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Assessment of the hygienic efficiencies of processes for cooling meat at slaughtering plants

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Assessment of the hygienic efficiencies of processes for cooling meat at slaughtering plants

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SUMMARY

Meat from new slaughtered animals is warm. While the meat remains at warm temperatures, bacteria on the meat surfaces will rapidly increase in numbers. Those bacteria can include pathogenic species. It is therefore essential for the safety of the food that processes for cooling meat are well controlled.

The rates at which individual items cool tend to be highly variable in any batch process for cooling meat. It is therefore difficult to define a hygienically satisfactory cooling process simply by specifying the temperature and the speed of the air delivered by refrigeration equipment into a chiller or freezer. That difficulty can be overcome by collecting temperature histories from a random sample of product items moving through a cooling process, and characterizing the hygienic consequences of each temperature history by integrating the history with respect to models describing the effect of temperature on the growth of an indicator organism, *Escherichia coli*. Then, each temperature history yields a unique value for *E. coli* proliferation, and the hygienic adequacy of the process can be described in terms of the distribution of *E. coli* proliferation values.

The use of that temperature function integration technique is illustrated by a series of studies, in which the hygienic efficiencies of several types of commercial meat cooling process were assessed. The hardware and software required for the temperature function integration analysis of meat cooling processes are detailed in appendices.

The temperature function integration technique allows cooling processes to be controlled on the basis of objective data. Such control is required for proper implementation of Quality Management and Hazard Analysis: Critical Control Point Systems.

RESUMÉ

Pendant la période où la viande d'animaux récemment abattus demeure chaude, les bactéries, souvent pathogènes, se multiplient rapidement à la surface de la viande. Il est donc essentiel pour une bonne hygiène alimentaire, que les méthodes de refroidissement de la viande soient bien contrôlés.

La température de refroidissement des éléments de lots de viande est souvent très variable. Il est pour cette raison plutôt difficile de pouvoir définir un processus de refroidissement qui soit hygiéniquement satisfaisant par rapport au fonctionnement de l'établissement de réfrigération. Ce problème peut-être réduit grâce à la compilation de données thermales provenant d'échantillons en cours de refroidissement, choisis au hazard et en caractérisant les conséquences hygiéniques de chaque température, puis en intégrant ces données thermales dans des modèles décrivant l'effet de la température sur la croissance d'un organisme indicateur: *Escherichia coli*. À partir de cette information, chaque donnée thermale réflétant une valeur particulière de croissance d'*E. coli* servira à formuler un procédé hygiénique adéquat sous forme de distribution des valeurs de croissance d'*E. coli*.

L'utilisation de cette technique d'intégration en fonction de la température est illustrée à l'aide d'études dans lesquelles, l'efficacité hygiénique provenant de plusieurs procédés commerciaux de refroidissement de la viande a été évaluée. Le logiciel et matériel informatique nécessaires à l'analyse de l'intégration de la température des procédés de refroidissement de la viande sont détaillés en annexes.

La technique d'intégration en fonction de la température, permet aux procédés de refroidissement d'être contrôlés sur une base de données objectives. Un tel contrôle est nécessaire pour la mise en application de La Gestion de la Qualité et Analyse des Risques: Systèmes de Maîtrise des Points Critiques.

INTRODUCTION

Bacteria capable of causing disease (pathogens) can be transferred to the surfaces of previously sterile edible tissues during dressing and breaking down of carcasses (Grau, 1986). There is no practicable method of establishing the absence of such organisms on meat so, for public health purposes, their presence on all fresh meat must be assumed. Regulation of meat processing therefore aims to ensure that transfer of pathogenic bacteria to edible tissues is minimal, and that opportunities for these organisms to grow on meat are severely restricted.

Control of pathogen transfer to meats is achieved by inspection, to maintain Good Manufacturing Practice (GMP), and my limited microbiological sampling for some objective assurance of GMP maintenance. Provided that such regulatory inspection adequately controls the addition of contaminants to fresh meats, then temperature abuse that permits pathogen proliferation is the major processing hazard. Currently, regulatory authorities attempt to control temperature abuse by stipulating a maximum ambient temperature for meat processing areas. Unfortunately, this requirement is of limited value because the temperatures relevant to bacterial growth are those of the product, not those of the environment. Moreover, this simplistic requirement may unnecessarily increase processing costs and restrict process flexibility without achieving the avowed objective. This inadequacy of current regulatory practice may be relieved by routine monitoring of product temperature histories and analysis of the data by an appropriate temperature function integration technique (Gill, 1986).

Temperature function integration refers to the mathematical technique for calculating the increase in bacteria numbers during a given time by integrating time-temperature data with respect to data relating bacterial growth to temperature. It has been shown, under practical conditions, that when the initial numbers of bacteria on the meat was known, the final numbers calculated from the temperature history and the number determined to be present on the meat by sampling can be in close agreement (Pooni and Mead, 1984). However, this will only be so when the data describing bacterial growth is appropriate for the environment that the product provides to the bacteria.

The necessary calculations could be for any site on a meat product. However, the calculation will only be meaningful if the site is likely to be contaminated by bacteria. Moreover, it is not possible to obtain temperature histories for every piece of product, or even for a statistically significant fraction of product units. The limited number of temperature histories that can be collected must therefore be characteristic of the process. For the purposes of hygiene control, it is appropriate to define the worst possible case, because if the worst possible case is acceptable then all better cases must also be acceptable.

The method of assessment therefore involves the collection of temperature histories that show the worst possible temperature conditions for product moving

through a process, identification of the type of bacterial growth that will occur at each stage of the process, and calculation of the extent to which an indicator organism could, in the worst possible case, grow during the process (Gill *et al.*, 1988).

It should be appreciated that it is the process that is being assessed, not the absolute hygienic status of individual units leaving the process. The assessment of hygienic adequacy will assure that the time and temperature conditions that product experiences during the process do not cause unacceptable degradation of product hygiene. Such assessment does not assure that product entering the process is hygienically adequate, or that a source of extraneous contamination does not exist in the process. Those latter causes of hygienic inadequacy must be controlled by other means.

The assessment of the hygienic efficiency of a process is based on estimation of the greatest possible growth of pathogens on meat passing through the process.

A pathogen is any organism that can cause disease. Bacteria that are pathogenic for humans are associated with food animals and can be found on the meat derived from them. All the pathogenic bacteria associated with meat are capable of growth at 37°C, the normal temperature of the human body. Most of those bacteria cannot grow at chiller temperatures. However, in recent years, pathogens that can grow at chiller temperatures have been identified. Although those psychrotrophic (cold-tolerant) pathogens must pose some health risk, the risk is small, and can be considered an acceptable minor risk associated with the consumption of meat that has been properly handled according to current criteria. Assessments of cooling processes can then be based on calculations that indicated the possible growth of mesophilic (cold-intolerant) pathogens.

