HYGIENICALLY APPROPRIATE TIME/TEMPERATURE PARAMETERS FOR RAW MEAT PROCESSING

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SUMMARY: During processing of raw meat, the product necessarily experiences temperatures that allow the growth of mesophilic pathogens. It is essential for product hygiene that the product temperature history does not permit excessive growth of any such organism contaminating the product. The undesirable effects of inadequate temperature control during processing are amply demonstrated in the poor microbiological quality of much offal.

The microbiological consequences of any temperature history can be characterized by integrating the temperature history with respect to data describing the responses of an indicator organism to temperature. Sufficient data exists to characterize the hygiene adequacy of meat processing procedures by estimation of the opportunity afforded for growth of the accepted indicator organism Escherichia coli. The quantification of the time/temperature aspect of Good Manufacturing Practice in meat processing would be advantageous in that process supervision in that area could be based on routinely-collected objective data referred to practicable criteria, rather than on subjective judgments and hypothetical criteria.

A temperature function integration technique can be applied in commercial practice only if there is available both suitable hardware, for collection of product temperature histories, and software that will allow analysis of temperature history by non-expert personnel. Electronic temperature data loggers, designed for collection of product temperature history during storage and transport are simply modified to provide suitable hardware. Suitable software must be carefully constructed to ensure that only temperature histories appropriate to process assurance can be collected and analysed.

Such equipment has been used for temperature function integration analysis of carcass cooling and hot boning processes. It is suggested that data for beef carcass cooling can be used to define the permissible proliferation of the indicator organism during processing of meat under Good Manufacturing Practice, and that such criterion could be widely applied to establishing Good Practice in non-traditional processes such as hot boning.

INTRODUCTION: During dressing of carcasses, bacteria are transferred, both directly and indirectly, from the hide to the freshly exposed surfaces of previously sterile edible tissues. Further bacteria will be transferred to edible tissues from equipment and hands as carcasses are broken down and the meat is processed. Such contamination of meat by extraneous organisms is unavoidable in commercial practice (Grau, 1987).

It must be assumed that contaminants will include both spoilage and potentially pathogenic bacteria. Regulatory activity must therefore aim both to minimize transfers of all bacteria to edible tissues and to

restrict within tolerable limits the opportunity for pathogenic organisms to grow on the meat.

Meats present a rich medium for support of microbial growth but, immediately after dressing, the evaporation of water from warm carcasses can dry carcass surfaces sufficiently to inhibit bacterial proliferation (Nottingham, 1982). Such surface drying is critically important to the microbiological stability of carcass meat in traditional butchery practice, where carcasses are allowed to cool in non-refrigerated facilities. It can also be exploited in industrialized butchery, but in many current processes conditions during carcass cooling are arranged to restrict water, and thus weight, loss. When evaporation of water from carcasses is restricted, inhibition of bacteria by surface drying becomes unlikely. Moreover, with meats in other than the carcass form, surface drying is difficult or impossible to arrange. The only other general factor then controlling the growth of bacterial on raw meats is temperature, as the growth rate of any bacterium declines with temperature, until growth ceases when the minimum temperature for growth is passed. Therefore, to assure that excessive growth of pathogenic species cannot occur, it is essential to properly define appropriate time/temperature parameters for raw meat processing.

Although the need for temperature control in meat processing is very evident to regulatory authorities, attempts to regulate in that area have not met with unqualified success. Consider the situation with respect to cooling beef carcasses.

The relevant EEC regulation stipulates that carcasses cannot be further fabricated or transported until they have attained a temperature throughout of 7°C or below (EEC, 1978). The limiting temperature of 7°C derives from the wide acceptance that growth of Salmonella in particular, and other mesophilic food-borne pathogens in general, will not occur at or below that temperature (Smith, 1985). Little exception can be taken to that aspect of the regulation. However, the absence of any time parameter vitiates the regulation as a serious guide to process temperature control, because it in no way restricts the extent of pathogen growth before the limiting temperature is attained.

Others have expanded cooling criteria to stipulate a time within which a maximum chill temperature should be attained in the deepest tissues. Notably, the U.S. Department of Agriculture has recommended cooling all tissue to 4.5°C within 16 h (USDA, 1970), and similar, but somewhat more stringent requirements have been promulgated as regulation in other countries (ISI, 1963; SASO, 1979).

Although doubtless based on some logical line of reasoning, such regulations suffer from two major shortcomings. First, they do not preclude for small carcasses substantial periods at warm temperatures, with consequent possibilities for extensive proliferation of pathogens, before effective cooling is applied. Secondly, reliable cooling of large carcasses to the stipulated temperature within the stipulated time can only be achieved by initially blast freezing, so risking toughening of much of the product by cold shortening of the muscle tissue (Chrystall and Devine, 1983). Perhaps fortunately for consumers, few plants would have the facilities to cool beef carcasses in that manner.

