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Beef HACCP: intervention and non-intervention systems

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Abstract

While there are several generic beef HACCP documents available to the beef industry, these lack sufficient detail to be of any use other than as a general guide to HACCP. A document which clearly identifies and provides a sound scientific basis for potential critical control points (CCPs') and details critical limits, monitoring and corrective actions is clearly required.

The objective of this paper is to provide such information. A detailed description of CCPs' for two different HACCP systems (an intervention and a non-intervention system) are presented and the advantages and disadvantages of each are discussed. Individual beef plants may then make an informed choice as to which HACCP system is most suitable for them and have all the specific information required for effective implementation. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Beef HACCP; Intervention HACCP systems; Non-intervention HACCP systems

1. Intervention systems

Specific interventions in beef slaughter are designed to reduce bacterial contamination on the carcasses and usually involve the application of heat, organic acids or both. Sofos et al. (1999a,b,c) and Bacon et al. (1999) have recently published work on the effectiveness of decontamination in a number of beef plants in the USA. The decontamination treatments available in these plants are shown in Table 1. Each of these interventions will be discussed.

1.1. Cold / warm water washing

Carcasses are washed with cold (10–15°C) or warm (15–40°C) potable water to remove bone dust and blood clots. A number of investigations on the effect of spraying beef carcasses with cold or warm water have shown that decontamination to reduce bacterial numbers does not occur (Sheridan and Sherington, 1984; Gill et al., 1996a; Bell, 1997; McEvoy et al., 1999). However, in other studies, significant reductions were recorded, but only at specific carcass sites (Prasai et al., 1991; Jericho et al., 1995). In many cases washing simply redistributed bacteria from one area to another (Jericho et al., 1995; Gill et al., 1996b; Bell, 1997; McEvoy et al., 1999). Washing with cold or warm water is therefore not considered to be a decontamination step during slaughter as its effects are related solely to improving carcass appearance and not food safety.

1.2. Hot water washing

Water at 75–85°C may be applied to the carcasses under pressure as a spray or using a deluge system

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Table 1
Potential decontamination steps currently used in beef processing (Bacon et al., 1999)

Spraying/washing of carcasses:
Cold (10–15°C), warm (15–40°C) or hot (75–85°C) potable water in a cabinet system or hand sprayed at different pressures.
Steam vacuuming of small areas on the carcasses.
Steam pasteurisation at 100°C.
Organic acid washes (lactic or acetic) hot (50–55°C) or cold.
Zero tolerance and trimming.
Chilling.

which delivers sheets of water at 85°C onto the carcass (Gill et al., 1999; Bacon et al., 1999). The latter system consists of two horizontal headers each fitted with Floodjet™ nozzles arranged to deliver sheets of water in free-fall manner rather than under pressure. The main bactericidal effect of these systems is thermal, although there may also be a physical effect involving the removal of some bacteria as a result of washing.

Hot water is easier and more economical to generate than steam; however, commercial hot water washing systems in the USA use 85 to 90 gallons of water per minute and the heat may discolour the cut surfaces of the carcass. Numerous studies have demonstrated the ability of hot water washing to reduce bacterial contamination of beef carcass tissue using a range of water temperatures and pressures (Gorman et al., 1995; Dorsa et al., 1996, 1997). Research on the effect of hot water washing of beef carcasses under commercial conditions has also shown that this treatment may be commercially successful in reducing the levels of contamination on beef carcasses (Gill et al., 1999).

The critical limits for hot water washing are given in Table 2. The temperature of the water is monitored on a continuous basis. Corrective actions are preventive as any failure with the hot water wash stops the line, thus ensuring no carcass passes this stage without being adequately treated.

1.3. Steam vacuuming

Steam vacuum systems use hot water, steam and a vacuum to decontaminate small areas on the carcass. Vac-San (Kentmaster, Monrovia, CA) is an example of one commercially available system. The water lightly agitates the surface of the carcass at 85°C, killing and removing bacteria. Steam continually sanitises the hand-held unit and boosts water temperature while the vacuum removes the waste-water and contaminants.

Steam vacuuming is generally not used as a CCP in US beef plants because these systems are not always in operation. However, it is often applied as a GMP at different stages in the slaughter process, e.g. first/second legging, hide removal, pre-evisceration and/or trimming. Significant decontamination effects have been demonstrated in commercial experiments where small areas of beef carcasses were treated using a steam vacuum (Gill and Bryant, 1997b; Kochevar et al., 1997).