The mesophilic pathogens that can be found on meat have differing growth temperature ranges, and differing growth rates at any permissive temperature. It is not possible to evaluate temperature history data with respect to proliferation of all those organisms. Instead, the pathogen posing the greatest general risk can be considered, because if processing is adequate with respect to the species posing the greatest risk, then processing must be adequate for any species posing a lesser risk.

There is general agreement that *Salmonella* is the pathogenic species occurring on meat that poses the greatest risk. Growth rate data for this species could therefore be used for evaluation of temperature history data. However, there is a continuing need to validate the assessment technique under differing field conditions. This would not be a practicable possibility with *Salmonella*, as the organism is found on meat only sporadically and in small numbers. To overcome that difficulty, the program is based on data for *Escherichia coli*, a species closely related to *Salmonella*. It is generally accepted that *E. coli* is a suitable organism for indication of unsatisfactory product hygiene (NRC, 1985). *E. coli* is commonly present on meat in significant numbers. Although most strains are innocuous, some are enteropathogens. Comparison of lag

phases and growth rates for *E. coli* and *Salmonella* shows that *E. coli* will generally grow somewhat faster than *Salmonella*. The use of *E. coli* growth rate data will tend to exaggerate possible *Salmonella* proliferation and so provide an additional margin of safety in evaluating the hygienic adequacy of any process.

The characterization of a process will only be valid if temperature histories are obtained for sites on product that are:

- Possibly contaminated by bacteria.
- Will have a higher temperature for longer time than any other possibly contaminated point of the product unit.
- Part of those product units that experience the highest temperatures for the longest time when passing through the process; or that are adequately representative of the range of conditions experienced by product units passing through the process.

It is therefore critically important that temperature probes are correctly placed for each type of product, and that the monitored product is properly selected.

The deep tissues of meat are sterile (Gill, 1979). Bacteria will therefore be present only on meat surfaces that have, at some time, been exposed to the environment. However, the monitored point will not always be a surface exposed in the monitored product, as surfaces that have been exposed than covered again by other meat will still be contaminated. The point that should be monitored is usually obvious from consideration of contaminated areas and the part of the product that can be cooled least effectively. However, it may be impossible to monitor the ideal point of some types of product without damaging the product. In such circumstances, a convenient point that can be expected to have a temperature history very similar to that of the ideal point is monitored instead.

Processes consist of one or more relatively short periods when product is being prepared, and one or more relatively long periods when product is being cooled. Product temperature cannot be monitored during the short preparation periods. Instead such periods must be restricted to a maximum time, and a reasonable, assumed product temperature ascribed for that period. Temperature is monitored during the cooling periods.

All facilities is which cooling can take place are likely to have gradients of cooling efficiency within the facility (James and Bailey, 1990). To properly characterize the worst possible temperature history for product passing through a process, the monitored product should occupy an area of any cooling facility where the cooling efficiency is known to be the minimum for that facility. A cooling facility that is not a continuous, flow-through system will be loaded over a lengthy period as product is prepared, and may be unloaded relatively rapidly at the end of the cooling cycle. Moreover, different cooling conditions may be applied during loading and after

completion of loading. Thus, the duration and conditions of cooling may vary for product prepared at different times of a working period.

It is not usually possible to identify the product units that will experience the worst temperature conditions. Instead, a representative sample is obtained by collecting temperature histories from 21 or more product units selected at random.

Further explanation of the assessment technique is most readily accomplished by description of its application to particular cooling process.

ASSESSMENT OF CARCASS COOLING PROCESSES

Background and Method

Edible tissues become contaminated as the hide is split to expose the meat. In principal, temperature monitoring should commence at the start of carcass dressing. That, however, is wholely impracticable. Instead, temperature monitoring is initiated as the carcasses leave the dressing line, with the provision that the time between the start of dressing and the start of temperature monitoring does not exceed 40 minutes.

Temperatures must be recorded from the persistently warmest point on carcass surfaces (Gill *et al.*, 1991a). That has been identified as the area within the aitch-bone pocket (Fig. 1). For recording surface temperatures, a disc of stainless steel is held against the carcass surface by means of a plastic staple passed through holes in the disc. The disc is placed as medially and caudally as possible within the aitch-bone pocket. A cone-shaped slot designed to hold a temperature probe at the disc center runs across the diameter of the disc. Temperatures are recorded, at 2 minute intervals, by a miniature electronic data logger that is secured to the carcass by a skewer.

For calculating bacterial growth, it is assumed that, at the warm temperatures of freshly slaughtered carcasses, all bacteria placed on the carcass will have initiated growth before temperature monitoring commerces. Therefore, the only bacterial growth model that needs to be applied is one that describes the variation with temperature of the rate of aerobic growth of *E. coli.* Temperature monitoring must continue until there is certainty that all the monitored temperatures have fallen below 7°C, so that the growth of *E. coli* has ceased.

Figure 1. The site within the aitch-bone pocket from which the temperature histories of the slowest-cooling area of carcass surfaces were recorded. 1, psoas minor muscle; 2, psoas major muscle; 3, external oblique abdominal muscle; 4, straight abdominal muscle. The abdominal muscles are shown as reflected from their position medial to the psoas muscles. (•), position of temperature probe.

