of control programmes at breeding, multiplying and finishing farms. Thirdly, pre-slaughter, they advised on separate peer group transport, lairage and slaughter of the animals produced. This

final stage would aim to reduce the risk of cross contamination between animals just prior to slaughter.

Most researchers (Teufel, 1987; Huis In't Veld *et al.*, 1992; Edwards, 1996; Skovgaard, 1996; Snijders & Collins, 1997) advocate the implementation of the following more basic primary steps to reduce the incidence of pathogens in animals at the primary level. Some of these measures are difficult to achieve in practice.

1. Animals should be supplied with pathogen-free feed and water. Feed and water should not be stored under conditions where they may become contaminated.
2. Animals should be kept in clean well-ventilated buildings to avoid soiling. Buildings should be regularly cleaned and disinfected. Buildings should be designed to minimise the risk of cross-contamination and protect the animals against environmental contamination.
3. Animals kept outdoors should not be left on muddy soils and should be kept away from contaminated water, pasture, slurries and farm wastes.
4. Farms should operate, where possible, on an all-in/all-out policy.
5. There should be strict control of persons who have direct contact with animals.
6. Pathogen- (salmonella, campylobacter, etc.) free areas should be established in which to rear the animals.
7. Pathogen-free breeding stock should be established.
8. Animals should be transported and sold under conditions that do not allow cross-contamination.

A report by Hannan (1996) associated *E. coli* O157:H7 organism infection with (1) the application of slurry to pasture, (2) the warmer months of the year, (3) the age of the animal, calves and heifers are more likely to test positive than are adult cattle, (4) weaning and mixing of groups of calves before weaning, (5) small herd size and (6) the use of computerised feeders. However, in the opinion of Hannan (1996), there is insufficient information at present on which to base control measures.

3.1.2.1 Campylobacter

Campylobacter jejuni, which is the most commonly isolated campylobacter and causes 90% of cases of human enteritis in UK, colonizes the gastrointestinal tract of a range of animals. This is the critical site of amplification for the organism. These thermophilic organisms do not survive well in dry environments or where oxygen is not limited and are unlikely to find suitable conditions outside the gut for growth. Most campylobacter infections appear to occur sporadically without a clear indication of the mode of transmission. The vehicles incriminated include mostly milk and water for outbreaks but poorly cooked meat and uncooked foods have been indicated amongst others (Franco, 1988). The infective dose is very low for *C. jejuni* (10-100 cells) so there is a considerable risk of foodborne illness if contamination of meat surfaces occurs (Stanley & Jones, 2003).

Studies with cattle in Finland (n = 200) have identified a 5.5% incidence of *C. jejuni* from cattle faecal samples, whereas the incidence in Sweden (n = 90) was 19% (Franco, 1988). A study conducted in Norway identified 8.1 % incidence (n = 197) of *Campylobacter* spp. from the faecal samples taken from sheep on farm (Franco, 1988). Bailey *et al.* (2003) studied the excretion of *Campylobacter, Listeria* and *Yersinia* spp. in the faeces of slaughter age cattle and sheep in Australia, and found that there was higher prevalence of

Campylobacter spp. in cattle than in sheep. They found that campylobacter was most commonly isolated from feedlot cattle; 58% prevalence compared with dairy cattle 6%, pasture beef cattle 2%, mutton sheep 0%, and prime lambs 8%. Yersinia was only isolated from one dairy cow and Listeria was not isolated. Isolation and carriage rates are reported to vary greatly between herds and flocks. A range of incidence was found by Abatay & Corry (1998), from 37% and 40% to 79% in three different herds in the UK. Stanley *et al*. (1998a and b) found an even higher prevalence from a 2-year period of sample collection from the small intestine. Campylobacter was isolated from 89.4% of UK cattle submitted for slaughter (following enrichment), which was much higher than previous estimates. The same can be said of sheep, with an isolation level of 91.1% (following enrichment).

Campylobacter contamination appears to be more common on carcasses of pigs than on those of cattle and sheep (Franco, 1988). Pearce *et al.* (2003) found campylobacter to be highly prevalent in the intestinal tracts of swine arriving at the slaughter facility. *Campylobacter* spp. prevalence rates amongst live pigs and poultry may be up to 100%. Contamination of pig carcasses before chilling has been reported at 30% but reduced to below 3% following chilling (Mulder, 1995). Pearce *et al.* (2003) also concluded that campylobacter does not progress at all through the slaughtering operation and in their investigation, it was not detectable on the carcasses of pigs after overnight chilling. Post-slaughter chilling is said to suppress campylobacter replication on carcasses due to the drying effect of forced ventilation (Franco, 1988). Red meat contamination from this organism is therefore still relatively low and the majority of human enteritis as a result of the *Campylobacter* organism is still attributed to poultry (Stanley & Jones, 2003).

3.1.2.2 Salmonella

In depth investigation and effort has been made to reduce salmonella in pig production (e.g. introduction of Zoonosis Action Plan (ZAP) programme in the UK) and egg and poultry production in terms of food safety. Studies on beef and sheep production have not been so extensive. Smith & Grau (1973) took swab samples from five areas on the fleece and hides of 100 sheep and 100 cattle just after slaughter at 10 abattoirs; salmonella was detected on 57% of the cattle and 51% of the sheep. This finding indicates an increased potential risk of fleece/hide contamination of the meat surfaces of those animals. McEvoy *et al.* (2003a) also investigated *Salmonella* in bovine faecal, rumen and carcass samples from a commercial Irish abattoir. The samples were taken weekly over a one year period and prevalence in the rumen was similar to that in faecal samples, and prevalence on the carcase was higher than previously reported. Further results have also suggested that sub-clinical faecal salmonella shedding can persist in dairy herds for up to 18 months with no measurable effects on health or the production of individual cows (Huston *et al*., 2002). This provides increased potential for an individual animal to become contaminated from the environment, through the persistence of the organism within that environment, although without recontamination, the prevalence of the organism will decrease over time, with an associated reduction in risk.

3.1.2.3 VTEC Escherichia coli

Cattle and sheep are at present the major sources of infection with *E. coli* O157. This pathogen emerged as a major food-borne pathogen in the 1980s and 1990s (Thorns, 2000). Paiba *et al.* (2003) collected faecal samples from 4663 cattle between June and December 1999 to investigate the prevalence of *E. coli* O157 from cattle (dairy, suckler and fattening). Results overall indicated that the mean excretion prevalence of an individual was 4.2%, but was 10.3% among animals from infected herds. Within herd prevalence on positive herds was 1.1-51.4%. At least one animal was positive on 29 of the 75 farms. Overall, they concluded that herd prevalence in their study might be underestimated since the organism has

been reported to be excreted intermittently. This pattern has also been observed in other studies (Synge *et al.,* 2003). Synge (2000a) found, in Scottish finishing beef cattle, that *E. coli* O157 was isolated from 8.6% of animals, higher than that seen by Paiba *et al.* (2003), and from 23.7% of groups of animals sampled only once. Comparatively the above findings agree with the findings of Collis *et al.* (2004a) who identified a significantly higher prevalence of *E. coli* O157 recovered from faecal samples of beef cattle in Scotland than England/Wales.

McClusky *et al.* (1999) investigated the recovery of shiga-toxin producing *E. coli* (STEC) from lambs destined for slaughter in a US abattoir (n = 882) and found >50% of the lambs had evidence of STEC, and STEC was isolated from 15% of the faecal samples. *E. coli* (STEC) has been reported to be more prevalent in sheep and goats than in cattle (Beutin *et al*., 1993; Borczyk *et al*., 1987), although extensive studies in sheep have not been carried out.

A study conducted by McEvoy *et al.* (2003b) looked at the recovery of *E. coli* O157: H7 (n = 250 animals) from faecal samples (2.4%), rumen fluid (0.8%), and carcass samples (3.2%). Results were lower than other studies, but may reflect the intermittent nature of this organism and also the methodology used in each study. Following phage typing of the *E coli* in the faecal samples, these workers identified that in some instances the same phage types and virulence characteristic profiles were isolated from adjacent carcasses on the line. This finding highlights the potential for cross contamination between carcasses on the slaughter line.

3.1.2.4 Listeria

Listeria is also ubiquitous within animals produced for meat, normally without causing disease symptoms, although it can cause serious and fatal disease syndromes in cattle and sheep. It too may be shed in the faeces of these meat-producing animals and contaminate the surrounding environment and resultant carcass. In 1999, there were reported to be 106 laboratory confirmed cases of food-borne illness in humans as a direct result of *L. monocytogenes* (PHLS, 1999).

Shedding or the presence of listeria from animals produced for human consumption is largely attributed to diet (feed), silage and effluents (Snijders & Collins, 1997*)*. Diet has been shown to play, more specifically, a significant role in the incidence of *L. monocytogenes* (Fenlon *et al*., 1996). Animals on a grass diet tended to have no detectable listeria, whereas those on silage diets showed an increased incidence of listeria. Listeria, both pathogenic and non-pathogenic strains, is also known to be sourced directly from winter feeds such as silage, hay and concentrates (Stanley & Jones, 2003). This clearly demonstrates the potential sources of contamination to the meat animal prior to slaughter, and persistence criteria.

3.1.2.5 Shedding patterns

Overall, the most important factor to remember is that clinically healthy animals carrying any of these pathogenic microorganisms may change their excretion pattern from intermittent to constant shedding if an external factor upsets the equilibrium of their intestinal micro-flora. A disturbance or damage to the intestinal functions or immune system, commonly associated with ‘stress’, will lower the resistance of the live animal and facilitate the shedding of intestinal bacteria (Mulder, 1995). “Stress” is a term often used and has complex undertones. “Stress” is commonly associated with actions such as housing, handling, loading and transport (Mulder, 1995). All of these actions are carried out when producing animals for meat production, and mainly just prior to slaughter.

The information above provides a brief review of the presentation of the major food-borne pathogens in intestine contents and faeces of animals at slaughter. The main focus of this report is to review the current state of knowledge regarding factors that affect the 'dirtiness/cleanliness' of stock during production from birth to slaughter, and that may influence the cleanliness of the hide/fleece/skin and resultant carcass. Information has been sourced from studies conducted in the UK and abroad and includes information from scientific literature, personal communication and unpublished data.

3.1.3 Surface contamination of the animal

The edible tissues of healthy livestock prior to slaughter are considered to be bacteriologically sterile most of the time although transient bacteraemia may occur, but its significance is questionable (Bensink, 1972; Nottingham, 1982; Bell *et al.*, 1994), with the exception of the tongue and the gastrointestinal tract, which carry natural micro flora (Nottingham, 1982). Contamination present on a carcass, therefore, is found only on the surface tissue, with the deep muscle being uncontaminated in the vast majority of healthy animals (Gill, 1979). During the slaughter and dressing of meat animals, some degree of contamination of the carcass is unavoidable (Newton *et al.*, 1978; Bell *et al.*, 1994). The hide and viscera are reservoirs for microorganisms, as is the abattoir environment itself (Newton *et al.*, 1978). As anal bunging is carried out reduce the risk of leakage, contamination from the viscera predominantly occurs if they are ruptured during removal and is, therefore, believed to be a much less important source than the hide or fleece (Empey & Scott, 1939; Scaccia Scarafoni, 1957; Gerrand, 1975). Indeed, where the gut has been removed without accidental puncture or leakage of stomach or intestinal contents, enteric organisms rarely contribute to total microbial numbers present on the carcass (Newton *et al.*, 1978). It is widely accepted that the main risk for the transfer of food-borne pathogens onto the previously sterile meat surfaces at slaughter is from the hide/fleece at removal. For example, Stanley & Jones (2003) considered that most contamination by campylobacter occurs during the removal of the hide or from cross-contamination from hide to carcass via hands and instruments of slaughter men, although rates are still low compared to the levels seen in poultry. Kain *et al.* (2001) also investigated, during a 3-day period, 80 live cull cows that were delivered for slaughter and assessed. Factors significantly affecting bacterial counts ($P < 0.05$), after carcass washing, on these animals were batch number, ambulatory status and hide cleanliness. Interestingly they found that the most significant factors affecting carcass microorganism counts, after hide removal and after carcass chilling, were sampling date and batch number. *E. coli* O157 was not detected overall from these samples, but *Salmonella* was detected from 0%, 13.8% and 1.2 % of faecal (n = 77), hide (n = 80) and carcass (n = 427) samples respectively, suggesting transfer of the pathogen from hide to meat surface.

3.1.3.1 Visible cleanliness

A positive correlation has been demonstrated between the lack of visible cleanliness of hides and subsequent carcass contamination (Ridell & Korkeala, 1993; Hadley *et al.*, 1997; McEvoy *et al.*, 2000a). Ridell & Korkeala (1993) studied the effects of excessive faecal soiling of the hide on the subsequent microbial counts. Twenty-one excessively soiled cattle were slaughtered and dressed with extra care at a slower line speed than normal. For controls, 'normal' cattle were chosen at random. The brisket and shoulder sites were sampled at the end of the line using an excision technique. The results showed that, despite being processed at a slower speed with greater care, the bacterial contamination on the surface of carcasses originating from 'dirty' animals was greater than that on 'normal' carcasses. Van Donkersgoed *et al.* (1997), however, reported no consistent association between the cleanliness of cattle presented for slaughter and bacterial contamination of

carcasses in their study of two abattoirs in Canada. The apparent discrepancy between these two papers may, however, be attributable to differences in protocols for the scoring of cattle cleanliness. Ridell & Korkeala (1993) classified animals as 'dungy' when a solid layer of dung was present on the ventral and lateral areas of the hide, whereas Van Donkersgoed *et al.* (1997) measured the contamination of hides with 'tag', which comprises mud and bedding, in addition to manure. Additionally, the differences may also be affected by the line speed, layout and the skill of the staff. Although line speed was not given in the paper of Ridell & Korkeala (1993), it would be reasonable to expect it to be significantly slower in a Finnish abattoir, compared even with the slow line speed abattoir in Canada that had a throughput of 135 carcasses per hour. Results of this kind have led to the development of specific programs to improve the visual cleanliness of slaughtered animals. Since 1982, Finnish abattoirs have applied special regulations to reduce the number of 'excessively dirty' cattle. Ridell & Korkeala (1993) studied the effects of the improvement of the cleanliness of the animal since this date. They found that from 1983 to 1990 the proportion of 'excessively dungy' animals in one abattoir decreased by 85%.

In the UK, the implementation of the Meat Hygiene Service (MHS) Clean Livestock Policy (CLP), which categorises cattle and sheep as acceptable (MHS 1 and 2) or unacceptable (MHS 3, 4 and 5) for slaughter according to five categories of increasing visible dirtiness, has improved the cleanliness of animals delivered for slaughter (MHS Clean Livestock Policy, August 1997).

Further studies conducted in the British Isles using cattle (McEvoy *et al.*, 2000b) and sheep (Hadley *et al.*, 1997) have reported a positive correlation between livestock dirtiness scores according to the MHS system and the bacterial contamination of the carcasses. The study carried out by McEvoy *et al.* (2000b), for example, reported that Total Viable Counts (TVCs) at the hock and brisket sites were significantly higher in cattle scored as category 5, compared with cattle scored as category 2. Furthermore, the study conducted by Hadley *et al.* (1997) found a significant increase in Enterobacteriaceae counts on sheep carcasses in category 3 compared with category 2. The major difference between the criteria for the categories was in the origin, rather than the level, of soiling. Category 2 animals were soiled with non-faecal material, whereas those classified as category 3 were soiled predominantly with faecal material. Contamination with dung is cited as of more concern than that of soil (Gracey, 1997). The typical amount of faeces excreted by animals per day can be seen in Table 1, which highlights the potential for contamination of the hide/fleece/skin if measures to restrict soiling are not taken.

Table 1. Amount of excreta produced by livestock (source: Gracey, 1997)

Type of livestock	Typical volume (l/day)
Dairy cow	57.0
Beef bullock	27.0
Pig, dry meal fed	4.0
Pig, liquid fed	4.0-7.0
Pig, whey fed	14.0
Fattening lamb	2.2
Adult sheep	4.0

Van Donkersgoed *et al.* (1997) points out additional reasons why the use of visible hide cleanliness to judge contamination is useful. Processing of dirty livestock increases abattoir costs by decreasing line speeds by 10 to 12%, can increase labour costs by requiring

additional trimming, causes damage to the leather of the hide, and 'negatively affects consumer perception of the industry'.

As would be expected, surface contamination of an animal depends greatly on a) season, which is commonly linked with housing/grazing, and b) the faecal shedding of individuals and the cleanliness of the environment around the animals. Barham *et al.* (2002) studied the prevalence of *E. coli* O157 and salmonella in beef cattle from farm to slaughter and found an increased prevalence of salmonella on the hide (6% on farm) and in faeces (18% on farm) after delivery to the abattoir, when it rose to 89% and 46% respectively. Empey & Scott (1939) estimated that the problem was particularly acute with sheep during periods of wet weather where contamination of the fleece was principally comprised of vegetation, earth and faecal material. The contamination occurs primarily in the abdominal region and on all four limbs (Newton *et al.*, 1978). Cattle which have been winter-fattened indoors and provided with little straw for bedding will be more likely to have faecally contaminated hides than those provided with adequate bedding (Empey & Scott, 1939). Investigations by French & Morgan (1996) also showed that lambs that suffered from diarrhoea within one week of birth became 'daggy', i.e. had dry faecal matter attached to the fleece. Once 'daggy' such lambs had a tendency to remain so throughout their life. In addition, lambs born to 'daggy' ewes were themselves 'daggy'.

3.1.3.2 Coat length and clipping

Another factor that affects the cleanliness of the hide is the coat length. Davies *et al.* (2000) gathered information on 675 cattle arriving at five UK abattoirs in 85 batches and found that several factors influenced their cleanliness, of which one was coat length. Shorthaired animals had lower MHS categories awarded than medium- followed by longhaired cattle. Clipping also resulted in visually cleaner animals than unclipped animals. Biss & Hathaway (1995) also found that 'woollier' sheep tended to be more visibly and microbiologically contaminated than others.

Clipping is commonly considered to be an effective way of improving the visual cleanliness of dirty animals, but this improvement may not be reflected microbiologically. In the survey by Davies *et al.* (2000), 13.2% of cattle were clipped, presumably to remove visible contamination. Whilst this was found to improve visual cleanliness and MHS score, there is little evidence to suggest clipping cattle reduces microbial load on the carcass. Van Donkersgoed *et al.* (1997) recorded a reduction from 2.23 to 1.91 $\log_{10}$ most probable number of growth units/cm^2 when the belly and hocks of slaughter cattle were shaved, but considered this to be of little practical significance. Similarly, Roberts (1980) demonstrated that shearing the crutch of lambs had little effect on carcass microbiology and concluded that this was largely ineffective as a means of improving carcass hygiene. In contrast, several authors have previously advocated clipping as a method to reduce carcass contamination (Empey & Scott, 1939; Patterson, 1968; Gerrand, 1975), and this is also suggested by the MHS as a method to improve cleanliness for slaughter.

Clipping cattle also has some clear disadvantages from the point of view of health and safety and also leather quality. Slaughter cattle are normally not familiar with being restrained and clipped. This can make the clipping operation both difficult and dangerous, compromising the safety of the producer and the quality of the meat. Increased stress may also increase excretion of pathogens and multiple antimicrobial resistant organisms (Lowman *et al.*, 1998). There have been several reports of producers sustaining injuries whilst clipping cattle and this is now highlighted in the Health and Safety Executive Agriculture Information Sheet No. 34, entitled 'Preparing Cattle for Slaughter'. This leaflet recommends that clipping should

only be carried out using properly designed handling equipment and safe working techniques in order to minimise the risk of injury.

The act of clipping cattle, particularly with oscillating clippers, presents the risk of cutting the skin of the animal as the teeth of the comb cut the hair. These cuts cause distress to the animal and become visible on the hide during the leather making process, resulting in loss of value of the product (Pearson, 1998). This damage was not seen prior to the implementation of the Clean Livestock Policy, as cattle were seldom clipped. However, whilst still a cause for some concern, the incidence of excessive damage due to careless clipping has decreased as producers have invested in better equipment and gained skill in this area.

3.1.3.3 *Washing of cattle and sheep*

The cleaning of excessively dirty animals by washing of live animals may provide only a cosmetic improvement to visual appearance. Empey & Scott (1939) concluded that deeply soiled fleeces and hide could not be readily cleaned. They also stated that the microbiological population of a dry hide was increased by up to ten times by the resulting addition of moisture. Hadley *et al.* (1997) also demonstrated increased carcass contamination when comparing heavily soiled lambs with either wet or dry faecal soiling. Leech (1971), Patterson & Gibbs (1978) and Biss & Hathaway (1996a) have all agreed that wet animals present a greater risk to slaughter hygiene than dry animals.

However, a recent study by Byrne *et al.* (2000), using cattle inoculated with *E. coli* O157:H7, demonstrated an improvement in carcass microbiology when cattle were washed using a pressure of 150 psi and temperature of 10-18°C for 3 minutes. The authors suggest that washing cattle to improve carcass microbiology requires further investigation. However, the welfare implications of such a practice must be questioned. Lowman *et al* (1998) suggests that the use of power washers may result in carcass bruising and a subsequent reduction in value. Where washing of livestock is carried out, it is also important to allow sufficient time for the animal to dry prior to slaughter (Newton *et al.*, 1978; Patterson & Gibbs, 1978). This view is also expressed by the MHS who state in the Clean Livestock Policy that in "some circumstances, it may be beneficial to wash animals, but only if they are washed and dried prior to going for slaughter".

Pre-slaughter washing of sheep is widely used in New Zealand. High proportions of abattoirs wash all sheep irrespective of presentation status, although in some abattoirs, washing is restricted to those sheep where there is extensive faecal staining/smearing of the fleece, faecal material collected around the hind legs, and/or excessive accumulation of mud or dust in the fleece (Biss & Hathaway, 1995).

Washing with water is considered feasible only in the case of loosely attached dirt. The use of water sprays, directed at the sides, belly and legs, and a 12-inch deep footbath in the race leading to the stunning box was found to reduce initial bacterial contamination of hides by about one-half. Although they did not study pre-slaughter washing, one of the main conclusions of the spray washing work carried out by the UK Meat Research Institute (MRI) was that pre-slaughter cleaning was the long-term solution to clean carcasses (Bailey, 1971; 1972). The Australian and New Zealand view, at that time, was that if the pre-slaughter treatment produced dry, clean animals, and if the actual slaughtering was well executed, the carcasses did not become dirty and did not need much cleaning. Due to the combination of climate and abattoirs in the UK, the MRI concluded pre-slaughter washing was impractical and that some means of post-slaughter cleaning was required. It has been argued that cleaning before slaughter is unlikely to have much effect on dressing hygiene, unless there is a heavy layer of hardened filth adhering to the skin, over much of the area that must be

incised, that interferes with the clean removal of the hide (Gill, 1995). In New Zealand, according to Gill (1987), abattoirs were advised to exclude excessively dirty stock to avoid causing undue stress to the animals from repeated washings. The method commonly used in the UK to remove such filth is clipping of the dirty area prior to slaughter. This appeared to be effective in removing visible contamination (Davies *et al*., 2000), although it can result in increased hide wastage in terms of clipper-damaged hides, as previously stated. Sheep with excessive accumulations of faecal material around the anus generally undergo 'crutching' (shearing of the affected area) before slaughter in some countries. Work in the UK by Roberts (1980) did not find that shearing the crutch before slaughter reduced the number of bacteria on the carcasses after slaughter. This result was not influenced by the weather, and therefore, the wetness of the live animal. This suggests that, although visually soiled, the crutch region is not a significant source of microbiological contamination of the carcass. Washing of the crutch was shown to be equally ineffective. However using a detergent sanitizer produced a statistically significant, but relatively low (around 0.5 log units), reduction in bacterial numbers. Roberts (1980) concluded that cleaning live lambs has only a 'trivial' effect on microbiological contamination and 'is a waste of time bacteriologically'.

Gill (1987) stated that dirt readily shaken from a dry fleece might be expected to cause greater contamination than wet, adhesive dirt on a fleece. However, this cannot be supported from recent findings where bacterial contamination was shown to be spread more readily among wet cattle and sheep than dry animals ($P < 0.01$) (Collis, unpublished work). This may be because on a dry fleece, the microorganisms may be less viable and more firmly attached than on a wet fleece. Wetting of the surface will increase the recovery of organisms when samples are taken, so the judgement on reality is less clear. Studies conducted by Biss & Hathaway (1995) also identified that the washing of lambs was linked with higher resultant APC (Aerobic Plate Counts) ($n = 200$ lambs sampled). Their study used lambs that were judged to be 'dirty' or 'clean', with half of each subgroup (50 lambs) shorn or left unshorn ('woolly'), and of these half (25 lambs) were either washed or not washed before slaughter. Lambs categorised as being 'dirty' were stained with faecal material over the majority of the pelt and many had an accumulations of mud on the belly and legs, whereas lambs categorised as being 'clean' had no faecal material or mud on the pelt. After washing, the lambs were left overnight to reach a 'drip-dry' status. Mean levels of microbiological contamination on carcasses, traditionally dressed, immediately after pelting ranged from 4.63 $\log_{10}$ cfu cm^{-2} on those derived from dirty, woolly, washed lambs to 3.93 $\log_{10}$ cfu cm^{-2} on those derived from clean, shorn, unwashed lambs. Generally, the mean APC was higher on carcasses derived from lambs with long wool and/or dirty pre-slaughter status than on other carcasses. The mean APC was higher on carcasses derived from washed compared with corresponding unwashed lambs in all groups. These general trends were retained after pre-evisceration washing and at chiller entry. However, after overnight chilling, only long wool and pre-slaughter washing remained as significant factors associated with higher mean APCs. Biss & Hathaway (1996b) carried out further studies in greater numbers of abattoir and the results confirmed those of the previous study. Pre-slaughter washing resulted in higher mean APCs and *E. coli* counts on virtually all the carcasses, irrespective of the length of wool. The exceptions being the APCs of the forequarters and *E. coli* counts of the hindquarters of lambs from one particular abattoir, which used a mechanical inverted dressing system. Counts were generally higher on carcasses derived from woolly lambs than on those derived from shorn lambs. There was less visible contamination on the carcasses of washed lambs than on those of unwashed lambs.

It appears therefore that pre-slaughter washing results in visually 'cleaner' carcasses and a reduction in other contaminants on the wool prior to slaughter (dirt, sand, etc.) and of faecal

stains. However, these improvements do not relate to improvements in microbiological status, as washed lambs tend to have higher levels of microbiological contamination, with woolly, washed lambs having the highest levels. The results suggest that the effect of the pre-slaughter wash is impeded by the potential for 'wet' pelt/hide to directly contaminate the carcass during dressing (Biss & Hathaway, 1995). Since long wool stays wet for a longer period than short wool, the authors noted that there was the possibility that it also may provide an environment favourable to bacterial growth. Although pre-slaughter washing resulted in slightly higher bacteria levels, the authors concluded that washing was advantageous in a commercial sense i.e. visible cleanliness, fleece cleanliness. The second study (Biss & Hathaway, 1996c) concluded that where washing is not carried out, inverted dressing systems are more suitable in controlling visible contamination than traditional systems. Preliminary work on post-slaughter, pre-skinning treatment of cattle hide along the cut lines has showed that singeing of a previously clipped area of hide can significantly reduce the microbial load of the hide (Small *et al.*, 2004)

3.1.3.4 Washing pigs

The practice of washing or showering of pigs that is adopted in some abattoirs is somewhat different to the washing of sheep or cattle due to their relatively hair-free skin. The showering of live pigs prior to slaughter not only cleans the animals but also reduces stress. Cold water showers make the animals less restless and reduce fighting (Rahkio *et al.*, 1992). There is some evidence that cleaner animals may reduce the degree of fouling of scalding water when the animals are subsequently tank scalded. However, there is little evidence that this has an effect on carcass contamination.

There is a danger that dirty water from showered dirty animals may run off the carcass in the direction of the sticking point, particularly if the animal is bled on the rail. Troeger (1994) tested this possibility. Four pigs sprayed with an indicator organism, *Enterococcus faecalis* DS5 after stunning were stuck in a horizontal position or hanging by a hind leg. To prevent any internal contamination of the carcasses with the indicator organism that was not connected with the bleeding, the skins of the carcasses were removed. No difference was found between either technique. The indicator organism was not detected in the blood circulation system, but was found (in very low numbers) in the liver and kidney tissue of one animal.

An Irish study by Bolton *et al.* (2002) showed that washing of live pigs had no affect on carcass counts. The average APC on live animals, prior to transport to the abattoir (4 miles), were approx. 5 $\log_{10}$ cfu cm^{-2}. Salmonella was isolated from 27% of these animals. Washing (power-hosing) after arrival at the abattoir produced visibly clean pigs, although this process did not lead to any significant change in APCs, this remained at approx. 5 $\log_{10}$ cfu cm^{-2}. However, after power hosing, the incidence of salmonella was considerably lower (10%) than the incidence on animals "on-farm", but there is the risk that the organism would have been transferred via splashing and aerosolisation into the environment, and thus potentially contaminate subsequent batches of pigs.

3.1.3.5 Conclusion

The hide/fleece/external surfaces of animals are a significant source of contamination from the animal to the carcass. Evidence to date shows that food-borne pathogens can be carried on the external surfaces of animals, and to reduce the risk of food-borne pathogen contamination of meats it is vital that animals are presented visually clean and microbiologically low risk and dry for slaughter. Evidence from most workers however, describe a minimal microbial reduction as a result of the physical cleaning off of excessive

visible contamination. The presence of food-borne pathogens on the external surfaces of individuals also poses a high risk for the contamination of other animals and the surrounding environment, and this will be discussed in following sections.

3.1.4 The effects of feed and nutrition on the pre-slaughter cleanliness of animals

Diet and dietary manipulation have been recommended as methods to help produce visually clean animals prior to slaughter and in particular to improve the MHS category. The dry matter content of diets, for example, may significantly affect the cleanliness of cattle, as it influences both the amount and the consistency of faeces produced (Heasman, 2000). Rations containing a high proportion of cereals have a high fibre content, which slows the rate of passage through the gut. This normally increases the opportunity for the absorption of nutrients, whilst reducing both the output and the moisture content of the faeces, but commonly results in rapid fermentation with an increase in pathogen growth and acidosis of the gut, resulting in loose droppings. Diets such as silage have low dry matter content, and result in large amounts of low dry matter faeces being produced. Cattle, sheep and pigs, amongst other animals produced for human consumption, are recognised carriers of human food-borne pathogens and diet has been shown to affect the survival, growth and faecal shedding of pathogenic bacteria in ruminants. Kudva *et al.* (1997) found that *E. coli* O157:H7 remained viable in sheep faeces for 21 months and Bolton *et al.* (1999) demonstrated persistence in bovine faeces on pasture for 99 days.

Therefore the grazing of contaminated pasture is of considerable concern. Maule (2000) suggests that the use of aerobic digestion and aeration of manure piles, prior to application to land, significantly reduces the viability of *E. coli* O157. Clearly, the process of spreading untreated waste onto land used for vegetable or forage crops and for grazing presents a particular hazard due to the persistence of *E. coli* O157 in the environment, since re-infection through ingestion by the grazing animal may occur. It has also been shown that previous infection with a specific strain of *E. coli* O157 does not prevent re-infection with the same strain (Cray & Moon, 1995). Furthermore, application of manure to grass that is subsequently ensiled in conditions allowing aerobic spoilage may result in a significant increase in *E. coli* O157 numbers in the silage (Fenlon *et al*., 2000).

3.1.4.1 Faecal shedding of bacteria

Several investigators have evaluated the effect of diet on the faecal shedding of pathogens by cattle. Studies of feedlot cattle have shown that their high-energy diet results in a change in the rumen content may be inhibitory to salmonella (Frost *et al.*, 1988, Galland *et al.*, 2000), but conducive to the growth of campylobacter (Giacoboni *et al.*, 1993). Reports have also shown that adult pasture-grazed cattle commonly do not harbour campylobacter (Giacoboni *et al.*, 1993). The study by Ridell & Kokeala (1993) also shows that cattle slaughtered in the summer months are cleaner than at any other time of year, despite the low dry matter content of grazed grass. The cleanliness of cattle at this time, therefore, is likely to result from a combination of the relatively dry ground conditions and the animals having short, summer coats (Gracey, 1997).

The extent to which cattle that are finished off grass excrete human pathogenic bacteria, however, remains to be determined. In the study by Davies *et al.* (2000), animals finished on a 'barley-beef' diet were significantly cleaner, as measured by MHS category, than cattle finished on a silage-based diet. This was attributed to the difference in the dry matter content of the two diets. Beach *et al.* (2002) also found that salmonella contamination of the hide following transport to the abattoir, increased overall for both feedlot cattle and cattle grazed at pasture from 18% - 20% to 50%-56%. Whereas campylobacter levels fell from 25% to

13% for feedlot cattle and very little change was observed in the samples taken from the pasture grazed animals (1-2%). Salmonella contamination was also subsequently found on the carcasses, but campylobacter was not so readily isolated (2% of the feedlot cattle only). Dietary differences were not analysed separately in their study.

Thomas *et al.* (1977) found significant differences in the mesophilic and psychrotrophic mean counts of bacteria from carcasses of beef fed on different nutritional regimes. Counts on grass-fed steers were significantly higher than those fed on any other feeding regime. These results suggest that stock finished on a high dry matter diet should be cleaner and therefore constitute a lower hygiene risk at the abattoir. Work by Urlings *et al.* (1996) confirmed the importance of feed cleanliness concerning enteropathogenic infection of pigs. They also advocated the use of preservatives in feeds to reduce the proliferation of bacteria in feed troughs.

Diet has also been shown to play a significant role in the incidence of *L. monocytogenes* in animals (Fenlon *et al.*, 1996). They found that animals on a grass diet tended to have no detectable listeria, whereas those on silage diets showed an increased incidence of listeria.

Results from a study conducted by Heasman (2000) showed that animals fed a 'barley-beef' ration for two months prior to slaughter had significantly elevated faecal total *E. coli* counts, compared with animals on a silage-based diet. This result is in agreement with the findings of Diez-Gonzalez *et al.* (1998), who reported a positive correlation between the amount of grain in the diet and the number of *E. coli* in the faeces.

3.1.4.2 Diet change

Further studies support evidence that diet can affect the excretion of a number of pathogenic bacteria; Synge *et al.* (2003) identified distiller's grain as having a significant influence on the prevalence of *E. coli* O157 in herds of suckler cows. Nottingham (1982) noticed that the incidence of salmonella disease tends to be highest where intensive stock raising is practiced, but that the disease may also occur among animals raised on open pasture. Frost *et al.* (1988) examined the effect of feeding cattle a high energy, grain-based diet on the faecal shedding of salmonella. Cattle arriving at a feedlot in Queensland, Australia, were fed the ration for either two, 18 or 80 days prior to slaughter. Salmonella was isolated in the rumen of 20% of cattle sampled two days after arrival in the feedlot, and in 53% of cattle 18 days after arrival. Interestingly, all sampled cattle that had been at the feedlot for 80 days prior to slaughter were found to be negative for salmonella. The authors suggest that the three groups can therefore be thought of as representing stages in the progressive change in the host-parasite relationship; the susceptible animal recovering from the stress of travel, the rise in infection as the animal adjusts to the new diet, and the highly resistant animal, adapted to a stable diet.

The above example clearly demonstrates that diet change, in addition to the constituents of the diet itself, may play a pivotal role in the dynamics of pathogen populations in the ruminant gut. Research using both naturally and experimentally infected animals has shown clear effects of both diet change and feed withdrawal on the faecal shedding of pathogenic bacteria.

A study by Kudva *et al.* (1995), for example, used a sheep model to demonstrate the effects of a change in diet from alfalfa pellets to grazed sagebrush-bunchgrass. The study used animals that had been orally dosed with either 10^5 or 10^9 colony-forming units (cfu) of *E. coli* O157:H7, and uninfected controls. When moved on to the sagebrush-bunchgrass range, every animal, regardless of whether or not it had been dosed, shed the organism uniformly. Shedding of *E. coli* O157:H7 persisted for 15 days, after which time, all animals tested negative.