However, a number of problems has been identified with the application of the steam vacuum such as (Gill and Bryant, 1997b; Phebus et al., 1997; Castillo et al., 1999):

(i) inability to completely eliminate faecal pathogens
(ii) the temperature of the meat surface may only reach 34–49°C during treatment
(iii) at least 10 s is required for a pasteurising effect and operatives on-line may not have sufficient time for the job
(iv) the curvature of some surfaces may make proper contact with the vacuum head difficult, which can reduce the effectiveness of the treatment
(v) bovine faeces may be redistributed rather than removed
(vi) it is only suitable for decontaminating small areas of the carcass.

Table 2
The critical limits for hot water washing

Spray system	
Water temperature at nozzle	75°C to 85°C
Water pressure	9.7–13 Pa
Time	9–12 s

Deluge system	
Water temperature at nozzle	85°C
Water pressure	Not applicable
Time	10 s

The critical limits for the stream vacuum systems are given in Table 3. Monitoring involves checking and recording the parameters defined in the critical limits every hour using the gauges on the machine. The corrective action requires that the use of the steam vacuum be discontinued until the parameters defined in the critical limits have been adjusted back to the correct values. Affected carcasses receive additional trimming further down the line.

1.4. Steam pasteurisation

Steam pasteurisation systems, such as that produced by Frigoscania (Bellevue, WA) operate a process in which surface water is initially removed from the carcass before the steam is applied to kill pathogens. The carcass surface is then chilled with water. Steam pasteurisation may discolour the cut surfaces on beef carcass. The commercial effectiveness of steam pasteurisation in on-line cabinet systems for 6–6.5 s has been established for beef (Gill and Bryant, 1997b; Nutsch et al., 1997, 1998). However, it was noted that some sites, such as the neck, did not receive as complete a decontamination treatment as others (Nutsch et al., 1998). This was attributed to the fact that the target temperature of 82°C was only maintained at the neck for about 2 s and this site cooled the fastest. All the hindquarter sites, where the majority of the faecal contamination occurs, appeared to receive the maximum treatment temperatures. A synergistic effect between steam pasteurisation and chilling has also been reported (Gill and Bryant, 1997b).

Critical limits for steam pasteurisation are given in Table 4. A continuous monitoring system is available with the steam pasteurisation unit described above. As each side is processed, a printout is produced showing the side number, date, real time, process time, process temperature and any relevant process alarms. Should any side not attain the preprogrammed lower temperature limit or pasteurisation time, then an alarm sounds, the steam pasteurisation unit shuts down and the under-processed side is automatically rejected for processing. When the critical limits are breached, the affected carcasses are manually railed off and returned to the steam pasteurisation chamber for reprocessing.

Table 3
The critical limits for steam vacuuming systems

Water temperature	≥ 82°C
Water pressure	3.4–10.3 Pa
Air vacuum	−0.093 Pa
Steam pressure	20.7–34.5 Pa
Area decontaminated	No more than 2.5 cm^2

Table 4
The critical limits for steam pasteurisation

Water removal	Air velocity	1981 m/min
	Air volume	170 m^3/min
Pasteurisation	Atmospheric temperature inside steam chamber	82–94°C
	Time	6–8 s
Cooling	Water temperature	4.4°C
	Water pressure	27.6 Pa
	Surface temperature of carcasses	17.5–22.4°C
	Time	10 s

1.5. Organic acid application

Organic acids, such as lactic or acetic acid are usually applied using a spray cabinet. Organic acids are widely used in the USA, but are not permitted under EU regulations for beef carcass decontamination (Smulders and Greer, 1998). In some US beef plants, the organic acid wash is considered to be a GMP rather than a CCP because not all carcasses are treated (organic acids are not applied to carcasses with an open wound or leaking abscess). There are varying reports in the literature on the decontaminating effect of organic acids (Snijders et al., 1985; Prasai et al., 1991; Avens et al., 1996).

There is no clear evidence that they have a significant lethal effect on their own. The acid kill some cells and damage many others on the meat surface. The carcass are also discoloured as a result of this treatment and operators may experience respiratory and skin/eye irritation when acetic acid is used.