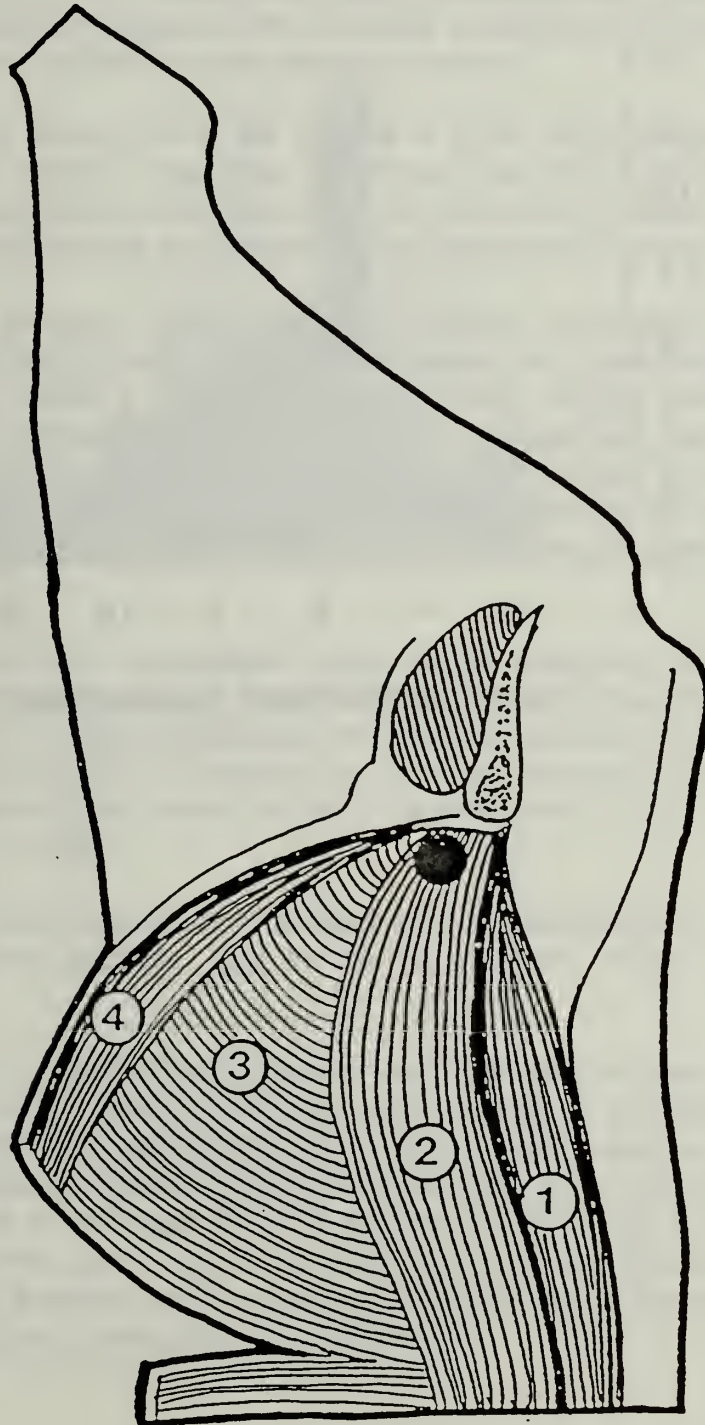
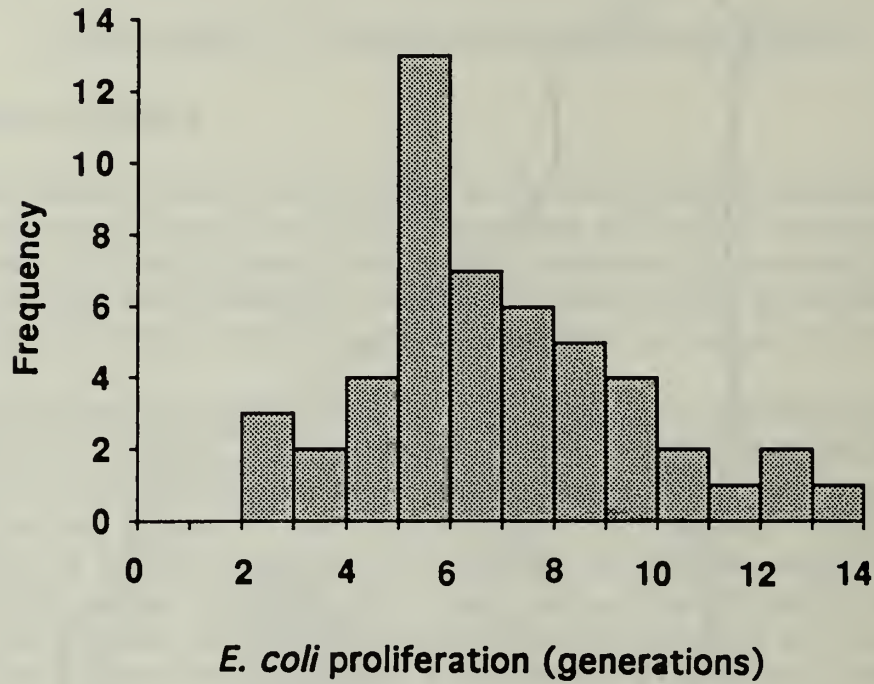


Figure 2. The frequency distribution of *Escherichia coli* proliferations calculated from temperature histories for the aitch-bone pocket sites of 50 beef sides cooling in a commercial chiller.



Results

A beef carcass process typical of overseas practice was examined (Gill *et al.* 1991a). The process differs from common North American practice in that sides of beef are loaded by hand to a relatively small chiller (capacity, 500 sides), and the sides are not sprayed with water while they are being cooled. The *E. coli* proliferations calculated for 50 sides ranged from 2 to 14 generations (Fig. 2). As the process had been identified as one that, by conventional criteria, complied with Good Manufacturing Practice, it was possible to suggest from that data a temperature function integration criterion for acceptable practice in meat cooling processes.

The suggested criterion is in the form of a three class attributes acceptance sample plan (Jarvis 1989). That type of criterion permits a marginally defective grouping, which would make some allowance for the many factors that can affect proliferation, and for imprecision in the collection of temperature history data.

A three-class attributes acceptance plan requires specification of the highest count (**m**) of the pertinent microbe(s) that is associated with satisfactory product, the microbial count (**M**) which if exceeded renders the product unacceptable, the proportion of counts (**c**) between **m** and **M** that can be tolerated, and the number of samples (**n**) that must be examined to make decision with respect to a product lot. To use such a plan for decision making, sampling must necessarily be random, and the number of samples should be sufficient for there to be a low probability of a defective lot being accepted.

In applying that form of criterion, it was found necessary to also specify, a maximum average proliferation value (**a**), to adequately define acceptable distributions of values. The criterion then stipulates that, for a random sample of > 20 units, 80% of proliferation values should be < 10 generations, none should be > 14 generations, and the average proliferation value should not be > 7 generations. *i.e.* **n** > 20; **m**=10 gen.; **M**=14 gen.; **a**=7 gen.; **c**=20%.

That criterion was subsequently applied in the assessment of a typical North American spray chilling process, and in the assessment of pig carcass cooling processes.

Examination of a spray-chilling process was desirable, because the practice of spray-chilling is still viewed with concern by some regulatory authorities. The study showed that carcass cooling was rather better than in the none-sprayed process (Gill *et al.*, 1991b), with the process yielding proliferation values of 87% < 10 generations, none > 12 generations and an average value of 6.8 generations (Fig. 3). Moreover, the assessment showed that some sides were being cooled so fast that the eating quality of the meat might be affected, and that such fast cooling could be eliminated without compromising the hygienic adequacy of the process.

Figure 3. The frequency distribution of the *E. coli* proliferations calculated from temperature histories for the area of persistent highest temperature on the surfaces of beef sides in a sample of 24 sides from each of the two chillers used in a commercial spray-chilling process for carcass beef.