In a further study, Kudva *et al.* (1997) examined the effects of a change in diet from grass/hay to corn and alfalfa or *vice versa* in sheep experimentally infected with *E. coli* O157:H7. In this case, changing from a corn-based to a grass-based diet resulted in an increase in the number of animals shedding *E. coli* O157:H7, whereas a change from a grass-based diet to corn and alfalfa resulted in a reduction in the number of animals shedding *E. coli*. Dietary change resulted in an increase in the number of culture positive animals, compared with animals remaining on the same diet throughout the study. This indicates that dietary disruption *per se* may alter the environment within the gastrointestinal tract to induce proliferation of *E. coli* O157:H7, with the composition and characteristics of both diets being important in determining the exact response.

3.1.4.3 Feed withdrawal

Feed is commonly withheld from animals during transportation to the abattoir, and in ruminants, this may also include the withdrawal of rations on the day prior to transport. Whether stock should be fed whilst awaiting slaughter is still under question. Some authors are of the opinion that the viscera of animals should be as empty as possible to reduce the risk of rupture during evisceration with resultant contamination of carcasses, whereas Grau *et al.* (1968) showed that complete feed withdrawal increases the level of salmonella recovered from the animals.

Furthermore, on arrival at the abattoir, feed is not commonly offered to animals due to be slaughtered the same day, as the Welfare of Animals (Slaughter or Killing) Regulations 1995 states "a sufficient quantity of wholesome food is provided for an animal on its arrival at the lairage and twice daily thereafter, except that no animal needs to be fed within 12 hours of the time at which it is slaughtered or killed". However Grau *et al.* (1968) found that feeding in the lairage after starvation produced a significant increase in the percentage of cattle containing *Salmonella* in the rumen or in the faeces.

Snijders & Collins (1997) recommend that feed should be withdrawn from pigs for up to 12 hours before slaughter to empty the stomach. Patterson (1969) pointed out that in practice, it is found that a minimum amount of hay provided during longer periods of retention appears to keep animals more contented and prevents restlessness and fighting. Harvey *et al.* (2001) investigated feed withdrawal and transport in pigs on the caecal environment and campylobacter concentration. They concluded that fasting of 48 hours increased pH by 1 unit ($P < 0.05$), decreased acetic and propionic acid concentrations ($P < 0.05$) by 61% and 71% respectively, and led to a two-fold $\log_{10}$ increase in cfu/g caecal content of campylobacter ($P < 0.01$), and this did not change following transport. However, Morgan-Morrow *et al.* (2002) concluded that feed withdrawal of pigs prior to slaughter (12 and 24 hours tested) did not increase or significantly decrease the prevalence of *Salmonella* colonization or the risk of carcass contamination. Such variable observations are likely to be caused by differences in complex combinations of conditions in which the animals are placed.

In the pilot study of Kudva *et al.* (1995), the effects of feed withdrawal on the faecal excretion of *E. coli* O157:H7 by an experimentally infected and a non-dosed control ram were studied. Whilst on an alfalfa diet, the faeces of the non-dosed ram was negative for the organism, but following the withdrawal of feed and water for 24 hours, faecal shedding of the pathogen was observed. Both rams were then fed a diet of kochia weeds, and faecal shedding of *E. coli* O157:H7 by both rams was arrested. However, following feed and water deprivation for a 48-hour period, both rams were found to be excreting the organism once again.

The study by Brown *et al.* (1997) goes some way to confirming the relationship between feed withdrawal and pathogen excretion, using experimentally infected calves, at six to eight weeks of age. In this study, three out of four calves that were shedding *E. coli* O157:H7 at low levels were found to significantly increase the rate of shedding following feed deprivation. However, in a group of calves shedding larger populations of the pathogen, the effects of feed withdrawal were variable, with shedding rates increasing in four animals, decreasing in seven animals, and remaining constant in three animals, although the underlying reasons for this variation in response are not clear.

Although these studies clearly demonstrate that feed withdrawal has a role to play in the faecal shedding of pathogens by ruminants, studies conducted in finished animals prior to slaughter are of greatest relevance in determining potential sources of contamination in the meat production chain.

The withdrawal of feed has also been shown to significantly affect the number of pathogens both in the rumen and faeces using a sheep model. Grau *et al.* (1969) investigated the effects of feed withdrawal in rams experimentally infected with *E. coli* and salmonella. Withdrawal of feed resulted in a 2000-fold increase in *E. coli*, and a 300-fold increase in salmonella numbers in the rumen after 24 and 48 hours respectively. On resumption of feeding after 72 hours, salmonella and *E. coli* numbers in the rumen increased for 12 and 6 hours respectively, and then fell after further feeding. This pattern was generally reflected in the numbers of *E. coli* and salmonella excreted in the faeces, although the timing of faecal shedding lagged 24 to 48 hours behind changes found in ruminal fluid.

Jordan & McEwan (1998) conducted a study to determine the interactive effects of diet change and fasting on the concentrations of *E. coli* Biotype 1 in cattle faeces. Finishing cattle were fed entirely on a high-energy diet, typical of that used in Ontario, Canada, or switched for four days onto a high roughage diet. This was followed by a period of fasting and water depravation, in order to mimic conditions before slaughter. Faecal samples were collected 0, 24 and 48 hours after the commencement of fasting, and the concentration of *E. coli* Biotype 1 (a change in components of the *E. coli* form to a more pathogenic strain or a defined challenge strain) was determined. Results indicated that the ration, the duration of fasting, and their interaction had significant effects on faecal *E. coli* Biotype 1 concentration. Cattle on the high roughage diet for four days had significantly lower faecal *E. coli* Biotype 1 counts than steers on the high-energy diet, prior to the commencement of fasting. However, following 48 hours of fasting, cattle that had been switched to the high roughage diet had significantly higher concentrations of *E. coli* Biotype 1 in their faeces, compared with animals fasted immediately following the high energy ration.

Heasman (2000) also examined the interactive effects of diet and switching to a straw-only diet prior to slaughter on faecal shedding of pathogens by cattle. The study examined the effects on the faecal excretion of human pathogenic bacteria by beef cattle when fed a straw-only diet for zero, one, two or three days prior to slaughter, following either a 'barley-beef' or a silage-based finishing ration. In cattle finished on the 'barley-beef' ration, there was a positive correlation between the number of days of straw-only feeding and the number of cattle detected shedding *E. coli* O157. However, following feeding a silage-based ration, insufficiently few cattle were found to be shedding *E. coli* O157 to determine any specific effects of straw-only feeding. When total *E. coli* counts were considered, however, straw-only feeding was found to have no significant effects on faecal shedding, irrespective of the finishing ration. Conversely, TVCs in faecal samples were significantly affected by straw-only feeding, and were highest in animals that were not transferred to a straw-only diet, irrespective of finishing ration.

3.1.4.4 Diet ingredients

The mechanisms underlying the ability of diet and diet change to alter the faecal shedding of pathogenic bacteria by ruminants are likely to be complex, and may be related to alterations in the normal populations of bacteria in the rumen. The studies by Diez-Gonzalez *et al.* (1998) and Rasmussen *et al.* (1993), however, indicate that changes in intestinal pH and volatile fatty acid (VFA) concentrations may mediate the faecal excretion of *E. coli* by cattle. Cereal-based diets are rich in starch, which passes through the rumen to be fermented in the hindgut. Volatile fatty acids, such as acetate, butyrate and propionate, are degradation products of the hindgut fermentation of starch, and result in a reduction in colonic pH. Shifts in the pH and VFA profile of the intestine as a result of diet change, therefore, may be responsible for alterations in the pattern of faecal shedding of pathogens.

In the study of Rasmussen *et al.* (1993), for example, rumen liquor was obtained from fistulated cows, and pH and VFA concentration was adjusted to simulate conditions in the rumen of well-fed or fasted animals. The specific growth rate of *E. coli* O157 was found to be inhibited in conditions simulating the ruminal environment of a well-fed animal (i.e. VFA concentration > 75 mM, and pH < 6.4), and was highest for the combination of low VFA concentration and high pH, typical of the rumen environment of a fasted animal. These results were confirmed by repeating the measurement of specific growth rate in samples of rumen liquor taken from fistulated cattle 4, 24 and 48 hours post-feeding. Again, growth rate of enterohaemorrhagic *E. coli* strains were found to be significantly lower in rumen fluid collected from animals 4 hours after feeding, compared with the growth rate measured either 24 or 48 hours post-feeding.

The results of the study by Rasmussen *et al.* (1993) also show that colonic pH in cattle decreases with increasing rates of inclusion of grain in the diet. Again, the decrease in intestinal pH was associated with an increase in the number of *E. coli* present in faecal samples. Furthermore, this study showed feeding diets containing different levels of grain also influenced faecal shedding of acid-resistant *E. coli.* This is of particular significance as the ability of bacteria to act as food-borne pathogens depends upon their ability to survive the low pH of the gastric environment and to colonise the intestinal tract in humans. *E. coli* cultures have been found to develop extreme acid resistance when they are grown at mildly acidic pH, whereas *E. coli* grown at neutral pH are acid sensitive, and are killed by the low pH of gastric juices. Fu *et al.* (2003) studied *E. coli* strains *in vitro* and *in vivo* in 54 crossbred steers given grain-based or fibre-based diets. Acid resistance was induced by the presence of acetate and butyrate. These findings showed that the pH of the bacterial culture and the volatile fatty acid content affected the acid resistance of *E. coli.* These workers concluded that development of acid resistance may be minimised by control of volatile fatty acid levels in the colon, e.g. by modification of cattle diets.

Further evidence can be found in a study by Folmer *et al* (2001), in which the diet of feedlot steers (n = 90) was investigated. They investigated the effects of reduced starch in the diet on colon pH and how this influences *E. coli* prevalence. Three diets were fed; a) a low starch diet containing corn bran and wet corn gluten feed, b) a medium starch diet which contained the same as the low starch diet, but with high moisture corn, and c) a high starch diet contained dry rolled corn. All diets were offered *ad libitum* following adaptation. Cattle on the low and medium starch diets (higher colonic pH and lower VFA) had a reduced number of acid-resistant coliforms ($P < 0.01$) and acid-resistant *E. coli* ($P<0.01$). The total number of *E. coli* was lower for the medium starch diet than the others ($P < 0.01$). The authors concluded that diets lower in starch increase faecal pH, lower VFA, and reduce numbers of acid-resistant *E. coli* in the faeces. Klopfenstein *et al.* (2002) concluded in their study of

feedlot steers that removal of starch from the diet did not affect *E. coli* O157:H7 prevalence in faeces, whilst feeding competitive exclusion products showed a potential to reduce shedding.

Sindt *et al.* (2002) investigated the finishing performance, carcass characteristics, acid resistant *E. coli* and total coliforms from steers (n = 615) fed combinations of 0, 30 and 60% wet corn gluten feed (WCGF) and steam-flaked corn. With an increase in the WCGF, a linear decrease in VFA was observed in the rumen ($P = 0.01$) and in faeces ($P = 0.06$), and linearly increased acetate: propionate ratio ($P< 0.01$) and ruminal and faecal pH ($P< 0.05$) were also seen. Dietary manipulations that reduce acid concentrations in the gut may not correspond to changes in acid resistance of *E. coli* and total coliform populations detected in the gastrointestinal tracts of cattle, as in this study, diet did not affect the levels of *E. coli* or total coliforms. Similar patterns can be seen in pigs. Prohaska & Baron (1980) studied the effect of increased dietary protein, which increases gastric acid pH (> 5) to a range favouring the multiplication of enteropathogenic porcine *E. coli* strains, in piglets weaned at 3-4 weeks. Beyond 8-9 weeks of age, the pigs develop acid-base elimination and therefore show greater resistance to colonization with *E. coli*. Bosworth *et al*. (2002) suggested that to reduce *E. coli* in the gut of pigs a reduction in the level of soya bean meal and total protein in the diet should be undertaken, although there are implications in terms of reduced carcass weight and meat quality.

Regular all-concentrate diets of sheep, typically containing around 5% acid-detergent fibre, when fed as a sole nutrient source, increase faecal shedding of *E. coli* O157:H7. Whilst increasing the acid-detergent fibre content of the concentrate diet to between 10 and 20%, using alternative feed ingredients, decreases faecal shedding of *E. coli* O157:H7 in sheep and reduces subsequent contamination of meat surfaces without adverse effects (Lema *et al*., 2002). Edrington *et al.* (2003) suggested in their results that an experimental chlorate product, administered in the feed of sheep, was effective in reducing *E. coli* O157:H7 from the hind gut of sheep as evidenced by lower caecal and rectal, but not ruminal, concentrations. Feeding chlorate therefore may be an effective method to decrease *E. coli* O157:H7 populations in ruminant animals prior to slaughter.

A further factor that has the potential to affect faecal shedding of pathogens is the presence of therapeutic and non-therapeutic antimicrobial compounds within feeds. A number of plant metabolites have been shown to inhibit the growth of pathogenic bacteria in culture. Coumarins, for example, are found mainly in leguminous plants, including clover, and are hydrolysed in the gut to form alglycones, such as esculetin. In laboratory trials, esculetin was found to inhibit the growth of *E. coli* more markedly than the commensal anaerobic bacteria tested (Duncan *et al.*, 2000). This theory has yet to be tested *in vivo*, but if proven favourable it has the potential to be used in finishing cattle to reduce their burden of human pathogenic bacteria prior to slaughter.

3.1.4.5 Feed and water as vectors

Animal feed is also often considered a common source of pathogens such as *Salmonella*, due to contaminated feed ingredients and contamination during or after feed production or processing (Edwards, 1996). Yadava (2002) detailed how fishmeal was responsible for infection with *Salmonella* in an outbreak of piglet diarrhoea. Processed feed may acquire *Salmonella* from contaminated sacks and in storage where rats, mice and wild birds may transfer the organism. Certain serovars of the organism can be harboured by these pests but more commonly they act as vectors, transferring organisms from another contaminated environment. If feed is wetted, *E. coli* O157 can proliferate rapidly if present, and this commonly occurs in mixed rations (Besser *et al*., 1999). Feeding contaminated feed to pigs

destined for slaughter will increase the risk of *Salmonella* contamination on the finished carcass. Feed is said to be one of the most common sources of infection with *Salmonella* in pigs and eliminating this organism from the feed will help to eliminate the infection from the pigs (Yadava, 2002). Williams & Newell (1968) also believed that the primary source of contamination, spread via the environment, was probably the salmonella-excreting pig, which had consumed contaminated feed ingredients on its farm of origin. Their conclusion was that the slaughter of *Salmonella*-free pigs would avoid any cross-contamination. In Denmark, the SPF (specific pathogen free) concept approach has given promising results (Skovgaard, 1987). Davis *et al.* (2003) investigated cattle feedstuffs and the transmission of *E. coli* O157 and *Salmonella* to animals. Faecal and feed (feed and feed mill) isolates were compared and found to closely resemble one other. These results provide evidence of the potential role of feed in the transmission of *E. coli* O157:H7 and salmonella to the animal.

Water troughs used for livestock may also be a reservoir for infection between batches of animals and have been found to contain *E. coli* O157:H7 (Faith *et al.*, 1996; Shere *et al.*, 1998). LeJeune *et al.* (1997) found that the organism could survive in the sediments of water troughs for four months. The positioning of water troughs, therefore, has an important role to play in minimising infection, as does good management practice, in terms of avoiding fouling, frequent cleaning and maintenance. Control of organisms both within feed and water is very important to aid the control of *E. coli* O157 persistence in animals because it serves to reduce the intake of enteric bacteria (Besser *et al.*, 1999).

3.1.4.6 Conclusion

There is compelling evidence to show that feed, diet, feeding regimes and the feeding environment are all significant on-farm factors influencing the probability of animals acting as reservoirs for human pathogenic bacteria. No single factor stands out as the main influencing factor amongst these four categories.

3.1.5 The effect of husbandry practices on pre-slaughter cleanliness

Husbandry practices can influence the survival of food borne pathogens in the environment and the persistence of these organisms within the animals themselves. For example, the survival of *E. coli* O157 in faeces, on pasture and in the water table presents difficulties in the control of spread to crops and pasture via slurry, farm yard manure, sewage sludge, irrigation and direct animal contact (Maule, 2000; Edwards, 1996). Besser *et al* (1999) state that herd prevalence of *E. coli* O157 is not associated with the application of manure to grazing land, although pastures are reported to remain contaminated for longer when pathogens are applied or excreted in higher numbers, i.e. $\geq 10^5$ organisms per gram faeces (Ogden *et al.*, 2002).

3.1.5.1 Manure and waste management

Manure and abattoir waste are regularly used to improve soil fertility of agricultural land in the UK (Day, 2000), and these can be stored in a number of ways. Using traditional methods, a lot of bedding would be mixed with the manure produced by animals and the composting process of this solid farm manure kills pathogenic bacteria over time. However, the introduction of slats and bare scraped concrete in animal housing has led to the production of liquid slurry, which also contains urine, parlour washings and rain water. Studies into the storage of slurries have shown that *C. jejuni* persists in slurry tanks, showing little die-off in storage (Stanley & Jones, 2003). Aerobically digested slurries spread in the UK in the summer are reported to contain less campylobacter than non-aerated slurries spread in winter. However, survival of the organisms is said to be better during the winter months and contaminated run-off is reported to be a greater risk at this time of year (Stanley and Jones 2003). Turner (2002) investigated the environment required for pig manure to kill

E. coli (lab strain as an indicator of the pathogenic organism) and showed that temperatures in excess of 55°C for 2 hours was required for the inactivation of *E. coli*. Inactivation at temperatures below this depended on the moisture content and nature of the material, and for the inactivation of other pathogenic organisms, higher temperatures than this may be required.

Fenlon *et al.* (2000) investigated the spreading of slurry (5% dry matter) containing 5.3 x 10^4/ml *E. coli* and 30 *E. coli* O157 per 100ml in early March, in Scotland. Initially almost all the *E. coli* organisms were retained in the upper layers of the soil, but *E. coli* numbers declined to less than 1% of that applied by day 29, and O157 was only detected in soil and on grass for one week after application. About 2% of the total *E. coli* was transported to the deeper layers of the soil, and about 7% of the *E. coli* was transported to drains, but this was dependant on rainfall. There was some indication that heavy rainfall can cause heavy losses of *E. coli* by leaching and run-off. Similar results were obtained by Ogden *et al.* (2001) investigating the survival and transport of *E. coli* and *E. coli* O157 after cattle slurry was applied on pasture. The also showed that the significant risk of water pollution with *E. coli* was highest immediately after application of slurry, and this would be similar with *E. coli* O157 because its behaviour in slurry is similar to that of *E. coli*. *E. coli* on grass that is ensiled under conditions that allow aerobic spoilage can multiply to numbers exceeding 10^6/g of silage (Fenlon *et al.*, 2000). Listeria, both pathogenic and non-pathogenic strains, are also known to be sourced from winter feeds such as silage, hay and concentrates (Stanley & Jones, 2003). These findings present particular difficulties in the control of spread of human pathogenic bacteria as they clearly demonstrate the potential sources of contamination to the meat animal prior to slaughter, and the persistence of the organism in the environment.

Figures given by Maule (2000) show that over 460,000 tonnes of sewage sludge was applied to agricultural land in 1992 and it is suggested that this will double by 2005 following the ban on disposal at sea. This may result in an increase of pathogen contamination or grassland and pastures if the material is not properly treated. Sewage sludge may be an important means of introducing new pathogens associated with foreign travel and imported foodstuffs into domestic livestock production.

3.1.5.2 General farm environments

The study by Rahn *et al.* (1997) clearly implicates the farm environment as a reservoir for *E. coli* O157 infection. Samples of faeces and environmental swabs were taken from eight Ontario dairy farms. These farms had been identified as positive for *E. coli* O157:H7 as part of a previous longitudinal study, with the interval since the last isolation of *E. coli* O157 ranging from 3 to 15 months. *E. coli* O157:H7 was isolated in faecal samples taken from cattle at a rate of 0.5%, but other serotypes of verocytotoxic *E. coli* were found in 49% of calves and 17% of cows. *E. coli* O157:H7 was not isolated in faecal samples taken from cats, rodents, wild birds or flies, or from environmental swabs taken at the eight farms, but VTEC were isolated from feed mangers and water bowls at rates of 15 to 20%, which suggests that these may play a role in animal-to-animal transmission.

Farm buildings have also been shown to harbour *E. coli* O157 for extended periods. In a series of experiments conducted by Randall *et al.* (1999), the organism was recovered from wood, straw and breezeblocks for up to 38 weeks post inoculation. Sumner (1991) demonstrated *E. coli* survival in bedding materials including sawdust, peat and macerated wood bark and suggested that daily removal of bedding might reduce coliform counts. Klopfenstein *et al.* (2002), however, concluded in their study of feedlot steers that pen cleaning (monthly or just prior to slaughter) did not affect *E. coli* O157:H7 prevalence in faeces. The differences viewed here reflect the frequency in which the bedding is removed.

Hurd *et al.* (2001b) placed uninfected pigs in an environment where the faeces of pigs infected with S*almonella* had been previously placed, and all groups became positive. They concluded that pigs can become infected during housing or holding periods, such as marketing or lairage, even when exposed to relatively low amounts of *Salmonella* organisms, which again implicates the water system, the bedding and contaminated surfaces of the pen.

In indoor beef production, fresh straw is commonly added on top of old litter to soak up waste and create a new cleaner layer (deep litter system). Young calves spend a great deal of time in contact with bedding material and therefore are at great risk of ingesting organisms of faecal origin from the bed, food or water. Hide contamination is also very likely. It must therefore be assumed that unless the environment is cleaned, beef animals are likely to re-cycle organisms that are excreted in the pen (Stanley & Jones, 2003).

Nottingham (1982) reported that the incidence of *Salmonella* tends to be highest where intensive stock rearing is practiced, but that the disease may also occur among animals raised on open pasture. Following an outbreak of human VTEC in Sweden, a study was carried out on infected calves at pasture (n = 6) and housed (n = 6) during one summer, and faecal samples were taken once a month. The calves at pasture were sample negative following a period of turnout whereas the housed calves remained positive, ranging between one and six animals testing positive on each occasion. One calf was found to be positive on four consecutive occasions (Jonsson *et al.*, 2000).

Synge (2000a) found from faecal samples taken from Scottish beef finishing cattle herds (n = 952) that the shedding of *E. coli* O157 was also higher in housed animals (P = 0.001) and shedding in housed animals is also affected by season with a drop in winter (P = 0.05) and a rise in spring (P = 0.04). The prevalence of *Listeria monocytogenes* is also reported to be higher at housing than at pasture (Stanley & Jones, 2003).

Synge (2000b) also found in his investigation that restocking significantly affected the levels of *E. coli* O157 shed by cattle. Farms that bred their own replacement animals had significantly lower numbers of cows shedding *E. coli* O157 than farms that bought in replacement cattle (P= 0.02). Paiba *et al.* (2003) also suggested that *E. coli* O157, based on the high levels observed in their study, is ubiquitous in the national cattle population, and therefore the mixing of animals at markets or the importation of stock on to farms makes it possible for the organism to spread within the cattle population across the country. In support of this, Synge (2000a) and Synge *et al.* (2003) found that an increase in the number of cattle in any group was associated with an increase in the levels of *E. coli* O157 shed on-farm. Hoar *et al.* (2001) also concluded that increased herd size was associated with an increase in the number of cattle that are tested positive for campylobacter, and they also identified a significant association with the number of female cattle in the herd.

Murray *et al.* (2001) found lower APCs on beef carcasses in Northern Ireland that were processed in the spring than on those processed in the winter, associated with cattle being at pasture or housed indoors and the consequential effect on hide cleanliness (cattle were dirtier when housed). Patterson (1969) noted that in the UK, cattle fed on grass in the summer usually have comparatively clean hides, but in wet summers with heavy soil and sometimes poor drainage, cattle can arrive at the abattoir wet and with muddy feet and bellies. He suggested that if these cattle were housed on slatted floors or on clean straw for 24 hours before being presented for slaughter, they would be in a much cleaner condition. He was also of the opinion that cattle fattened in winter, either in stalls or in covered yards, presented a greater problem. The use of solid floors, which was common at that time, was condemned as allowing the build up of straw and dung, and hence a gross accumulation of dung on hides

and fleeces. Patterson suggested that the use of slatted floors was one possible solution to this problem.

Thermophilic campylobacter and the subsequent risk to human contamination have largely been associated with poultry as infection spreads throughout a poultry population very quickly, reaching 100% within-flock prevalence in a very short period. This is due to the ideal environment for the amplification of the organism, because poultry have a core temperature of 42°C and are densely stocked. Studies have identified a greater risk to broiler flocks where cattle and sheep are also present on-farm (Stanley & Jones, 2003). More recent investigation has identified that cattle and sheep may shed *C. jejuni* which are capable of causing disease in the local community, e.g. via contaminated water from agricultural run-off and improperly pasteurized milk (faecal contamination or, rarely, *Campylobacter* mastitis) (Stanley & Jones, 2003). A high incidence of *C. jejuni* has also been found in feedlot cattle compared with cattle at pasture (Garcia *et al.*, 1985). Isolation and carriage rates are however, very variable between herds and flocks.

3.1.5.3 Livestock markets

As concluded by Hurd *et al.* (2001b), the livestock market environment is another site where increased shedding of organisms can occur following the stress, related to handling and unfamiliar surroundings, of the 'sale' and further cross-contamination may occur within and between pens of animals. Very few studies have investigated the 'market' involvement in this process. Collis *et al.* (2004b) found that at the market, where there was an initial prevalence of 9% of animals positive for non-pathogenic hide markers in the pre-sale pen, the sale ring, or in the post-sale pen, by the end of the market process, prevalence of contaminated animals in each of the handling areas listed had increased to 22.5%, 7.5% and 15%, respectively. In addition, widespread contamination of the market environment with the hide markers was observed.

3.1.5.4 Other vectors

Rodents, insects and birds such as pigeons, crows, geese, ducks and cranes may also be vectors of *Salmonella* spp., *Y. enterocolitica*, *E. coli* and *Campylobacter* spp. (Wray & Davies, 1996; Edwards, 1996). *C. jejuni* has been isolated from wild birds, that might visit grazing/silage pastures (Stanley & Jones, 2003). Synge *et al.* (2003) identified a significant increase in the levels of *E. coli* O157 in beef cattle where dogs were kept on farm and wild geese were seen on the farm. Collis *et al.* (2004a) also identified higher levels of food-borne pathogens recovered from faecal samples taken from beef cattle farms where sea gulls had been seen on pasture. Human activity however, is probably one of the most important vectors (Berends *et al.*, 1996a). Boots, overalls and equipment contaminated with faeces can spread greater numbers of salmonella than any rodent, insect or bird can excrete although sometimes there are – 10^7 salmonella per mouse dropping, 100 droppings per day, directly into feeders. Human contamination is a mode of transmission well recognized in the poultry industry (Stanley & Jones, 2003).

Examples of the vectors on the farm responsible for contamination/infection of the live animal are presented in Table 2.

Table 2. Risk factors that influence microbial contamination/infection in the live animal (adapted from Snijders & Collins, 1997)

Pathogen	Risk factors				
	Feed	Water	Silage	Effluents	Transport
Salmonella spp.	+++	+++		++	***
Campylobacter spp.		++	?	+	**
Verotoxigenic *E. coli*	+	+	+/-	++	**
Listeria monocytogenes	+	+	++	+	?
Clostridium perfringens	++		+	++	**
Yersinia enterocolitica	+	+		+	**

+ to +++: degree of risk * to ***: likelihood of increased risk

Water is a common vector for food-borne pathogen transmission. Humphrey & Beckett (1987) reported that 10 of 12 cattle herds with access to river water shed campylobacter, at least temporarily. Van Donkersgoed *et al.* (2001) also implicated a contaminated water trough as a vector for cross contamination of *E. coli* O157. *E. coli* O157 has been reported to persist for at least 4 months in sediments in the trough and may even multiply. Some strains of *E. coli* O157 have also been known to persist on-farm for two years (Besser *et al.*, 1999), not necessarily by survival in the environment, but through serial infection of the animals. Control of organisms within water is very important to aid the control of *E. coli* O157 persistence in animals, because it can reduce the intake of enteric bacteria (Besser *et al.*, 1999). LeJeune *et al.* (2001) investigated the microbial quality of cattle drinking water in 473 troughs located at 99 different farms. The degree of *E. coli* contamination was positively associated with the proximity of the water trough to the feeder, protection of the trough from direct sunlight, lower concentrations of protozoa in the water and warmer weather. *E. coli* O157 in water troughs was also investigated experimentally and reduction in protozoa was associated with increased O157 of faecal origin. They concluded that water troughs are a major source of exposure of cattle to enteric bacteria, including a number of food-borne pathogens, and the degree of bacterial contamination appeared to be associated with potentially controllable factors.

3.1.5.5 Use of veterinary products

Another approach to control of *E. coli* O157, suggested by Besser *et al* (1999), is increasing the host resistance to colonization by, for example, strategic colonization with bacteria that compete with the pathogens or inhibit it (competitive exclusion). This method is well documented for *Salmonella* in broiler chicks (Besser *et al.*, 1999).

A further husbandry factor that may influence carriage and shedding of human pathogenic bacteria by ruminants is antimicrobial use (Shere *et al.*, 1998). In a longitudinal study of *E. coli* O157:H7 dissemination on four dairy farms in the USA, farms that routinely used antimicrobial compounds were found to have a higher prevalence of *E. coli* O157 in cattle (5.8-10.1%) compared with farms that only used antimicrobials occasionally (0-0.2%). In the USA, antimicrobials are commonly used for growth promotion, disease prevention and for treatment of clinical illness. The authors suggested that the use of antimicrobials might influence the microbial flora of cattle, enabling *E. coli* O157 to multiply within the digestive tract, but that further research is needed to confirm this theory. Whether antimicrobials that are used routinely in the UK impact on *E. coli* numbers remains to be determined, although routine worming treatments of cattle are recommended to reduce endoparasite-related

diarrhoea (Lowman *et al*., 1998) and intestinal damage may favour colonisation by foodborne pathogens.

3.1.5.6 Conclusion

There seems little doubt that food-borne pathogens are common in the farm environment and the list of sources from which organisms has been isolated is large. This highlights the need to fully understand factors affecting the contamination and persistence of human pathogens in the environment, in order to minimise the risks presented on-farm.

The studies of Williams & Newell (1968) support the view that the build up of Salmonella in pig herds is largely via contact with a contaminated environment. Their clear conclusion was that the slaughter of *Salmonella*-free pigs would avoid any cross-contamination. Moves in this direction are already meeting with some success. For example, in Denmark the SPF (specific pathogen free) concept approach has given promising results (Skovgaard, 1987). Work in the Netherlands suggest that using such approaches, Campylobacter-free pig populations can also be established by combining a 'top-down approach' (Campylobacter-free top-breeding farms) with a strict regime of hygiene management (Weijtens *et al*., 1996; 1997). By starting with Campylobacter-free pigs, the percentage of animals infected with Campylobacter can be kept at a significantly lower level than on average pig farms if intensive biosecurity measures are maintained. While agreeing that Campylobacter could theoretically be eliminated from pigs, Skovgaard (1996) contends that this is not possible in the case of cattle and that control measures should be focused on improved hygiene at the processing end.

3.1.6 The effect of season on the pre-slaughter cleanliness of animals

Longitudinal surveys of the prevalence of human pathogenic bacteria in the faeces of livestock have revealed that levels may fluctuate in a seasonal pattern (Hancock *et al.*, 1994; Stanley *et al.*, 1998; Jones *et al.*, 1999). Hancock *et al.* (1994), for example, found seasonal variation in the prevalence of non-sorbitol-fermenting bacteria in cattle faeces, a property used in the initial screening to identify presumptive *E. coli* O157:H7 colonies. Lowest numbers were reported for December and January, whilst the highest number was found in June. The mechanisms underlying this seasonality remains to be determined, but may be related to diet and management practices.

Similarly, Synge (2000a) found from faecal samples of Scottish beef finishing cattle (n = 952 herds) that the shedding of *E. coli* O157 increased in the summer months, which was thought to be attributed to the presence of wild geese on cattle pasture. McEvoy *et al.* (2003a) also investigated Salmonella in bovine faecal, rumen and carcass samples from a commercial Irish abattoir. These samples were taken weekly over a one-year period. The highest occurrence was again during August to October. Currier *et al.* (1986) however found that in pigs the total number of Salmonella isolates did not vary with season, but indicated that during hot, dry summer and autumn seasons a greater number of different serovars were detected compared with the cooler, wetter winter and spring seasons. Other workers have also seen a pattern of increased shedding in summer/autumn (Synge 1999; Mechie *et al.* 1997; Clarke *et al.* 1994). The same pattern has also been observed among sheep. Kane (1979) investigated the prevalence on Salmonella in sheep at slaughter over 17 months, and his study investigated an equal number of lambs, 1-2 year old sheep and older sheep (total sample n = 2027). Overall incidence was 4.7% and there was no difference between the two abattoirs involved. The incidence of infection tended to be highest in March-May and lowest October-December.

Laven *et al.* (2003) also identified a seasonal effect in the recovery of *E. coli* from slaughter cattle presented to the abattoir, and a marked reduction was observed from late summer/autumn (August/September) to winter. It is proposed that further seasonal variations in recovery may be due to the viability of the species in the natural environment, and to changes in animal husbandry practice at different times of year and their location. McEvoy *et al.* (2003b) also investigated the recovery of *E. coli* O157:H7 from commercial beef cattle, and samples taken from faeces, the rumen and carcasses (n = 250 animals), identified a higher frequency of isolates during the spring and summer months than during autumn and winter.

Ridell & Korkeala (1993) studied the effects of the improvement of the cleanliness of cattle presented for slaughter. They found that from 1983 to 1990 the proportion of 'excessively dungy' animals in one abattoir decreased by 85%. As would be expected hide cleanliness was also shown to be seasonal, the majority of 'excessively dungy' animals occurred between October to March, which corresponds with recovery of VTEC O157 in the majority of studies.

Seasonal differences in the rates of faecal shedding of *Campylobacter* have also been observed, in ewes and lambs (Jones *et al.*, 1999) and dairy cattle (Stanley *et al.*, 1998a). Jones *et al.* (1999) found the greatest prevalence of *Campylobacter* spp. in sheep faeces coincided with lambing and correlated with outbreaks of rotavirus, salmonella and cryptosporidium in young lambs. Although these animals would not be presented for slaughter, such increases were also associated with weaning and movement onto new pasture, which may represent periods of higher stress levels in the production cycle and result in contaminated pasture. Transmission has been reported to be horizontal rather than vertical in lambs, i.e. previously faecal negative ewes begin to excrete campylobacter within 3 days of lambing and lambs begin to shed approximately 5 days following birth (Stanley & Jones, 2003). Le Valley *et al.* (2002) tested samples taken from 2,226 sheep carcasses pre- and post-evisceration, and highlighted a marginally greater yield of *Salmonella* spp. (1.9%) in the winter compared to the spring samples (1.2%).

A true seasonality was also uncovered in a 2-year longitudinal study of dairy cows. Each herd had two peaks per year, in spring and autumn, which correlates with traditional periods of calving, and also when the metabolic stress of milk production is greatest. In general, this finding has been reported on other farms located in temperate areas (Stanley & Jones, 2003).

The 'peaks' of *E. coli* O157 shedding, i.e. shedding periods interspersed with longer periods of no shedding, have been associated with warmer weather and therefore possibly associated with environmental proliferation (Besser *et al.*, 1999). It may however reflect changes in diet or water source corresponding to the transitions between winter housing and summer grazing (Stanley & Jones, 2003).

Interestingly, seasonal variation in the number of campylobacter in the small intestines of beef cattle at slaughter was not found in the study of Stanley *et al.*, (1998a). Typically, these cattle are finished between 18 and 24 months of age, and during this time they will generally experience a number of management practices, such as intensive finishing, or finishing off grass following a store winter. As the cattle used in the study were sampled at the abattoir, little is known of their origins, age or the management system under which they were reared. The great variance amongst cattle that this would undoubtedly produce may be sufficient to mask any true seasonality in the shedding of campylobacter by beef cattle. Alternatively, the reported lack of seasonality may be due to the fact that beef cattle do not experience the seasonal variations in reproductive hormones, or the stresses of calving, that are present in dairy herds, but this is clearly an area that requires further investigation.

3.1.6.1 Conclusion

Evidence shows that the shedding and presence of many foodborne pathogenic organisms from animals produced for human consumption fluctuate according to season and this may be linked to diet, location and management of the animals as well as 'stress' such as lambing, calving or peak lactation in dairy cows (metabolic stress). Interestingly, increased shedding has not been associated with the period where animals are most at risk of becoming visibly dirty from inadequate bedding (housing). It is evident however, that a warm environment encourages environmental proliferation and potential recontamination of animals within a herd or flock.