The critical limits for organic acid application are given in Table 5. These are continuously monitored (once an hour) and all the equipment required for

Table 5
The critical limits for organic acid application

Acid concentration	2.5–10% (v/v) to allow for the dilution effect when applied to the carcass
pH of acid	2.8
Temperature of acid	25–55°C
Pressure of application	13.8–27.6 Pa
Volume of acid applied	500 ml
Duration of application	35 s

this is calibrated at least once per day. The corrective action requires that all the carcasses since the last acceptable carcass be re-sprayed either by re-routing through the spray cabinet or by using hand-held sprays.

1.6. The combination of hot water washing and organic acid application

A commercial system of hot water pasteurisation followed by organic acid pasteurisation has been developed for use in beef slaughter at pre-evisceration and/or prior to chilling (Chad, Olathe, KS). A chill water spray may be required after the treatment to reduce the surface temperature of the carcass prior to entering the chiller. This cooling step minimizes the opportunity for condensation in the chiller and helps the refrigeration system cool the carcasses as quickly as possible.

Organic acids, in combination with other treatments such as heating or chilling, may have a beneficial effect (Dickson, 1992). The decontaminating effect of hot water and organic acid pasteurisation on beef was demonstrated under experimental conditions using a model spray cabinet designed by Chad (Castillo et al., 1998). In this study, the beef was subjected to a high pressure water wash prior to treatment.

The critical limits for this system are given in Table 6 and are checked once an hour. All the equipment required for this are calibrated at least once per day. As with organic acid application, the corrective action involves re-treating all the carcasses back to the last acceptable carcass by re-routing through the Chad cabinet.

1.7. Zero tolerance and trimming

The recent introduction of 'zero tolerance' by the USDA/FSIS (Anonymous, 1996) has placed greater emphasis on the trimming of visible contamination from the carcass surface. Zero tolerance means that every carcass must be free of faeces, ingesta and milk (in the case of cows). Each carcass is thoroughly inspected and any contamination found is removed by trimming using a knife. Trimming significantly reduces carcass contamination when the knives and hooks are sterilised between carcasses (Prasai et al., 1995; Reagan et al., 1996; Kochevar et al., 1997).

The critical limit requires that there be no visible faeces, ingesta or milk on the carcass. Every carcass should be inspected for visible contamination during trimming to ensure that zero tolerance is being achieved. In addition to this continuous monitoring, at least three carcass per hour should also be checked by a manager/supervisor to ensure this stage is being performed correctly. To correct any failure at this CCP, all carcasses since the last acceptable carcass are re-trimmed and re-inspected. In some US plants, affected carcasses are marked with a red tag and trimmed in the chillers. If there are three or more failures, the inspection and trimming process is reviewed.

Table 6
The critical limits for hot water washing in combination with organic acid application (Castillo et al., 1998)

High pressure wash	(1) Volume	1.51 (hand wash)
	Time	90 s
	Pressure	6.9 Pa
	(2) Volume	51 (cabinet wash)
	Time	9 s
	Pressure	172.5–276 Pa
	Temperature	35°C
Hot water wash	Temperature	95°C
	Pressure	24 psi
	Time	5 s
Lactic acid	Acid concentration	2% (v/v)
	Temperature of acid	55°C
	Pressure of application	27.6 Pa
	Volume of acid applied	200 ml
	Duration of application	11 s

1.8. Chilling

Chilling is not generally regarded as an intervention but is included here as it may be used as a CCP as part of an intervention type HACCP system. Carcasses are chilled immediately after carcass washing until the temperature of the deep round reaches 7°C or lower (Fresh Meat Directive 95/23/EEC). Data from the scientific literature is variable and shows that bacterial numbers can increase, decrease or remain unchanged during chilling (Gill and Bryant, 1997a; Nutsch et al., 1997; Bacon et al., 1999; McEvoy et al., 1999). The chilling parameters (air temperature, relative humidity, air speed and carcass spacing) that achieve a reduction in bacterial contamination on beef carcasses have yet to be established. When these are defined, they may be used as critical limits.

At present, the critical limit for chilling may be set at achieving a temperature of 7°C or lower in the deep-round muscle. Carcasses of similar proportions should be refrigerated together to achieve uniform results and should be placed at least 6 cm apart to allow circulation of air (Mackey and Roberts, 1993). Chilling is monitored by checking the deep round temperature of a number of randomly selected carcasses per rail in the chiller, prior to release for further processing. This is done every hour and the values are recorded.