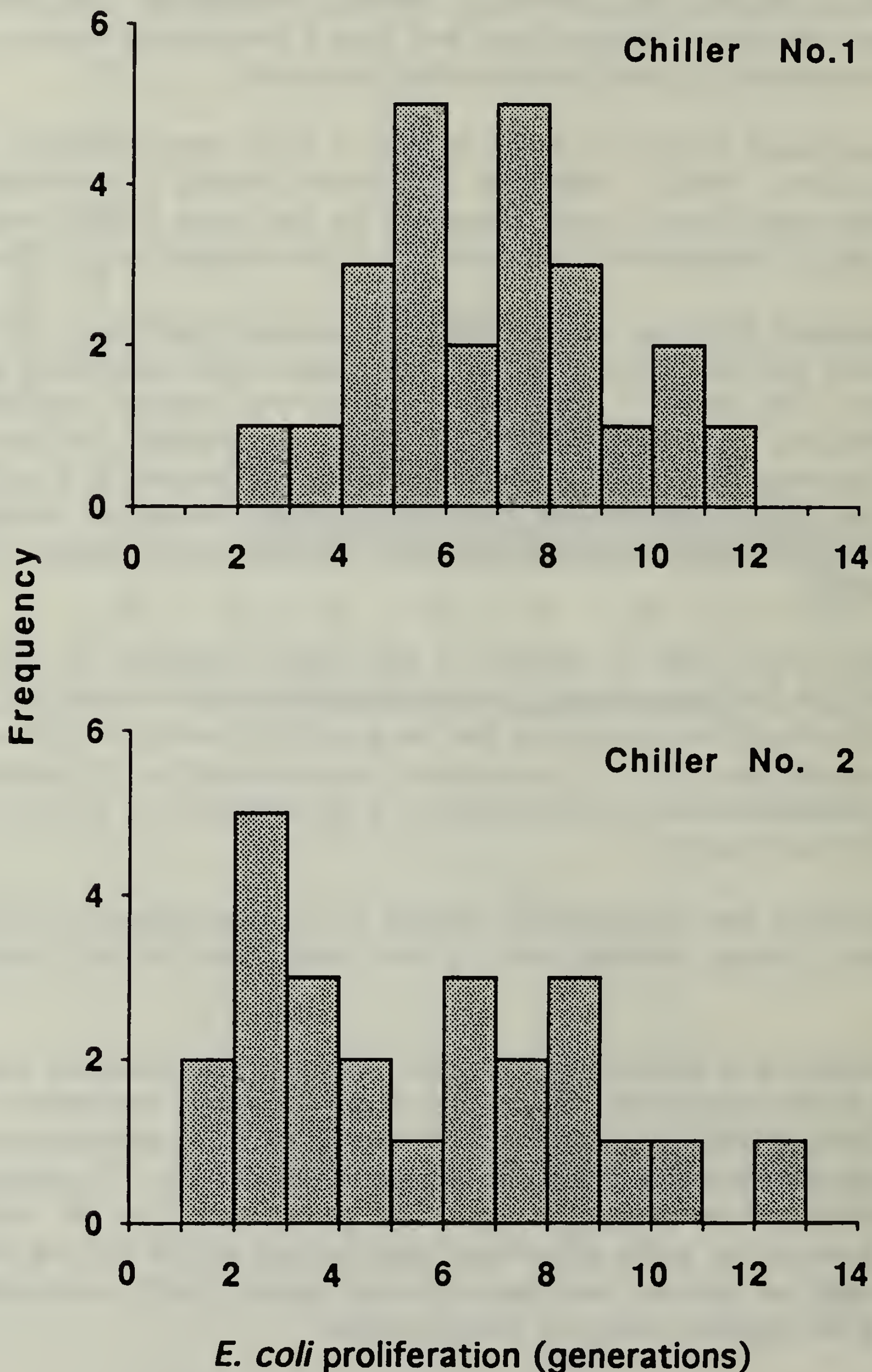
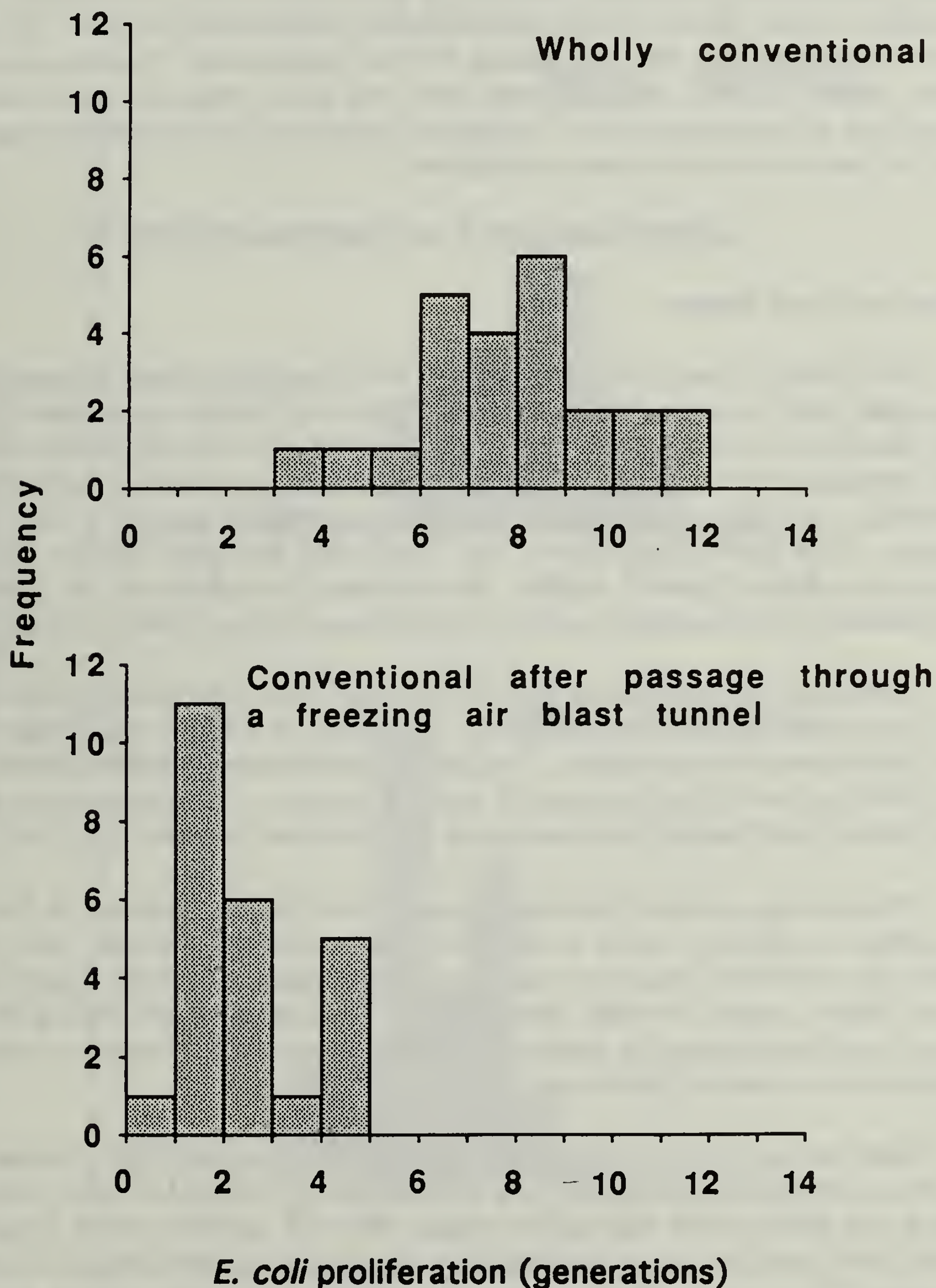


Figure 4. The frequency distributions of *Escherichia coli* proliferations calculated from temperature histories for the warmest site on the surface of each unit in samples of 24 pig carcasses cooling in commercial processes that are wholly conventional or conventional after the passage of carcasses through a freezing air blast tunnel.