3.1.7 The effects of breed and age on the cleanliness of pre-slaughter animals

In the UK, a wide range of breeds of animals is produced for meat production. These breeds, in the case of sheep and cattle, often reflect the environmental conditions in which they are reared, with traditional British breeds such as the Aberdeen Angus or Welsh Black cattle and Scottish Black Face sheep being suited to harsh, upland conditions, whereas the continental breeds generally perform better in more favourable lowland environments. As a result it is very difficult to determine whether or not breed significantly impacts on the visible and microbiological cleanliness of animals, due to the confounding effects of environment, finishing regime, and, to some extent, age. Age may be considered a confounding factor in cattle, because continental breeds are often slaughtered earlier than traditional breeds that are frequently finished on more extensive systems. Currently cattle over the age of 30 months are also excluded from the food chain in the UK. Sheep production, and to some extent store cattle production, in the UK is very stratified, resulting in numerous animal movements prior to slaughter, and batches of animals presented for slaughter often contain animals from numerous sources and of varying breeds and ages.

3.1.8 Coat and fleece length

One area in which breed might directly affect the cleanliness of cattle and sheep is coat length. The traditional more 'hardy' British upland breeds tend to have longer coats compared with continental and lowland breeds, and this may significantly affect the ability of dung and bedding to adhere to the coat. In the study by Davies *et al.* (2000), for example, animals were classified according to coat length, and this was found to have a positive correlation with dirtiness score. Animals with a short coat length (i.e. <15 mm) had a mean MHS score of 1.45, compared with scores of 1.73 and 2.17 for animals with medium (16-25 mm) and long (<26 mm) coats respectively. However, as this study was conducted in late March, when cattle had already begun to shed their winter coats, there were too few cattle in the 'long coat' category to obtain a good estimate of the true impact of coat length on cattle cleanliness.

A number of studies carried out with sheep have clearly demonstrated a positive correlation between fleece length and contamination of the coat (French & Morgan, 1996; French *et al*., 1998), and subsequent contamination of the carcass (Ellerbroek *et al.*, 1993; Biss & Hathaway, 1994; Hadley *et al.*, 1997). This suggests that breeds with characteristically long coats have a greater risk of becoming dirty, and therefore contaminating the carcass at slaughter.

One method to relieve animals of a long coat is to clip, but this can have deleterious effects on the hide/fleece if damaged during the procedure, can cause stress to the animal and is a significant health and safety hazard for personnel carrying out the task.

3.1.8.1 Age

A number of studies have identified the age of the animal as a significant factor affecting the prevalence of human pathogenic bacteria (Synge, 2000). Growing cattle 3-18 months of age are reported to have a higher prevalence of *E. coli* O157 than suckling calves or adult cattle, which probably reflects the less stable nature of the gut micro-flora at this age (Besser *et al.*, 1999). In dairy cattle studies, for example, Rahn *et al.* (1997) reported that 48% of calves under the age of three months were found to be shedding VTEC, compared with 17% of mature cows, while Hancock *et al.* (1994) found *E. coli* O157:H7 in 0.65% and 0.2% of calves and adult cattle respectively. In the study of Wray (1990), faecal shedding of *E. coli* O157 was also found to continue for longer in pre-weaned calves than in adult cattle following experimental infection, although the rate of shedding varied between the groups.

Zhao *et al.* (1995) also reported differences in the prevalence of *E. coli* O157:H7 between pre-weaned and weaned calves, finding levels of 2.9% and 5.3% respectively, in herds where *E. coli* O157 had been isolated previously. This suggests that suckled calves may be protected from *E. coli* infection to some degree, although this has yet to be confirmed in a suckler beef herd. Although the high prevalence rates reported in calves is not likely to be a direct influence on contamination of beef carcasses, it is interesting to note that due to the high survival rates of *E. coli* O157 in the environment, this may be a potential source of re-infection of older animals.

Age-related differences in faecal shedding of campylobacter have also been reported by Stanley *et al.* (1998a), with levels being 100 times greater in calves than in finished beef animals. In fact, calves 30-60 days old are reported to display high levels of campylobacter numbers in their faeces, similar to those seen in broiler chickens at 40 days old (just prior to slaughter). At 6 months of age the average level of campylobacter in calf faeces is still 10 (3.7 $\log_{10}$ cfu g^{-1} *C. jejuni*) to 100 times higher than levels found on beef carcasses at slaughter or in adult faeces (Stanley & Jones, 2003).

Nielsen (2002) found that groups of adult cattle harboured a broader range of Campylobacter serotypes than groups of calves. The major environmental reservoirs of thermophilic Campylobacter are the intestines of warm-blooded mammals and birds, where it is thought that they are non-pathogenic, at least in older animals (Stanley & Jones, 2003). An underdeveloped rumen may increase the ease of colonization of the lower intestinal tract of the younger animal but the organism must pass through the rumen of adult animals if re-infection is to occur during adult life (Stanley & Jones, 2003). Franco (1988) suggests that *Campylobacter* spp. in cattle is transferred from adult to calves but not between adults. Likewise, lambs are reported to horizontally acquire campylobacter from ewes 5 days following birth (Stanley *et al.*, 1998b).

Campylobacter spp. are also more readily isolated from young piglets (weanlings) than older pigs (Franco, 1988). Weijtens *et al.* (1997) concluded in a study of sows and their piglets that, as observed with sheep and cattle, sows infected with campylobacter transmitted the organism to their piglets. Prohaszka and Baron (1980) proposed that after 8-9 weeks a pig develops the ability of gastric acid segregation, which provides the pig with a greater ability to resist enteric infection by organisms such as *E. coli.* This was concluded from a study investigating the effect of increased dietary protein, which increases gastric acid pH in piglets weaned at 3-4 weeks to a range favouring the multiplication of enteropathogenic porcine *E. coli* strains.

The same pattern has been associated with salmonella; Kranker *et al.* (2001) found a strong association between seroprevalence of salmonella in sows and the occurrence of the organism

in weaners. It has also been shown that isolating the organism from weaners is a risk factor for high seroprevalence in finishers. Mature cows have also been reported to be more likely to shed Salmonella organisms than unweaned calves (Huston *et al.* 2002). Kane (1979) investigated the prevalence on salmonella in sheep at slaughter over 17 months, and investigated an equal number of lambs, 1-2 year old sheep and older sheep (total sample n = 2027). Overall they concluded that 1-2 year old sheep had the highest incidence (32% in April) of salmonella.

Survey data, conducted by Davies *et al.* (2000), also identified that age was also related to the visual cleanliness of slaughter cattle. Cattle under the age of 20 months were found to be visibly cleaner than cattle aged between 20 and 30 months. However, these results are likely to be confounded by differences in the diet and management practices experienced by animals of different ages.

3.1.8.2 Conclusion

Evidence suggests that age and indirectly breed significantly influence the shedding of pathogenic microorganisms and visible contamination of animals produced for meat. Certain management factors or regimes may be adopted to reduce and/or control the risk of potential cross contamination.

3.1.9 The effects of transport on the cleanliness of pre-slaughter animals

Once animals have been finished and are ready for slaughter they require transportation, either to the market for sale or directly to the abattoir for slaughter. The collection of animals from the farm, their transport to the market or abattoir and the holding time and conditions before slaughtering seem to induce the spreading of organisms, resulting in higher contamination and an increased number of carrier animals (Mulder, 1995). The procedures used during this phase can have a dramatic effect on the levels of visible contamination. Stolle & Hiepe (1996) noted that slaughter animals are often considered as commodities, which have to be loaded and transported as fast as possible. Consequently, animals are often loaded in an unsatisfactory, noisy and forceful manner. This results in an increase in urination and defecation with subsequent cross-contamination of the animal's external surfaces, i.e. the fleece, hide or skin (Holder & Hadley, 1996). Transportation has been identified by some researchers as a particularly important critical control point regarding cross-contamination (Barham *et al.,* 2002). The design of vehicles and holding areas is important to avoid contamination and holding animals in vehicles or lairages without adequate litter and/or drainage can also result in faecal soiling of the skin/fleece/hide.

3.1.9.1 Transport-related stress

Stress during transport and lairage may cause a breakdown of the state of animals carrying infections, occasionally producing overt disease, but frequently results in a greatly increased excretion of organisms (Nottingham, 1982). Close contact between animals in the lairage then facilitates the spread of infection. A model built by Alban & Stark (2002) to investigate the reduction of Salmonella on the resultant pig carcass indicated an increase to a maximum of 18% of the pathogen in the animals from loading to the time of kill. They also found that this was not reduced unless the higher shedders were not delivered to the abattoir, because these posed a higher risk for animal contamination. Mixing of animals and long durations in transport and lairage were considered to increase the proportion of contaminated pigs and carriers. Transporting herds of different shedding/carrier status in different vehicles did not significantly influence the level of contamination at kill, probably because contamination transfer occurred at lairage/abattoir. Wong *et al.* (2002) identified the significant influence stress had on the shedding of salmonella. They concluded that transport and associated

handling could significantly increase the number of pigs excreting salmonella on arrival at the abattoir and in lairage, which exposes uncontaminated pigs to salmonella. Therefore, the two major factors influencing the level of salmonella pre-abattoir are the introduction and transmission of the organism within and between herds. Results from these studies indicate that efforts at reducing the risk of contamination should be aimed at primary production, transportation and abattoir.

Isaacson *et al*. (1999) demonstrated the effect of stress during transport before slaughter, transportation increasing the proportion of pigs positive for *S. typhimurium* in the ileocaecal content, as compared with pigs that had not been transported. Berends *et al.* (1996) reported that between 5-30% of Dutch finishing pigs are still excreting salmonella at the end of the finishing period and this prevalence can double as a result of transport and lairage. Marg *et al.* (2001) also observed a similar negative effect of transportation stress on the shedding rate and the general condition of experimentally infected pigs.

Barham *et al*. (2002) concluded that transportation might be a potential stressor for cattle transported to slaughter resulting particularly in an increased shedding of salmonella. This was because they found *E. coli* O157 and *Salmonella* spp. on trailers at a rate of 5.4% and 59% prevalence respectively following transport for slaughter. Reports have also shown that transport stress increases the shedding of salmonella in feedlot cattle (Frost *et al.*, 1988, McCaughey *et al.*, 1971), although Beach *et al.* (2002) found from rectal swabs that pre- and post-transport faecal shedding rates of salmonella (3 and 5%) and campylobacter (64 and 68%) stayed relatively constant for feedlot cattle. This was not the case for adult cattle taken from pasture where an increase in salmonella shedding was evident (rising from 1% to 21%), but campylobacter levels remained constant (6% and 7% respectively).

Other workers have reported that stress during transport also increased colonisation of *E. coli* O157:H7 in the gut of cattle (Hannan, 1996). Mackey & Roberts (1993) have demonstrated that withdrawing feed for 3-6 hours may help to reduce the source of faecal contamination. However, fasting cattle prior to slaughter results in an increase in rumen pH, which can favour the survival of salmonella, and if the animals are then fed during lairage these microbes can multiply rapidly (Gregory, 1994). There is some evidence that *E. coli* O157:H7 proliferates in the ruminal fluid of fasted cattle, but not in that of well-fed cattle (Hannan, 1996). In contrast, Harmon *et al.* (1999) found no significant effect of feed withdrawal on the faecal shedding of *E. coli* O157:H7 in calves.

3.1.9.2 Pre-transport feed strategies

Isaacson *et al.* (1999) investigated the effect of feed withdrawal and transport on pigs (n = 86) inoculated with *S. typhimurium.* Faeces and ileocaecal content samples were collected. They found that pigs that had had their feed withdrawn for 24 hours and transported 140 miles (approximately 4 hours) did not shed the organism in their faeces, despite the presence of the organism in the ileocaecal content at the same levels as in inoculated pigs that had not been transported. A significant interaction was identified between the level of *S. typhimurium* ($P = 0.01$) isolated from ileocaecal content at slaughter and the pre-slaughter feeding and transportation procedures. Pigs that were fed up to the point of transport had significantly higher levels of ileocaecal Salmonella than the inoculated pigs that were not transported ($P = 0.01$). These findings suggest that the stress of transport itself cannot be implicated wholly in the proportion of *Salmonella* spp. positive animals, but it is suggested that feeding and feed withdrawal can also have a large influence. The importance of these effects will depend on the likelihood of contamination of the edible carcass with gut contents, and this in turn depends on a number of other practices within the plant. Miller *et al.* (1997) found that feed withdrawal before slaughter significantly reduced the incidence of punctured

viscera in pigs during the dressing procedures, as the gut was less distended, and this may have an effect on carcass hygiene by reducing the risk of contamination as a result of gut puncture. Ideally the restricted feed system would reduce both gut fill (reducing puncture risk) and the shedding of organisms.

3.1.9.3 Washing/disinfecting of livestock transporters

The use of vehicles with multi-decks is becoming more commonplace as animals travel greater distances and longer times to slaughter. It is essential that the animals on the lower decks cannot become contaminated with the faeces (and urine) produced by the animals on the upper decks (Patterson, 1968; McGrath & Patterson, 1969), and thus the decks must have enclosed drainage to prevent this occurring. This problem has been highlighted for many years and Patterson (1969) condemned the practice of multi-level transport of sheep as unhygienic. Following the outbreak of Foot and Mouth Disease in 2001 it is now mandatory in the UK for hauliers and producers to clean their transport between loads. Ensuring that livestock vehicles are cleaned before re-use will minimise cross-infection (Mackey & Roberts, 1993). The efficacy of washing and sanitising trailers and pens used for the transport and housing of pigs was studied by Rajkowski *et al.* (1998) and bedding from 30 trailers were collected and tested for *Salmonella* and *E. coli*. All samples were positive for *E. coli*, with levels ranging from <1 to 8.4 $\log_{10}$ cfu g^{-1} and *Salmonella* were isolated and confirmed in 80% of the bedding samples tested, with levels ranging from 1 to >110 MPN g^{-1}. The recovery incidence was reduced to 50% during the winter months. *Salmonella* was isolated from 78% of trailers before washing, with levels as high as >110 MPN cm^{-2} in some cases. All trailer floors were positive for *E. coli* before washing, and some trailer floors had levels as high as 5 $\log_{10}$ cfu cm^{-2}. Washing significantly reduced the incidence of salmonella from 41.5% to 2.7% and *E. coli* counts by an average of 2 log units.

Childers *et al.* (1977), however, did not find that the sanitisation of transportation trailers had much influence on subsequent carcass contamination. Pigs were transported in a trailer that, prior to loading, had been cleaned and sanitised with either a 500 ppm solution of potassium chlorophenylphenate (quaternary ammonium compound) or a 500 ppm solution of sodium hypochlorite adjusted to pH 6.0. Control pigs were transported in a non-sanitised trailer and were handled in a similar manner. All pigs were identified and swabbed several times throughout the routine slaughtering process. The results showed that using chlorophenylphenate or hypochlorite to sanitise the vehicles and pens had little significant effect on the incidence of *Salmonella* spp. or *E. coli* on the resultant pork carcasses.

Berends *et al.* (1996) point out that cleaning and disinfection of trucks can only prevent cross-contamination from different transport loads not cross-contamination between animals in the same group. Thus, if groups of animals are known to be potentially infected with organisms such as *Salmonella* spp. they should not be transported with groups of animals that are thought to be clear. Mulder (1995) also commented that mixing pigs prior to transport increases social stress and therefore the risk of shedding and contamination with pathogenic organisms.

3.1.9.4 Transport distance and time

Extended journey times and distances have been found to increase visual contamination of beef cattle (Davies *et al.*, 2000) and this may have serious implications for the future. Information from the Meat and Livestock Commission shows that the number of abattoirs in the UK has declined dramatically (MLC, 2003). This clearly affects the time and distance that stock will have to travel to the point of slaughter and may have adverse effects on both hygiene and welfare. Davies *et al.* (2000) gathered information on 675 cattle (from 85

batches) arriving at five UK abattoirs; several factors influenced their cleanliness of which one was transport time/distance. Animals that travelled over 150 miles (15%) were dirtier than the other animals.

Fenlon *et al.* (1996) found that prolonged transportation of animals could also significantly increase the level of *L. monocytogenes* excreted in the animals' faeces. Maximum levels of *L. monocytogenes* excreted tended to be less than 3 $\log_{10}$ cfu g^{-1}. However, this increase did not appear to affect the level of contamination of the meat in abattoirs. Swabbing of meat carcasses from these animals rarely gave positive results for *L. monocytogenes.* Similar findings were made by Barham *et al.* (2002) regarding Salmonella, but not for *E. coli* O157 in cattle. McClusky *et al.* (1999) investigated the recovery of shiga-toxin producing *E. coli* from lambs destined for slaughter in a US abattoir (n = 882). They found that lambs that were transported and held for >18 hours (23%) prior to slaughter had significantly more culture positive faecal samples than those held for <18 hours (77%) ($P < 0.01$). Conversely, Rajkowski *et al.* (1998) found that transport distance had no significant effect on the level of *Salmonella* spp. or *E. coli* recovered from either the bedding or floor of pens used by pigs after transport.

Young animals are particularly susceptible to various infections and colonisations with organism including *E. coli* O157 and Salmonellosis, but these animals are normally slaughtered at an age when they have recovered from such infections and are no longer shedding. The Richmond Report (1991) recommended that reducing the number of calves in transit 'would assist the production of microbiologically satisfactory meat by minimising the number of animals excreting salmonella and other organisms into lorries and the environment'.

A study carried out by Bach *et al.* (2002) investigated the effects of weaning and transport on the shedding of total *E. coli* and *E. coli* O157 by feedlot calves destined for slaughter. Overall they found that the calves weaned only one day prior to slaughter (as opposed to weaning 13 days prior and vaccinating 29 days prior to slaughter), and transported for 15 hours (as opposed to 3 hours) shed higher levels of *E. coli* ($P<0.005$) than any of the other combinations of weaning date and journey times. Following transport more calves from this group were also positive for *E. coli* O157 ($P < 0.05$), whereas no evidence of this organism was isolated before transport. The authors suggested that the feedlot and close proximity of animals during transport might be implicated in the infection of the calves in the study. Overall the study suggests that the reduction of stress by shortening journey time and care over weaning date may reduce the risk of the faecal shedding of pathogens.

Studies by Grønstøl *et al.* (1974a), also on transporting young calves, found that calves infected with salmonella did infect previously uninfected calves during a 7-hour trailer ride, despite being separated by a double partition. The authors postulated that cross-contamination could have occurred via droplets or faecal splashes. After slaughter, *S. Dublin* was isolated from the inner and/or outer surface of five of six carcasses, demonstrating that when one calf was infected at slaughter, several carcasses could become contaminated on their surfaces. After dressing, carcasses were cooled in a chill room at 0°C, and after 1 week, salmonella could not be isolated from carcasses except one from an animal that had persistently excreted salmonella while alive. Similar results were shown in a further experiment (Grønstøl *et al.,* 1974b), when five weeks after the last occasion on which salmonella had been demonstrated in faecal samples, four calves were transported for 7 hours together with two uninfected calves, which were separated from them by a double partition. The following day, three of the four calves and both control calves were positive for salmonella from faecal samples. Thirty-six hours after transportation all six calves were

slaughtered and all except one became contaminated on the surface of their carcasses during the slaughter operations. Salmonella was also recovered from the intestines, the mesenteric lymph nodes, or the gall bladder of one or more animal, and caecum samples from all but one calf were positive. After refrigerated storage of the carcasses at 4°C for 3 days, no carcasses were positive for salmonella on the surface.

It is also important to keep animals dry. Animals destined for slaughter should be dry at loading, during transport and at unloading. The transport of wet animals provides an increased opportunity for the cross-contamination from the external surfaces of the animals and via the lorry environment, and this again includes across pen contamination as well as within pen contamination (Tinker, personal communication).

3.1.9.5 Conclusion

Evidence clearly shows that transportation of animals destined for human consumption increases the risk of carcass contamination with food-borne pathogens. Transportation induces and enhances the shedding, spread and carrier state of the animal of these pathogens, and procedures during transport can have a dramatic effect on this. It is clear that animals are often considered a commodity and are therefore commonly treated unsatisfactorily with noisy and forceful loading. Clear considerations are evident to minimise the stress and contamination transfer of organisms during transport, these are; good transporter design, adequate ventilation and drainage, adequate bedding, minimal transport time, minimal or no mixing of animals, separate transportation of herds of different carrier status and ensuring the animals are dry.

3.1.10 The effect of lairaging on the contamination of pre-slaughter animals

The lairage is the delivery and final point where the animal is penned before slaughter. Following arrival at the abattoir, animals are placed in the lairage for a holding period. This holding period serves a number of purposes; it allows animals to recover (to a certain extent) from the stresses associated with marketing and transport; it provides the opportunity for animals to clean up and/or dry out if required; and it is reported that 'resting' pigs in lairage for at least 12 hours leads to better bleeding, a reduction of endogenous contamination, a restoration of glycogen content and a reduction of intestinal bacterial load with the intake of plenty of water (Yadava, 2002).

3.1.10.1 Lairage design and facilities

The design and facilities provided in lairages vary between establishments. Traditional, solid floor pens have a tendency to facilitate waste build up and become slippery. This increases the likelihood of animals falling and lying in waste, and McGrath & Patterson (1969) demonstrated that solid floors increase contamination of the feet and hide. A study carried out by Small *et al.* (2003) showed that roughened or grooved concrete was the most common flooring used in the ruminant abattoirs in South West England. Some modern lairages have a suspended wire mesh floor, based on a New Zealand design (Holder & Hadley, 1996) that allows waste to fall through and so reduce contamination. This improves air circulation, which may have an advantageous drying effect (Gerrand, 1975).

Rostagno *et al.* (2003) studied the levels of salmonella in the holding pens of two high-capacity abattoirs (n = 24 groups of pigs). Their study demonstrated that the lairage pens became highly contaminated, and the water source was also found to be contaminated. This was identified as the critical source of infection because pigs that were negative following transport subsequently became positive after penning.

The lairage bedding itself can be implicated as a means of cross contamination, but investigations by Mackey & Roberts (1993) noted that lairaging in clean straw is only effective for up to 3 hours, since after this time the straw will be dirty and there will be an increased risk of cross-contamination. Small *et al.* (2003) noted, from a study of ruminant abattoirs situated in South West England, that straw bedding was used in the majority of lairage pens but the rate of renewal varied from replacement between batches (5%), daily (60%), weekly (15%) and to monthly (10%) replacement of the bedding. This, coupled with evidence that pathogens such as *E. coli* O157, salmonella and campylobacter can survive in the environment for >1 week (from *in vitro* studies), especially on straw and hide, demonstrates the potential for such organisms to contaminate subsequent batches of animals.

3.1.10.2 Prevalence of pathogens

Small *et al.* (2002) investigated the unloading-to-skinning areas of six abattoirs (3 sheep and 3 cattle) in the UK. Overall the prevalence of food-borne pathogens on lairage surfaces was; *E. coli* O157, 27.2% and 2.2%; salmonella, 6.1% and 1.1%; and campylobacter, 1.1% and 5.6% in cattle and sheep lairages respectively. This was reflected on hide and fleece samples where prevalence was; *E. coli* O157, 28.8% and 5.5%; salmonella, 17.7% and 7.8%; and campylobacter, 0% and 0% respectively. The most frequently contaminated regions in the cattle abattoirs were the holding pen floors (50% of swabs positive for one or more of the three pathogens studied), entrance gates of stun boxes (27.8% positive swabs) and stun box floors (22.2% positive swabs). Contamination was more frequently located from the unloading ramp (33.3% positive swabs), holding pen floors (22.2% positive swabs) and water troughs (22.2% positive swabs) in the sheep abattoirs. This study therefore identified a higher level of contamination recovered from cattle lairage facilities and hides than sheep lairages and fleeces.

Minihan *et al.* (2003) investigated the levels of *E. coli* O157 shed by cattle delivered for slaughter and concluded that lairaging did not cause an increase in the prevalence of the organism. They demonstrated that animals delivered to slaughter (n = 109 and 59) with a prevalence of 13% and 1.7% prevalence respectively following transport, and 12% and 0% respectively at lairage, went on to have 0% for both samples taken from the carcass. A suitably detailed description of the lairaging system and slaughter technique was not available to compare with other reports.

3.1.10.3 Animals as carriers of pathogens

Many workers have identified that abattoir lairages play an important role in the transmission of pathogens, such as salmonella, through a group of animals, and campylobacter is reported to be more frequently isolated from sheep lairages than other pathogens (Small *et al.*, 2002). High shedders, i.e. those animals shedding $>10^5$ organisms per gram faeces of say *E. coli* O157 or campylobacter, present the highest risk for cross-contamination on hide/fleece in lairage, in addition to the risk posed from the primary production source on-farm, including from water courses and grazing (Stanley & Jones, 2003).

Lundbeck *et al.* (1955) suggested that a major outbreak of Salmonellosis in Sweden was due to animal-to-animal transfer, which had probably occurred in the lairage. This is not surprising, as Berends *et al.* (1996) found that within 2-6 hours of transport and lairage, the numbers of animals that excrete *Salmonella* spp. can sometimes more than double. This is also consistent with the work of Grau & Smith (1974) who found that previously salmonella-free animals rapidly became infected when placed in lairage pens contaminated with the organism, and this increased with both time and degree of initial pen contamination. Their work in Australia showed that the fleece of uncontaminated sheep becomes contaminated

with salmonella within 24 hours if they were placed in a contaminated pen, even when there was less than one *Salmonella* organism per gram of soil. They found that the degree of fleece contamination was greater the more salmonella was present in the soil of the holding pen and the longer the animals were held there. Salmonella was first shed in the faeces after 2-3 days in the holding pen and the fleece appeared to be a significant source of salmonella contamination of the carcass. Four of 15 wool samples taken from sheep in a highly contaminated pen had >40 salmonella cm^{-2}, and one sample had 400 salmonella cm^{-2}. Further, studies in Australia by Grau *et al.* (1968) also showed that increasing the time in lairage before slaughter increased the incidence of salmonella in the rumen and faeces of cattle. They also found that feeding in the lairage after starvation produced a significant increase in the percentage of cattle with salmonella in the rumen or in the faeces, and in salmonella numbers recovered from the rumen.

Boes *et al.* (2001) investigated the lairaging of pigs and identified similar findings to those of sheep and cattle, that there was significant cross contamination between pigs positive for Salmonella and those from Salmonella-free herds during lairage penning. Cross contamination was low where the environment was contaminated in pen 1 (carcass contamination 1.7%) and clean pigs were contained in pen 2 (carcass contamination 0.8%). In the second phase, which consisted of mixing Salmonella positive and negative pigs in pen 1 (carcass contamination 4.5%) and having Salmonella-free pigs in pen 2 (3.6%), carcass contamination from positive pigs overall was 10.4%. These workers, however, suggested that slaughter line hygiene might be more important than abattoir pens despite the high degree of cross-contamination that occurs there.

Studies at an abattoir, using a harmless marker strain of *E. coli* demonstrated that an initial prevalence of animals positive for the hide marker (11%) inoculated at unloading increased to 100% (on hide) and 88.8% (on skinned carcass) of slaughtered animals. In addition, a second marker (*Pseudomonas fluorescens*) inoculated on environmental surfaces in lairage pens, races and stunning box, was detected on 83.3% (on hide) and 88.8% (on skinned carcass) of slaughtered cattle (Collis *et al.*, 2004b). These and further reports from Small, Reid & Buncic (2002) and Small (2003) clearly demonstrate that the unloading-to-skinning process at abattoirs allows extensive spread of microbial contamination on hides not just within, but also between, batches of animals. Similar findings have been identified for sheep, which also implicates bedding, the lairage pens and races leading to the slaughter line as significant factors in the cross contamination between lambs prior to slaughter (Reid, unpublished data, Small *et al.*, 2002).

3.1.10.4 Time in lairage

Lairage conditions should minimise stress and thereby reduce faecal contamination. The Richmond Report (1991) highlighted a risk attached to the practice of keeping very young calves in the lairage until sufficient numbers have been accumulated to justify economic slaughter. The report stressed that should any of the calves be carrying salmonella they are highly likely to start excreting them and quickly infect other animals. The report recommended 'that all calves should be slaughtered on the day of arrival at the slaughterhouse'.

In general, lairaging time is considered to significantly influence contamination. The prevention of an excessively long period of holding in lairage and prevention of overcrowding, especially in pigs, has been reported to considerably reduce the proportion of animals found contaminated at slaughter (Mulder, 1995). Morgan *et al.* (1987) found that *Salmonella* isolations from caecal and carcass surfaces increased with increased lairage time. *Salmonella* was isolated from 9.3% of pig carcasses held for less than 24 hours in lairage,

12.8% of pig carcasses held a further 24 hours in lairage, and 27.3% of pig carcasses held for 66 hours in lairage before slaughter. They also found that pen size was another factor, with smaller pens helping to reduce salmonella contamination specifically. Conversely, a previous investigation by Craven & Hurst (1982), using the same laboratory, reported that the number of salmonella isolated from the caecum of slaughtered pigs decreased with holding time. In their study salmonella was isolated from 70% of pigs killed on the first day, 49% on the second and 41% on the third. Morgan *et al.* (1987) contended that the pigs studied in the earlier work had been exposed to greater handling and transport stress and had hence reached a maximal level of caecal infection, accounting for the opposite pictures found in the two studies by the difference in the initial levels of salmonella in the pigs studied. These authors concluded that lairage time could be used to manipulate the prevalence of Salmonella in pigs. If pigs come into lairage with a high prevalence of salmonella, it may be possible to keep them overnight in lairage until the number of infected animals is reduced. Pigs with a low prevalence of salmonella should be slaughtered as soon as possible to avoid a build up of salmonella infection. A study in Hong Kong (Chau *et al.*, 1977) supports this strategy through showing that the longer pigs stayed in lairage the more likely they were to pollute it and infect other pigs via cross-contamination.

Studies on the optimum time for pig lairaging have produced contrasting results. Warriss (2003) recommends that the optimal time for lairage is 1-3 hours, which allows the pig to recover. No benefit can be associated with long lairage times, only increased risk of cross contamination from the lairage, as the reservoir of infection by pathogenic bacteria may increase. Interestingly, Davies *et al.* (1999), investigating the prevalence and distribution of salmonella on pig carcasses, concluded that the rate of isolation of organisms from pigs held in lairage overnight was less than that seen in pigs slaughtered within 2-3 hours of arrival. This work is in agreement with Yadava (2002) who reported that the optimal time for pig lairaging is 12 hours but concluded that a stay beyond 36 hours should be prohibited. He emphasised the specific combined advantages of lairaging for 12 hours on the endogenous bacterial content as well as the benefits for meat production. However, it is evident from these workers that should the environment be already contaminated, a longer lairaging time increases the risk for cross-contamination.

3.1.10.5 Cleaning and Disinfection

The above findings emphasise the need for thorough cleaning and disinfection of lairage pens between batches (Patterson, 1968; Morgan *et al.* 1987; Yadava, 2002) and that extended lairage times be avoided (Morgan *et al.* 1987; Mackey & Roberts, 1993). Small *et al.* (2003) found that ruminant lairages in South West England commonly wash down surfaces with cold water without detergent or disinfectant, which would not have a significant influence on the elimination of pathogens, but would reduce the load. The need for cleaning and disinfection is also confirmed by the study by Grau & Smith (1974) that identified that the fleece of sheep can be an important vector for introducing salmonella to the slaughter floor by their lying down during long periods of lairaging. In two commercial flocks held for one day in highly contaminated pens, salmonella was detected on 43% of the carcasses. At this stage, anal swabs were negative for salmonella but the fleece was extensively contaminated. salmonella was subsequently detected on the brisket, thigh and back of carcasses from these sheep.

Salmonella prevalence in lairage was also estimated when pigs were present, after normal cleaning and disinfection, and following more intense disinfection (Swanenburg *et al.*, 2001). Salmonella was isolated from 70-90% of the samples taken when pigs were present, and levels were reduced to 25% following normal cleaning and disinfection. However, following

improved cleaning and disinfection, levels were reduced further to 10% positive samples, but cleaning and disinfection in this instance did not eliminate the pathogen. They also concluded that a waiting period in lairage of at least 2 hours carries a substantial risk of slaughter pigs becoming infected with salmonella, and was the factor posing the greatest risk for contamination. In the UK, lairage time was limited to a maximum of 72 hours in order to minimise such risks (Fresh Meat (Hygiene and Inspection) Regulations, 1995), however, following the outbreak of Foot and Mouth Disease in 2001, lairaging time has been reduced further to a maximum of 48 hours. Hurd *et al.* (2001a) concluded that pigs that had become internally contaminated with salmonella after leaving the farm, possibly while they are in lairage pens, did not increase shedding following an 18 hour period in clean facilities, and interestingly, lairaged pigs had a lower shedding rate ($P < 0.05$) than those remaining on farm.

3.1.10.6 Conclusion

It is clear from the findings of research work in this area, that the lairaging period and the lairage environment provide the perfect medium for the spread and proliferation of pathogens associated with food-borne illness, if not managed efficiently. *Campylobacter* spp. has been reported to be the mot commonly recovered bacterium, but survival time is short, except in the winter, and bedding or water sources provide the perfect medium for cross contamination of all food-borne pathogens, particularly where the bedding is infrequently changed and disinfection is sparse, which appears to be common practice in many UK lairages. A long residency time in the lairage also assist in establishing a reservoir of infection within a group and encourages recumbence in the animal, increasing the risk of contamination along the cut line due to contamination being transferred from bedding materials to the coat of the animal.

3.1.11 General conclusions

It is clear from work to date that bacterial contamination and proliferation on meat surfaces are significantly influenced by the state of the animal at slaughter, the liberation of contaminants during the slaughter process and the conditions of storage and distribution, including time, temperature and other aspects (Nottingham, 1982). Therefore, whilst good slaughter hygiene is essential, actions on the farm up to slaughter may have an even greater role to play in risk management than currently realised. A reduction in the levels of contamination of the animal in primary production will reduce the likelihood of proliferation during the following stages, because meat provides all the essential nutrients required for the proliferation of most micro-organisms (Ayres, 1955; Nottingham, 1974). It is therefore in the interests of all concerned to reduce initial microbial contamination to a minimum in order to produce a safe product with adequate shelf-life (Gerrand, 1975).

Strategies or management regimes to reduce the level of pathogens excreted/carried during primary production should be adopted. Evidence to date suggests that there may not be single clear factors that would achieve this, but a combination of good practice measures that incorporate many of the factors discussed within this report should be applied. The limitation of contamination on the farm is where the quality and safety of the product can be greatly influenced, before animals are grouped in closer proximity to each other both during transport and in the lairage, where cross contamination can occur. It may be that intervention in the lairage, by segregating shedders from non-shedders, is the most significant action that can be taken in reducing the risk of pathogen transfer.

It must, however, be kept in mind that the aim is to minimise, rather than eliminate sources of contamination, which is impossible to achieve because many food-borne pathogens are

ubiquitous in animals and are widespread in the natural environment, including birds, deer and other wildlife (Besser *et al.*, 1999).

Clearly, the most beneficial consequence of an improvement in the microbiological status of carcasses for human consumption would be a reduction in the number and magnitude of outbreaks of food-borne illness in humans. Outbreaks not only result in economic losses, such as the cost of health care for the affected people and loss in national productivity, but a significant long term impact can occur as a result of loss of consumer confidence in meat products which is very difficult to reverse.

3.1.12 References

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3.2 Task 1.2 Survey of lairages via questionnaire

A survey of a large number of abattoirs was conducted via a questionnaire. This was designed to obtain information on:

- Throughput, species slaughtered, and catchment area.
- General unloading-to-stunning layout;
- Type of materials used;
- Use and type of bedding;
- Details on cleaning/sanitation regimes;
- Any monitoring/verification of lairage hygiene.

The design of the questionnaire was finalised after much consultation with the FSA. The information was required to enable identification of "common lairage practices", as well as selecting representative abattoirs for the following task. An edited version of the full survey form, the accompanying letter and the full overall data are provided in the appendix (Section 7).

3.2.1 Study Design

A 5-part questionnaire was produced which contained questions to provide an initial overview of abattoir throughput and a lairage plan, followed by a 36-question section on each of cattle, sheep, pigs and other species. The section on each animal species incorporated questions on the construction and design of the lairage, lairage management and cleaning procedures. The questionnaire was sent to a total of 374 red meat slaughterhouses in England, Scotland and Wales, using a database provided by the Competent Authority. A further short questionnaire was sent to non-respondents to find out why they had not responded to the initial questionnaire.