The temperature of the air in the chiller may be automatically monitored and controlled on a continuous basis using a System Control And Data Acquisition (SCADA) or other similar system. This would also alert the production manager (or other designated personnel) when the critical limits are breached, automatically take immediate corrective action and produce an ongoing record of performance. Carcasses that have not reached the target temperature are chilled for an additional period until the target temperature is obtained.

2. The non-intervention system

The intervention HACCP system described above may not be the most appropriate approach for European beef plants. Interventions that require the application of organic acids, for example, are not permitted in the EU as these are perceived to be a means of concealing or compensating for poor hygiene practices during slaughter. In addition, EU legislators believe that adherence to strict hygiene measures is sufficient to overcome the threat posed by *E. coli* O157, *Salmonella* and other pathogens. Other interventions, such as the application of steam and hot water may also be unsuitable as these treatments discolour the cut surfaces of the carcasses.

Non-intervention systems, like the Hygiene Assessment Scheme (HAS) in operation in the UK, recognise good hygiene and management practices and focus on those operations where hygiene control is particularly important. The HAS system is based on a hygiene audit that assesses performance in 5 main categories. Each category is scored and weighted according to its importance in relation to carcass hygiene. The higher the score, the better the hygiene level at the plant. A recent study by Hudson et al. (1996) has shown that this non-intervention system is effective in reducing the microbial levels on beef carcasses. Bacterial counts of less than 2 $\log_{10}$ cfu/cm^2 have been obtained and these compare favourably with those recorded using intervention systems in the USA (Bacon et al., 1999).

The non-intervention HACCP system described in this paper is based on the principles of the HAS scheme but instead of regular audits, those operations where hygiene control is especially important are monitored on a continuous basis using an online monitoring system similar to that described by Bolton et al. (1999). In this system of online monitoring, each carcass is inspected and faecal contamination is related to a particular operation.

There are four critical control points, namely (1) de-hiding, (2) evisceration, (3) removal of the spinal cord and (4) chilling (Fig. 1). The first two operations are particularly important from a carcass hygiene perspective, as failure to follow correct procedures at these stages will inevitably lead to faecal/rumen material getting onto the carcass. Failure to completely remove the spinal cord may expose consumers to the risk of acquiring vCJD.

2.1. CCP 1: de-hiding

During dehiding, the hide is initially removed from the hock and butt areas with a knife. It is then