The cooling of pig carcasses was studied to ascertain the hygienic effects of carcasses being passed through a freezing blast tunnel before they enter a conventional carcass chiller (Gill and Jones, 1992a). By conventional criteria the blast cooling process has some modest hygienic advantage over the wholely conventional process. However, the temperature function integration analyses showed a large hygienic advantage for the blast cooling process (Fig 4), with the blast cooling process yielding proliferation values of 100% < 10 generations and an average value of 5.8 generations, while values for the conventional process were 42% > 10 generations, none > 14 generations, and an average of 10.3 generations. From examination of the cooling curves it was demonstrable that the poor hygienic performance of the conventional process was due to ineffective cooling during the first few hours after the chiller had been loaded with warm carcasses.

ASSESSMENT OF A HOT BONING PROCESS

Background and Method

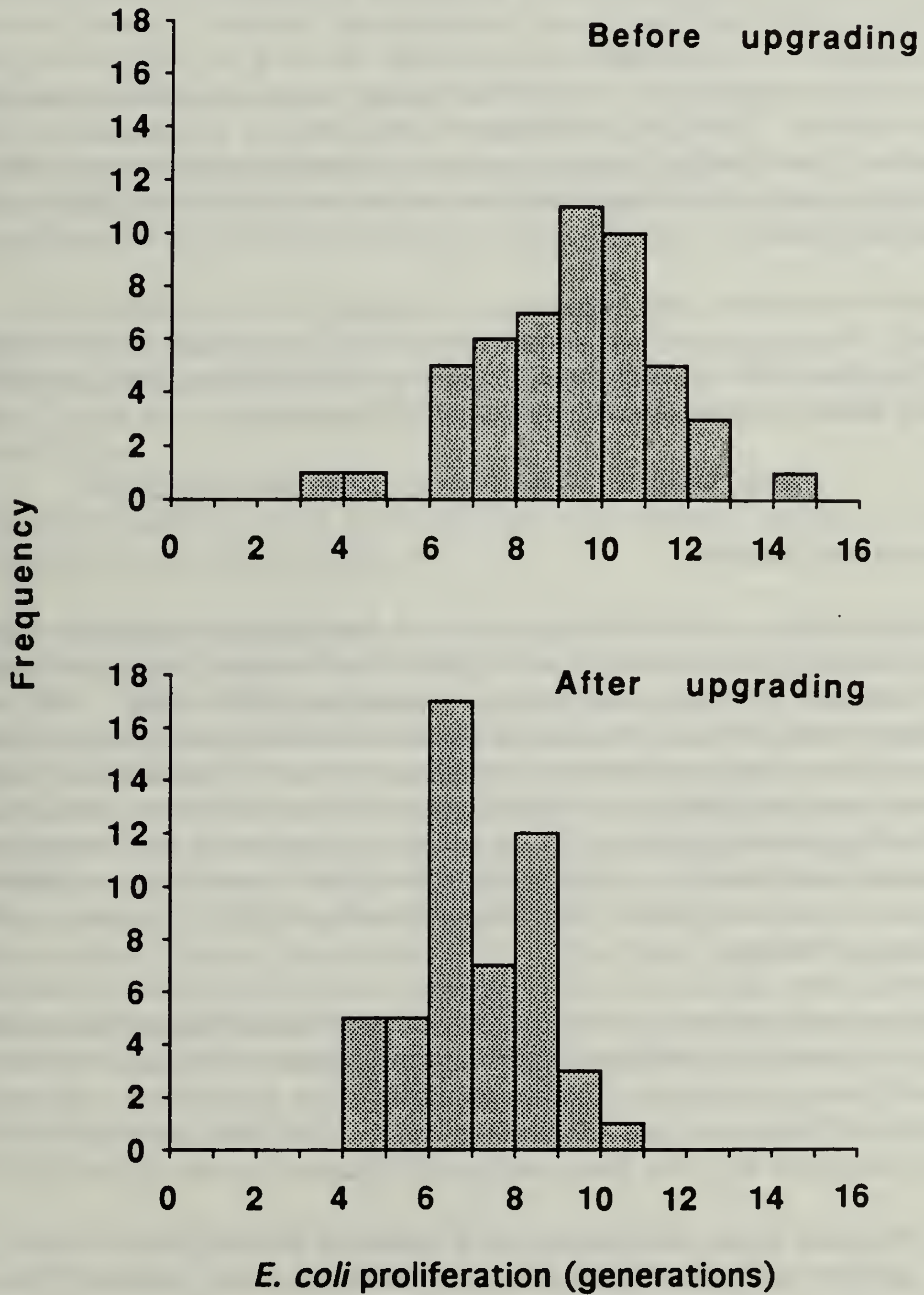
Hot boning of carcasses immediately after slaughter offers substantial economic advantages over conventional processes of boning chilled carcasses (Cuthbertson, 1980). Despite that, hot boning has been adopted only cautiously by the meat industry, in part because of the logistical difficulties of integrating a novel hot boning process with an existing cold boning process, and partly because of concerns over the hygienic adequacy of hot boning processes (Van Laack and Smulders, 1989). To resolve the uncertains over the hygienic aspects of hot boning, a commercial hot boning process was assessed by temperature function integration technique (Reichel *et al.*, 1991).

In the hot boning process, breaking of beef sides commences within 30 minutes of the completion of carcass dressing. The meat is packed into boxes immediately after it is removed from the sides. The filled boxes are assembled on racks in a cooled area. Filling a rack takes between 8 and 15 minutes. After each rack is filled, it is loaded into a blast freezer that operates at an off-coil air temperature of -30°C.

The cooling process obviously occurs in two distinct phases. In the first phase, beef sides are cooling as in a normal carcass cooling process, and temperature histories for that time must be collected as for carcass cooling processes. In the second phase, boxes of meat are cooled. The temperature history of the boxed product must be collected by inserting temperature probes to monitor temperatures at the geometric centres of filled boxes.

Each temperature logger must necessarily be removed from the beef side when breaking commences, and placed with a filled box of product from the same side. The hiatus in the temperature history that arises with the transfer of the logger from beef side to boxed product is accommodated by stipulating that the break in the record must not exceed 20 minutes. During the period of the break, the product temperature is assumed to be the higher of the temperatures at the beginning and end of the break.

Figure 5. Frequency distribution of calculated *E. coli* proliferation values obtained during assessments of a commercial hot boning process.