A total of 157 abattoirs responded to one or other of the questionnaires. Thirty eight completed questionnaires on lairage design and management were returned, 41 abattoirs had closed down, 8 did not participate as they were concerned about confidentiality, and 70 had insufficient time, or felt that there was already too much paperwork involved in their normal activities. Nine abattoirs were visited after receipt of the completed questionnaire in order to validate the information received, and observations on the day of the visit matched the statements given in the received responses. Of the 38 abattoirs participating in the study, five were Scottish, two were Welsh, three were anonymous and the remaining 28 represented a broad distribution across England. Nine abattoirs were Low-throughput premises under the definition of the Fresh Meat (Hygiene and Inspection) Regulations 1995. Twenty seven of the abattoirs processed cattle, two of these being cull cow/bull plants, 27 processed sheep and 23 processed pigs. Of the single-species abattoirs, 7 processed cattle only, 5 processed sheep only and 4 processed pigs only. Three abattoirs processed both cattle and sheep, but no pigs. No abattoir processing other species, for example deer or horses, participated in the study.

3.2.2 Construction of Lairages

The lairages surveyed ranged from new (constructed within the previous 5 years) to 93 years of age.

3.2.2.1 Flooring

Floors were often replaced after 20-25 years, however, the original floor remained in 50% of the structures, and the oldest reported floor was 41 years of age.

A variety of floor surfaces were present in lairages (Figure 1), and 23 (61%) of the lairages had more than one floor type in the lairage. Roughened concrete, grooved concrete and smooth concrete were the commonest floor finishes, being present in 45%, 42% and 37% of premises, respectively. Smooth concrete was present in 78% of small premises, roughened concrete in 22% and grooved concrete in 11%. Four small premises, one large multi-species, one pig-only premise and one sheep-only premise had smooth concrete flooring throughout. One small premise had a brick floor, and one had wood slats. In large multi species premises, roughened concrete was the commonest floor type, being present in 77% of lairages, followed by grooved concrete (54% of lairages) and then smooth concrete (30%). One lairage had concrete slats as flooring and one had metal slats.

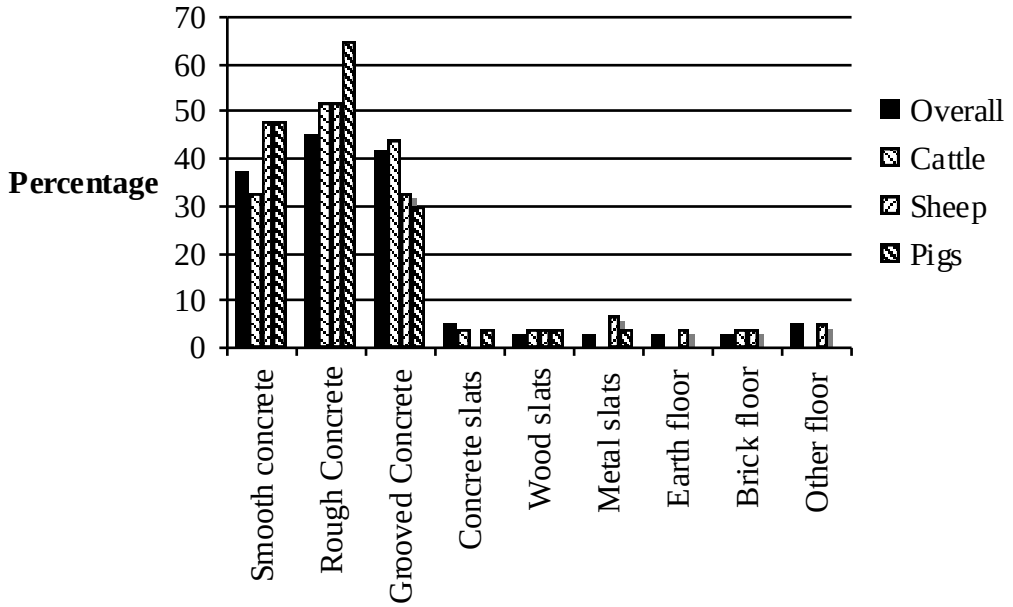

Figure 1. Type of floor construction used in lairages

More cattle-only lairages had grooved concrete flooring (4 of 7) than roughened concrete (3 of 7), and no other flooring type was reported in cattle-only facilities. Whilst in sheep-only premises, smooth, roughened or grooved concrete were each present in 2 of 5 premises. Three sheep-only lairages reported alternative floors, namely earth, plastic and wire grid. Of the 4 pig-only lairages, roughened concrete flooring was found in 3, grooved concrete in 2 and smooth concrete in one, whilst another used concrete slats in the holding pens.

In one lairage, a small operation, a resin-based sealant been applied to the floor. Thirty-four premises (98.5%) had a sloped floor with the 4 exceptions having the brick floor, the plastic floor, the wire grid, and one grooved concrete. Each of these four premises had a single floor type throughout the pre-slaughter area.

3.2.2.2 Perimeter Walls

Perimeter walls of lairages ranged from 0.9 to 6 m in height, and were predominantly constructed of rendered block (27 of 38 premises, 71%) (Figure 2). In eleven lairages, metal comprised part of the perimeter wall, and six lairages had brick walls. Unrendered block was used in 2 premises, whilst three premises reported plastic cladding, concrete or fibrocement panels. In 12 lairages (32%), the wall surface had been painted.

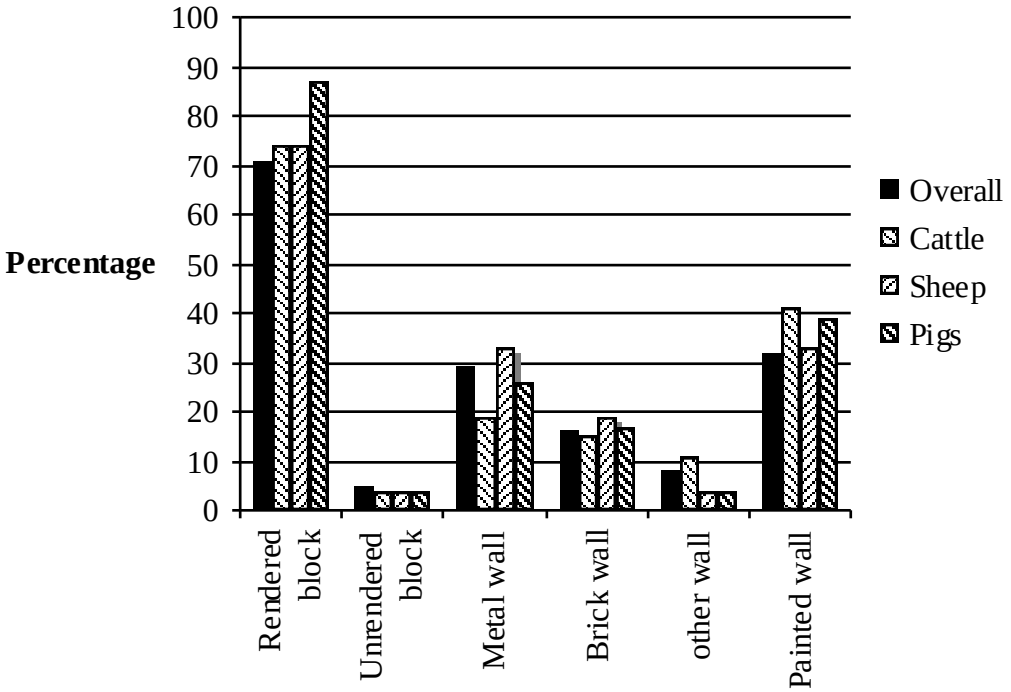

Figure 2. Materials used to construct perimeter wall

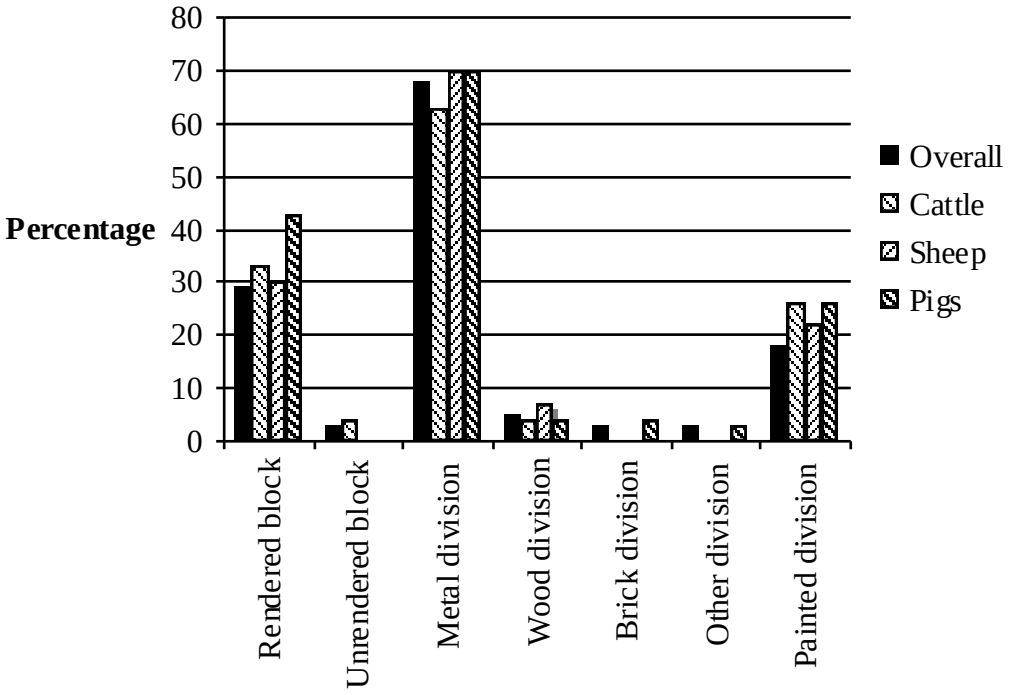

Figure 3. Materials used to construct pen dividers

3.2.2.3 Pen Divisions

Within lairages, pen divisions were up to 2.5 m in height, the lowest being 0.9 m for sheep, 1.1 m for pigs and 1.2 m for cattle. Metal pen divisions were used in 68% of lairages, and rendered block in 29% (Figure 3). Two small premises had wooden pen divisions, one pig-

only lairage had brick, one cattle-only lairage had unrendered block, and one pig-only lairage had concrete slats dividing the pens. At 7 premises, all multi-species, the pen divisions had been painted.

3.2.2.4 Pen Gates

Pen gates ranged from 0.9 m to 2.5 m in height, and were made of metal in 95% of cases. Wooden gates were only present in 2 of the 9 (22%) small abattoirs.

3.2.2.5 Drinkers

Troughs were used in 17 (45%) lairages to supply drinking water, and bowls in 18 (47%). Nipple drinkers were used in 3 of 4 pig-only abattoirs, and were present in one large multi-species abattoir. In small plants, bowls were more common (78%) than troughs (22%), and bowls were more often used in facilities processing sheep (66%) and pigs (61%), than troughs (33% and 13% respectively).

3.2.2.6 Ventilation

Eighteen (47%) premises, all with large throughputs, used a combination of ventilation strategies with Yorkshire boarding (16 premises, 42%) and raised roof ridge (11 premises, 29%) being the most common single ventilation technologies (Figure 4). Windows were present in a third of the small premises, and a raised ridge in 2 (22%).

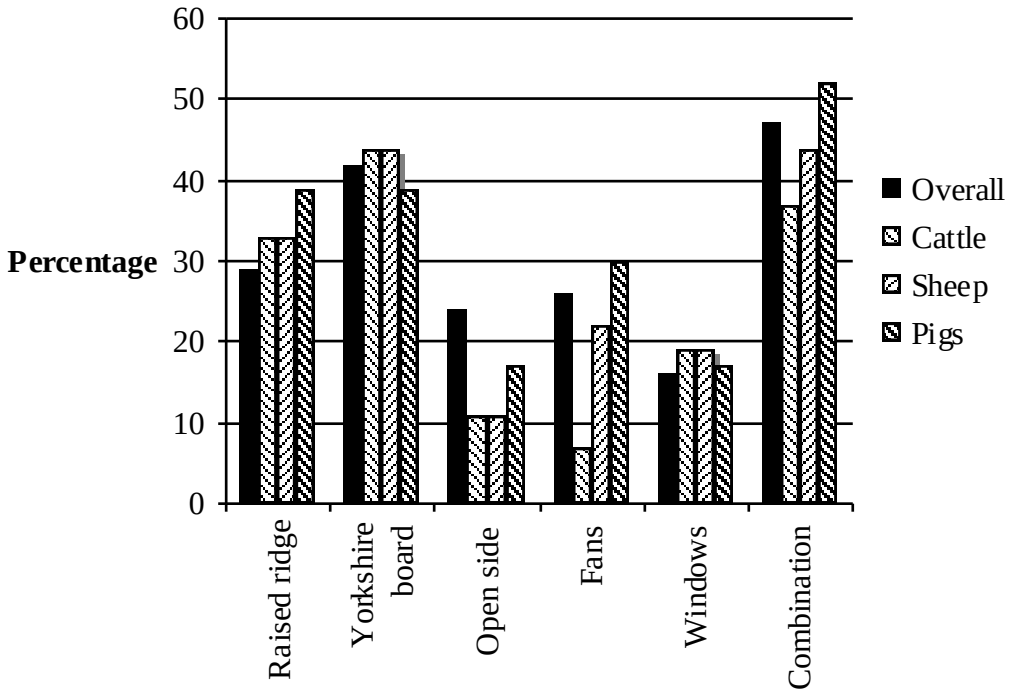

Figure 4. Types of ventilation used in lairages

In all four pig-only lairages, there were both fans and an open side, whilst Yorkshire boarding or raised ridge were only used in one pig-only lairage each. Fans were not used in any of the 7 cattle-only lairages, and a raised ridge was only present in one. Yorkshire boarding or fans were present in 3 sheep-only lairages, whilst raised ridge, windows or open side were represented in one sheep-only lairage apiece.

3.2.2.7 Race, Stun Box and Roll-out Areas

Twenty-four abattoirs gave information on the race leading up to the stun box. Races ranged from 3 to 30 m in length in single species, and would hold up to 15 cattle, 21 sheep or 30 pigs. In multi-species premises, the races were shorter, and held up to 4 animals in small plants and up to 5 in larger plants. Group stunning pens were used for sheep and pigs in all small premises, and in the majority of large premises (92% of multi-species, 20% of sheep-only and 75% of pig-only premises). One multi-species abattoir and four sheep-only abattoirs had a restrainer-conveyor system, and one pig-only abattoir used gas stunning.

Overall, solid concrete was by far the most common construction for the roll out area for stunned animals (Figure 5). In all small premises surveyed the roll out area was solid concrete. While this was the case in 6 of 13 (46%) large multi-species premises, 3 of 7 (43%) cattle-only premises, 1 of 5 (20%) sheep-only premises and 3 of 4 (75%) pig-only premises. Stunned animals rolled onto solid steel in one each of the single-species abattoirs, and onto a slatted steel or grid surface in 5 of 13 (38%) multi-species premises, 3 of 7 (43%) cattle-only premises and 3 of 5 (60%) sheep-only premises. One multi-species abattoir, which processed sheep, pigs and calves, but no adult cattle, shackled the animals in the stun box, which had a concrete floor, and one had a tiled roll-out area.

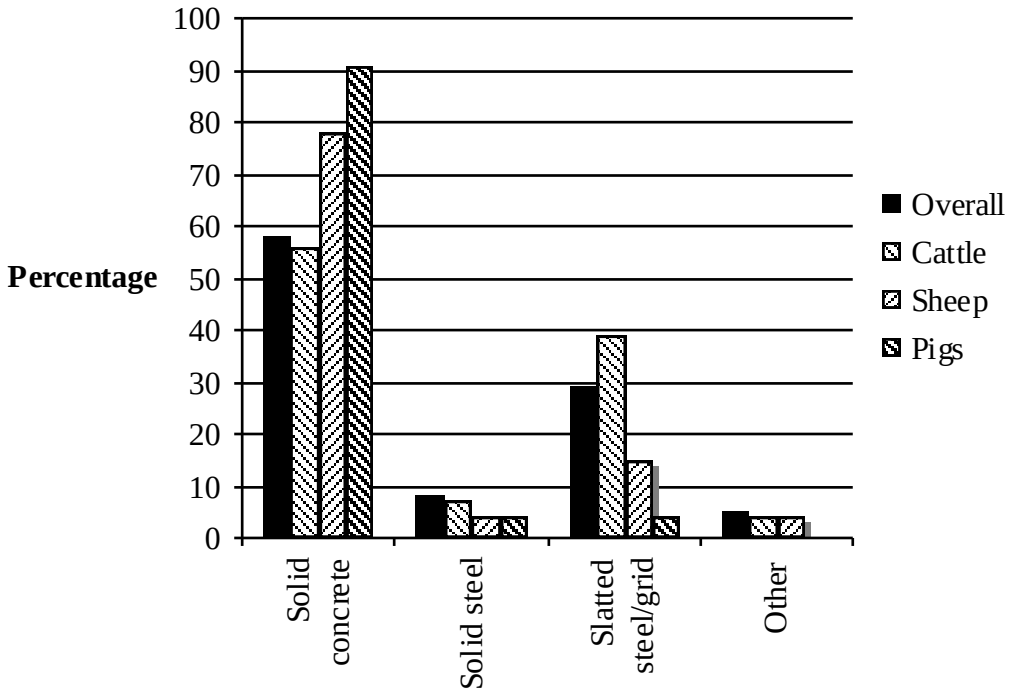

Figure 5. Surfaces used for roll out area

3.2.3 Animal Handling Practices

3.2.3.1 Animals Processed

In Low-throughput (small) plants, operating on one day each week, animals were delivered in small groups of less than 6 cattle or less than 25 sheep or pigs in the majority of cases. One of the 9 small plants estimated that up to 10% of deliveries of sheep would be greater than 25, but less than 100. Up to 7 cattle, 70 sheep and/or 50 pigs may be processed each week in a small plant. Among the large (Full-throughput) plants, multi-species plants reported up to

320 cattle, 2000 sheep and 1500 pigs processed each week, being delivered in small, medium and large groups. Large single-species operations received predominantly medium (6-18 cattle or 26-100 sheep/pigs) or large deliveries of animals, and processed up to 1500 cattle, 11000 sheep or 75000 pigs each week.

3.2.3.2 Holding of Animals

Animals that were slaughtered on the day of arrival were held for up to 6 hours (mode 2 hours) in the lairage prior to slaughter, the single species abattoirs successfully reducing this to less than 4 hours, whilst animals held overnight remained for up to 48 hours in the holding pens (mode 16 hours). Ten of the 38 abattoirs (26%), of which 8 were small abattoirs, never held animals overnight. Most premises attempted to keep producer groups of animals separated during pre-slaughter holding (30 of 38, 79%), but two multi-species large plants and one cattle-only plant declared that mixing was common, and mixing occurred occasionally in one small plant, two multi-species large plants, one cattle-only plant, one sheep-only plant and two of four pig-only plants. During a working day, up to 25 groups of animals (mode 2) would pass though each holding pen, except in one large sheep-only abattoir, where up to 200 groups of sheep could pass through a holding pen in a single working day. Animals progressed from the holding pens to the stunning area via a droving passage in 30 of 38 abattoir lairages (79%), and were moved from pen to pen in 9 abattoirs (24%). One small abattoir used both routes to move animals through the lairage. Pen to pen transfer was used in half of the small abattoirs (5 of 9) and in 2 of 4 large pig-only abattoirs, in 2 multi-species large abattoirs and in one cattle-only abattoir.

3.2.3.3 Bedding

Straw was the most common type of bedding used in the lairages (Figure 6). Wood shavings were used in one small premise, two large multi-species premises, and one pig-only premise. Amongst the abattoirs providing bedding to animals, the pig-only and cattle-only premises provided bedding only to animals held overnight, whilst in sheep-only abattoirs bedding was provided to all animals in 2 and overnight only in one. In small premises, one gave bedding to all animals, and one gave bedding only to animals held overnight, whilst in large multi-species premises, 6 (55%) gave bedding to all animals, and 4 (36%) gave bedding only to animals held overnight. Abattoirs that normally did not normally provide bedding would provide bedding when they considered appropriate, e.g. when animals were wet or dirty.

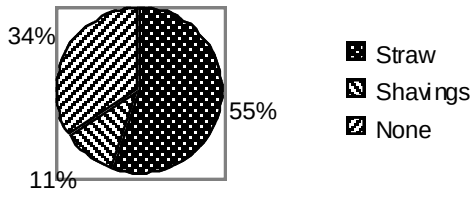

Figure 6. Percentage of lairages using different types of bedding

3.2.3.4 Field Lairages

Twelve abattoirs (32%) had field lairages, of which eight provided shelter. Up to 1000 sheep, 220 pigs or 150 cattle could be held in these facilities, and producer groups would seldom be mixed.

3.2.4 Cleaning Practices

3.2.4.1 Cleaning of Holding Pens

Most of the lairages that provided bedding to the animals, removed the stale bedding on a daily basis or after each group of animals (Figure 7). Neither cattle-only nor sheep-only plants removed bedding after each group, unlike 1 out of 3 pig-only plants. Two of 3 pig-only and 2 of 3 cattle-only plants removed bedding on a daily basis, whilst 2 of 3 sheep-only premises removed bedding weekly. Fresh bedding was laid after each group of animals in 5 large multi-species lairages and 1 pig-only lairage, overall 24% of premises providing bedding. Eleven premises (44%) gave fresh bedding daily, and only one small premises and one sheep-only plant reported fresh bedding being given on a weekly basis.

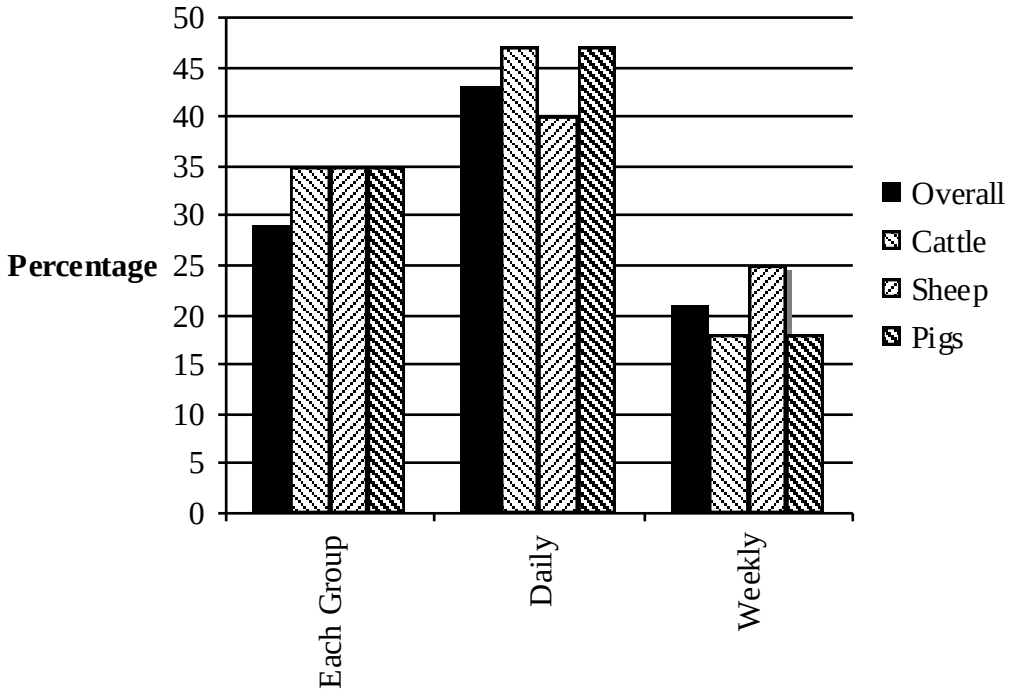

Figure 7. Frequency of removing bedding, as a percentage of lairages that used bedding

Holding pens were washed out after each group of animals in 7 lairages (18%), daily in 15 (39%) and weekly in 11 (30%). In cattle-only premises and pig-only premises, pens were washed out daily or after each group, whilst in sheep-only premises, the pens were washed out daily or weekly. Pressure washing or steam-cleaning was carried out after each group in 2 premises (5%), in 18 premises (47%) daily and in 11 premises (30%) weekly. One small abattoir and one large multi-species abattoir reported the use of detergents in the holding pens after each group of animals, but on the whole, the use of detergents and disinfectants tended to be on a weekly basis (30% and 34% of premises, respectively) rather than daily (18% and 13%). Two premises reported that chemicals were never used in the holding pens, whilst the sheep lairage with the wire grid floor was blow-torched once a week.

3.2.4.2 Cleaning of Drinkers

Thirty-one premises gave information on the method of cleaning of the drinkers in the lairage, and 33 gave information on how often the drinkers were cleaned. Pressure washers or Steam cleaners were used in 15 premises (48%) to clean the drinkers, manual cleaning was used in 9 (29%), and in five premises (16%), the drinkers were hosed. A further 2 premises reported a continuous flow of water was used to clean the nipple drinkers. Manual cleaning was used in 3 large multi-species lairages, in 2 cattle-only lairages and in all 5 of the sheep-only lairages, 2 of which described drinker cleaning as "with a cloth". All the small premises that responded used pressure washers (86%) or hosing (14%) to clean the drinkers. In most premises (70%), drinkers were cleaned on a daily basis, but in large multi-species lairages, the drinkers were cleaned weekly in 9 of 13 plants (69%) and daily in 3 (23%). Two small plants, and one each of large multi-species, cattle-only and sheep-only cleaned the drinkers after each group of animals.

3.2.4.3 Cleaning of Race, Stun Box and Roll-out Areas

The race was cleaned after each group of animals in five premises, four of which were small plants, and the fifth a multi-species large plant. In 14 lairages (37% overall), the race was cleaned during each break, and in 12 (32%) on a daily basis. Two of five sheep-only plants cleaned the race once a week, whilst the remaining three cleaned the race each break. Three pig-only plants cleaned the race each break, and the fourth did not answer this question. Of the cattle-only plants, 4 of 7 (57%) cleaned the race daily, and 3 of 7 (43%) after each group, whilst in the multi-species plants 6 of 13 (46%) cleaned the race daily, and 5 of 13 (38%) after each group. Two abattoirs reported that they never used chemical cleaning agents in the race, and two used chemicals sometimes. Half of the small premises used chemicals daily when cleaning the race, as did a third of multi-species and a third of pig-only plants. Of the sheep-only plants, one used chemicals each break, two daily and two weekly, while two cattle-only plants used chemicals in the race weekly.

Five premises cleaned the stun box between groups of animals, one of which was a sheep-only plant, and four were small plants. One of these small plants used a chemical cleaning agent in the stun box between each group. The majority (45%) of premises cleaned the stun box each break and 32% cleaned it on a daily basis (Figure 8). Four abattoirs (10%) did not answer this question. Single species premises were more likely to clean the stun box each break (cattle 71%, sheep 60%, pigs 75%) than daily (29%, 20%, 25%), whereas the multi-species premises showed an even split between each break and daily. Two premises never used chemicals when cleaning the stun box, and two used chemicals sometimes. Forty-one % of the abattoirs that responded used chemicals daily in the stun box and 18% in breaks (Figure 8).

In 6 premises (16%), four of which were small plants and two large multi-species plants, the rollout ramp was cleaned between animals. In a further 6, 3 small and 3 large multi-species, it was cleaned after each group, and in four it was cleaned daily. The majority (47%) of large premises (6 of 13 multi-species, 46%, 6 of 7 cattle-only, 86%, 4 of 5 sheep-only, 80%, 2 of 4 pig-only, 50%) cleaned the rollout ramp at each break. Chemical cleaning agents were used on a daily basis in 43% of plants and at each break in 11%. Five percent of plants each claimed to use chemicals when cleaning the rollout ramp after each animal, after each group and on a weekly basis, while two abattoirs never used chemicals on the rollout area.

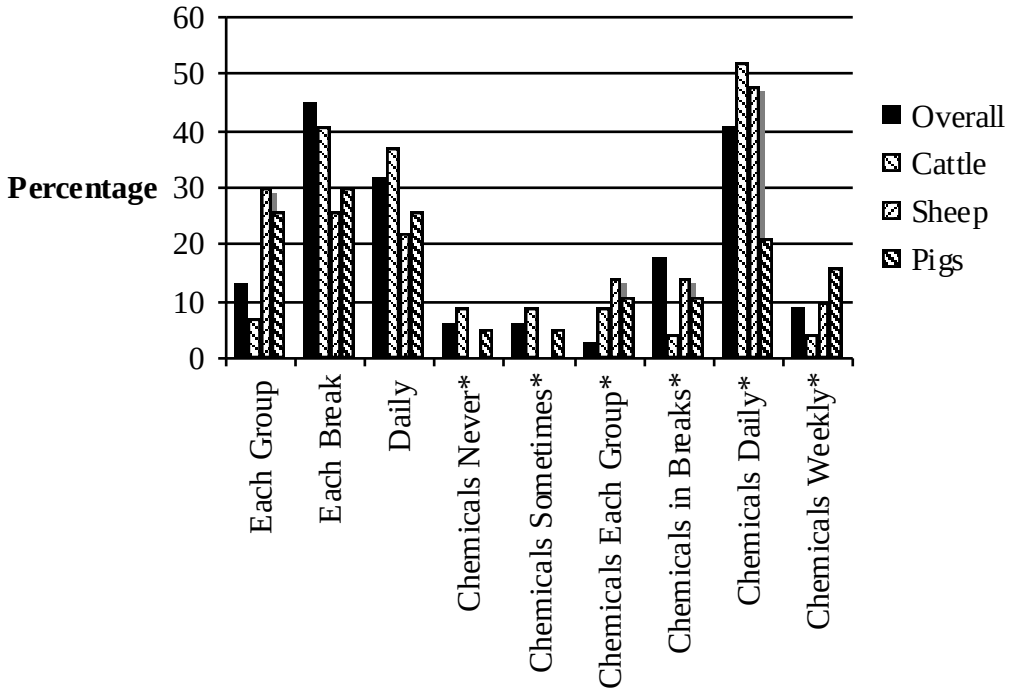

Figure 8. Frequency of cleaning and use of chemicals in stun box, * adjusted for number of responses

3.2.4.4 Use of Chemical Cleaning Agents

A total of 22 branded cleaning chemicals were used in the pre-harvest area in the 38 abattoirs surveyed. Eleven abattoirs indicated that chemicals were never used in the lairage. Of the active ingredients reported, half were acidic or alkaline detergents, a quarter were chlorinated products and a quarter were Quaternary Ammonium Compound based sanitisers. The chemicals were mixed using automatic dosing equipment in 13 abattoirs (48%), manually using a jug in 10 abattoirs (37%), and "judged by eye" in one. The small abattoirs used a jug or visual measuring, whilst automatic dosers were used in the large multi-species and two sheep-only abattoirs. Of the 27 premises using chemicals, 10 rinsed the chemical solution off with plain water. Choice of chemical was based primarily on efficacy (41% of respondents) and operator safety (31%), while 15% chose a chemical because 'it was recommended by the Competent Authority' and two chose the product based on price.

3.2.5 Discussion and conclusions

Overall, the method of construction found in UK commercial red meat abattoir lairages at the present time seem similar to those premises described in the literature, consisting of concrete flooring, or concrete or wood slats, with solid walls and a tubular metal gate and straw bedding (Cockram & Corley, 1991; Jarvis & Cockram, 1995; Jarvis *et al.*, 1996).

The main recommendations in respect to animal welfare (Grandin, 1990), the provision of non-slip flooring, had been adopted in 31 of the 38 abattoirs (82%), although the preferred grooved flooring was present in only 42% of lairages. Research in the USA in the 1990s found that all their sheep and pig abattoirs had good non-slip flooring in the opinion of the researcher, but only 80% of cattle abattoirs had acceptable flooring (Grandin, 1997). The results are comparable with the findings of the current study. Small premises in the UK were more likely to have smooth flooring than non-slip flooring, suggesting that animal welfare may be compromised in such premises, but large plants were commonly fitted with rough or

grooved flooring. Such welfare-friendly flooring, however, may prove to be less easily to clean than smooth concrete flooring. Slatted flooring, although recommended for abattoir lairages to help maintain animals cleanliness (McGrath & Patterson, 1969), was only found in three of the 38 abattoirs (8%) surveyed. This may be an indication of the industry commitment to welfare over hygiene in designing lairaging facilities. Alternatively, it may be a function of the increased building costs associated with slatted or grid flooring, since below the floor there must be a cleanable slurry tank. Metal pen divisions were slightly more common that solid brick, block or wooden pen divisions, but information was not gathered as to whether these metal divisions were solid or tubular steel. Solid pen divisions may be considered desirable, as animals in pens with solid walls appear more relaxed and quiet than those in open walled pens (Grandin, 1990), and a solid partition would prevent the transfer of manure and soiled bedding from one group of animals to those in the adjacent pen.

The majority of premises handling sheep and/or pigs used a group stun pen. A restrainer conveyor was present in one multi-species and four sheep-only premises, while one pig-only abattoir used a gas stun system. Both these latter stunning systems involve high capital outlay in installation, so for commercial reasons, a group stun pen is the common scenario. Cattle races varied considerably in length, and therefore in capacity, similar to those described in the 1990s (Jarvis *et al*., 1995). A variety of ventilation systems and water delivery units were in use at UK red meat abattoirs. Where bedding was used, straw was the medium most commonly provided, similar to situations previously reported (Jarvis & Cockram, 1995). However, current practice varies from giving bedding to all animals (55% of premises), to giving no bedding at all (34% of those providing bedding). A number of premises (36%) gave bedding only to animals held overnight, while others gave bedding only to groups of animals considered to be dirty. McGrath & Patterson (1969) recommended bedding as a method of encouraging coats to dry and tag to fall off. Provision of bedding may encourage animals to lie down (Gordon & Cockram, 1995), which could be considered an undesirable effect with regard to hygiene, unless the bedding was sufficiently deep, clean and dry to prevent coat contamination, but is considered good practice from an animals welfare point of view, animals choosing straw as a lying substrate over for example slats (Gordon & Cockram, 1995).

The lairage of red meat abattoirs has long been considered a place of resting of animals prior to slaughter, and many animals will lie down. This is particularly true after a period of three hours or more in the lairage, and for young animals such as calves, which are excessively exhausted by the rigours of transportation (Cockram, 1990; Kim *et al*., 1994; Jarvis & Cockram, 1995). Researchers in the early 1990s reported lairaging times commonly between 11 and 28 hours for cattle (Cockram, 1991) and sheep (Jarvis & Cockram, 1995). Warriss et al. found that 40% of lambs remained in the lairage for over 14 hours, while around a third remained for less than 4 hours (Warris *et al*., 1990). The current study found that animals arriving on the day of slaughter were held for up to 6 hours (mode 2 hours) comparable with a 2003 study on pig handling in lairages, which quoted an average of 3.5 hours lairaging, up to a maximum of 5.3 hours (Rostagno *et al*., 2003). Animals held overnight prior to slaughter were found in the current study to remain in the lairage for an average of 16 hours, but up to a maximum of 48 hours, somewhat less than the suggested 72 hours or more of the 1970s (Grau & Smith, 1974).

Social regrouping, or mixing of producer groups, of animals has long been known to have deleterious effects on meat quality due to the stress caused by the subsequent hierarchical interactions of the animals concerned (Tennessen *et al*., 1985; Gracey & Collins, 1992; Jarvis & Cockram, 1994). As such it is interesting to note that 21% of the premises surveyed admitted that mixing of producer groups did occur in the lairage, and that there was no clear

trend observed within particular subtypes of premises. Even in premises where producer groups were kept separate, up to 25 groups of animals could pass through a single holding pen in a working day. This would mean that microbial contaminants from 25 different sources could potentially be deposited in the holding pen, and the micro-organisms from each of the preceding lots could pose a risk of contaminating the animals subsequently passing through the pen (Small *et al.*, 2002; Collis *et al.*, 2004). Thus, there is a significant possibility of cross-contamination with foodborne pathogens occurring in the lairage of these abattoirs.