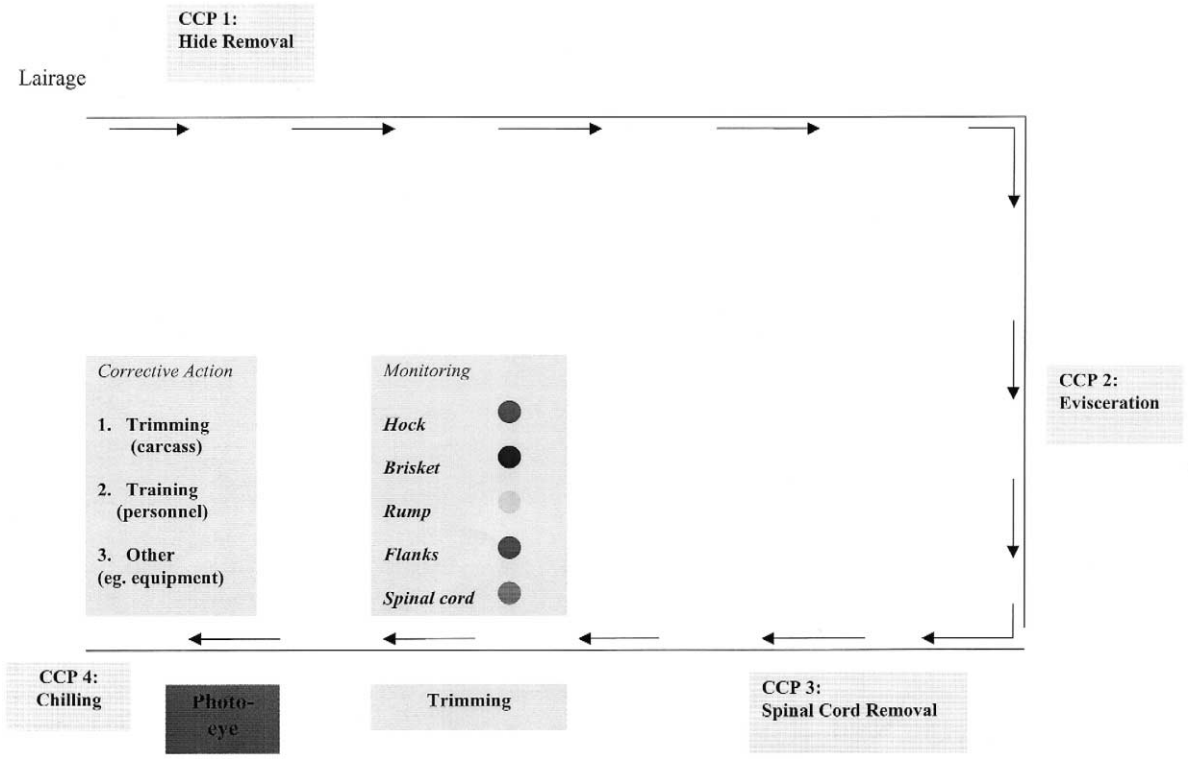

Fig. 1. A non-intervention HACCP system.

cut down the midline and removed from the flank, brisket and forelegs using knives or flayers. Each of these operations may involve cutting through faecal matter on the hide, which is inevitably deposited on the area of the carcass immediately beneath the hide incision, i.e. on the hock, flank and brisket (Gill et al., 1995; Doherty et al., 2000) (Fig. 2).

There is one GMP associated with de-hiding. All equipment should be sterilised in water at 82°C to prevent cross-contamination from the hide to the carcass and between carcasses.

2.2. CCP 2: evisceration

If the rectum is nicked or faecal material leaks from the anus, the rump area of the carcass may be contaminated (Gill et al., 1995). Bursting of the visceral contents may also cause spillage of faecal/rumen matter onto the brisket (Gill et al., 1995) (Fig. 2). There are a number of GMPs associated with this CCP; rodding, bagging and tying of the bung and sterilisation of all the equipment used.

2.2.1. Rodding

The oesophagus (wizzand) is separated from the trachea using a knife. A rodder is placed around the oesophagus and pushed upwards to free the upper part of the oesophagus. A crocodile clip or plastic ring is placed on the end of the oesophagus and forced upwards with the rodder until it reaches the entry point to the stomach. It is then released to seal the oesophagus.

Alternatively, a potato starch cone is placed on the end of an applicator and the applicator is pushed up the oesophagus as far as the stomach. A button is pressed to draw a vacuum from the tip of the applicator and cause the oesophagus to enter the inner part of the cone thus holding it in place. An advantage of this system is that the cone is completely degraded during rendering. There is no evidence to

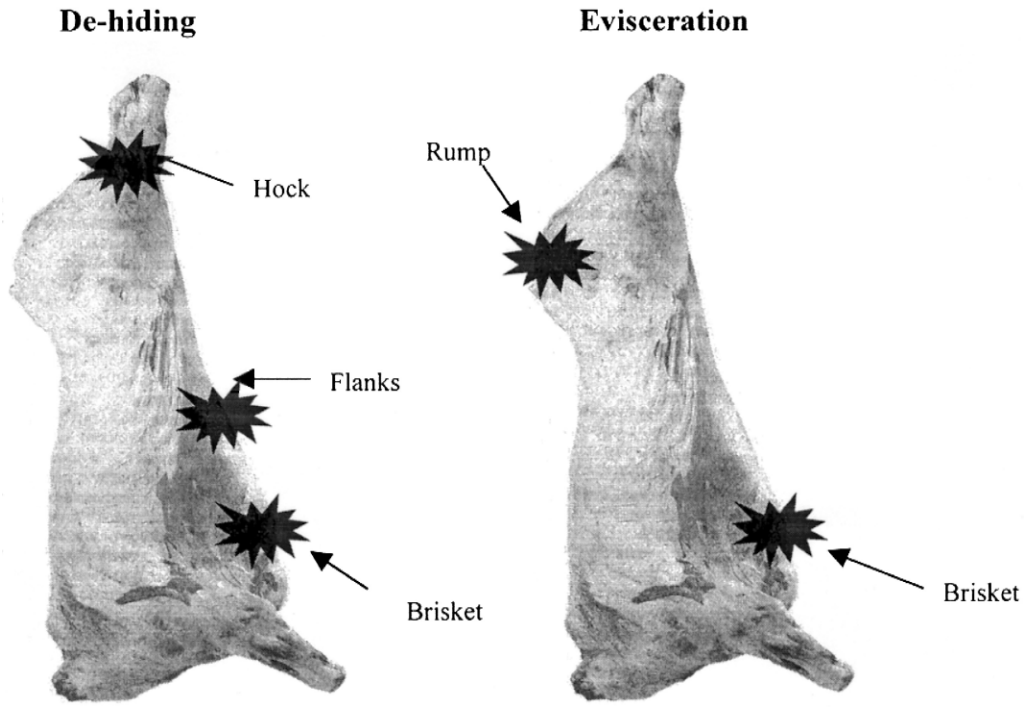

Fig. 2. The areas of a beef carcass contaminated during de-hiding and evisceration.