For calculating proliferation, aerobic growth is assumed until the end of the break between the two phases. The conditions at the center of a box of meat will be anaerobic, and the imposition of anaerobic conditions will induce a lag in the growth of *E. coli*. Therefore, proliferation in the boxed meat is calculated by first calculating the resolution of the lag phase, and then calculating the anearobic growth of *E. coli*. Thus, three models must be employed to properly calculate *E. coli* proliferation.

Results

In an initial assessment, using 50 beef sides, the process did not comply with the suggested criterion. Only 62% of calculated values were < 10 generations, 2% were < 14 generations, and the average proliferation value was 9.3 generations. The cause of that inadequate performance was identified as the insufficient refrigerative capacity of the blast chilling units.

On that information, the freezers were boosted by the installation of an additional compressor. Then, a second assessment show that the process could comply with the criterion (Fig 5) as 98% of proliferation values were < 10 generations, none were > 11 generations and the average proliferation was 7.1 generations.

ASSESSMENT OF AN OFFAL COOLING PROCESS

Background and Method

Offals are commonly found to be of poor microbiological quality. Although that has been considered an unavoidable characteristic of such product, it arises largely from inappropriate collection and cooling procedures (Gill, 1988). The widespread mishandling of offals in slaughter plants results in such product being unnecessarily hazardous to consumer health, and is the cause of much product being degraded, or wholely lost, through spoilage. A means of identifying processes appropriate to offal collection is clearly needed to avoid such hazard and waste. A commercial process for the collection and freezing of offals was therefore examined, to determine if a temperature function integration assessment could usefully characterize the process (Gill and Jones, 1992b).

The process involves the collection of several disparate types of beef offal, some of which are trimmed and washed before they are packed in boxes, others are vacuum packed, and some are packed in boxes with little or no preparation. Moreover, boxes of three different sizes are used for packing offals. The times between the removal of offals from carcasses and their being packed into boxes does not exceed 30 minutes.

All the filled boxes are passed to a common assembly area where they are strapped, labelled, and assorted to separate pallets for each individual type of offals. When each pallet load is completed, it is transferred by a forklift-truck to an adjacent

freezer operated at an off-coil air temperature of -25°C. The different offals accumulate at different rates, so the times the offals remain in the ambient temperature assembly area vary from about one to several hours.

Monitoring of offal temperatures can be initiated only after the boxes have been filled. The conditions at the centre of a box of offals will be anaerobic, but as the warm offals are usually collected together before they are placed in the boxes, it can be assumed that there is no significant lag before *E. coli* commences growth on product at the centres of boxes. Therefore, temperature histories from the centres of boxes were integrated with respect to a model describing the variation with temperature of the anaerobic growth of *E. coli*.

Monitoring of all types of offal was impracticable. Instead, head meats, hanging tenders, livers and hearts were examined, as those products encompassed a range of pre-packing treatments, final units sizes, and dwelling times in the assembly area.

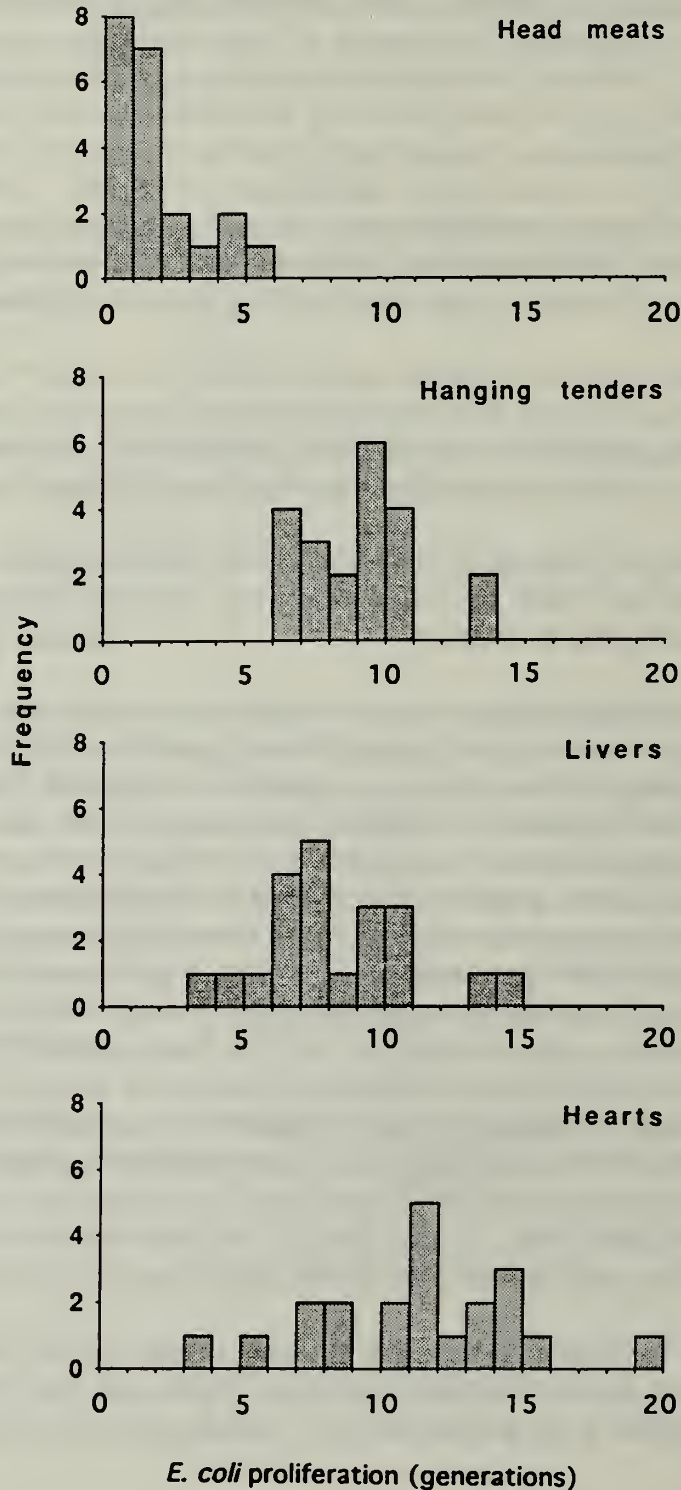
Results

Only the cooling of head meats was fully satisfactory. The cooling of hanging tenders and livers was somewhat inadequate, and the cooling of hearts was grossly inadequate (Fig 6).

Several deductions could be made from the differing ranges of proliferation values obtained for each type of product.

The head meats are packed in the largest size of box, and boxes of those products can remain in the box stacking area for periods close to the maximum for any product. Their handling in the freezer is identical to that of the other products. Therefore, the very low proliferation values observed for the head meats can be ascribed to the relatively low initial temperatures of these products. All the offal types for which temperature histories were not collected had initial temperatures that were similar to those of the head meats. Moreover, all those offals were packed in smaller boxes than those used for the head meats. Therefore, it can be safely assumed that all of the offals from which temperature histories were not collected would yield very low proliferation values similar to those obtained from the head meats. Thus, all offals with a temperature at packing about 25°C, because of their small size, high surface to mass ratio, and/or washing with cold water, were apparently handled very adequately with respect to public health concerns in the box stacking and freezing operations.