Cleansing practices in the premises surveyed were very variable. Small premises were more likely to thoroughly wash and disinfect the lairage after each working day. This may be a function of the fact that these premises operate on one day each week, and have more time available to thoroughly clean the premises. On the whole, holding pens were washed out on a daily basis, and the race, stun box and roll-out ramp at each break. Chemical agents tended to be used daily in the stun box and roll-out areas, which are more likely to be considered as part of the slaughterhall, and weekly in the race and holding pens, if they were used at all. A wide variety of cleaning programmes were reported, and a wide variety of chemical agents. This could reflect the limited guidance available to plant operators, and the plethora of commercial cleaning agents on the market.

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3.3 Task 1.3 Survey of selected lairages via visits

A representative number of abattoirs were selected on the basis of the previous tasks to be visited. The main goals of the visits were to:

- Draw-up a detailed process diagram for lairage-to-stunning operations;
- Identify the routine cleaning/sanitation practices;
- Evaluate the effectiveness of the routine cleaning/disinfection by comparing before and after the treatment, a) the visible cleanliness of the lairage; and b) microbiological parameters from the lairage-to-stunning using environment swabs.

The overall aim was to assess the general status of lairage hygiene, as well as lairage cleaning effectiveness, in commercial abattoirs. This information also helped to guide the experimental approach to identify potential improvements (Objective 2).

3.3.1 Methods

3.3.1.1 Origin of Samples

Five abattoirs participated in the study, and each was visited on two or more occasions to collect samples.

Plant A was a medium sized sheep and cattle plant, processing approximately 700 steers/heifers, 150 bobby calves and 1000 sheep each week. In this plant, pressure washing and quaternary ammonium cleaning products were used in routine cleaning of the stun boxes and roll-out area involved. Cleaning of the holding pens entailed removal of soiled bedding using a pitchfork and scraper, followed by the addition of fresh straw bedding. At the end of each week, all bedding was removed and the pens steam-cleaned and allowed to dry before fresh bedding was laid.

Plant B was a small multi-species plant, processing 6 cattle, 10 pigs and 10 sheep each week, and all areas were cleaned at the end of the processing day using a pressure wash with quaternary ammonium cleaning products.

Plant C was a medium sized multi-species plant processing 1000 pigs, 2000 sheep and 500 bobby calves each week. The stun box was cleaned on a daily basis with a pressure washer and a hypochlorite solution. Whilst the cleaning regime for the holding pens involved removal of soiled bedding and brushing out on a daily basis. The pens were pressure washed using a broad-spectrum virucidal disinfectant solution once weekly, on a rotational basis.

Plant D was a large sheep and cattle plant, processing 1500 steers/heifers and 5000 sheep each week; and plant E was a medium sized cull cow/bull plant, processing 800 cows/bulls each week. Plants D and E were owned by the same company and the cleaning regimes were identical. Stun boxes were cleaned at the end of each working day using a pressure wash, followed by detergent foam clean. This was then rinsed and a terminal quaternary

ammonium sanitizer was applied. The holding pens were pressure washed after each batch of animals, but no chemicals were used.

The stunning facilities used for cattle in all abattoirs A, B, D and E comprised a race leading to an individual stunning box, from which the animal, once stunned, would roll out to be shackled and hoisted. In abattoir D, sheep were processed using a restrainer-conveyor system, with the stunned sheep rolling onto a bleeding table, whilst in abattoirs A, B and C, all the small species (sheep, pigs and calves) were processed through a group stunning pen, where the stunned animal would fall to the floor of the group pen where it was shackled and hoisted.

3.3.1.2 Collection of Samples

A total of 556 samples were taken from various positions in the lairages. The samples were taken from the holding pens and stunning areas early in the morning before animals were delivered and processing began. The lairages had undergone routine cleansing operations at the end of the previous day's processing. Within the holding pens, samples were taken from the floors, walls, edges (two-dimensional junction of floor and wall) and corners (three-dimensional corner between the floor and two walls). In the stunning areas, samples were taken from the stun box walls, floors and corners (three-dimensional corner between the floor and two walls), and from the roll-out ramp in the case of cattle stun boxes or sheep restrainer-conveyor systems.

Samples were collected using gauze swabs (Readiwipes Super, Robinson Healthcare 5345) pre-soaked in 100 ml Buffered Peptone Water (BPW, Oxoid CM0509). Excess BPW was squeezed from the swab into the transport container, and the swab was rubbed vigorously over a measured area 50 cm by 50 cm before being returned to the transport container. Swabs were then stored on ice and returned to the laboratory within 2 hours of collection.

3.3.1.3 Sample Processing

On return to the laboratory, the transport containers containing the swab and BPW were vigorously shaken, and 10 ml decanted into a universal container (UNI1). The original samples were then refrigerated at 4°C. From UNI1, a decimal dilution series was made in BPW, and a 100 µl aliquot from each dilution was spread plated onto TBX agar (Oxoid CM0945) for enumeration of *Escherichia coli* in the samples. The TBX plates were incubated for 4 hours at 37ºC, then transferred to 44ºC for a further 18 hours. Presumptive *E. coli* colonies, showing blue on TBX Agar, were counted on each plate. The dilution series was incubated for 24 hours at 37°C. After this enrichment phase, 0.1 ml was taken from UNI1 and from the refrigerated original sample, and was inoculated into DIASALM selective enrichment medium (Merck 1.09803), and this was incubated at 41.5°C for 24 hours. The original sample and the dilution series were stored under refrigeration at 4°C. On the third day, a 10 µl loopful was taken from each of the DIASALM plates and streaked onto Rambach Chromogenic Agar (Merck 1.07500) for the identification of *salmonella* spp. and incubated at 37°C for 24 hours.

Where cultures showed a presumptive identification of *Salmonella* spp. on Rambach Agar (cerise coloured colonies), the associated dilution series was removed from refrigeration and 0.1 ml from each dilution enriched and plated using DIASALM and Rambach Agar as outlined above. An estimation of the numbers of *Salmonella* organisms in the original sample could then be made, based on the lowest dilution at which *Salmonella* spp were identified on Rambach Agar (Table 3). Presumptive *Salmonella* isolates were confirmed using Api20e strips (Biomerieux 20100). The proportions of samples containing *Salmonella* spp were calculated and compared by χ^2 test, using MINITAB software.

E. coli counts for each sample were expressed as $\log_{10}$ cfu cm^{-2}, and analysed by ANOVA and cross-checked using a Mann-Whitney test, using MINITAB software.

Table 3. Estimation of numbers of Salmonella organisms in original sample

Lowest dilution giving positive result	**Interpretation**
Neat	1-10 organisms in the sampled surface area
-1	10-100 organisms in the sampled surface area
-2	100-1,000 organisms in the sampled surface area
-3	1,000-10,000 organisms in the sampled surface area
-4	10,000-100,000 organisms in the sampled surface area

3.3.2 Results

3.3.2.1 Presence of Escherichia coli

Analysis of the *E. coli* counts from all abattoirs showed that in the holding pens, the walls (HW, -1.2 $\log_{10}$ cfu cm^{-2}) carried significantly less ($P<0.01$) contamination than did the floors (HF, 1.4 $\log_{10}$ cfu cm^{-2}), corners (HC, 1.3 $\log_{10}$ cfu cm^{-2}) and edges (HE, 1.4 $\log_{10}$ cfu cm^{-2}), in which sites the mean *E. coli* counts were not statistically different (Table 4).

Table 4. Mean log *E. coli* counts in holding pens

	Site			
Abattoir	Holding Pen Floor	Holding Pen Wall	Holding Pen Edge	Holding Pen Corner
A	2.6^{a} (0.8)	$-1.2^{c,e}$ (1.0)	2.6 (0.7)	2.8 (0.8)
B	0.4^{b} (1.7)	$-1.7^{d,e}$ (0.8)	1.0^{f} (0.9)	$0.3^{g,h}$ (2.5)
C	0.8^{b} (1.9)	$-1.3^{c,d,e}$ (1.1)	1.2^{f} (2.0)	$1.3^{g,h}$ (1.9)
D	2.1^{a} (1.0)	-0.7^{c} (1.2)	1.2^{f} (1.0)	1.7^{h} (0.7)
E	0.7^{b} (1.9)	$-1.5^{d,e}$ (0.8)	0.3^{f} (2.1)	0.1^{g} (1.7)
Overall means	1.4^{i} (1.7)	-1.2 (1.1)	1.3^{i} (1.7)	1.4^{i} (1.7)

Standard deviations shown in parenthesis, Values sharing similar superscripts are not statistically different.

Counts on holding pen floors at abattoirs A and D were significantly greater than those on holding pen floors at abattoirs B, C and E, while counts on holding pen walls were similar at each abattoir. Abattoir A also showed significantly higher *E. coli* counts at the holding pen edge (2.6 $\log_{10}$ cfu cm^{-2}) and at the holding pen corners (2.8 $\log_{10}$ cfu cm^{-2}) than the other abattoirs visited (mean 1.3 $\log_{10}$ cfu cm^{-2}), suggesting that the cleaning regime in place at this abattoir was less effective than those utilised at the other premises.

E. coli counts in the stun-box-roll-out area (Table 5) were on the whole substantially lower than those found in the holding pens, with the exception of the holding pen walls. The highest counts found in the immediate pre-slaughter areas were in the corners of cattle stun boxes (1.3 $\log_{10}$ cfu cm^{-2}), where residual faecal matter had been trapped. The corners of small species group stun pens yielded lower counts than cattle stun boxes, possibly due to the nature of the small species facility, being a larger space, with easier personnel access for cleaning. There was little difference in mean *E. coli* count in the stun-box-roll-out area between individual abattoirs, although abattoir A did have a significantly greater count on the small species stun box floor (2.0 $\log_{10}$ cfu cm^{-2}) than other similar facilities (mean –0.4 $\log_{10}$ cfu cm^{-2}).

Table 5. Mean log *E. coli* counts in the stun-box-roll-out area

Abattoir	Site						
	Cattle Stun Box Floor	Small Species Stun Box Floor	Cattle Stun Box Wall	Small Species Stun Box Wall	Cattle Stun Box Corner	Small Species Stun Box Corner	Cattle Roll-out Ramp
A	$0.8^{a,b}$ (1.1)	2.0^{b} (0.0)	$-2.0^{e,f}$ (0.0)	$-1.7^{f,I}$ (0.7)	$1.0^{j,k}$ (0.5)	$1.0^{k,m}$ (0.5)	-0.2^{n} (1.0)
B	0.6^{c} (1.2)	$-1.1^{c,d}$ (1.4)	$-1.6^{e,g}$ (1.0)	$-1.8^{g,I}$ (0.6)	$0.3^{j,l}$ (1.6)	-1.3^{l} (1.2)	-2.0^{p} (0.0)
C	No cattle facility	-1.1^{d} (1.4)	No cattle facility	-2.0^{i} (0.0)	No cattle facility	2.5^{m} (1.8)	No cattle facility
D	1.1^{a} (1.9)	Restrainer conveyor	$-2.0^{e,h}$ (0.0)	$-2.0^{h,I}$ (0.0)	1.0^{j} (2.0)	Restrainer conveyor	$-1.7^{p,q}$ (0.7)
E	0.3^{a} (1.9)	No small species	-1.4^{e} (1.1)	No small species	2.1^{j} (0.9)	No small species	$-0.5^{n,q}$ (1.9)
Overall means	0.2^{r} (1.7)	$-0.4^{r,s}$ (1.8)	-1.6^{t} (0.9)	-1.9^{t} (0.4)	1.3^{u} (1.4)	$0.4^{s,u}$ (2.1)	-1.1 (1.4)

Standard deviations shown in parenthesis, Values sharing similar superscripts are not statistically different.

3.3.2.2 Presence of Salmonella *spp.*

Overall, 36 of the 556 (6.5%) samples taken were positive for *Salmonella* spp, and the numbers present ranged from <10 to <10,000 (Table 6). No *Salmonellae* were found on the stun box walls or the roll-out ramps. High estimated numbers of organisms were not associated with any one particular sampling site, but positive samples originated from sites where the swab collected visual contamination, or where the integrity of the surface sampled had been broken due to corrosion of metal or shattering of concrete. These areas are those where cleaning had been insufficient to remove contamination, either due to lack of cleansing in pens where physical removal of bedding was the cleaning method employed, or due to the damage in the corners and edges of the lairage and pre-slaughter areas allowing contamination to collect and be by-passed by the cleansing process.

Table 6. Samples taken at each abattoir (showing numbers of samples positive, with estimated numbers of *Salmonellae* in each positive sample in parenthesis)

	Abattoir A		Abattoir B		Abattoir C		Abattoir D		Abattoir E		Total	
Sample site	N =	N = Positive	N =	N = Positive	N =	N = Positive	N =	N = Positive	N =	N = Positive	N =	N = Positive
Holding pen wall	20	0	15	0	25	0	25	1 (1-10)	15	0	100	1 (1-10)
Holding pen floor	20	3 (10-100)	15	0	25	3 (10-100) 2 (1-10)	25	1 (1-10) 1 (10^2-10^3)	15	0	100	1 (10^2=10^3) 6 (10-100) 3 (1-10)
Holding pen corner	12	1 (10-100) 1 (10^2-10^3)	5	0	23	0	13	4 (1-10)	12	0	65	6 (1-10) 1 (10-100) 1 (10^2-10^3) 1 (10^3-10^4)
Holding pen edge	12	0	4	0	26	5 (1-10) 1 (10^3-10^4)	13	1 (1-10) 1 (10-100) 1 (10^2-10^3)	10	0	65	4 (1-10) 1 (10-100) 1 (10^2-10^3) 1 (10^3-10^4)
Stun box wall	6 beef 6 sheep	0 0	12 beef 11 smalls	0 0	6 smalls	0	6 beef 12 sheep	0 0	15	0	39 beef 17 smalls 18 sheep	0
Stun box floor	6 beef 6 sheep	2 (10-100) 1 (1-10)	12 beef 11 smalls	0 0	9 smalls	0	6 beef	0	15	1 (10^2-10^3) 1 (1-10)	39 beef 20 smalls 6 sheep	1 (1-10) 2 (10-100) 1 (10^2-10^3) 1 (1-10)
Stun box corner	4 beef 4 sheep	1 (1-10) 1 (10-100)	6 beef 7 smalls	0 0	5 smalls	1 (10^2-10^3)	4 beef	1 (10^2-10^3)	610	1 (10-100)	24 beef 12 smalls 4 sheep	1 (1-10) 2 (10-100) 1 (10^2-10^3) 1 (10^2-10^3)
Roll-out ramp	12 beef	0	11 beef	0	-	-	8 beef 24 sheep	0 0	12	0	43 beef 4 sheep	0
										Total	556	36

In the holding areas, it would be expected that abattoirs A and C, where physical removal of bedding was the main cleaning method, would have a greater incidence of *Salmonella* contamination than in abattoirs B, D and E. Abattoirs B and E yielded no *Salmonella* positive samples in the holding pens, suggesting that the cleaning regime in these lairages was sufficient to remove contamination. However, in abattoir D, where the cleaning regime was identical to that of abattoir E, the incidence of *Salmonella* contamination in the holding pens (13.2%) was similar to that in abattoirs A and C (7.8% and 11.1% respectively) (Table 7). Overall incidence of *Salmonella* contamination in the holding areas was 10%, the walls being the least often contaminated. Within individual abattoirs, the contamination of a particular sample site may be as much as 30.8% (holding pen corners, abattoir D). The difficulty of cleaning a corner may contribute to this high result, but also, at this particular abattoir, the drainage for the pens was situated in the pen corners, and it is possible that contamination gathers around the drains.

Table 7. Percentage of samples containing *Salmonella* spp by sampling site

Sample Site	Abattoir A	Abattoir B	Abattoir C	Abattoir D	Abattoir E	Total	Overall
Holding pen wall	0	0	0	4%	0	1%	10.0%
Holding pen floor	15%	0	20%	8%	0	10%	
Holding pen corner	16.7%	0	0	30.8%	0	9.2%	
Holding pen edge	0	0	23.1%	23.1%	0	13.8%	
Total Holding Pens	7.8%	0	11.1%	13.2%	0		
			Cattle				
Stun box floor	33.3%	0	0	0	13.3%	10.3%	16.7%
Stun box corner	50%	0	0	25%	10%	10%	
Total Stun Box	40%	0	0	10%	12%		
			Small Species (Pigs, Sheep, Calves)				
Stun box floor	16.7%	0	0	0	0	3.8%	4.8%
Stun box corner	0	0	20%	0	0	6.3%	
Total Stun Box	10%	0	7.1%	0	0		
Overall Lairage Incidence	9.3%	0	10.1%	9.5%	2.9%		6.5%

16.7% of samples taken from cattle stun boxes were positive for *Salmonella* spp, and the corners (10.3%) and floors (10%) were more likely to harbour contamination than the walls (0). Contamination in the cattle stun box in abattoir A was high (40%), but this facility in particular showed heavy corrosion in the corners and wear to the floor, making it difficult to clean thoroughly. The incidence of *Salmonella* spp in the stunning pens for small species was lower (4.8%) than that for cattle (16.7%), which was not expected, as pigs and calves would be expected to carry greater risk of excreting *Salmonella* spp than cattle. However, the number of samples taken in these areas is relatively low, and this may be an artefact of sample size, rather than an indication that cleaning was more effective in small species stunning facilities that in those for cattle.

Overall incidence of *Salmonella* spp. in the lairages of abattoirs B (0) and E (2.9%) was significantly lower ($P<0.05$) than the incidence in the lairages of abattoirs A (9.3%), C

(10.1%) and D (9.5%), and the incidence of *Salmonella* spp. on holding pen walls (1%), stun box walls (0) and Roll-out Ramps (0) was significantly lower (P<0.01)`than on the other sites sampled. There were no statistically significant differences between the incidences found on holding pen floors (10%), holding pen corners (9.2%), holding pen edges (13.8%), stun box floors (cattle 10.3%, small species 3.8%) and stun box corners (cattle 10%, small species 6.3%).

3.3.3 Observations on the fabric of commercial lairages

During visits to commercial lairages, some specific examples of construction materials, lairage design and potential impediments to good cleansing were observed and photographed.

3.3.3.1 Unloading Areas

Unloading areas at large abattoirs were generally well designed, allowing free movement of animals from vehicles into the lairage, with secure barriers and non-slip flooring (Figure 9), and they were often raised to reduce the slope of the vehicle ramp (Figure 10). The majority of unloading ramps were open to the elements, although some were fitted with a canopy overhead. Unloading areas at small plants were more likely to consist merely of a doorway into the lairage, up to which the vehicle would reverse, and temporary gates or hurdles would be used to guide the animals into the building (Figure 11).

Figure 9. Unloading ramp at a large abattoir

Figure 10. Raised unloading ramp

Figure 11. Unloading area at a small abattoir

3.3.3.2 Holding Pens

A variety of concrete flooring types were seen in commercial lairages: slatted (Figure 12); grooved (Figure 13); and roughened (Figure 14). Slatted flooring was chosen to allow faeces

and urine to drain easily from the pen, and similarly grooved flooring was considered to drain liquids more effectively than roughened concrete floors. However, it was observed that faeces and bedding became compacted in the grooves, and when washing the floor, both grooved flooring and slats appeared to cause a wide dissemination of water, as it splashed back off the vertical surfaces of the slats and grooves. In some lairages, more than one type of flooring was in use (Figure 15), often associated with later additions to the lairage, and where floorings joined, there were often areas of damaged concrete, where bedding, faecal matter and soiled water were observed to collect (Figure 16, Figure 17). Similarly, where the floor joined rendered block walls, there were often areas of damage where contamination could be harboured (Figure 18, Figure 19), and this deterioration was particularly marked around drains (Figure 20). In one premises, heavy corrosion was apparent at the base of galvanised steel pillars supporting the pen gates (not photographed) and faecal material had collected within the structure of the pillar.

Figure 12. Slatted concrete flooring in cattle pens

Figure 13. Straw bedding on grooved concrete flooring

Figure 14. Roughened concrete flooring and galvanised steel holding pen divisions

Figure 15. Join between sections of flooring

Figure 16. Damage to concrete at join between sections

Figure 17. Damage to concrete flooring

Figure 18. Damage to floor-wall junction

Figure 19. Damage to floor-wall junction

Figure 20. Deterioration of concrete around drains

Pen divisions were predominantly made of rendered block or galvanised steel. Some steel divisions were solid, or partially solid (Figure 14), while others were open in structure (Figure 21). In some abattoirs, attempts had been made to prevent cross-contamination between pens by blocking the gap between the floor and the steel pen division with concrete (Figure 22). This concrete strip was showing signs of deterioration at the junction with the floor, making cleansing difficult.

Figure 21. Open structure pen divisions

Figure 22. Concrete sealing base of pen divisions

In some lairages, old doorways (Figure 23) or extensive areas of damage to the fabric of the pen walls (Figure 24, Figure 25) presented significant obstacles to thorough cleansing of the premises.

Figure 23. Unused gateway in holding pen wall

Figure 24. Extensive damage to lairage wall

Figure 25. Loose block in lairage wall

3.3.3.3 Drinkers

A variety of drinker installations were observed in commercial lairages, from mobile drinking bowls (Figure 26) to permanent fixtures. Some were mounted on concrete (Figure 27), affording structural support, while others were hung upon the walls (Figure 28). It was noted that in the latter case, there was plenty of space around bowls to allow cleaning, but troughs that were mounted on legs rather than on concrete often had a quantity of soiled bedding trapped below them (Figure 29). Some modern lairages had troughs fitted into the pen divisions that could be tipped over completely to allow cleaning (Figure 30).

Figure 26. Mobile drinker

Figure 27. Drinking bowl on concrete support

Figure 28. Wall-mounted drinking bowl

Figure 29. Soiled bedding collecting under water trough

Figure 30: Rotating water trough for easy cleaning

3.3.3.4 Races

Galvanised steel formed the walls of most races, and the majority were solid walled (Figure 31), with non-slip flooring, although tubular steel races (Figure 32, Figure 33) were present in some premises, particularly where sheep were being directed to a restrainer-conveyor. Animals commonly came into contact with the walls of the races, and polished areas were apparent on the walls at the height of sheep or cattle bodies (Figure 34). Areas of thick grease from the animal coats surrounded these polished areas. The gates of races also showed polished areas where the rumps of cattle had contacted them on a regular basis, and faecal material was also evident on these gates (Figure 35).

Figure 31. Cattle race

Figure 32. Tubular steel cattle race

Figure 33. Sheep races

Figure 34. Polished area at animal height

Figure 35. Soiling of race gates

3.3.3.5 Stun Box

Stun boxes for sheep and pigs were on the whole, group pens with rendered concrete walls and smooth concrete floors, in good repair and easily cleanable. Some had had stainless steel cladding applied to the walls. This was particularly apparent around the exit to the bleed area and at the shackle return point, both of which, are areas that would be subject to regular impact. Where restrainer-conveyors were used, these were of smooth plastic (Figure 36), and appeared relatively easy to clean, although soiling was sometimes evident where the segments overlapped. Cattle stun boxes, however, seemed very difficult to clean, being solid boxes some 80cm wide and 300cm long, with access only from the race. The side door lifted or rotated to allow the stunned animal to roll out, but this was not a route of access for cleaning. The box also contained various nooks and crannies formed by the installation of head restraining equipment (Figure 37, Figure 38) and the sloped segment designed to guide the body out of the box (Figure 39).

Figure 36. Restrainer-conveyor

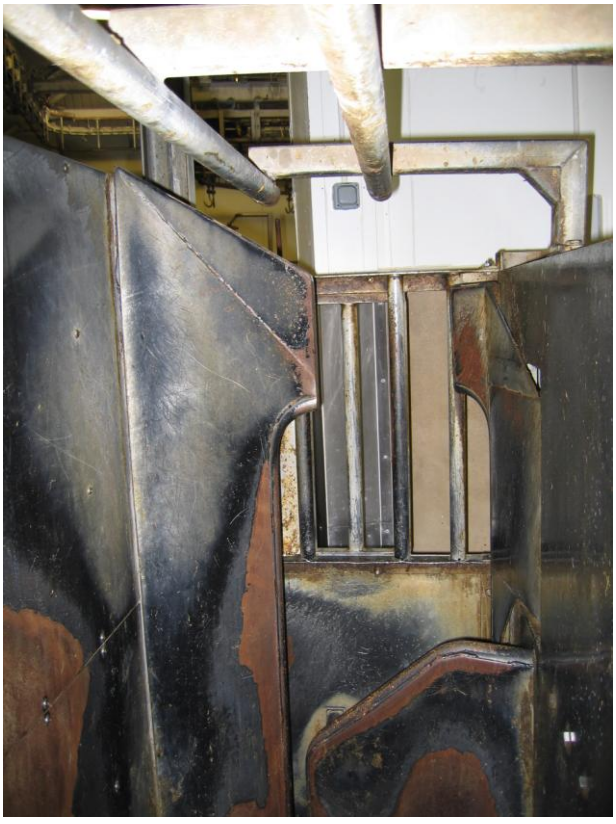

Figure 37. Interior of cattle stun box seen from rear access gate

Figure 38. Cattle stun box head restraint equipment, seen from above

Figure 39: Interior of cattle stun box showing slope and stepped flooring designed to guide the stunned animal out to the left of the picture

3.3.3.6 Roll-out Areas

The majority of sheep and pigs fell to the concrete floor of the group stun pen when stunned, and were hoisted from there, but those processed using a restrainer-conveyor were deposited onto a stainless steel table where they were stuck and hoisted (Figure 40). Cattle rolled from the stun box onto a dry landing area within the slaughterhall proper. This was either the solid concrete flooring of the slaughterhall, which was prone to deterioration with age (Figure 41), or onto a steel grid (Figure 42), which had the advantage that contaminated material could easily be washed away from the landing area. These grids were in good repair, although the edge of the concrete ramp leading to the grid was a vulnerable area and damage was noted in some premises (Figure 43).

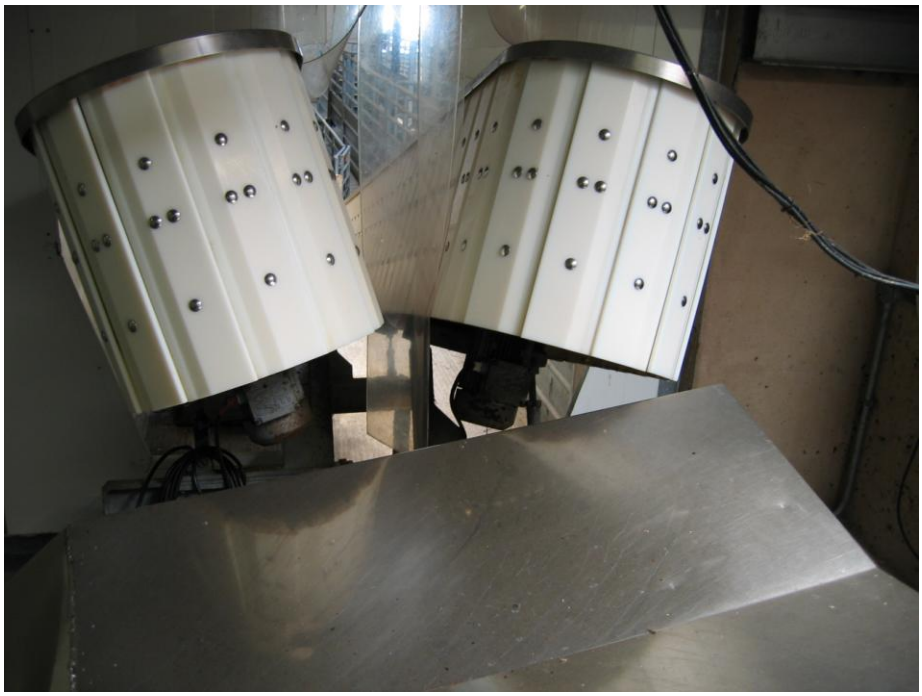

Figure 40. Solid steel roll-out table

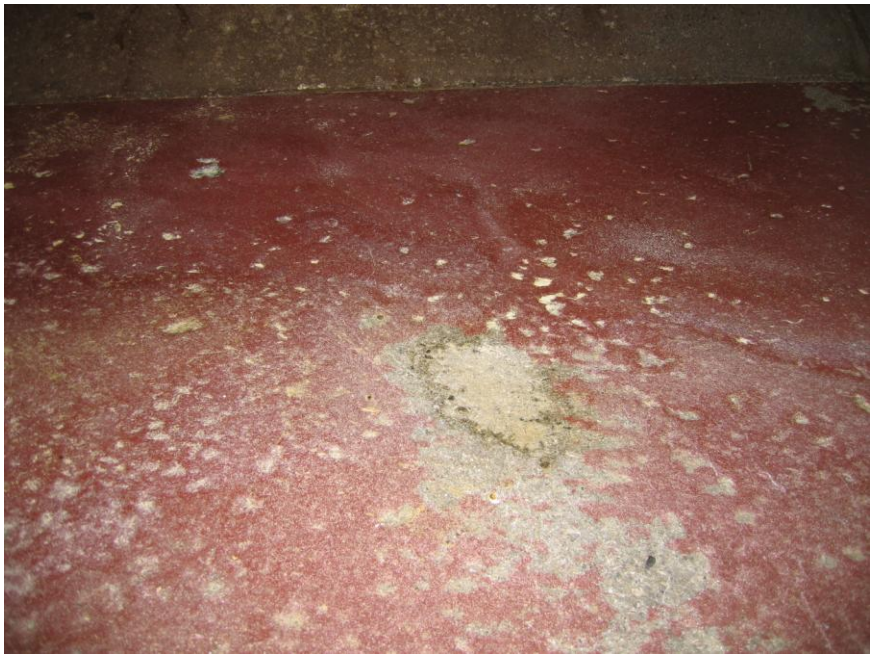

Figure 41. Damaged concrete on cattle roll-out ramp

Figure 42. Steel grid roll-out ramp

Figure 43. Damaged concrete at edge of roll-out ramp

3.3.3.7 Cleaning of Lairages

Following routine cleaning of lairages, the premises appeared at first glance to be of an acceptable standard of cleanliness. However, on closer inspection, remnants of bedding and faeces were often found in the grooves of the flooring, around drains and in the corners of pens. This situation was exacerbated in areas where there was damage to the integrity of the fabric of the lairage.

Figure 44. Grease firmly adherent to race gates

In all premises, a thick layer of grease was found to be firmly adherent to all types of wall material at the level of the animals' trunks (Figure 44), and in one premises, dried faecal matter could be peeled from the wall, where it had been deposited through direct transfer from the floors during pressure-hosing (Figure 45).

Figure 45. Dried faeces on the pen walls

3.3.4 Discussion and conclusions

Microbiological examination of five commercial abattoir lairages found that routine cleaning practices did not entirely remove microbiological contamination, with up to 2.8 $\log_{10}$ cfu cm^{-2} *E. coli* remaining at some sites. This finding concurs with that of a number of other authors (Royal *et al.*, 1970; Oosterom & Notermans, 1983; Swanenburg *et al.*, 2001; Small *et al.*, 2002a; Schmidt *et al.*, 2004). This suggests that there is a significant risk of foodborne pathogens being carried over from one slaughtering day to the next, as these organisms can persist in the environment, particularly in the presence of faecal material (Gibson, 1961; Small *et al.*, 2002b; 2003). Animal holding pens have been shown to quickly become contaminated with organisms such as *Salmonella* spp. (Heard *et al.*, 1972), and animals subsequently held in such pens will in turn become contaminated and pose a risk to the carcass when processed (Grau & Smith, 1974; Hurd *et al.*, 2001; Collis *et al.*, 2004; Larsen *et al.*, 2004).

This study shows that *E. coli* contamination often remains in UK lairage holding pens after routine cleaning operations. It would appear that there are significant differences in the effectiveness of lairage cleaning programmes at commercial abattoirs, and that the stun-box-roll-out areas are often cleaned to a better standard than the holding areas. The cleaning regimes in use in lairages at UK red meat abattoirs are often insufficient to remove *Salmonella* contamination from the holding pens and stun boxes. As a result, there is the risk of *Salmonella* spp persisting in the environment and potentially contaminating animals and carcasses processed on subsequent days. Abattoir managers should take care to ensure that the state of repair of the facility is such that cleaning can be carried out effectively, and put

into place a system of monitoring of the effectiveness of cleaning in removing pockets of contamination.

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4 Objective 2: Identification of best practices for cleaning/disinfection of lairage-to-stunning areas under experimental abattoir conditions

4.1 Task 2.1 Evaluate experimentally various cleaning/disinfection techniques for lairage surfaces

The purpose of this task was to look at the efficiency of different cleaning systems in removing physical and microbial debris of the type likely to be found on lairage surfaces. From the results of the abattoir survey and trials it was clear that floors were more highly contaminated than other surfaces. It was also clear that concrete was the most common surface likely to be found in a commercial situation. It was therefore agreed that the experimental trials would concentrate on the cleaning of a reproducible contaminated concrete floor.

Initially it was thought that the experiments could be carried out in two stages.

1. Systems that were most effective at producing a visually clean surface would be identified.
2. The microbial reductions achieved by the best visual systems would then be evaluated and their performance optimised.

A search was carried out to identify a method of physically contaminating a surface, that would a) be repeatable, b) be similar to that occurring in an abattoir and c) allow the effect of different systems to be quantified. A number of possible contaminants i.e. shaving foam, butter, honey, powder paint, grease, etc were identified. However, in initial trials none were found to even approach the performance required. With some, it was difficult to produce a repeatable application on a concrete surface. With others, all the cleaning methods of interest either removed all traces of the contaminant very quickly or failed to remove them at all. Initial trials with typical lairage contamination showed that in practice most rudimentary cleaning systems could produce a visually clean surface very quickly.

A decision was therefore made to concentrate on the microbial reductions that could be achieved. To achieve this aim 1) a standard surface was required, 2) a standard method of contaminating and inoculating the surface had to be developed and 3) a repeatable method of carrying out the cleaning process identified. A set of identical concrete slabs from the same production batch were purchased and a standard faecal slurry was developed that could be inoculated with the organisms of interest. To overcome the un-repeatability of cleaning by hand a cleaning rig that would accurately control variables such as the distance and angle of attack of the cleaning system to the surface and the cleaning time was then constructed.

4.1.1 Design of rig

In order to achieve consistent repeatable application of the cleaning methods to the test surfaces, a mechanical rig was designed. An aluminium support frame was constructed of beams with 44 mm square profile and T-slot and plates to support a movable carriage and the transmission and the motor used for moving the carriage (Figure 46).

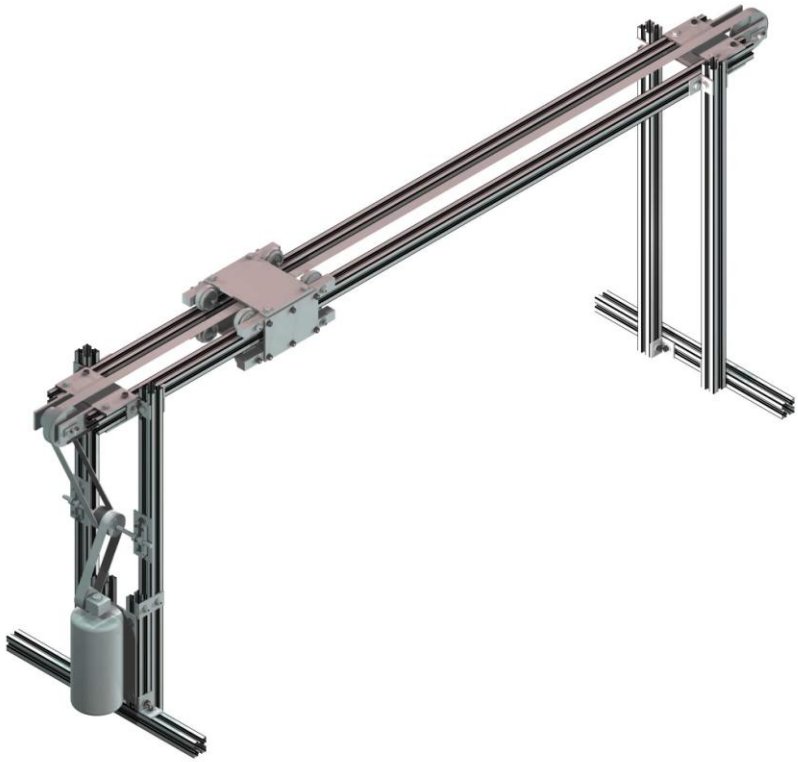

Figure 46. Illustration of full support structure of lairage cleaning rig

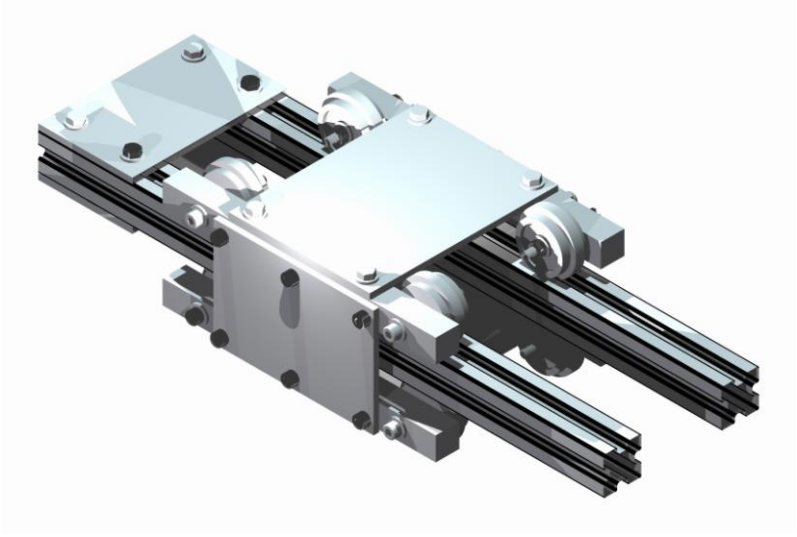

Figure 47. Illustration of carriage and support structure of cleaning rig

The carriage (Figure 47) was designed to hold the spray nozzles and lances in a fixed orientation and move them at a constant speed. The carriage was using a cogwheel-belt system, connected to a frequency-controlled motor (Figure 48). To be able to repeatably set the speed of movement of the cleaning head a relationship was obtained between the motor frequency and the speed of linear movement. This provided a range of carriage speeds from 68 to 300 mm s^{-1}. Figure 49 and Figure 50 give the relationships between frequency and rotation and linear speed.