show which of these two systems is the most effective in terms of reducing contamination. Sterilisation of the knife and rodding applicator in water at 82°C are also GMPs.

2.2.2. Bagging and tying of the bung

In this procedure, a plastic bag is used to cover the bung to prevent contamination of the carcass (Nesbakken et al., 1994). One hand is placed in the bag, which is used to catch the bung (anus). The second hand is used to free the bung and rectum from the surrounding pelvic tissue by severing the attachments with a knife. The bung is pulled upwards and outwards and the bag is pulled down over the rectum and sealed with an elastic band or piece of string. The latter is the most successful. An automated system of sealing the rectum ('safe seal') has been developed in Australia and has been shown to more effective in reducing contamination than the manual system (Sheridan, 1998). Sterilisation of the knife in water at 82°C is also a GMP.

2.3. CCP 3: carcass splitting and spinal cord removal

Spinal cord removal is the third CCP in this HACCP plan. The agent or prion that causes BSE in cattle is also responsible for vCJD in humans (Collinge et al., 1996; Bruce et al., 1997; Starks and Poe, 1997). All materials from cattle containing these prions, which include the spinal cord, are referred to as Specified Risk Material (SRM) and must be completely removed, permanently stained and sent directly to a specially dedicated rendering plant, where they are rendered and stored pending destruction by incineration. This ensures that they are excluded from human food and animal feed chains (Anonymous, 2000).

2.4. CCP 4: chilling

As previously discussed, chilling may be a CCP in beef slaughter HACCP if the conditions under

Table 7
Relating contamination on the carcass to a specific operation

Location on carcass	Inspected for	Causative operation
Hock	Faecal specks/smear/small stains	De-hiding
Flank	Faecal specks/smear/small stains	De-hiding
Brisket	Faecal specks/smear/small stains	De-hiding
Rump	Faecal specks/smear/small stains	Evisceration (cutting around the bung)
Brisket	Large faecal stains/patches often extending down to the neck	Evisceration (removal of the viscera)
Spinal column	Pieces of spinal cord tissue	Spinal cord removal

which bacterial growth is prevented or pathogens levels are reduced can be defined in terms of air temperature, relative humidity, air flow, carcass grade and spacing.

2.5. Online monitoring

At the core of the non-intervention HACCP plan is an online monitoring system which consists of five push-buttons linked to a PC in the QA managers or other office and/or electronic visual display boards in the relevant operational areas, a photo-eye (which counts the total number of carcasses processed) and an alarm (optional) and is available from Integrated Quality Management Systems (Ireland). The first three CCPs' are monitored at the trimming stand (Fig. 1). Every carcass is visually inspected by specifically appointed personnel or the online trimmers for faecal contamination and the spinal column is checked to ensure the spinal cord has been completely removed.

Each faecal contamination event is recorded on the PC by pressing a push-button located on the slaughter-line at the monitoring stage (trimming). There are five push-buttons, each of a different colour and corresponds to a different area on the carcass. If, for example, faeces is detected on the hock, the red button is pushed, if on the brisket, the blue push-button is used and so on. An alarm system and electronic display boards may also be linked into the system to alert the operators.

The key to using this monitoring system as part of HACCP is being able to relate the area of contamination on the carcass to a specific operation (Table 7). As already stated, incorrect de-hiding results in faecal contamination of the hock, flank and brisket areas of the carcass. Evisceration (cutting around the bung) may contaminate the rump. However, in common with de-hiding, the brisket may also be contaminated. Distinguishing between de-hiding and evisceration as the culprit operation when the brisket is contaminated is based on the amount and pattern of contamination. Contamination as a result of de-hiding will usually appear as faecal specks while contamination during evisceration would cause relatively large blotches of green faecal staining. Ineffective removal of the spinal cord can be easily detected by visual inspection.