Figure 6. Frequency distribution of calculated *E. coli* proliferation values obtained during the assembly of 21 boxes in stacks at room temperature and subsequent freezing of various types of offal in a commercial process.



The proliferation values for livers and hanging tenders were very similar, despite a substantial difference in their maximum residence times in the box stacking area. The main effect of longer delays before exposure of the hanging tenders to freezing air was to eliminate proliferation values < 6 generations, of which a few were obtained for the livers. Reduction of the maximum times that products reside in the box stacking area could therefore have only a relatively modest effect on the general hygienic condition of the products that finally leave the process.

The very poor hygienic performance of the process with respect to hearts indicates an expected large effect of the unit product mass on cooling of the mass centre. Clearly, it would be hygienically advantageous to pack the warmest offals in the smallest size of box compatible with commercial requirements.

Finally, the wide spreads of proliferation values observed for livers and hearts showed that the cooling conditions experienced in the freezer differed widely between individual product units. In conjunction with the other deductions, this suggested that better management of the in-freezer portion of the process was the major requirement for substantial improvement of the hygienic adequacy of the process with respect to those offals that are packed at near body temperature.

Investigation of the conditions in the freezer confirmed those deductions, as there was great variation in the rates of air flow over product stacks at different locations within the freezer. The process could obviously be greatly improved by simply arranging for all the offals that are packed at near-body temperatures to be placed in regions of the freezer where they will be subjected to consistently high air flows.

ROUTINE USE OF THE TEMPERATURE FUNCTION INTEGRATION TECHNIQUE

After a cooling process has been assessed as complying with the temperature function integration criterion, routine monitoring and evaluation of the data collected will be necessary, to assure that compliance is maintained (NACMCF, 1992).

A temperature history from a product unit passing through the process should be collected each day. In multi-product processes, like offal cooling, the temperature histories should be collected from the product type with the worst performance in the cooling process. The time of placing the logger with product should be selected at random for each day, to assure a random collection of temperature histories.

At the end of each weekly period, the twenty one most recently accumulated proliferation values should be used to calculate the number of proliferation values exceeding **m** and the average proliferation (**a**). The highest proliferation value in that group should also be identified. Then, the highest proliferation value, the number of values exceeding **m**, and **a** should be plotted on a suitable graph maintained for that purpose. The weekly recalculation and plotting of those process parameters will allow any drifts in the parameters to be discerned. If the process shows evidence of drifting towards any of the criterion limits, then action can be taken to identify the cause, and counteract the movement before the criterion limits are exceeded.

CONCLUSIONS

Meat cooling processes in slaughtering plants can be objectively characterized as to their hygienic adequacy by a temperature function integration technique. Such objective characterization allows the ready identification of those aspects of a process that have the greatest effects upon its hygienic adequacy. It is then very evident what changes to process management or plant will be necessary to improve the process. Moreover, the effects of any changes to the process can be easily quantified. Then, commercially convenient variant practices can be adopted with confidence when their hygienic adequacy is easy demonstrated, while practices adopted for their supposed hygienic effect can be dispensed with should they prove to be ineffective.

Thus, temperature function integration analysis offers a very powerful tool for the objective management of meat cooling processes at slaughtering plants. Such a tool will become very necessary with the increasing regulatory demand that all meat plant processes be objectively monitored and controlled with respect to their hygienic adequacy. That control will have to be implemented and continuously documented by plant personnel, so that regulators can verify compliance with their requirements by inspection of plant records. Temperature function integration analysis is certainly worth considering for that purpose, as it is less costly and more precise than any other means of establishing and routinely demonstrating the hygienic adequacy of meat cooling processes.

ACKNOWLEDGMENTS

The technique of temperature function integration analysis was developed over several years with the assistance of members of the staff of the Meat Industry Research Institute of New Zealand (MIRINZ) and the Agriculture Canada Research Station, Lacombe. In particular, Mr. D. M. Phillips of MIRINZ has been largely responsible for implementing the hardware and software that is now available to facilitate application of the technique.

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APPENDIX 1. EQUIPMENT FOR TEMPERATURE HISTORY COLLECTION

Development of the temperature function integration technique required the availability of a temperature data logging device that was; sufficiently rugged to withstand the meat plant environment; of a conveniently small size, so that the logger could be placed with product without interfering with normal processing; accurate, reliable and secure against unauthorized interference with the data it collects; and capable of being interfaced with a computer, for convenient analysis of the data.

At the time that work was initiated, no such instrument existed. It was therefore necessary to design a temperature data logger, and computer software for setting the logging functions and retrieving collected data. That system is now licensed, by the Meat Industry Research Institute of New Zealand, for manufactured by Tru Test Distributors Ltd., Auckland, New Zealand. A number of similar instruments are now available from various suppliers. However, those other instruments are not compatible with analytical software (see Appendix 2) that has been developed on the basis of the MIRINZ/Delphi temperature data logging system.

The characteristics of the MIRINZ/Delphi temperature logger are:

Temperature Logger:

Physical Characteristics

- Compact Size: 160mm x 96mm x 22mm
- Weight: 204.5 Grams
- Power Supply: Lithium cell, meeting US Fed Reg CFR 173.206
- Battery Life: Approximately 5 years
- For in-plant monitoring of product temperatures the model fitted with an external, Teflon probe should be specified.

Recording Characteristics

- Temperature Range: -20 °C to + 40 °C
- Accuracy: $\pm$ 0.25 °C over operating range
- Resolution: 0.25 °C
- Start delay: up to 85 days
- Data Security: 4 Character Password
- Number of Temperature Recordings: 8000 8-bit logs
- Recording Time Intervals: Min 1/32 hour, Max 7.96 hour
- Recording period (Interval x 8000)
  - 10 Days if recording interval is 1/32 hour
  - 333 Days if recording interval is 1 hour
  - 667 Days if recording interval is 2 hours
- Downloading time: 64 seconds

Logger to Computer Interface:

- Communications : Utilises RS 232c Serial Link
  : Data format : 8 bits plus 1 stop bit at 1200 baud

- Power Supply: Internal, 9V cell type 216
- Size: 120mm x 68mm x 34mm
- Weight: 216 Grams
- Cable Length: 1.5 metres
- Terminating Connector : For PC: 25 pin D type female
  : For Epson HX-20: 3 pin DIN
- Battery Failure Indicator for Logger and Interface

Controlling Software

Capabilities

- Set up logger for recording
- Read logger data and summary
- Display of logger status
- Graphics display of logger data
- Printed report on logger status, tabulated data and graph data
- Database version (Optional)

Features

- Menu driven, function key control
- Multiple display windows
- On-screen status and data summary
- Expanded on-screen data plot
- Automatic alarm indication for temperature outside preselectable range
- Selection of limits on data of interest
- Data storing on disk and loading from disk
- Customized report selection
- Installation program to set custom options
- Automatic logger error detection
- Fail safe against user errors
- Compensated for Time Zone differences
- Operates in degrees Centigrade or Fahrenheit

Compatible Computer and Printer Systems

The recommended computer system is IBM PC or compatible.