Figure 48. Main transmission system on cleaning rig

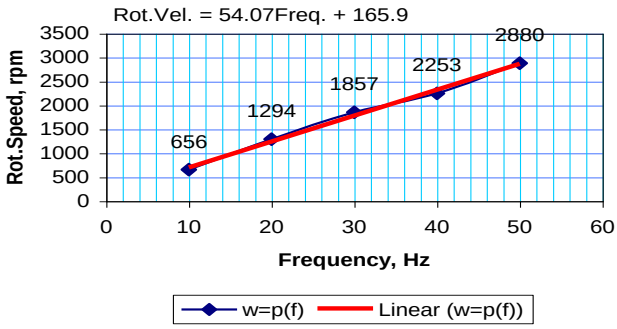

Figure 49. Relationship between rotational speed and supply frequency

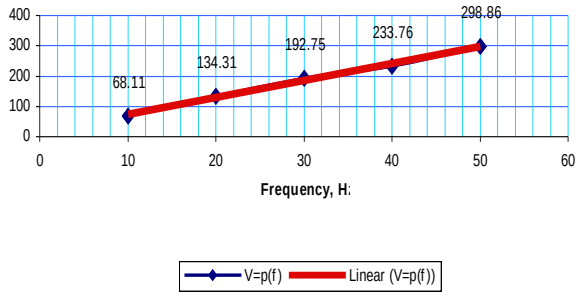

Figure 50. Relationship between frequency and linear speed of carriage

Seven replicated trials were carried out at frequencies between 10 and 59Hz to provide calibration data for the speed of the rig (Table 8).

Table 8. Average carriage speeds at different frequencies

Frequency (Hz)	Distance (m)	Time (s)	Velocity (mm/s)	Motor (r/min)
10	0.97	14.24	68.11	656
20	1.02	7.69	134.31	1294
30	1.09	5.66	192.75	1857
40	1.18	4.78	233.76	2253
50	1.3	4.35	298.86	2880

The carriage bore a simple plate (Figure 51) with two clamps and angle-fixing device for attachment of cleaning lances or spray nozzles. The width of the jets using mains or pressurised was slightly wider than the width of the concrete slab.

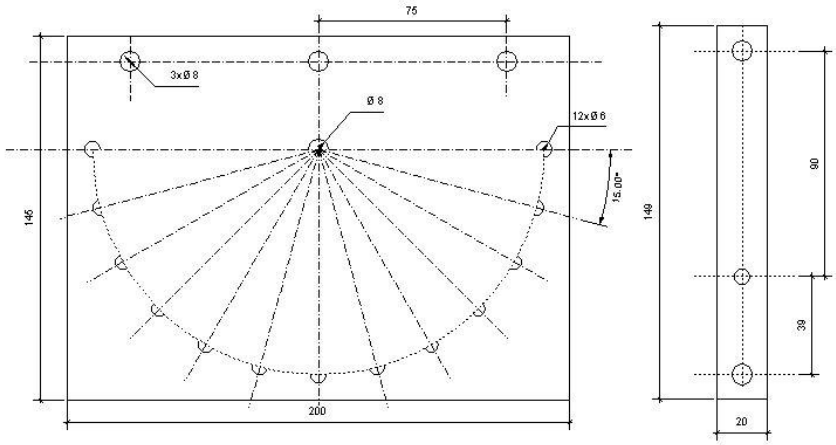

Figure 51. Plate attachment for pressure washer lance

Initial trials, however, showed that to achieve a good visual cleaning action with the steam system the maximum width of the steam jet had to be less than 0.04 m. Therefore, to cover the full width of the slab, a mechanism to provide a side-to-side lateral movement was incorporated into the rig. The mechanism was designed and controlled to produce eight full lateral returns in the course of a single advance pass across the slab.

The rig fitted with a steam-cleaning lance is shown in Figure 52 and in operation in Figure 53.

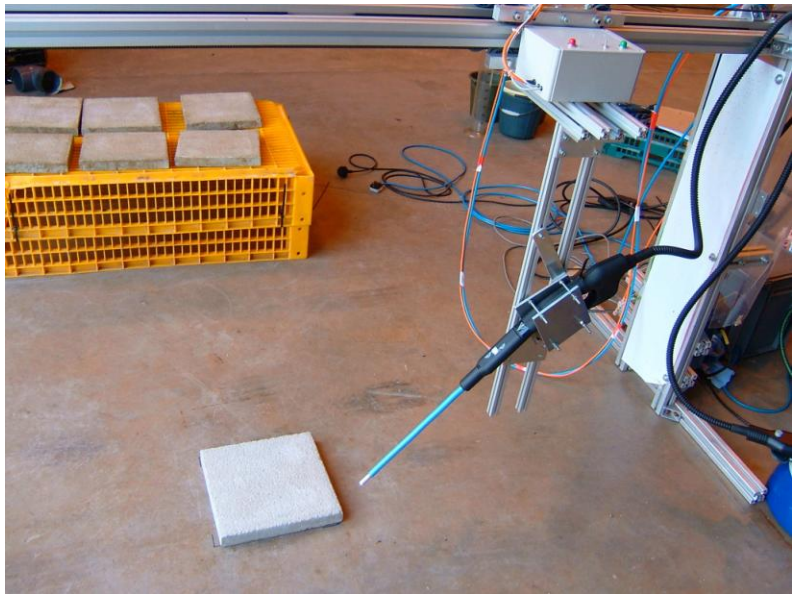

Figure 52. Cleaning rig with steam cleaning system mounted

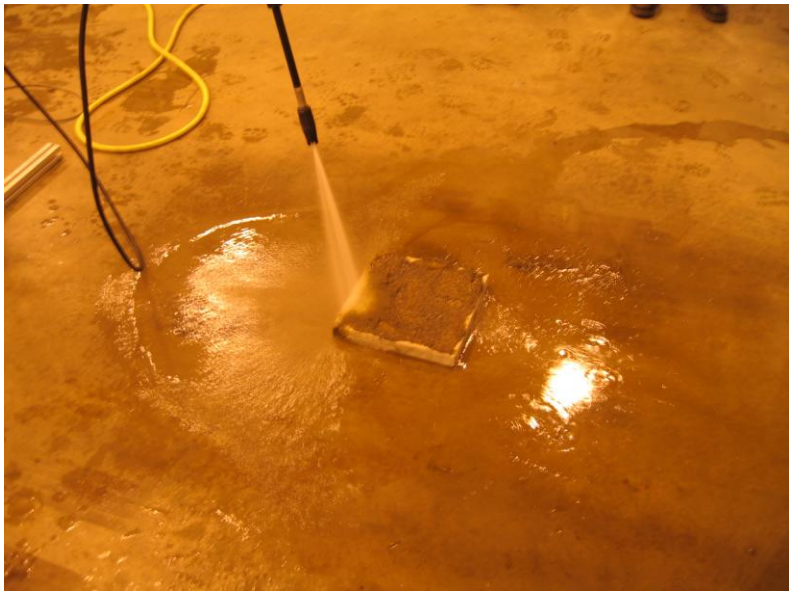

Figure 53. Cleaning of contaminated concrete slab

4.1.2 Experimental trials

Concrete tiles artificially contaminated with field strains of *Escherichia coli* and *Salmonella kedougou*, with and without the presence of bovine faecal matter, were cleaned using the specially designed mechanical rig. Cleaning was carried out using 1) water under mains pressure (PH), 2) water under pressure (PW), 3) water under pressure with a proprietary sanitising agent (J), 4) steam under pressure (S) and combinations of 5) mains water followed by steam under pressure (HS) or 6) water under pressure followed by steam under pressure (PS).

4.1.3 Method

Concrete slabs measuring 0.3 by 0.3 m were prepared to give visually clean but contaminated surfaces (C) by the application of an overnight mixed broth culture of *Salmonella kedougou* and *Escherichia coli*. Applying fresh cattle faeces spiked with the same mixed culture produced visually dirty surfaces (D). Both organisms used had previously been isolated from a commercial abattoir. After preparation of the surfaces, they were allowed to dry for approximately 45 minutes prior to cleaning using the mechanical rig described above. Settle plates of Tryptone Glucose Yeast Agar (Plate Count Agar, PCA, Oxoid CM0325) for aerobic colony count and Violet Red Bile Glucose Agar (VRBG, Oxoid CM0485) for Enterobacteriaceae count were laid out around the rig at a 3 m distance, and also approximately10 m away, behind the rig, in the same air space, in accordance with the plan shown in Figure 54.

Each of 30 visually clean and 30 visually dirty concrete slabs were cleaned using the following methods:

1. Mains water (PH)
2. Pressurised water (PW)
3. Pressurised water with Janitol Sanitiser (DEB Limited, Belper, Derbyshire, UK) (J)
4. Steam under pressure (S)

Mains water (0.3 MPascals pressure) was supplied via a 0.5-inch (12.7 mm) hose to a spray gun (Standard Spray with Pistol Grip - 4605, Siroflex s.r.l., Italy) fitted with a full cone jet. The jet was positioned 1 m above the surface of the concrete slab at an angle of 40° to its surface. Pressurised water was supplied from a pressure washer (Wolf WPW-100, Wolf Power Tools, Omega Sales Ltd, Nottingham, UK) supplying 6.4 l m^{-1} at a pressure of 16 MPascal to a spray lance fitted with a parallel-sided V jet. The jet was positioned 0.35 m above the surface of the slab at an angle of 40° to its surface. Steam was supplied from a steam cleaner (Vaporetto Eco Pro 3000 Lux NV, Polti S.p.A., Bulgarograsso, Italy) supplying steam at a pressure of 0.5 MPascal to a spray lance fitted with a full cone jet. The jet was positioned 0.04 m above the surface of the slab at an angle of 40° to its surface. These highs and angles are typical of those naturally used by a manual operator in a commercial situation.

The width of the jets using mains or pressurised was slightly wider than the width of the concrete slab. However, initial trials showed that to achieve a good visual cleaning action with the steam system the maximum width of the steam jet had to be less than 0.04 m. Therefore to cover the full width of the slab, a mechanism to provide a side-to-side lateral movement was incorporated into the rig. The mechanism was designed and controlled to produce eight full lateral returns in the course of a single advance pass across the slab. In treatments 1, 2 and 3 the motor was set to give a linear speed of 290 mm s^{-1}. For treatment 4 it was set to give a linear speed of 70 mm s^{-1}.

As a result of the data gathered two further sets of 30 visually dirty slabs of concrete were cleaned:

5. Mains water followed by steam (HS).
6. Pressurised water followed by steam (PS).

Samples were taken from each concrete slab immediately prior to the onset of cleaning, immediately after cleaning and after a one-hour drying period, using a wet/dry swab technique over a template area of 100 cm². Samples were placed in a peptone salt solution (Maximum Recovery Diluent, MRD, Oxoid CM0733) in all cases, except for those samples taken after the use of Janitol Sanitiser. In this case, the samples were placed in DEN Rediswabs (International Bio-products), a proprietary neutralising medium for use in situations where chemical sanitisers are used. All the samples were transported to the laboratory and processed within 2 hours of collection. At the laboratory, each sample was vortexed for 1 minute and a decimal dilution series in MRD prepared. The dilution series was then spread plated onto VRBG for the enumeration of Enterobacteriaceae and incubated at 37°C for 24 hours, and onto TBX Medium (Oxoid CM0945) for the enumeration of *E. coli*, and incubated at 37°C for 4 hours, followed by 44°C for 18 hours. The original sample in each case was also plated onto Petrifilm Entero (3M) to reduce the detection limit for Enterobacteriaceae. Following incubation, Enterobacteriaceae and *E. coli* were enumerated for each sample, and mean counts were calculated. Results were analysed by ANOVA and linear regression using MINITAB software.

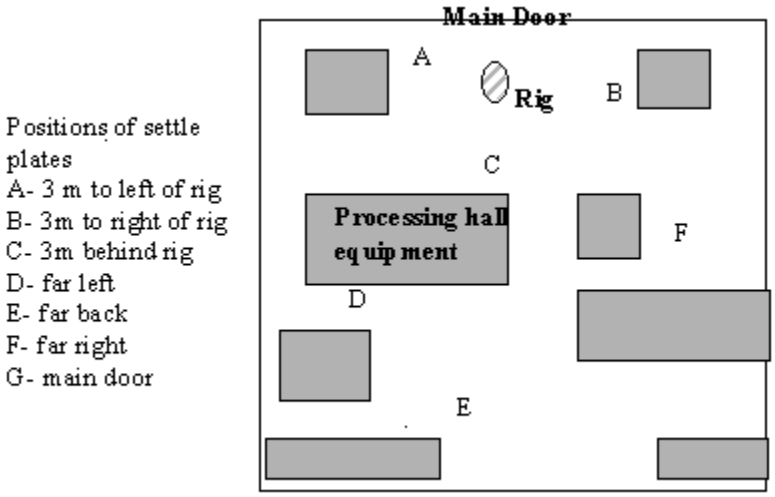

Figure 54. Layout of settle plates around the cleaning rig

4.1.4 Results

The settle plates showed a low level of background microflora in the environment, as indicated by the counts at sites D, E and F. Counts at sites A, B, C and G, 3 m from the cleaning process were greater than those at sites D, E and F some 10 m away. Use of a pressure washer gave a sharp increase in the counts on the settle plates at sites A, B, and G, in all cases when the sanitiser was not used. Using the pressurised steam system (S) resulted in slightly higher counts at sites A, B and G than when mains water (PH) was used (Figure 55 and Figure 56).

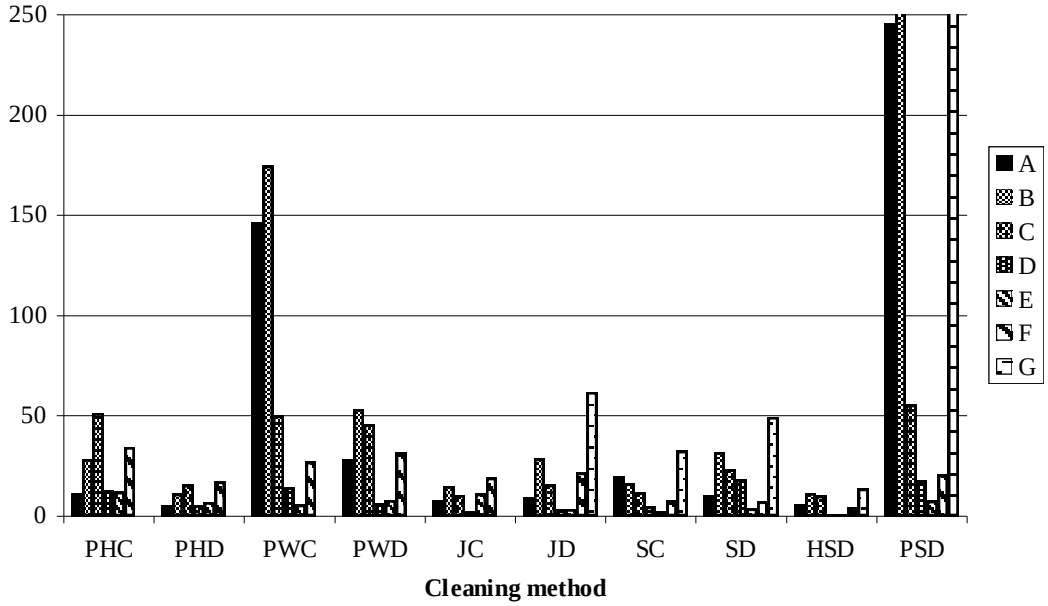

Figure 55. Aerobic plate count on settle plates around cleaning rig (C or D code at the end of each cleaning method code denotes its application to visibly clean (C) inoculated slabs or visibly dirty (D) inoculated slabs)

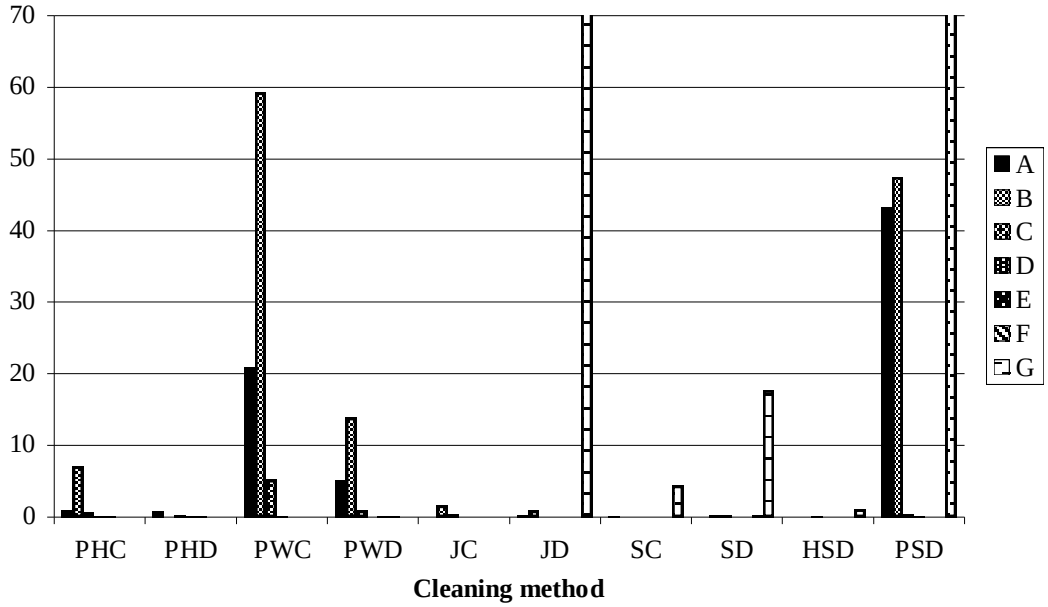

Figure 56. Enterobacteriaceae count on settle plates around cleaning rig (C or D code at the end of each cleaning method code denotes its application to visibly clean (C) inoculated slabs or visibly dirty (D) inoculated slabs)

The effect of each of the cleaning methods on Enterobacteriaceae and *E. coli* count is shown in Figure 57 and Figure 58 respectively, and detailed in Table 9 and Table 10. Regression analysis of the 864 paired Enterobacteriaceae and *E. coli* counts gave a line of best fit of the

equation "Enterobacteriaceae count = 0.442 + 0.983 *E. coli* count" (Figure 59), and a Pearson's correlation coefficient of 0.941, indicating a good positive correlation between the two sets of data.

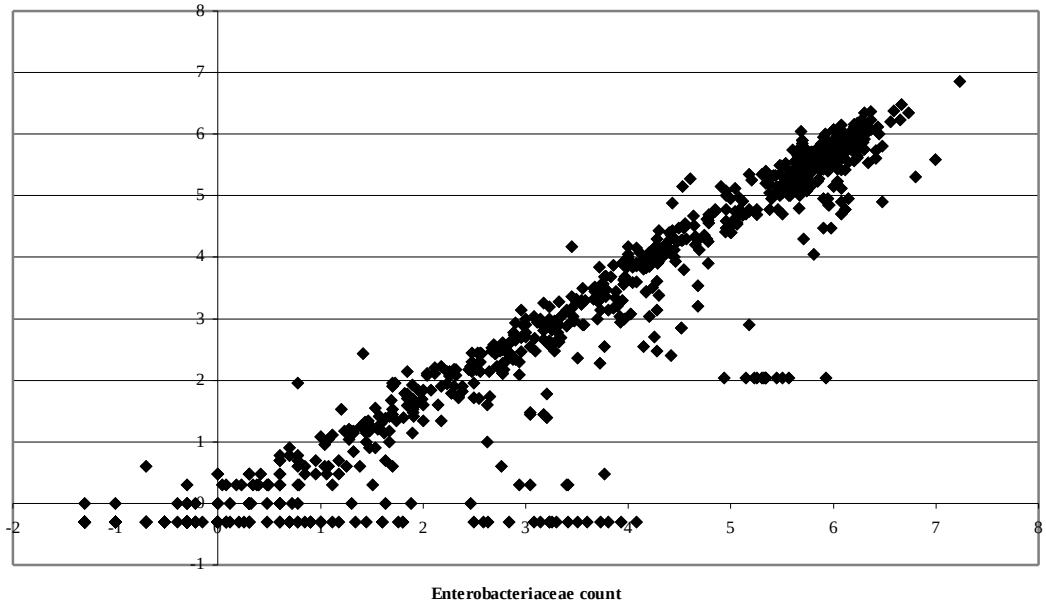

Figure 57. Comparison of Enterobacteriaceae and *E. coli* counts (log_{10} cfu cm^{-2})

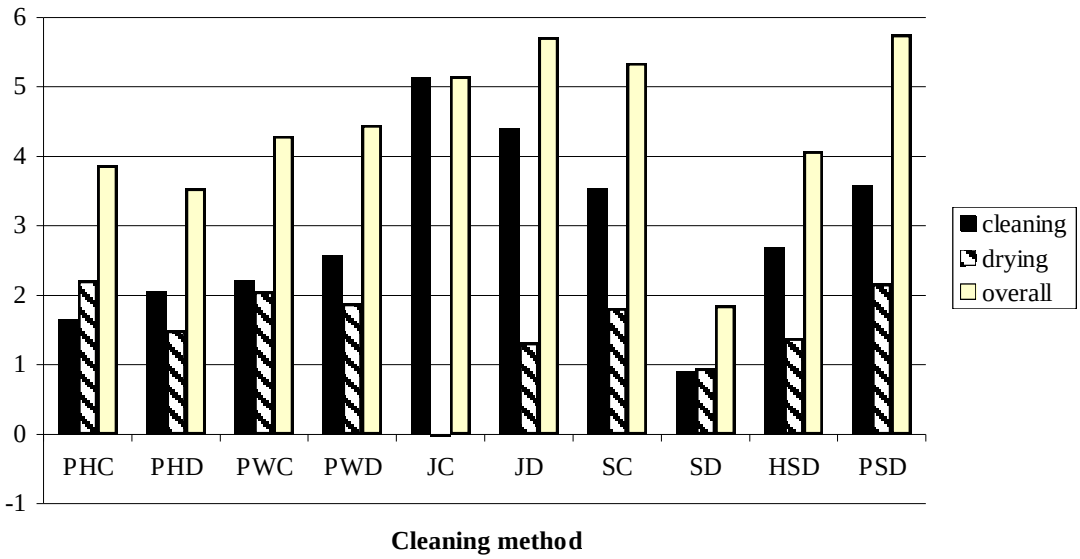

Figure 58. Mean reductions in Enterobacteriaceae count (log_{10} cfu cm^{-2}) as a result of cleaning (C or D code at the end of each cleaning method code denotes its application to visibly clean (C) inoculated slabs or visibly dirty (D) inoculated slabs)

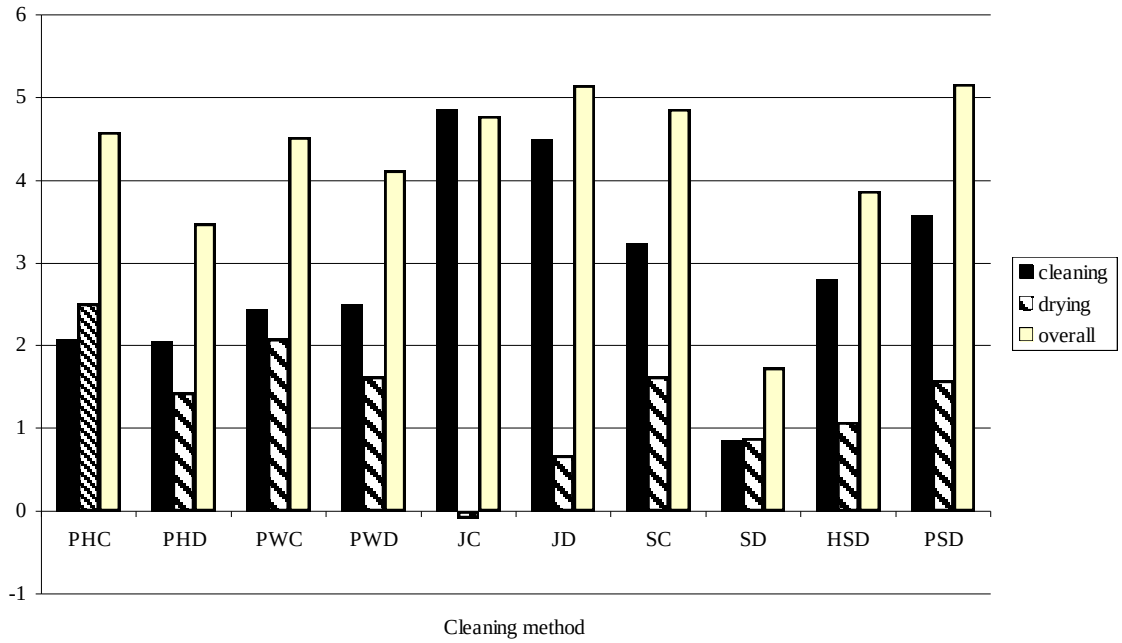

Figure 59. Mean reductions in *E. coli* count (log_{10} cfu cm^{-2}) as a result of cleaning (C or D code at the end of each cleaning method code denotes its application to visibly clean (C) inoculated slabs or visibly dirty (D) inoculated slabs)

Table 9. Reductions in Enterobacteriaceae count (log_{10} cfu cm^{-2}) as a result of cleaning

Status of Concrete	Contaminated with spiked faecal matter "Dirty" (D)						Contaminated with broth culture "Clean" (C)			
Cleaning Treatment	Plain hose (PH)	Pressure wash (PW)	Pressure wash with sanitiser (J)	Steam under pressure (S)	Plain hose followed by steam under pressure (HS)	Pressure wash followed by steam under pressure (PS)	Plain hose (PH)	Pressure wash (PW)	Pressure wash with sanitiser (J)	Steam under pressure (S)
Reduction immediately after treatment (s.d.)	2.1 (0.5)	$2.6^{a,b}$ (0.6)	4.4 (1.0)	0.9 (0.8)	2.7^{a} (0.6)	3.6 (0.7)	1.7 (0.2)	2.2^{b} (0.6)	5.2 (1.0)	3.7 (1.7)
Overall reduction after treatment plus 1 hour drying (s.d.)	$3.5^{c,g}$ (1.8)	$4.4^{c,h}$ (1.7)	5.7^{d} (0.8)	1.8 (1.6)	4.1^{c} (1.4)	5.8^{d} (1.8)	$3.9^{e,g}$ (1.3)	$4.3^{e,h}$ (1.5)	5.2^{f} (0.7)	5.5^{f} (1.1)

Note: Standard deviations in parenthesis, values showing similar superscripts are not statistically different at P<0.01

Table 10. Reductions in *E. coli* count (log_{10} cfu cm^{-2}) as a result of cleaning

Status of Concrete	Contaminated with spiked faecal matter "Dirty" (D)						Contaminated with broth culture "Clean" (C)			
Cleaning Treatment	Plain hose (PH)	Pressure wash (PW)	Pressure wash with sanitiser (J)	Steam under pressure (S)	Plain hose followed by steam under pressure (HS)	Pressure wash followed by steam under pressure (PS)	Plain hose (PH)	Pressure wash (PW)	Pressure wash with sanitiser (J)	Steam under pressure (S)
Reduction immediately after treatment (s.d.)	$2.1^{i,l}$ (0.6)	$2.5^{i,j,m}$ (0.7)	4.5^{n} (0.9)	0.9 (0.7)	2.8^{j} (0.5)	3.6 (0.6)	$2.1^{k,l}$ (0.9)	$2.4^{k,m}$ (0.9)	4.9^{n} (0.9)	3.4 (1.4)
Overall reduction after treatment plus 1 hour drying (s.d.)	$3.5^{p,t}$ (1.7)	$4.1^{p,q,u}$ (1.7)	$5.2^{r,w}$ (0.5)	1.7 (1.6)	3.9^{p} (1.2)	$5.2^{q,r}$ (1.3)	$4.6^{s,t}$ (1.7)	$4.5^{s,u}$ (1.6)	$4.8^{s,w}$ (0.7)	5.1^{s} (0.7)

Note: Standard deviations in parenthesis, values showing similar superscripts are not statistically different at P<0.01

There was no significant difference in overall reduction in Enterobacteriaceae count between mains water (PH) and the pressure washer (PW) on visually clean (C) surfaces. However, pressure washing gave a greater reduction in Enterobacteriaceae count immediately after cleaning. No significant difference was found in overall reduction in Enterobacteriaceae count between Janitol Sanitiser (J) or steam under pressure (S) on visually clean surfaces. Similarly there were no statistically significant differences between the overall reduction in *E. coli* count produced by any of the four treatments on visually clean surfaces, although the Janitol Sanitiser and steam gave significantly greater immediate reductions (4.9 log_{10} cfu cm^{-2} and 3.4 log_{10} cfu cm^{-2} respectively) (P<0.01). On a visually clean surface, the drying phase gave a greater reduction in count than on a visually dirty (D) surface with all cleaning methods, except the sanitiser, where there was a slight increase in count on the visually clean surfaces during the drying phase, possibly as a result of recontamination. On dirty (faecally contaminated) surfaces, the reductions in *E. coli* counts were similar to those produced on clean surfaces when mains water, pressure wash and Janitol Sanitiser were used. However, steam produced a significantly lower reduction in *E. coli* count on dirty surfaces (0.9 log_{10} cfu cm^{-2} immediate, 1.7 log_{10} cfu cm^{-2} overall) than on clean surfaces (3.4 log_{10} cfu cm^{-2} immediate, 5.1 log_{10} cfu cm^{-2} overall) (P<0.01). For Enterobacteriaceae, there was no significant difference between the overall reductions achieved by mains water and pressure wash on dirty concrete, when compared with clean concrete, nor between the immediate reductions obtained using pressure wash. However, mains water gave a greater immediate reduction in Enterobacteriaceae count on dirty concrete (2.1 log_{10} cfu cm^{-2}) than on clean concrete (1.7 log_{10} cfu cm^{-2}) (P<0.01), while Janitol Sanitiser gave a greater immediate reduction on clean (5.2 log_{10} cfu cm^{-2}) than on dirty (4.4 log_{10} cfu cm^{-2}), but less overall (5.2 log_{10} cfu cm^{-2} versus 5.7 log_{10} cfu cm^{-2}) (P<0.01). The use of steam under pressure produced large reductions in Enterobacteriaceae count (3.7 log_{10} cfu cm^{-2} immediate, 5.5 log_{10} cfu cm^{-2} overall) and *E. coli* count (3.4 log_{10} cfu cm^{-2} immediate, 5.1 log_{10} cfu cm^{-2} overall) on a clean

surface. These overall reductions being statistically similar to those achieved using the Janitol Sanitiser. However, in the presence of faecal material, steam under pressure gave the poorest reduction in both Enterobacteriaceae count (0.9 $\log_{10}$ cfu cm^{-2} immediate, 1.8 $\log_{10}$ cfu cm^{-2} overall) and *E. coli* count (0.9 $\log_{10}$ cfu cm^{-2} immediate, 1.7 $\log_{10}$ cfu cm^{-2} overall) ($P<0.01$). Of the single treatments, the Janitol Sanitiser produced the greatest immediate reduction in Enterobacteriaceae (5.2 $\log_{10}$ cfu cm^{-2} on clean and 4.4 $\log_{10}$ cfu cm^{-2} on dirty surfaces) and *E. coli* count (4.9 $\log_{10}$ cfu cm^{-2} on clean and 4.5 $\log_{10}$ cfu cm^{-2} on dirty surfaces) as a result of the cleaning process, but there was little further effect of drying.

Using a combination of pressure wash followed by steam on a visually dirty surface gave overall reductions in Enterobacteriaceae (5.8 $\log_{10}$ cfu cm^{-2}) and *E. coli* counts (5.2 $\log_{10}$ cfu cm^{-2}) comparable with those achieved using sanitiser (5.7 $\log_{10}$ cfu cm^{-2} and 5.2 $\log_{10}$ cfu cm^{-2}) ($P<0.01$), but there was a greater affect of drying where the combination cleanse was used. This combination also gave reductions comparable with those seen using steam alone on a visually clean surface (5.5 $\log_{10}$ cfu cm^{-2} and 5.1 $\log_{10}$ cfu cm^{-2}), but a combination of mains water and steam was less effective in cleansing a visually dirty surface. This combination gave results comparable with those achieved using a pressure wash alone (4.1 $\log_{10}$ cfu cm^{-2} and 3.9 $\log_{10}$ cfu cm^{-2} versus 4.4 $\log_{10}$ cfu cm^{-2} and 4.1 $\log_{10}$ cfu cm^{-2}) ($P>0.01$). It is possible that allowing a drying phase between the two phases of the pressure and steam combination may give greater reductions in Enterobacteriaceae and *E. coli* count.

4.1.5 Conclusion

Where a surface is visually clean, the use of a proprietary sanitiser at maximum recommended concentration, or the application of steam under pressure will give greater reductions in microbial contamination, than the use of a plain hose or pressure wash. However, these latter two methods yield similar results and are only slightly less effective than the former two. Where a surface is visually contaminated with the faecal material, the use of a pressure wash followed by immediate steam application will give reductions in microbial contamination comparable with the use of a proprietary sanitiser at maximum recommended concentration. The use of a pressure wash alone, or plain hose followed by immediate steam application would rank second in effectiveness, both giving similar reductions in microbial contamination, and the use of plain hose alone would rank third. The use of steam alone on a visually dirty surface is not an effective means of reducing microbial contamination.

Further work is required to explore the interactions between angle of application, pressure of jet, and temperature of cleaning fluid, all of which may impact upon the effectiveness of the cleaning procedure. Similarly, alternative proprietary chemical cleaning agents may have effects dissimilar from the Janitol sanitiser used in this study, and there may be a significant impact of climatic or environmental conditions on the change in microbial contamination of a surface during the drying phase.

4.2 Task 2.2 Evaluate various techniques to control cross-contamination within stunning box/roll-out (SBRO) unit

Cross contamination between animals comes from rub point/surfaces on raceway, within stunning box and on rollout zone. The animal dropping onto the floor of the pen and its own (probably dirty) hooves after stunning increases contamination of the critical brisket area.

A survey and brainstorming session was carried out to identify what hygiene improvement measures had the potential to substantially reduce contamination and in a number of cases improve animal welfare and/or improve handling in the stunning box/roll-out (SBRO) area.

Some of the ideas are suitable for retro-fit to existing slaughter facilities while a number would be more suitable for installation in a newly constructed abattoir or during a major refit.