Every time a push-button is pressed, a score is registered against that carcass area (and hence against the causative operation) on the PC. These scores are continually counted. In addition, a photo-eye, which counts the total number of carcasses processed, may also be linked to the PC. So the computer has two numbers: the total number of carcasses processed and the total number of contamination events for a given operation. By performing a simple calculation, the frequency of contamination can then be expressed as a percentage contamination rate. If, for

Table 8
The causes of errors and the relevant corrective actions

Contamination cause	Error	Corrective action
Personnel	Incorrect procedure	Review procedure Employee training Replace/rotate employee Adjust work environment
Equipment	Failure	Replace/repair/adjust Check sterilisers Add equipment
Other factors	Unforeseen	Appropriate to correct

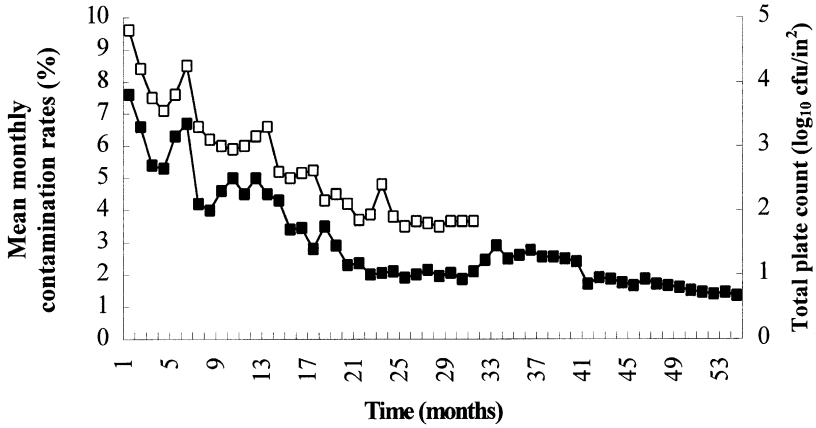

Fig. 3. Mean monthly contamination rates (%) (■) and the corresponding total plate counts ($\log_{10}$ cfu/in^2) (□) from June 1993 to October 1997.

example, faeces was detected on the hock on 10 different occasions, the red push-button should have been pressed 10 times. If, during that period, the photo-eye had counted 100 carcasses (i.e., 100 carcasses had been processed), then the percentage contamination rate would have been $10/100 \times 100 = 10\%$.

The critical limits for de-hiding and evisceration are set as percentage contamination rates and typically apply to a given shift or for a single days production. The initial critical limit is usually based on a preliminary study that establishes the average percentage contamination rate and the initial critical limit is set at this figure minus 2 standard deviations. After every 2 months, the critical limit is reset at the average for the previous 2 months minus 2 standard deviations. The critical limit for spinal cord tissue is always zero (i.e., the spinal cord must be completely removed).

When faeces or spinal cord tissue is detected, these are immediately removed by trimming. With faeces, an area of not less than 2.5 in. around the stain must also be removed.

When the critical limit for the shift is breached, other corrective actions are also required. This may involve retraining/replacing the person performing the operation, which is contaminating the carcass, replacement of knives, steels and scabbards, checking the sterilisers etc. (Table 8).

As well as counting contamination events and identifying the operation most likely to have caused these occurrences, the online monitoring system also automatically records this data. The only other records then required are documents detailing the corrective actions taken and verification.

A non-intervention system, similar to that described above has been successfully applied to pork slaughter in the USA (Bolton et al., 1999), where carcass contamination levels decreased from approximately 8% to 1.5% with a concomitant 99.8% decrease in aerobic plate counts (Fig. 3).

3. Intervention vs. non-intervention HACCP systems

A beef HACCP system may use interventions, like hot water washing or steam pasteurisation, be based solely on the non-intervention system described above or use a combination of both. Interventions have the advantage of achieving a consistent reduction in bacterial contamination and require less manual input. However, they may also discolour the carcasses, produce large quantities on waste water (which must be recycled) and are relatively expensive to set-up and run. Non-intervention systems have the advantages of being relatively inexpensive, easy to implement and are more preventive as the exact cause of contamination on the carcass is identified, allowing preventative corrective actions to be taken. However, these systems are heavily reliant on

human effort and the opportunity for error is considerably higher than with intervention systems.

Regardless of which CCPs' are used and how these are operated, there is now sufficient research data available to allow beef plants to implement effective, science-based, HACCP systems, which will lead to reduced carcass contamination and safer beef for consumers.

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