- MS-DOS or PC-DOS Version 2.0 or later
- 640 KByte RAM
- 640 x 200 resolution graphics controller and monitor
- Minimum of 2 x 360 KByte floppy disk drives
- Hard disk optional but highly recommended
- RS 232 serial interface
- Printer interface

Any printer can be used but it must have graphics capability. Currently supported are IBM, EPSON and Printek. Others can be adopted as required.

APPENDIX 2. INTEGRATION OF TEMPERATURE HISTORY DATA WITH RESPECT TO THE GROWTH OF *ESCHERICHIA COLI*

Models for the variation of the growth rate and lag phase of *E. coli* with temperature were developed from data for cultivation of wild types strains in half-strength Brain Heart Infusion (Gill *et al.*, 1988). The triphasic model for aerobic growth has the form:

$y = (0.0513x - 0.17)^2$	when x is between 7 and 30;
$y = (0.027x + 0.55)^2$	when x is between 30 and 40;
$y = 2.66$	when x is between 40 and 47; and
$y = 0$	when x is < 7 or > 47;

where x is the temperature in °C and y is the growth rate expressed as generations/h. The model is an extension of that used by Lowry *et al.* (1989) for estimating *E. coli* proliferation during thawing of meat, and shown by those workers to give values for increases in numbers comparable with measured proliferation under aerobic conditions.

The model for the lag induced in *E. coli* by a shift from aerobic to anaerobic conditions has the form of a linear interpolation between values for factors which convert the period during the lag phase at a given temperature to the equivalent fraction of the lag phase at a temperature where the lag is 11 h (approx. 8°C). The 'equivalent lag factor' has the value:

11 (h)/observed lag at x°C(h).

The data set used is found in Table I.

TABLE I

Data for the model relating temperature and the lag imposed by an aerobic to anaerobic shift. See the text for explanation of the equivalent lag factor.

Temperature (°C)	Equivalent lag factor
< 7	0
7	0.95
12	3.2
15	6.6
17	12.8
19	17.6
21	28.8
22	36.8
23	47.0
24	40.0
25	76.4
25	Infinity

The triphasic model for anaerobic growth has the form:

$y = (0.0433x - 0.15)^2$	when x is between 7 and 30.5;
$y = (0.0163x + 0.676)^2$	when x is between 30.5 and 40;
$y = 1.77$	when x is between 40 and 45; and
$y = 0$	when x is < 7 or > 45;

where x is the temperature in °C and y is the growth rate expressed as generations/h.

The model is that used by Gill and Harrison (1985) for evaluation of the hygienic efficiency of offal cooling procedures, and shown to give values for increases in numbers comparable with measured proliferation under anaerobic conditions.

These models are applied in a computer program that requires a logger to be associated with a particular process before temperature monitoring commences. The process must then be specified as consisting of one phase or two phases (Gill *et al.* 1988).

Monitoring must commence with recording of carcass or side surface temperature. The probe must be placed within 10 min of the carcass leaving the slaughter line. To assure that this is achieved, the program will not run if the initial temperature of the temperature history is below 25°C. If the carcass is then cooled to below 7°C before it is further processed, the process consists of a single phase only. If the carcass is further processed while its temperature is above 7°C, the probe must be removed from the carcass and replaced with the further processed product from the carcass within 20 min. When that sequence occurs, the process consist of two phases.

When interrogating a logger, the program requests definition of the times that temperature history recording began and ended for one- and two-phase processes. For two-phase processes only, the times of probe removal from the carcass and re-insertion with further processed produce are requested. If the period between those times exceeds 20 min, the program will not run. For purposes of calculation, the product temperature during that period is assumed to be the higher of the temperatures at the start and end of that period.

For calculations, any initial lag before aerobic growth commences is assumed to be resolved before temperature monitoring starts.

For one-phase processes, growth is calculated from the model for aerobic growth during each record interval, and the total growth is derived by summation of the incremental proliferations.

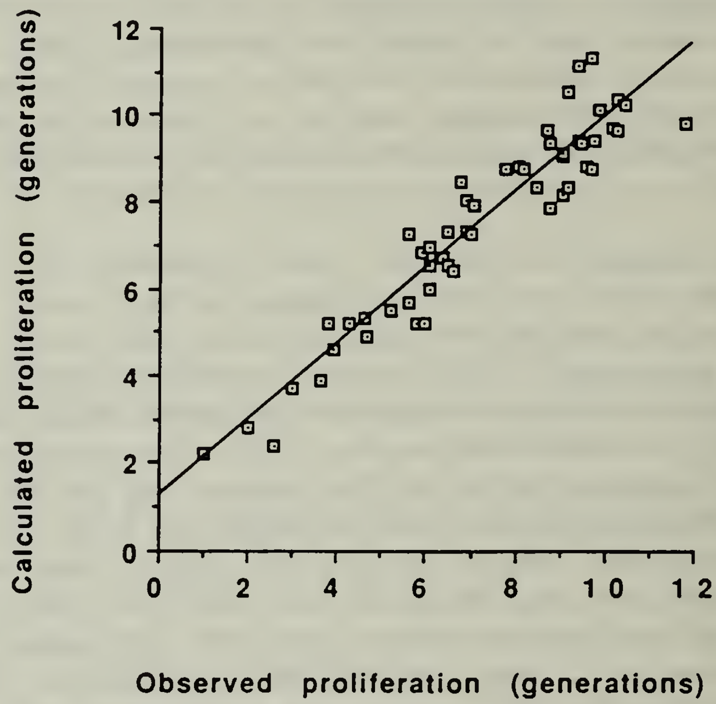
For two-phase processes, calculation of growth from the start of the record to replacement of the probe with further processed products proceeds as for one-phase processes. After that, the program calculates from the lag-phase model the portion of the standard lag time that would be resolved during each record interval and subtracts that from the standard lag time. When the lag before anaerobic growth commences is calculated to be resolved, further growth is calculated from the model for anaerobic growth in the same manner as for aerobic growth. Total growth is obtained by summation of the calculated aerobic and anaerobic growths.

No process is considered complete until the product temperature falls permanently below 7°C. If the temperature record stops with the product above that temperature, the program will not run.

The proliferation values calculated by the program have been shown to closely agree with proliferations measured in a two phase, commercial process (Fig. 7).

A software package for the described temperature function integration analysis of raw meat cooling processes is available from The Meat Industry Research Institute of New Zealand, Hamilton, New Zealand.

Figure 7. Plot of calculated against observed growth of *E. coli* on beef, during the preparation of frozen, boned product in a commercial hot boning process.



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