4.2.1 Raceway

Current raceways are basically corridors with flat walls that are perfectly designed to maximise the surface contact between dirty hides/fleeces/skin and surrounding surfaces and consequently maximise cross contamination. The installation of horizontal rubbing bars or strips on the raceway walls at animal shoulder level would substantially improve the situation. It would:

1. Reduce the area for cross contamination to occur by a number of orders of magnitude.
2. Make cleaning far easier as the precise location of animal contact will be known and the area of surface to be cleaned substantially reduced.
3. Allow targeted application of smaller amounts of cleaning fluids at higher concentrations without increasing the total used.

Another major source of contamination in the raceway is from the hoofs of the animals. The amount of contamination present could be reduced with the introduction of efficient hoof cleaning systems. These are best located at entry to the lairage and at entry to the raceway. Those positioned at entrance to the raceway should incorporate an air knife to remove excess water from the hoofs. This would ensure that the hoofs would have time to dry before entering the slaughter zone that needs to be kept as dry as possible. Footbaths, sprays, bristly mats or a combination of these could be used. If used, additional measures to ensure hoof-cleaning systems are themselves kept clean would be required.

Introduction of a brisket rubbing strip may have a calming effect and provide first step in a carcass 'catching' system as described below.

4.2.2 Stun box

Currently after cattle are stunned there legs collapse under them and they impact on the floor with contamination on the hoofs and legs being transferred to the brisket and other areas. The carcass then rolls out of the box in an uncontrolled manner. By this time the legs have become rigid before they start to kick. During this process they have to be shackled and stuck as soon as possible.

Catching the carcass before it before collapses onto it's own hooves would reduce contamination of the brisket area and also introduces substantial possibilities for improving the shackling operation. A number of potential methods were discussed. Bars protruding from stun box wall, rising systems from stunbox floor, slings from above were all considered to have potential. Some degree of automation would be required for these systems and problems of interacting with a live animal need to be addressed. However, automated milking systems have been in use for a number of years that have obviously solved these issues. Carcass cradles are sometimes used in ritual slaughter methods; there maybe some technology to transfer from these.

Carcass supports in contact with the animal may be able to assist in the stunning operation, especially those in region of the chest. Supporting the carcass in a known position after stun is a good starting point from which to consider automated shackling systems.

Stunbox wall surfaces could be replaceable and thus regularly removed for cleaning with new clean 'covers' being fitted. This could be done between animals or batches depending on cycle times and production schedules. The equipment could be as simple as plastic sheets

attached to inside of box, or as complex as rolling/shifting walls that automatically retract into a cleaning mechanism.

Stunbox wall surfaces should be smooth and have rounded corners for ease of cleaning. Epoxy or flooring type resins (maybe in combination with stainless steel panels) could be used to smoothly plaster the internal surfaces. The legal requirement for a head restraint within the pen disrupts the possibilities of a totally smooth internal surface. However, it would be possible to create a heat restraint that was far easier to clean or would self clean the key contact areas.

If cattle were lifted from their feet in the raceway and conveyed to the stun zone in a similar manner to some pig and sheep systems it would minimise contamination problems in the race, stun box and roll out zone.

4.2.3 Rollout zone

Currently roll out zones can be constructed from concrete, galvanised steel plates or bar/mesh structures. As in races flat surfaces such as concrete or steel plate maximise the potential areas for contamination and hence cross contamination.

Using steel bars would substantially reduce the contact area and consequently the area to be cleaned. However, with the currently uncontrolled carcass roll out careful design would be required to make sure the shackling procedure was not impeded.

A drain channel across the rollout slope would provide the opportunity to wash the stun pen area without runoff wetting the rollout area.

A dry rollout zone is preferred to reduce the contaminating effect of debris 'soup'. However, a hose wash down would be effective at reducing levels of cross contamination. The addition of air knife or other similar technology to dry area after wash down could provide benefits.

4.2.4 Other ideas discussed

Pleasing (to cattle) visuals on walls to encourage entry to stun zone.

Cleaning methods as recommended by existing lairage practical work should be adopted.

5 Objective 3: Implementation, validation, and communication of the best practices under commercial conditions

5.1 Task 3.1 Validate "the best lairage-to-stunning practice" in a commercial abattoir

In a selected commercial, full-throughput abattoir, the experimentally characterised "best lairage-to-stunning practices" (including cleaning/disinfection of surfaces and controls for cross-contamination in SBRO unit) were implemented.

5.1.1 Method

In a selected commercial, full-throughput abattoir, the experimentally characterised "best lairage-to-stunning practices" were implemented. The mechanical cleaning rig described above was removed to a participating slaughterhouse and installed in a holding pen immediately after the removal of a group of cattle that had been held there overnight. The rig was used to clean strips of pen floor using the following methods:

1. Pressure water with no canopy (pw)
2. Pressure water with canopy, followed by steam (pwst)
3. Pressure water with canopy, one hour drying time, then steam (pw1hst)
4. Pressure water with Janitol Sanitiser (j)
5. Plain water followed by drying the surface using compressed air (ca)

A canopy was added to the spray head in some trials to investigate its effect on reducing the degree of spread of physical and microbial debris during the cleaning operation. It consisted of an A1 sized sheet of transparent plastic bent to form a semi-circular cross section and moved in conjunction with the spray head. It effectively stopped most of the sideway distribution of debris, but distribution in the direction of motion was not substantially reduced.

During the trials there was concern that recontamination of the cleaned areas may have occurred as a result of settling of aerosolised material or ingress of contamination by diffusion across the wet surface. Thus a trial was made to clean the holding pen floor by means of rinsing with plain water followed by drying the surface using compressed air.

Settle plates of Tryptone Glucose Yeast Agar (Plate Count Agar, PCA, Oxoid CM0325) for aerobic colony count and Violet Red Bile Glucose Agar (VRBG, Oxoid CM0485) for Enterobacteriaceae count were laid out around the rig at a 3-m distance, in positions A, B and G (Figure 55). Three samples were taken from the strip of floor to be cleaned prior to the onset of cleaning, three immediately after cleaning and three after a one-hour drying period, using a wet/dry swab technique over a an area of 100 cm^2. Samples were placed in a peptone salt solution (Maximum Recovery Diluent, MRD, Oxoid CM0733) in all cases except for those samples taken after the use of Janitol sanitiser, in which case the samples were placed in a DEN Rediswabs (International Bio-products) solution, a proprietary neutralising medium for use in situations where chemical sanitisers are used. After collection, the samples were chilled and returned to the laboratory for processing the same day. On arrival at the laboratory, each sample was vortexed for 1 min and a decimal dilution series in MRD prepared. The dilution series was then spread plated onto Violet Red Bile Glucose Agar (VRBG, Oxoid CM0485) and incubated at 37°C for 24 hours. The original sample in each case was also plated onto Petrifilm Entero (3M) to reduce the detection limit for

Enterobacteriaceae. Following incubation, Enterobacteriaceae were enumerated for each sample, and mean counts were calculated.

5.1.2 Results

The mean Enterobacteriaceae count on the holding pen floor prior to cleaning was 4.5 $\log_{10}$ cfu cm^{-2} (range 4.0-5.2 $\log_{10}$ cfu cm^{-2}). The use of the Janitol Sanitiser (j) gave the greatest initial reduction in count (4.5 $\log_{10}$ cfu cm^{-2}) (Figure 60), followed by Pressure Wash (pw) (4.1 $\log_{10}$ cfu cm^{-2}) and Pressure Wash with immediate Steam (pwst) (4.0 log). Pressure Wash followed by Steam one hour later (pw1hst) gave an initial reduction of 1.9 $\log_{10}$ cfu cm^{-2}. With each of these treatments, there appeared to be some recontamination of the surface during the following one-hour period. This recontamination was most marked on the areas that had been pressure washed alone (1.4 log) or pressure wash with steam after a one-hour delay (1.4 $\log_{10}$ cfu cm^{-2}), and in the areas that had been washed with the Janitol Sanitiser (1.2 $\log_{10}$ cfu cm^{-2}). The area that had been pressure washed followed by immediate steam application showed the least recontamination (0.2 $\log_{10}$ cfu cm^{-2}), and was also observed to appear visually clean and dry at the end of the on-hour post-cleaning period, in contrast with surfaces which had undergone other cleaning treatments. The recontamination of the cleaned areas may have occurred as a result of settling of aerosolised material or ingress of contamination by diffusion across the wet surface. Where an attempt was made to clean the holding pen floor by means of rinsing with plain water followed by drying the surface using compressed air (ca), there was little reduction in Enterobacteriaceae count (0.1 log), and the surface appeared visually dirty and greasy. There were little differences between the contamination detected on the settle plates during different cleaning operations, Enterobacteriaceae count ranging from 4 to 68 on the plates set to either side of the rig during operation, and too numerous to count in front of the rig, while total count ranged from 46 to 576 at either side of the rig and too numerous to count in front of the rig. There appeared to be little benefit in using a canopy over the lance to try to prevent cross-contamination from the pressure hose.

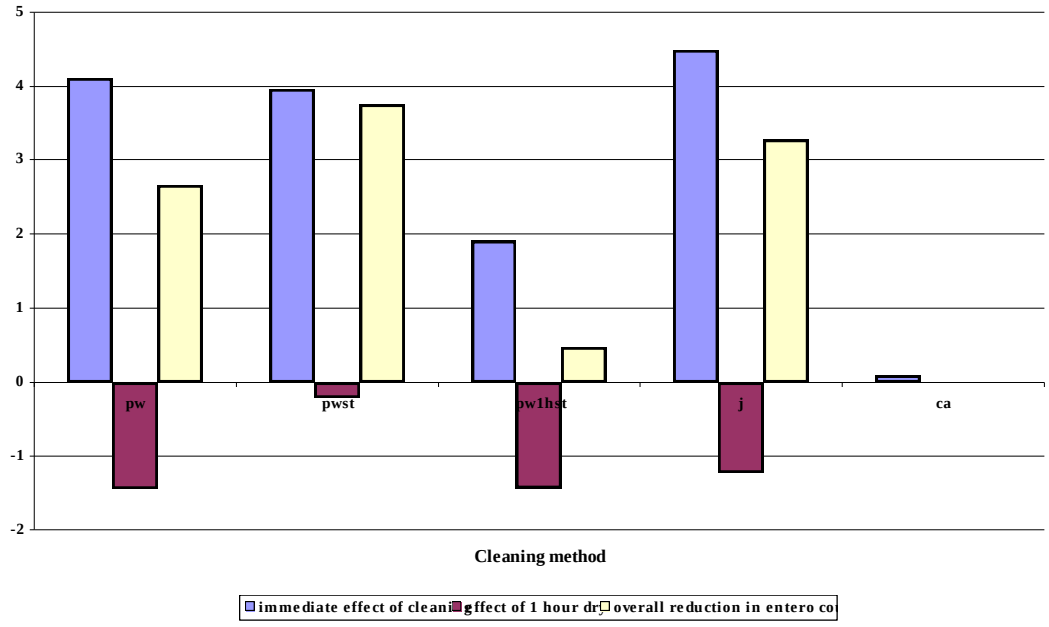

Figure 60. Results of commercial trial of cleaning methods (counts: $\log_{10}$ cfu cm^{-2})

5.1.3 Discussion and conclusions

A variety of cleaning protocols exist in UK red meat slaughterhouse lairages (Rostagno *et al*., 2003), some of which involve the use of chemical cleaning agents, and some that do not. The use of a chemical cleaning agent has been reported to be an important step in reducing microbial numbers on stainless steel for the dairy industry (Dunsmore, 1981), but the efficacy of chemical disinfectants or sanitisers is often much reduced in the presence of organic material (Sprenger 1997), or by usage with water at temperatures below 25°C (Gelinas *et al*., 1984). This study found that where a concrete surface is visually clean, the use of a proprietary sanitiser at maximum recommended concentration, or the application of steam under pressure gave the greatest reductions in microbial contamination. Mains water or pressure washing gave similar results to one another, findings similar to those reported in the 1970s comparing hot water at low pressure to cold water at high pressure (Dempster, 1977), and were only slightly less effective than steam or sanitiser. Where the concrete surface was visually contaminated with the faecal material, the use of a pressure wash followed by an immediate steam application gave reductions in microbial contamination comparable with the use of a proprietary sanitiser at maximum recommended concentration. The use of a pressure wash alone, or mains water followed by immediate steam application ranked second in effectiveness, both giving similar reductions in microbial contamination, and the use of mains water alone would rank third. Organic material forming a protective layer containing the organisms, and becoming firmly adhered to the concrete surface during the post-deposition period may explain the reduced effect observed in the presence of faecal contamination. The use of steam alone on a visually dirty surface was not an effective means of reducing remove visual faecal contamination let alone microbial contamination.

The results of the commercial trial indicated that pressure washing followed immediately by steam application is the best method of cleaning a holding pen floor, followed by the use of a sanitising agent at the greatest concentration recommended by the manufacturer, and then by pressure washing alone. All cleaning methods appeared to be less effective in the commercial situation than under laboratory conditions. This may be due to faecal matter and microbial contamination becoming more adhered to the surface during the prolonged interval between deposition and cleaning (Hood & Zottola, 1997), or due to recontamination of the surface from aerosolised contamination produced in adjacent pens. The use of pressure washing on farms has been shown to produce aerosolised Salmonella organisms, and contributes to the spread of infection in animal housing (Hinton *et al*., 1983), and a similar effect may be occurring in the commercial abattoir lairage. Pressure washing followed by a delayed steam application appeared to give a poor final result on the surface, possibly due to recontamination of the surface between treatments. However, insufficient samples were taken during the commercial trial to allow these observations to be substantiated statistically.

From the results of the current study, the cleaning methods evaluated can be ranked according to efficacy (Table 11), and the authors suggest that a high-ranking cleansing procedure should be incorporated into the lairage-to-stunning phase in the HACCP-based abattoir hygiene system.

Table 11. Suggested Best Practice

Rank (best to worst)	Cleaning Method	Mean Reduction in Enterobacteriaceae count
1	Pressure Wash immediately followed by steam under pressure	5.8 log
2	Pressure Wash with proprietary QAC sanitiser used at maximum recommended concentration	5.7 log
3	Pressure Wash	4.4 log
4	Plain Hose Wash immediately followed by steam under pressure	4.1 log
5	Plain Hose Wash	3.5 log
6	Steam under pressure	1.8 log

As already stated further work is required to explore the interactions between angle of application, pressure of jet, and temperature of cleaning fluid, all of which may impact upon the effectiveness of the cleaning procedure. Similarly, alternative proprietary chemical cleaning agents may have effects dissimilar from the Janitol Sanitiser used in this study, and there may be a significant impact of climatic or environmental conditions on the change in microbial contamination of a surface during the drying phase.

5.1.4 References

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5.2 Task 3.2 Communicate "the best lairage-to-stunning practice" in a commercial abattoir

Based on available literature and results of this study, the following bullet points are suggested for the basis of an industry guide:

"Must" principles (pre-requisites)

Pre-abattoir phase:

- Ensure clean animals are dispatched from farms
- Do not mix different batches of animals
- Use cleaned-disinfected transport vehicles
- Minimize animal transport duration

Lairaging phase:

- Separate animals of different cleanliness categories
- Separate different batches of animals
- If bedding is used, ensure it is clean and fresh for each group of animals
- Minimize lairaging duration
- Enable sanitation through lairage design and materials
- Regularly clean-then-disinfect lairage
- Send for slaughter in order "dirtier animals last"
- Minimize animal contact with surfaces pens-races-stunning

"Should" principles (best practice)

- Use disinfectant footbaths for animals at lairage entrance
- Use raised floors
- Remove any bedding before cleaning
- The better physical cleaning, the better subsequent disinfection
- Clean-disinfect pen-race surfaces between batches
- Minimise creation of aerosols
- Clean-disinfect stunning-rollout surfaces between animals
- Sanitation based on pressure wash followed by either pressure-steam- or QAC sanitiser treatments
- Ensure good drainage; prevent water pooling in lairage
- Enable drying after sanitation
- Regular sanitation of water troughs

Potential for further developments in lairage hygiene

- Re-design lairages with sanitation as a priority

- Develop system for quick, automated cleaning-disinfection
- Re-design stun-rollout system to prevent cross-contamination

The following articles/papers on the work are currently in press or have been published:

Small, A., James, C., James, S., Davies, R., Howell, M., Hutchison, M. & Buncic, S. (2006) Presence of *Salmonella* spp. in the red meat abattoir lairage after routine cleansing and disinfection, and on carcasses. *Journal of Food Protection*.

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6 Further work requirements

As a result of the data gathered during the project there are 3 areas of further work, that were not fully covered in the current work programme, that could be incorporated in a short extension of the project. They cover:

1. Design of a cleanable lairage.
2. Development of a cost effective cleaning system.
3. Modifications to stun boxes.

6.1 Design of a cleanable lairage

Current lairages have not been designed with ease of cleaning in mind. Apart from a recommendation to use a raised (slatted) floor there appears to be no detailed guidance in the new draft meat safety guide documentation. Few of the lairages in the survey had a raised floor and all contained areas that were difficult to clean effectively.

6.1.1 Stage 1: Review 'easy clean' design

A review will be carried out of the designs used in other clean areas to produce easy to clean structures. These will include high care areas in the food industry, operating theatres, pharmaceutical assembly, electronic component assembly, commercial washrooms and domestic kitchens/bathrooms/wet rooms. The review will cover materials of construction and key design features i.e. minimum radius for joins, minimum fall on drainage, suspended floors, etc.

The features identified will be ranked in order of potential application in both a new build and as a retrofit to an existing typical.

6.1.2 Stage 2: Development of best ideas

The top 10 features identified in stage 1 will be examined in detail and their ease of application in an existing or newly constructed lairage quantified. The features will be quantified in terms of ease of application, cost effectiveness and likely reduction in bacterial contamination. A detailed specification will be produced of the best options and an overall 'easy clean' design plan as a discussion document to help in the development of recommendations for the industry.

6.2 Development of cost effective cleaning system

A power wash together with the required level of sanitiser has been shown to be effective at removing visible detritus and microbial contamination. However, current systems only clean a small area at a time and therefore require a large manpower and time input to fully clean a pen. In addition they spread contamination to surrounding areas. A system that effectively cleans a surface in less than a tenth of the current time is required.

6.2.1 Task 1 Identify 'best' system currently available

Trials will be carried out to identify the minimum impact force and the best jet angle required to produce a wash jet to remove visual and 'microbial' contamination. The likely conditions will be identified using an ATP sensing system and confirmed using microbial sampling. From the force data the flow rate and pressure required to produce these conditions over a 20 cm plus wide path will be calculated. This is 10 times the path produced with existing systems. Existing power wash and pump delivery systems will be reviewed to determine those with the required delivery characteristics. The cheapest identified will be purchased together with a second with a higher delivery specification. The performance of both

systems using a standard delivery lance will be quantified in terms of time taken to clean a specified area to the required cleanliness, amount of water/detergent used and spread of contamination to adjacent surfaces.

6.2.2 Task 2 Optimise delivery system

A delivery manifold that will clean a 20 cm strip will be designed, constructed and the angle of delivery, pressure and flow distribution optimised using the ATP sensors and final microbial verification. Once the delivery system is optimised the best way of shielding the delivery manifold to reduce if not eliminate contamination of adjacent surfaces will be investigated. The ability to collect contaminated water, filter bulk detritus and dry the cleaned surface will be examined at the same time.

The performance of the optimised delivery system will be quantified in terms of time taken to clean a specified area to the required cleanliness, amount of water/detergent used and spread of contamination to adjacent surfaces at Langford. Finally its performance will be compared to the current cleaning system in a commercial abattoir.

If requested by the FSA a demonstration day will be organised for industry.

6.3 Evaluation of Stun Box Modifications for Reduction of Cross-Contamination between animals

Task 2.2 of the FSA lairage project (MO1028) identifies a number of possibilities to reduce cross-contamination between lairage and shackling. Ideas included modifications to the raceway, stunbox, and rollout zone. This outline considers evaluation of the stunbox related concepts.

Calves will be used for the studies as they are cheaper to purchase, easier to process, and their smaller size and weight reduces the scale of experimental stunboxes required.

6.3.1 Stage 1: Determine Dimensions and Build Basic Experimental Stunbox

Existing stunbox dimensions will be determined. Calf and adult cattle anatomical measurements will be made. Of particular importance are the positions of the rear of the fore leg and the front of the hind leg, as this is required for the catching system. The relative sizing of existing stunboxes for adult cattle will be used to determine sizing of the experimental calf stunbox from calf dimensions.

A heavy duty, modular, machine building system (similar to big Meccano) will be used to construct an experimental stunbox frame that can accommodate the concepts to be evaluated. The modular nature of the construction technique allows for adjustments and changes to be made readily during the development/evaluation trials.

6.3.2 Stage 2: Initial evaluation of panel replacement and/or materials of construction

6.3.3 Stage 2.1: Build panels

Two possibilities for reducing cross-contamination are addressed here:

1. Using stunbox wall materials that are more readily cleaned
2. Adding fresh clean animal contact surfaces between animals or batches of animals

Interchangeable floor, wall and end panels of different materials will be used to evaluate materials of construction, and benefits of changing surfaces between animals. Whilst one concept is to automatically change surfaces between animals, the process will not initially be automated. Manual exchange of panels between animals will evaluate any benefits, and if

proven worthwhile, the time cost and effort required to construct automatic change systems can then be justified.

6.3.4 Stage 2.2: Evaluate panel materials

Wall, floor and end panels of different materials will be installed in the experimental stunbox. Initial bacteria levels will be determined. Batches of 20 calves will be processed through the box and contamination levels determined before and after cleaning. Contamination levels on the carcasses will also be assessed.

Comparison between different panel types will show relative contamination rates and cleanability. These measurements will also form the benchmark against which other concepts will be evaluated.

6.3.5 Stage 2.3: Evaluate changing panels

A small batches (5) of calves will be processed with bacterial assessment carried out as in stage 2.2. A new clean panel will be put in place before the next small batch. Comparison with large batch results from stage 2.2 would show the potential benefits of construction of an automated panel changing system.

6.3.6 Stage 3: Initial evaluation of animal 'catching' system

6.3.7 Stage 3.1: Construct catching system.

Before committing substantial resource to building an automated system, a manual system is proposed. Basic leg position data will be taken from stage 1 and stunbox side panels with a series of holes for 'catch' bars will be built. The holes will be located such that the bars will pass through the stunbox below the calf belly. The bars will be supported such that one side panel can be removed. Some testing with live calves may be required to allow for the range of stance positions within box. This testing could be run in conjunction with stage 2.

6.3.8 Stage 3.2: Evaluation of catching system

After each calf has entered box, but before stunning, the catch bars would be inserted across the box. After stunning the calf will be supported on the bars. One side panel will be removed for carcass removal by sliding along the bars. In the completed system the carcass would be shackled from the bars avoiding cross contamination in the roll out zone. Carcass brisket microbiological analysis will be compared to that from stage 2 to determine benefits of the catching system. The effects of cleaning catching bars between uses will also be assessed.

6.3.9 Stage 4. Build improved stun box

The results from initial evaluations will be used to define calf stunbox. Automated systems to implement the most beneficial concepts will then be constructed.

6.3.10 Stage 5. Evaluate improved stunbox

Multiple batches of animals will be processed through the automated experimental stunbox to validate automation, and reductions in cross-contamination through comparison with microbiological benchmark established in stage 2.

6.4 Estimated timescale and costs of extensions

- Design of a cleanable lairage.

4 months to complete and estimated cost £12,000

- Development of a cost effective cleaning system.

5.5 months to complete and estimated cost £21,000

- Modifications to stun boxes

7 months to complete and estimated cost £37,000

7 Appendix: Survey letter and questionnaire

Food Standards Agency Research Project M01028

Abattoir Questionnaire Lairage Cleaning and Disinfection

The University of Bristol are currently undertaking a research project for the Food Standards Agency to provide information on the effectiveness of cleaning and disinfection techniques in the animal holding areas prior to slaughter.

We would very much appreciate your help with this project and we hope that you or an appropriate person in your business will find the time to complete the following questionnaire. The experimental phase of the project is directed at determining how to effectively clean the range of current lairaging systems, and the questionnaire aims to gather information about current lairage conditions in commercial abattoirs in the UK, to assist us in developing the experimental protocols. The findings of the project will be communicated to the industry as information that could be considered in the context of procedures based on HACCP principles.

All completed questionnaires will be entered into a prize draw, the winner of which will receive a Seasonal Food Hamper. Please indicate below if you do not wish to be entered into the draw. As participants you will receive a summary of the results, which will form the basis for the experimental phase of the research project.

Please return the questionnaire in the enclosed prepaid envelope by 28th August 2004. Your cooperation is very much appreciated

This questionnaire is divided into sections based on species processed, as some lairages will be multi-species holding different species in the same pens at different times, whilst others will have separate areas for each species, and others will be single-species lairages. Please complete all sections applicable to your lairage.
If you have any difficulty completing the questionnaire please contact:

Alison Small: **Bristol University School of Veterinary Science**

a.h.small@bristol.ac.uk
Office: 0117 928 9414 **Mobile: 07740202266**

For further information on the Food Standards Agency Meat Hygiene Research Programme, please contact:

Mary Howell: **mary.howell@foodstandards.gsi.gov.uk**

Office: 0207 276 8373

SECTION 1: General

Q1 Abattoir ID code:

Q2 What is your position within the business? Please enter your job title.

_____

Tick here if you do NOT wish to be entered into the prize draw ❑

Q3 Weekly throughput of animals: Please complete the table below with average figures

Species	Slaughter Generation animals	Cull animals
Cattle		
Sheep		
Pig		
Other		

Q4 Size of the lairage

Please use the grid provided to draw a sketch plan of the lairage, or append a plan. Use hatching to indicate solid walls, and indicate in each pen the number of animals of each species held (average and maximum). Please also mark water troughs on the plan, and indicate type and direction of drainage

Please indicate dimensions on the plan.

Dimensions are in (please tick) Metres ❑ Feet and Inches ❑

SECTION 2: – Cattle

Animal Groups

Q5 Number of loads of cattle received on a typical day:

Please estimate the percentage of loads that typically comprise:

1-6 cattle: _____

7-12 cattle: _____

13-18 cattle: _____

over 18 cattle: _____

Q6 Are producer groups kept separately? Yes ❑ No ❑ Sometimes ❑

Q7 How long do animals remain in the pens before slaughter?

Animals arriving on the day of slaughter: _____hours

Animals held overnight for slaughter: _____hours

Q8 How many groups of animals pass through each pen each day? Give a range of

minimum _____ maximum _____

Q9 How are animals moved through the lairage to the stun point?

Moved from pen to pen ❑ Moved into droving passage ❑

Q10 Is there a field lairage or holding yard?

Yes ❑ No ❑

a) What size is this facility? Square metres _____or, Square feet _____

b) Does it have a shelter? Yes ❑ No ❑

c) What is the maximum number of cattle this facility could hold? _____

d) Would producer groups be mixed in this facility?

Often ❑ Sometimes ❑ Rarely ❑ Never ❑

Lairage Construction

Q11 Year of construction of lairage (or estimated age): _____

Q12 Is the floor the original floor? Yes ❑ No ❑

If not, how long ago was the newest floor laid? _____

Q13 Please indicate percentage of flooring made of each of the following materials, and in which parts of the lairage these floors are found:

e.g. 80% Roughened Concrete holding pens
20% Grooved Concrete passages

Percentage	Floor Type	Situation
	Smooth Concrete	
	Roughened Concrete	
	Grooved Concrete	
	Concrete Slats	
	Width: Gap:	
	Wooden Slats	
	Width: Gap:	
	Metal Slats	
	Width: Gap:	
	Earth	
	Brick	
	Unglazed Tile	
	Glazed Tile	
	Other (detail)	

Q14 Has a sealant, e.g. concrete floor paint or silicone, been applied onto the floor?

Yes ❑ No ❑ Part ❑

If so, what sealant has been used?

Q15 Is the floor sloped to help with water drainage?

Yes ❑ No ❑ Part ❑

Q16 How high are the perimeter walls of pens?

Metres _____ or, Feet _____

Q17 Please indicate percentage of wall made of each of the following materials:

Percentage	Material	Percentage	Material
	Rendered Block		Unrendered Block
	Metal		Wood
	Brick		Other (detail)

Q18 Have the walls been painted? Yes ❑ No ❑ Part ❑

Q19 What height are the pen Divisions? Metres _____ or, Feet_____

Q20 What are the pen divisions made of?

Please indicate percentage made of each of the following materials:

Percentage	Material	Percentage	Material
	Rendered Block		Unrendered Block
	Metal		Wood
	Brick		Other (detail)

Q21 Have the dividing walls been painted? Yes ❑ No ❑ Part ❑

Q22 What type of drinkers are used?

Trough ❑ Bowl ❑ Cup ❑ Nipple ❑

Q23 At what height are the drinkers? Metres_____ or Feet _____

Q24 How are the drinkers cleaned?

Q25 How often are the drinkers cleaned?

After each group ❑ At each break ❑ Every day ❑ Every week ❑

Q26 What height are the Pen Gates? Metres_____ or Feet_____

Q27 What are the Pen Gates made of? Wood ❑ Metal ❑

Q28 What Ventilation is there in the lairage?

Yorkshire Boarding ❑ Windows ❑
Open Side ❑ Raised Ridge ❑
Fans ❑ Other (detail) ❑

Q29 If fans are used, what is the position of the exhaust: (e.g. roof) _____

Q30 What type of bedding is used?

Straw ❑ Sawdust / Shavings ❑ Paper ❑ Other ❑ None ❑

Q31 Is bedding used for all animals? Yes ❑ No ❑

Q32 Is bedding only used for animals held overnight? Yes ❑ No ❑

Please append a copy of the lairage protocol if available

Q33 Please describe the Cleaning Regime by completing the table below:

	After each group	Daily	Weekly	Other (detail)
Bedding removed				
New bedding				
Washed out				
Pressure Wash / Steam				
Detergent used				
Disinfectant used				

Q34 Briefly describe the cleaning procedure for the Lairage, indicating tools used, or append a copy of the cleaning schedule:

Q35 Which chemicals are used in the holding area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Holding Pens	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20 sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

Pre-Slaughter Handling System

Q36 How long is the race? Metres _____ or, Feet _____

Q37 What is the maximum number of cattle that would be held in the race?

Q38 What surface do the stunned animals land on in the Roll-out Area?

Solid Concrete	❑	Solid Steel	❑
Slatted Concrete	❑	Slatted Steel / Grid	❑
Other	❑		

Q39 How often are these areas cleaned?

Race		Are Chemicals used?
After each animal		Yes ❑ No ❑ Sometimes ❑
After each batch		Yes ❑ No ❑ Sometimes ❑
At each break		Yes ❑ No ❑ Sometimes ❑
At main breaks		Yes ❑ No ❑ Sometimes ❑
At the end of the day		Yes ❑ No ❑ Sometimes ❑
Weekly		Yes ❑ No ❑ Sometimes ❑
Stunning Area		
After each animal		Yes ❑ No ❑ Sometimes ❑
After each batch		Yes ❑ No ❑ Sometimes ❑
At each break		Yes ❑ No ❑ Sometimes ❑
At main breaks		Yes ❑ No ❑ Sometimes ❑
At the end of the day		Yes ❑ No ❑ Sometimes ❑
Weekly		Yes ❑ No ❑ Sometimes ❑
Roll-out Area		
After each animal		Yes ❑ No ❑ Sometimes ❑
After each batch		Yes ❑ No ❑ Sometimes ❑
At each break		Yes ❑ No ❑ Sometimes ❑
At main breaks		Yes ❑ No ❑ Sometimes ❑
At the end of the day		Yes ❑ No ❑ Sometimes ❑
Weekly		Yes ❑ No ❑ Sometimes ❑

Q40 Which Chemicals are used in the pre-slaughter area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Stun box	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

SECTION 3: – Sheep

Animal Groups

Q41 Number of loads of sheep received on a typical day:

Please estimate the percentage of loads that typically comprise:

1-25 sheep: _____

26-100 sheep: _____

over 100 sheep: _____

Q42 Are producer groups kept separately? Yes ❑ No ❑ Sometimes ❑

Q43 How long do animals remain in the pens before slaughter?

Animals arriving on the day of slaughter: _____hours

Animals held overnight for slaughter: _____hours

Q44 How many groups of animals pass through each pen each day? Give a range of

minimum _____ maximum _____

Q45 How are animals moved through the lairage to the stun point?

Moved from pen to pen ❑ Moved into droving passage ❑

Q46 Is there a field lairage or holding yard?

Yes ❑ No ❑

a) What size is this facility? Square metres _____or, Square feet _____

b) Does it have a shelter? Yes ❑ No ❑

c) What is the maximum number of sheep this facility could hold? _____

d) Would producer groups be mixed in this facility?

Often ❑ Sometimes ❑ Rarely ❑ Never ❑

Lairage Construction

Q47 Year of construction of lairage (or estimated age): _____

Q48 Is the floor the original floor? Yes ❑ No ❑

If not, how long ago was the newest floor laid? _____

Q49 Please indicate percentage of flooring made of each of the following materials, and in which parts of the lairage these floors are found:

e.g.	80%	Roughened Concrete	holding pens
	20%	Grooved Concrete	passages

Percentage	Floor Type	Situation
	Smooth Concrete	
	Roughened Concrete	
	Grooved Concrete	
	Concrete Slats Width: Gap:	
	Wooden Slats Width: Gap:	
	Metal Slats Width: Gap:	
	Earth	
	Brick	
	Unglazed Tile	
	Glazed Tile	
	Other (detail)	

Q50 Has a sealant, e.g. concrete floor paint or silicone, been applied onto the floor?

Yes ❑ No ❑ Part ❑

If so, what sealant has been used?

Q51 Is the floor sloped to help with water drainage?

Yes ❑ No ❑ Part ❑

Q52 How high are the perimeter walls of pens?

Metres _____ or, Feet _____

Q53 Please indicate percentage of wall made of each of the following materials:

Percentage	Material	Percentage	Material
	Rendered Block		Unrendered Block
	Metal		Wood
	Brick		Other (detail)

Q54 Have the walls been painted? Yes ❑ No ❑ Part ❑

Q55 What height are the pen divisions? Metres _____ or, Feet_____

Q56 What are the pen divisions made of?

Please indicate percentage made of each of the following materials:

Percentage	Material	Percentage	Material
	Rendered Block		Unrendered Block
	Metal		Wood
	Brick		Other (detail)

Q57 Have the dividing walls been painted? Yes ❑ No ❑ Part ❑

Q58 What type of drinkers are used?

Trough ❑ Bowl ❑ Cup ❑ Nipple ❑

Q59 At what height are the drinkers? Metres_____ or Feet _____

Q60 How are the drinkers cleaned?

Q61 How often are the drinkers cleaned?

After each group ❑ At each break ❑ Every day ❑ Every week ❑

Q62 What height are the pen gates? Metres_____ or Feet_____

Q63 What are the pen gates made of? Wood ❑ Metal ❑

Q64 What Ventilation is there in the lairage?

Yorkshire Boarding	❑	Windows	❑
Open Side	❑	Raised Ridge	❑
Fans	❑	Other (detail)	❑

Q65 If fans are used, what is the position of the exhaust: (e.g. roof)_____

Q 66 What type of bedding is used?

Straw ❑ Sawdust / Shavings ❑ Paper ❑ Other ❑ None ❑

Q67 Is bedding used for all animals? Yes ❑ No ❑

Q68 Is bedding only used for animals held overnight? Yes ❑ No ❑

Please append a copy of the lairage protocol if available

Q69 Please describe the Cleaning Regime by completing the table below:

	After each group	Daily	Weekly	Other (detail)
Bedding removed				
New bedding				
Washed out				
Pressure Wash / Steam				
Detergent used				
Disinfectant used				

Q70 Briefly describe the cleaning procedure for the Lairage, indicating tools used, or append a copy of the cleaning schedule:

Q71 Which chemicals are used in the holding area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Holding Pens	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20 sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

Pre-Slaughter Handling System

Q72 How long is the race? Metres _____ or, Feet _____

Q73 What is the maximum number of sheep that would be held in the race?

Q74 Describe the Stunning Area for sheep:

Restrainer/Conveyor ❑ number of sheep held in conveyor: _____

Group stunning pen ❑ number of sheep held in pen: _____

Q74 What surface do the stunned animals land on in the Roll-out Area?

Solid Concrete ❑ Solid Steel ❑ Other ❑

Slatted Concrete ❑ Slatted Steel / Grid ❑

Q75 How often are these areas cleaned?

Race		Are Chemicals used?		
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Stunning Area				
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Roll-out Area				
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Q76 Which Chemicals are used in the pre-slaughter area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Stun box	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

SECTION 4: – Pigs

Animal groups

Q77 Number of loads of pigs received on a typical day:

Please estimate the percentage of loads that typically comprise:

1-25 pigs: _____

26-100 pigs: _____

over 100 pigs: _____

Q78 Are producer groups kept separately? Yes ❑ No ❑ Sometimes ❑

Q79 How long do animals remain in the pens before slaughter?

Animals arriving on the day of slaughter: _____hours

Animals held overnight for slaughter: _____hours

Q80 How many groups of animals pass through each pen each day? Give a range of

minimum _____ maximum _____

Q81 How are animals moved through the lairage to the stun point?

Moved from pen to pen ❑ Moved into droving passage ❑

Q82 Is there a field lairage or holding yard?

Yes ❑ No ❑

a) What size is this facility? Square metres _____ or, Square feet _____

b) Does it have a shelter? Yes ❑ No ❑

c) What is the maximum number of pigs this facility could hold?_____

d) Would producer groups be mixed in this facility?

Often ❑ Sometimes ❑ Rarely ❑ Never ❑

Lairage Construction

Q83 Year of construction of lairage (or estimated age): _____

Q84 Is the floor the original floor? Yes ❑ No ❑

If not, how long ago was the newest floor laid? _____

Q85 Please indicate percentage of flooring made of each of the following materials, and in which parts of the lairage these floors are found:

e.g.	80%	Roughened Concrete	holding pens
	20%	Grooved Concrete	passages

Percentage	Floor Type	Situation
	Smooth Concrete	
	Roughened Concrete	
	Grooved Concrete	
	Concrete Slats Width: Gap:	
	Wooden Slats Width: Gap:	
	Metal Slats Width: Gap:	
	Earth	
	Brick	
	Unglazed Tile	
	Glazed Tile	
	Other (detail)	

Q86 Has a sealant, e.g. concrete floor paint or silicone been applied onto the floor?

Yes ❑ No ❑ Part ❑

If so, what sealant has been used?

Q87 Is the floor sloped to help with water drainage?

Yes ❑ No ❑ Part ❑

Q88 How high are the perimeter walls of pens?

Metres _____ or, Feet _____

Q89 Please indicate percentage of wall made of each of the following materials:

Percentage	Material
	Rendered Block
	Metal
	Brick

Percentage	Material
	Unrendered Block
	Wood
	Other (detail)

Q90 Have the walls been painted? Yes ❑ No ❑ Part ❑

Q91 What height are the Pen Divisions? Metres _____ or, Feet_____

Q92 What are the pen divisions made of?

Please indicate percentage made of each of the following material:

Percentage	Material
	Rendered Block
	Metal
	Brick

Percentage	Material
	Unrendered Block
	Wood
	Other (detail)

Q93 Have the dividing walls been painted? Yes ❑ No ❑ Part ❑

Q94 What type of Drinkers are used?

Trough ❑ Bowl ❑ Cup ❑ Nipple ❑

Q95 At what height are the drinkers? Metres_____ or Feet _____

Q96 How are the drinkers cleaned?

Q97 How often are the drinkers cleaned?

After each group ❑ At each break ❑ Every day ❑ Every week ❑

Q98 What height are the Pen Gates? Metres_____ or Feet_____

Q99 What are the Pen Gates made of? Wood ❑ Metal ❑

Q100 What Ventilation is there in the lairage?

Yorkshire Boarding	❑	Windows	❑
Open Side	❑	Raised Ridge	❑
Fans	❑	Other (detail)	❑

Q101 If fans are used, what is the position of the exhaust: (e.g. roof) _____

Q 102 What type of bedding is used?

Straw ❑ Sawdust / Shavings ❑ Paper ❑ Other ❑ None ❑

Q103 Is bedding used for all animals? Yes ❑ No ❑

Q104 Is bedding only used for animals held overnight? Yes ❑ No ❑

Please append a copy of the lairage protocol if available

Q105 Please describe the Cleaning Regime by completing the table below:

	After each group	Daily	Weekly	Other (detail)
Bedding removed				
New bedding				
Washed out				
Pressure Wash / Steam				
Detergent used				
Disinfectant used				

Q106 Briefly describe the cleaning procedure for the Lairage, indicating tools used, or append a copy of the cleaning schedule:

Q107 Which chemicals are used in the holding area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Holding Pens	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20 sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

Pre-Slaughter Handling System

Q108 How long is the race? Metres _____ or, Feet _____

Q109 What is the maximum number of pigs that would be held in the race?

Q110 Please Describe the Stunning Area for pigs:

Restrainer/Conveyor ❑ number of pigs held in conveyor:

Group stunning pen ❑ number of pigs held in pen:

Gas system ❑ number of pigs held in crate:

Q111 What surface do the stunned animals land on in the Roll-out Area?

Solid Concrete ❑ Solid Steel ❑ Other ❑

Slatted Concrete ❑ Slatted Steel / Grid ❑

Q112 How often are these areas cleaned?

Race		Are Chemicals used?		
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Stunning Area				
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Roll-out Area				
After each animal		Yes ❑	No ❑	Sometimes ❑
After each batch		Yes ❑	No ❑	Sometimes ❑
At each break		Yes ❑	No ❑	Sometimes ❑
At main breaks		Yes ❑	No ❑	Sometimes ❑
At the end of the day		Yes ❑	No ❑	Sometimes ❑
Weekly		Yes ❑	No ❑	Sometimes ❑

Q113 Which Chemicals are used in the pre-slaughter area?

Name of Cleaning Product	Name of Supplier	When used	Where Used	Concen-tration Used	How is this measured?	How is the product applied?	What is the application rate?	What contact time is allowed?	What is the next step?	Why was this product chosen?	What was the source of the informatio n on which the choice was made
Example Superkleen	ACME Ltd	End of kill	Stun box	1 pint per 40 gall	Jug	Pressure hose	40 gallons to 20sq yds	overnight	Next animals arrive	Non-hazardous	Sales Rep

MO1028 Lairage Questionnaire Overview

Question	Overall				Low throughput	Full Throughput			
	All	Cattle	Sheep	Pigs		Multi-species	Cattle only	Sheep only	Pigs only
Number represented	38	27	27	23	9 total 1 no pigs 2 no cattle	13 2 ruminants only 1 smalls only	7	5	4
No of animals weekly		1-1,500	6-11,000	3-7,500	1 – 7 cattle 6 – 70 sheep 5 – 50 pigs	5 – 320 cattle 7 – 2,000 sheep 10 – 1,500 pigs	650 – 1,500	500 – 11,000	4,600 – 75,000
Percentage of loads arriving of different sizes									
% small loads	0 - 100	0 - 100	0 - 100	0 - 100	90 – 100	0 - 100	4 – 70	10 – 30	0 – 33
% medium	0 - 100	0 - 100	0 - 75	0 - 100	0 – 10	0 - 100	4 – 50	6 – 75	1 – 54
% large	0 - 100	0 - 90	0 - 100	0 - 99	0	0 - 100	5 - 70	5 - 20	33 – 99
Separation									
Yes	30/38 = 79%	20/27 = 74%	21/27 = 78%	19/23 = 83%	8/9 = 89%	9/13 = 69%	5/7 = 71%	4/5 = 80%	2/4 = 50%
No	2/38 = 5%	4/27 = 15%	1/27 = 4%	0	0	2/13 = 15%	1/7 = 14%	0	0
Sometimes	6/38 = 16%	3/27 = 11%	5/27 = 18%	4/23 = 17%	1/9 = 11%	2/13 = 15%	1/7 = 14%	1/5 = 20%	2/4 = 50%
Holding day									
Range	0 – 6 hrs	0 – 6 hrs	1 – 6 hrs	0 – 6 hrs	1 – 6 hrs	0 – 6 hrs	0 – 4 hrs	1 – 4 hrs	0 – 2 hrs
Mean	2.5	2.5	2.8	2.5	2.6	3.1	2.4	2	1
Mode	2	2	2	2	2	2	/	/	1
Holding o/n									
Range	7 – 48 hrs	7 – 20 hrs	10 – 48 hrs	10 – 20 hrs	0 – 15 hrs	0 – 20 hrs	7 – 20 hrs	10 – 48 hrs	0 – 17 hrs
Mean	16.1	14.8	15.7	15.3	/	16.9	15.3	19.2	15.7
Mode	16	16	16	16	/	16	/	/	/
Never	10/38 = 26%	8/27 = 30%	9/27 = 33%	13/23 = 57%	8/9 = 89%	1/13	0	0	1/4 = 25%
Min groups	0 – 50 mode 1	0 – 5 mode 1	0 – 50 mode 1	0 – 2 mode 1	1 – 15 mode 1	0 – 5 mode 1	0 – 2 mode 1	1 – 50 mode 1	0 – 2 mode 1
Max groups	0-200 mode 2	1 – 25 mode 2	1 – 200 mode 3	0 – 10 mode 2	2 – 30 /	1 – 25 mode 2	5 – 12 /	0 – 200 /	0 – 4 mode 1

Transfer of animals to stun box									
Droving Passage	30/38 = 79%	22/27 = 81%	21/27 = 78%	17/23 = 74%	5/9 = 56%	11/13 = 85%	7/7 = 100%	5/5 = 100%	2/4 = 50%
Pen to pen	9/38 = 24%	7/27 = 26%	7/27 = 26%	7/23 = 30%	5/9 = 56%	2/13 = 15%	1/7 = 14%	0	2/4 = 50%
Field lairages									
Number	12/38 = 32%	5/27 = 19%	8/27 = 30%	1/23 = 4%	4/9 = 44%	4/13 = 30%	1/7 = 14%	2/5 = 40%	1/4 = 25%
FL size (sqm)	4 – 120,000	4 – 120,000	50 – 120,000	533	50 - 600	18 – 120,000	600	10 - 330	533
FL shelter	8/12	4/5	3/8	1/1	4/4	1/4	1/1	1/2	1/1
FL capacity	6 – 1,000	6 - 144	25 – 1,000	220	6 - 600	18 – 1,000	144	100 - 400	220
FL mixing	5 never	2 never	3 never	sometimes	sometimes	4 never	rarely	1 never	sometimes
Lairage Age	4 – 93 yrs	4 - 93	5 - 93	5 - 93	5 - 93	6 - 41	4 - 8	10 - 27	14 – 41
Original Floor	19/38 = 50%	15/27 = 56%	17/27 = 63%	13/23 = 56%	6/9 = 67%	9/13 = 69%	3/7 = 43%	2/5 = 40%	1/4 = 25%
Age of floor	1 - 41	1 - 41	1 - 41	1 - 41	1 - 41	1 - 41	1 - 10	1 - 27	1 - 22
Floor construction									
Smooth concrete	14/38 = 37%	9/27 = 33%	13/27 = 48%	11/23 = 48%	7/9 = 78%	4/13 = 30%	0	2/5 = 40%	1/4 =25%
Roughened concrete	17/38 = 45%	14/27 = 52%	14/27 = 52%	15/23 = 65%	2/9 = 22%	10/13 = 77%	3/7 = 43%	2/5 = 40%	3/4 = 75%
Grooved concrete	16/38 = 42%	12/27 = 44%	9/27 = 33%	7/23 = 30%	1/9 = 11%	7/13 = 54%	4/7 = 57%	2/5 = 40%	2/4 = 50%
Concrete slats	2/38 = 5%	1/27 = 4%	0	1/23 = 4%	0	1/13 = 8%	0	0	1/4 =25%
Wood Slats	1/38 = 3%	1/27 = 4%	1/27 = 4%	1/23 = 4%	1/9 = 11%	0	0	0	0
Metal slats	1/38 = 3%	0	2/27 = 7%	1/23 = 4%	0	1/13 = 8%	0	0	0
Earth floor	1/38 = 3%	0	1/27 = 4%	0	0	0	0	1/5 = 20%	0
Brick floor	1/38 = 3%	1/27 = 4%	1/27 = 4%	0	1 ruminants only, not sloped	0	0	0	0
Other floor	2/38 = 5%	0	1 wire grid 1 plastic	0	0	0	0	1 wire grid 1 plastic	0
Sealant used	1 low throughput, multi-species				1 multi-species	None			
Floor sloped	No 4/38 = 11%	No 2/27 = 7%	No 4/27 = 15%	No 1/23 = 4%	Not in brick floor	1 not sloped	0	2 not sloped – grid or plastic	0

Perimeter Wall construction									
Height (m)	0.9 – 6	1.2 – 6	0.9 – 5	1.8 – 5	1.2 - 5	1.8 - 5	2 - 6	0.9 - 2	1.2 – 2.4
Rendered block	27/38 = 71%	20/27 = 74%	20/27 = 74%	20/23 = 87%	7/9 = 78%	12/13 = 92%	3/7 = 43%	1/5 = 20%	4/4 = 100%
Unrendered block	2/38 = 5%	1/27 = 4%	1/27 = 4%	1/23 = 4%	1/9 = 11%	0	1/7 = 14%	0	0
Metal wall	11/38 = 29%	5/27 = 19%	9/27 = 33%	6/23 = 26%	1/9 = 11%	4/13 = 31%	0	4/5 = 80%	2/4 = 50%
Brick wall	6/38 = 16%	4/27 = 15%	5/27% = 19%	4/23 = 17%	3/9 = 33%	1/13 = 8%	0	1/5 = 20%	1/4 = 25%
Other wall	3/38 = 8%	1 plastic 1 concrete 1 fibrocement panel	1 plastic	1 plastic	1 plastic	0	1 concrete 1 fibrocement panel	0	0
Painted wall	12/38 = 32%	11/27 = 41%	9/27 = 33%	9/23 = 39%	3/9 = 33%	6/13 = 46%	2/7 = 29%	0	1/4 = 25%
Pen Divisions construction									
Height (m)	0.9 – 2.5	1.2 – 2.5	0.9 – 2.5	1.1 – 2.5	1 – 2.5	1.5 – 2.5	1.7 – 2.2	0.9 – 1.5	1.1 – 1.2
Rendered block	11/38 = 29%	9/27 = 33%	8/27 = 30%	10/23 = 43%	1/9 = 11%	7/13 = 54%	0	0	3/4 = 75%
Unrendered block	1/38 = 3%	1/27 = 4%	0	0	0	0	1/7 = 14%	0	0
Metal division	26/38 = 68%	17/27 = 63%	19/27 = 70%	16/23 = 70%	6/9 = 67%	9/13 = 69%	4/7 = 57%	4/5 = 80%	3/4 = 75%
Wood division	2/38 = 5%	1/27 = 4%	2/27 = 7%	1/23 = 4%	2/9 = 22%	0	0	0	0
Brick division	1/38 = 3%	0	0	1/23 = 4%	0	0	0	0	1/4 = 25%
Other division	1/38 = 3%	0	0	1 concrete slats	0	0	0	0	1/4 = 25%
Painted division	7/38 = 18%	7/27 = 26%	6/27 = 22%	6/23 = 26%	2/9 = 22%	5/13 = 38%	0	0	0
Drinkers construction									
Trough	17/38 = 45%	14/27 = 52%	9/27 = 33%	3/23 = 13%	2/9 = 22%	6/13 = 46%	6/7 = 86%	3/5 = 60%	0
Bowl	18/38 = 47%	13/27 = 48%	18/27 = 66%	14/23 = 61%	7/9 = 78%	7/13 = 54%	1/7 = 14%	2/5 = 40%	1/4 = 25%
Nipple	4/38 = 11%	0	0	4/23 = 17%	0	1/13 = 8%	0	0	3/4 = 75%
Drinker height	30-100 cm								

Drinker cleaning method									
Hosed	5/38 = 13% 5/31 = 16%*	4/27 = 15% 4/21 = 19%*	5/27 = 19% 5/23 = 22%*	5/23 = 22% 5/20 = 25%*	1/9 = 11% 1/7 = 14%*	4/13 = 31% 4/12 = 33%*	1/7 = 14% 1/4 = 25%*	0	0
Pressure Wash/Steam	15/38 = 39% 15/31 = 48%*	10/27 = 37% 10/21 = 48%*	9/27 = 33% 9/23 = 39%*	9/23 = 39% 9/20 = 45%*	6/9 = 67% 6/7 = 86%*	5/13 = 38% 5/12 = 42%*	2/7 = 29% 2/4 = 50%*	0	2/4 = 50% 2/3 = 67%*
By Hand	7/38 = 18% 7/31 = 23%*	6/27 = 22% 6/21 = 29%*	7/27 = 26% 7/23 = 30%*	4/23 = 17% 4/20 = 20%*	0	3/13 = 23% 3/12 = 25%*	2/7 = 29% 2/4 = 50%*	3/5 = 60%	0
Cloth	2/38 = 5% 2/31 = 6%	0	2/27 = 7% 2/23 = 9%*	0	0	0	0	2/5 = 40%	0
Continuous flow of water	1/38 = 3% 1/31 = 3%*	1/27 = 4% 1/21 = 5%*	0	1/23 = 4% 1/20 = 5%*	0	1/13 = 8% 1/12 = 8%*	0	0	1/4 = 25% 1/3 = 33%*
Drinker cleaning interval									
Each group	4/38 = 11% 4/33 = 12%	2/27 = 7% 2/24 = 8%*	4/27 = 15%	1/23 = 4% 1/21 = 5%*	2/9 = 22%	1/13 = 8%	1/7 = 14% 1/4 = 25%*	1/5 = 20%	0
Daily	23/38 = 61% 23/33 = 70%*	18/27 = 67% 18/24 = 75%*	16/27 = 59%	15/23 = 65% 15/21 = 71%*	6/9 = 67%	3/13 = 23%	3/7 = 43% 3/4 = 75%*	3/5 = 60%	2/4 = 50% 2/2 = 100%*
Weekly	6/38 = 16% 6/33 = 18%*	4/27 = 15% 4/24 = 17%*	7/27 = 26%	5/23 = 22% 5/21 = 24%*	1/9 = 11%	9/13 = 69%	0	1/5 = 20%	0
Pen Gates Construction									
Height (m)	0.9 – 2.5	1.2 – 2.5	0.9 – 2	0.9 – 2	1 – 2.5	1.5 – 2.3	1.7 – 2.2	0.9 – 2	1.1 – 1.2
Wood	2/38 = 5%	1/27 = 4%	2/27 = 7%	1/23 = 4%	2/9 = 22%	0	0	0	0
Metal	36/38 = 95%	26/27 = 96%	25/27 = 93%	22/23 = 96%	7/9 = 78%	13/13 = 100%	7/7 = 100%	5/5 = 100%	4/4 = 100%
Ventilation Methods Used									
Raised Ridge	11/38 = 29%	9/27 = 33%	9/27 = 33%	9/23 = 39%	2/9 = 22%	6/13 = 46%	1/7 = 14%	1/5 = 20%	1/4 = 25%
Yorkshire Board	16/38 = 42%	12/27 = 44%	12/27 = 44%	9/23 = 39%	1/9 = 11%	8/13 = 62%	3/7 = 43%	3/5 = 60%	1/4 = 25%
Open Side	9/38 = 24%	3/27 = 11%	3/27 = 11%	4/23 = 17%	1/9 = 11%	1/13 = 8%	2/7 = 29%	1/5 = 20%	4/4 = 100%
Fans	10/38 = 26%	2/27 = 7%	6/27 = 22%	7/23 = 30%	0	2/13 = 15%	0	3/5 = 60%	4/4 = 100%
Windows	6/38 = 16%	5/27 = 19%	5/27 = 19%	4/23 = 17%	3/9 = 33%	4/13 = 31%	0	1/5 = 20%	0
Combination	18/38 = 47%	10/27 = 37%	12/27 = 44%	12/23 = 52%	0	7/13 = 54%	2/7 = 29%	3/5 = 60%	4/4 = 100%

Bedding Used									
Straw	21/38 = 55% 21/25 = 84%*	15/27 = 56% 15/17 = 88%*	18/27 = 67% 18/20 = 90%*	15/23 = 65% 15/17 = 88%*	4/9 = 44% 4/5 = 80%*	9/13 = 69% 9/11 = 82%*	3/7 = 43% 3/3 = 100%*	3/5 = 60% 3/3 = 100%*	2/4 = 50% 2/3 = 67%*
Shavings	4/38 = 11% 4/25 = 16%*	3/27 = 11% 3/17 = 18%*	3/27 = 11% 3/20 = 15%*	2/23 = 9% 2/17 = 12%*	1/9 = 11% 1/5 = 20%*	2/13 = 15% 2/11 = 18%*	0	0	1/4 = 25% 1/3 = 33%*
None	13/38 = 34%	10/27 = 37%	7/27 = 26%	6/23 = 26%	4/9 = 44%	2/13 = 15%	4/7 = 57%	2/5 = 40%	1/4 = 25%
All animals bedding	10/38 = 26% 10/28 = 36%*	7/27 = 26% 7/17 = 41%*	10/27 = 37% 10/20 = 50%*	6/23 = 26% 6/17 = 35%*	1/9 = 11% 1/5 = 20%*	6/13 = 46% 6/11 = 55%*	0	2/5 = 40% 2/3 = 67%*	0
Overnighters only	13/38 = 34% 13/28 = 46%*	8/27 = 30% 8/17 = 47%*	8/27 = 30% 8/20 = 40%*	10/23 = 43% 10/17 = 59%*	1/9 = 11% 1/5 = 20%*	4/13 = 31% 4/11 = 36%*	3/7 = 43% 3/3 = 100%*	1/5 = 20% 1/3 = 33%*	3/4 = 75% 3/3 = 100%*
Bedding removed									
Each Group	8/38 = 21% 8/25 = 32%*	6/27 = 22% 6/17 = 35%*	7/27 = 26% 7/20 = 35%*	6/23 = 26% 6/17 = 35%*	2/9 = 22% 2/5 = 40%*	5/13 = 38% 5/11 = 45%*	0	0	1/4 = 25% 1/3 = 33%*
Daily	12/38 = 32% 12/25 = 48%*	8/27 = 30% 8/17 = 47%*	8/27 = 30% 8/20 = 40%*	8/23 = 35% 8/17 = 47%*	2/9 = 22% 2/5 = 40%*	5/13 = 38% 5/11 = 45%*	2/7 = 29% 2/3 = 67%*	1/5 = 20% 1/3 = 33%*	2/4 = 50% 2/3 = 67%*
Weekly	5/38 = 13% 5/25 = 20%*	3/27 = 11% 3/17 = 18%*	5/27 = 19% 5/20 = 25%*	3/23 = 13% 3/17 = 18%*	1/9 = 11% 1/5 = 20%*	1/13 = 8% 1/11 = 9%*	1/7 = 14% 1/3 = 33%*	2/5 = 40% 2/3 = 67%*	0
New bedding given									
Each Group	6/38 = 16% 6/25 = 24%*	4/27 = 15% 4/17 = 24%*	6/27 = 22% 6/20 = 30%*	5/17 = 29%	0	5/13 = 38% 5/11 = 45%*	0	0	1/4 = 25% 1/3 = 33%*
Daily	11/38 = 29% 11/25 = 44%*	8/27 = 30% 8/17 = 48%*	6/27 = 22% 6/20 = 30%*	5/17 = 29%	2/9 = 67% 2/5 = 40%*	4/13 = 31% 4/11 = 36%*	2/7 = 29% 2/3 = 67%*	2/5 = 40% 2/3 = 67%*	1/4 = 25% 1/3 = 33%*
Weekly	2/38 = 5% 2/25 = 8%*	0	2/27 = 7% 2/20 = 10%*	0	1/9 = 11% 1/5 = 20%*	0	0	1/5 = 20% 1/3 = 33%*	0
Pens Washed Out									
Each Group	7/38 = 18%	5/27 = 19%	6/27 = 22%	6/23 = 26%	2/9 = 22%	2/13 = 15%	2/7 = 29%	0	1/4 = 25%
Daily	15/38 = 39%	13/27 = 48%	10/27 = 37%	9/23 = 39%	4/9 = 44%	7/13 = 54%	2/7 = 29%	1/5 = 20%	1/4 = 25%
Weekly	11/38 = 30%	3/27 = 11%	6/27 = 22%	3/23 = 13%	2/9 =22%	2/13 = 15%	0	2/5 = 40%	0
Pens Pressure Hosed or Steamed									
Each Group	2/38 = 5%	2/27 = 7%	4/27 = 15%	3/23 = 13%	1/9 = 11%	1/13 = 8%	0	0	0
Daily	18/38 = 47%	13/27 = 48%	11/27 = 41%	12/23 = 52%	6/9 = 67%	6/13 = 46%	2/7 = 29%	1/5 = 20%	3/4 = 74%
Weekly	11/38 = 30%	7/27 = 26%	10/27 = 37%	7/23 = 30%	2/9 = 22%	6/13 = 46%	0	2/5 = 40%	1/4 = 25%

Detergent used in holding pens									
Each Group	2/38 = 5%	0	1	1	1/9 = 11%	1/13 = 8%	0	0	0
Daily	7/38 = 18%	7/27 = 26%	4/27 = 15%	3/23 = 11%	4/9 = 44%	2/13 = 15%	0	0	1/4 = 25%
Weekly	11/38 = 30%	8/27 = 30%	10/27 = 37%	8/23 = 35%	3/9 = 33%	6/13 = 46%	0	1/5 = 20%	1/4 = 25%
Never	2/38 = 5%	2/27 = 7%	0	0	0	1/13 = 8%	1/7 = 14%	0	0
Disinfectant used in holding pens									
Daily	5/38 = 13%	5/27 = 19%	3/27 = 11%	3/23 = 13%	2/9 = 22%	2/13 = 15%	0	0	1/4 = 25%
Weekly	13/38 = 34%	7/27 = 26%	10/27 = 37%	8/23 = 35%	2/9 = 22%	6/13 = 46%	0	3/5 = 60%	2/4 = 50%
Never	2/38 = 5%	2.27 = 7%	0	0	0	1/13 = 8%	1/7 = 14%	0	0
Other	1	0	1 blow torch weekly	0	0	0	0	1 blow torch weekly	0
Race Construction									
Length (m)	0 – 30	3 – 30	0 – 8	0 – 25	0 - 4	3 - 15	3 - 30	0 - 600	0 – 25
Mean	33.8	7.9	4	11	3.5	5.4	16.4	121.8	25
Responses (N)	24	22	7	5	2	11	7	3	1
Capacity (animals)	0 – 30	1 – 15 mean 3.8	0 – 10 mean 2.4	0 – 30 mean 16	1 - 3	0 – 5 mean 3.3	3 – 15 mean 6.4	0 – 21 mean 7	30
Stun System for Small Species									
Group pen	21/31 = 68% 21/27 = 78%*	N/A	18/27 = 67% 18/23 = 78%*	19/23 = 83% 19/20 = 90%*	6/9 = 67% 6/6 = 100%*	11/13 = 85% 11/12 = 92%*	N/A	1/5 = 20%	3/4 = 75%
Pen capacity	0 – 30		0 – 30	0 – 12	0 - 6	0 – 20		0 – 30	0 - 12
Restrainer conveyor	5/31 = 16% 5/27 = 19%*		5/27 = 19% 5/23 = 22%*	0	0	1/13 = 15% 1/12 = 8%*		4/5 = 80%	0
Gas System	1/31 = 3% 1/27 = 4%*		0	1	0	0		0	1/4 =25%
Roll-out Ramp Construction									
Solid concrete	22/38 = 58%	15/27 = 56%	21/27 = 78%	21/23 = 91%	9/9 = 100%	6/13 = 46%	3/7 = 43%	1/5 = 20%	3/4 = 75%
Solid steel	3/38 = 8%	2/27 = 7%	1/27 = 4%	1/23 = 4%	0	0	1/7 = 14%	1/5 = 20%	1/4 =25%
Slatted steel/grid	11/38 = 29%	9/23 = 39%	4/27 = 15%	1/23 = 4%	0	5/13 = 38%	3/7 = 43%	3/5 = 60%	0
Other	2/38=5%	1 shackled in box	1 tiles	0	0	1 shackled in box 1 tiles	0	0	0

Race Cleaning Frequency									
Each Group	5/38 = 13%	4/27 = 15%	6/27 = 22%	5/23 = 22%	4/9 = 44%	1/13 = 8%	0	0	0
Each Break	14/38 = 37%	8/27 = 30%	7/27 = 26%	3/23 = 13%	0	5/13 = 38%	3/7 = 43%	3/5 = 60%	3/4 = 75%
Daily	12/38 = 32%	12/27 = 45%	5/27 = 19%	5/23 = 22%	2/9 = 22%	6/13 = 46%	4/7 = 57%	0	0
Weekly	2/38 = 5%	0	2/27 = 7%	0	0	0	0	2/5 = 40%	0
Chemicals Never	2/38 = 5% 2/33 = 6%*	2/27 = 7% 2/24 = 8%*	0	1/23 = 4% 1/13 = 8%*	0	1/13 = 8% 1/12 = 8%*	1/7 = 14%	0	0
Chemicals Sometimes	2/38 = 5% 2/33 = 6%*	2/27 = 7% 2/24 = 8%*	1/27 = 4% 1/20 = 5%*	2/23 = 9% 2/13 = 15%*	0	2/13 = 15% 2/12 = 17%*	0	0	0
Chemicals at breaks	4/38 = 11% 4/33 = 12%*	3/27 = 11% 3/24 = 13%*	4/27 = 15% 4/20 = 20%*	1/23 = 4% 1/13 = 8%*	1/9 = 11% 1/6 = 17%*	0	0	1/5 = 20%	1/4 = 25% 1/3 = 33%
Chemicals daily	10/38 = 26% 10/33 = 30%*	7/27 = 26% 7/24 = 29%*	8/27 = 30% 8/20 = 40%*	4/23 = 17% 4/13 = 31%*	3/9 = 33% 3/6 = 50%*	4/13 = 31% 4/12 = 33%*	0	2/5 = 40%	1/4 = 25% 1/3 = 33%
Chemicals weekly	5/38 = 13% 5/33 = 15%*	5/27 = 19% 5/24 = 21%*	4/27 = 15% 4/20 = 20%*	1/23 = 4% 1/13 = 8%*	0	3/13 = 23% 3/12 = 25%*	2/7 = 29%	2/5 = 40%	0
Stun Box Cleaning Frequency									
Each Group	5/38 = 13%	2/27 = 7%	8/27 = 30%	6/23 = 26%	4/9 = 44%	0	0	1/5 = 20%	0
Each Break	17/38 = 45%	11/27 = 41%	7/27 = 26%	7/23 = 30%	0	6/13 = 46%	5/7 = 71%	3/5 = 60%	3/4 =75%
Daily	12/38 = 32%	10/27 = 37%	6/27 = 22%	6/23 = 26%	2/9 = 22%	6/13 = 46%	2/7 = 29%	1/5 = 20%	1/4 = 25%
Chemicals Never	2/38 = 5% 2/34 = 6%*	2/27 = 7% 2/23 = 9%*	0	1/23 = 4% 1/19 = 5%*	0	1/13 = 8% 1/12 = 8%*	1/7 = 14%	0	0
Chemicals Sometimes	2/38 = 5% 2/34 = 6%*	2/27 = 7% 2/23 = 9%*	0	1/23 = 4% 1/19 = 5%*	0	2/13 = 15% 2/12 = 17%*	0	0	0
Chemicals each group	1/38 = 3% 1/34 = 3%*	2/27 = 7% 2/23 = 9%*	3/27 = 11% 3/21 = 14%*	2/23 = 9% 2/19 = 11%*	1/9 = 11% 1/6 = 17%*	0	0	0	0
Chemicals at breaks	6/38 = 16% 6/34 = 18%*	1/27 = 4% 1/23 = 4%*	3/27 = 11% 3/21 = 14%*	2/23 = 9% 2/19 = 11%*	0	1/13 = 8% 1/12 = 8%*	3/7 = 43%	1/5 = 20%	1/4 = 25%
Chemicals daily	14/38 = 37% 14/34 = 41%*	12/27 = 44% 12/23 = 52%*	10/27 = 37% 10/21 = 48%*	4/23 = 17% 4/19 = 21%*	3/9 = 33% 3/6 = 50%*	6/13 = 46% 6/12 = 50%*	0	4/5 = 80%	1/4 = 25%
Chemicals weekly	3/38 = 8% 3/34 = 9%*	1/27 = 4% 1/23 = 4%*	2/27 = 7% 2/21 = 10%*	3/23 = 13% 3/19 = 16%*	0	3/13 = 23% 3/12 = 25%*	0	0	0

Roll-out Ramp Cleaning Frequency									
Each animal	6/38 = 16%	6/27 = 22%	0	1/23 = 4%	4/9 = 44%	2/13 = 15%	0	0	0
Each Group	6/38 = 16%	1/27 = 4%	7/27 = 26%	6/23 = 26%	3/9 = 33%	3/13 = 23%	0	0	0
Each Break	18/38 = 47%	12/27 = 44%	9/27 = 33%	5/23 = 22%	0	6/13 = 46%	6/7 = 86%	4/5 = 80%	2/4 = 50%
Daily	6/38 = 16%	3/27 = 11%	4/27 = 15%	4/23 = 17%	0	2/13 = 15%	1/7 = 14%	1/5 = 20%	0
Chemicals Never	2/38 = 5% 2/37 = 5%*	2/27 = 7% 2/22 = 9%*	0	1/23 = 4% 1/16 = 6%*	1/9 = 11% 1/7 = 14%*	0	1/7 = 14%	0	0
Chemicals Sometimes	3/38 = 8% 3/37 = 8%*	3/27 = 11% 3/22 = 14%*	0	1/23 = 4% 1/16 = 6%*	0	2/13 = 15%	1/7 = 14%	0	0
Chemicals each animal	2/38 = 5% 2/37 = 5%*	2/27 = 7% 2/22 = 9%*	0	0	1/9 = 11% 1/7 = 14%*	1/13 = 8%	0	0	0
Chemicals each group	2/38 = 5% 2/37 = 5%*	1/27 = 4% 1/22 = 5%*	2/27 = 7% 2/20 = 10%*	2/23 = 9% 2/16 = 14%*	1/9 = 11% 1/7 = 14%*	1/13 = 8%	0	0	0
Chemicals at breaks	4/38 = 11% 4/3711%*	2/27 = 7% 2/22 = 9%*	4/27 = 15% 4/20 = 20%*	1/23 = 4% 1/16 = 6%*	0	2/13 = 15%	0	1/5 = 20%	1/4 = 25% 1/2 = 50%*
Chemicals daily	16/38 = 42% 16/37 = 43%*	9/27 = 33% 9/22 = 41%*	9/27 = 33% 9/20 = 45%*	4/23 = =17% 4/16 = 27%*	4/9 = 44% 4/7 = 57%*	4/13 = 31%	3/7 = 43%	4/5 = 80%	1/4 = 25% 1/2 = 50%*
Chemicals weekly	2/38 = 5% 2/37 = 5%*	1/27 = 4% 1/22 = 5%*	2/27 = 7% 2/20 = 10%*	2/23 = 9% 2/16 = 14%*	0	2/13 = 15%	0	0	0
Cleaning Products used									
Chlorfoam	4/38 = 11%	3	4	3	0	3	0	1	0
Holquat	2/38 = 5%	2	2	2	0	2	0	0	0
Virkon	2/38 = 5%	1	1	2	0	1	0	0	1
Measuring technique									
Jug	10/38 = 26% 10/27 = 37%*	7	8	7	4	2	1	2	1
Automatic	13/38 = 34% 13/27 = 48%*	11	13	11	0	11	0	2	0
Eye	1/38 = 3% 1/27 = 4%*	1	1	1	1	0	0	0	0
Rinsing									
Rinsed	10/38 = 26% 10/27 = 37%*	8	8	8	1	6	1	1	1
Left on	16/38 = 42% 16/27 = 59%*	10	15	11	2	8	0	5	1

Why chosen									
Non hazardous	10/38 = 26% 10/27 = 37%*	8	9	9	2	6	0	1	1
Efficacy	11/38 = 29% 11/27 = 41%*	7	10	6	1	5	1	4	0
Price	2/38 = 5% 2/27 = 7%*	2	2	2	2	0	0	0	0
DEFRA/MHS	4/38 = 11% 4/27 = 15%*	3	3	4	0	3	0	0	1

Insurance requirements

The work associated with this contract / grant has been carried out in accordance with the highest academic standards and reasonable endeavours have been made to achieve the degree of reliability and accuracy appropriate to work of this kind.

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