It seems apparent that those simple types of regulation will either fail

to assure processing hygiene, or will so restrict processing possibilities as to impose severe economic penalties on meat processors and ultimately on consumers. Indeed, there must be suspicion that rigorous application of some regulation would, in practice, obtain both those undesirable results simultaneously. There is thus a practical need to consider an alternative approach to defining acceptable time/temperature parameters for meat cooling processes.

Temperature Function Integration:

As the hygienic purpose of stipulating cooling regimes for meat is to restrain pathogen proliferation within tolerable limits, any regime specified should ensure that a maximum tolerable proliferation cannot be exceeded. However, the carcasses of food animals vary widely in weight and form, within as well as between species. Moreover, substantial quantities of meat are cooled in other than a carcass form, examples being variety meats and hot-boned beef. Therefore, a cooling regime derived for some ideal carcass is likely to be inappropriate for many carcasses of the same general type as the ideal, and will be highly inappropriate for other types of product. To overcome the difficulties imposed by the wide variety of meat products that must be cooled, some means of quantifying possible pathogen proliferation in widely different circumstances is required. The obvious solution is to adopt a temperature function integration approach to assessing the hygienic efficacy of cooling regimes.

Temperature function integration, a relatively simple form of predictive microbiology (Roberts and Jarvis, 1988), refers to the calculation of bacterial growth from product temperature histories and data relating bacterial growth rate to temperature (Olley and Ratkowsky 1973). Application of temperature function integration techniques to muscle foods have in the past focused largely on prediction of remaining storage life (Olley, 1978; McMeekin and Olley, 1986). Practical application with fish and meats has to date met with only modest success, because of wide variations in initial levels of contamination of products with spoilage organisms, the changes in spoilage flora composition that occur with rising temperature, and the past inadequacies of available temperature monitoring equipment. However, the possibility of predicting the extent of bacterial growth on muscle foods with good accuracy has been amply demonstrated (Pooni and Mead, 1984). Moreover, with a food product of greater consistancy, pasteurized milk, a temperature function integration technique has been shown to predict spoilage with good accuracy, at least at temperatures not grossly abusive (Chandler and McMeekin, 1985).

For application of temperature function integration to assurance of process hygiene, it is necessary to identify both the point at which product temperature should be monitored for the temperature history to be appropriate for the intended purpose, and a model relating bacterial growth to temperature that is appropriate for interpreting the temperature history.

With regard to the point of temperature monitoring, it is evident that, for regulatory purposes, a process is characterized by the product of poorest hygienic condition that the process yields, rather than the average product condition (Gill et al. 1988). The relevant region of a product

unit for monitoring product temperature is therefore the area that will remain at the highest temperatures for the longest periods within those regions of the product likely to be contaminated by pathogenic organisms, provided that bacterial growth will not be inhibited in that region by some factor other than temperature.

In the case of carcasses, the tissue at the centre of the largest tissue mass will cool most slowly (Bailey and Cox 1976). However, deep tissue is generally sterile (Gill, 1979), so deep tissue temperatures are largely inconsequential for product hygiene. In contrast, all carcass surfaces will inevitably be contaminated. It follows that, for assurance of the hygienic efficiency of carcass cooling processes, the relevant region for monitoring product temperature is that area of the carcass surface that consistently cools most slowly because; the possibility of that area being contaminated by pathogens must be assumed; the area must be expected, in at least some cases, to remain sufficiently moist to allow bacterial growth throughout cooling; and temperatures in that area will permit the greatest bacterial proliferation.

In the case of cartoned or otherwise bulked product, material at the thermal center of the product mass will cool most slowly. In most circumstances, the thermal centre will be approximated by the geometric centre of a filled carton. As it is always possible for the geometric centre to be occupied by the necessarily contaminated, and moist, surface of a meat piece, the geometric centre of the carton is the point where the greatest bacterial proliferation can occur.

With regard to the model for bacterial growth, it is generally accepted that Escherichia coli is a suitable indicator of the behavior of the enteric pathogens associated with raw meat (NRC FPC 1985). Substantial data relating growth rate to temperature are available for this species and the related Salmonella, and temperature function integration calculations based on such data have been shown to be in good agreement with directly determined increases of both inoculated and naturally occurring populations on meat (Gill and Harrison 1985; Smith 1985; Mackey and Kerridge 1988). For aerobic conditions, any lag phase can often be neglected. The model need then refer only to the aerobic growth of E. coli on a rich substrate without inhibitory effect on growth of the organism. However, when meat is packaged in a film of low gas permeability, as in vacuum packaging, or is bulk packaged, anaerobic conditions will very rapidly develop at the package/meat interface and within bulked product. For those circumstances, a model must take account of any lag induced by the change from an aerobic to an anaerobic environment for the bacteria, as well as the anaerobic growth of E. coli on a rich, non-inhibitory substrate.

To apply a temperature function integration technique, equipment for conveniently collecting appropriate product temperature histories must be available. Ideally, the equipment used should allow routine collection of product temperature histories from commercial processes without significant disruption of those processes. The constraints of commercial circumstances dictate that the temperature logging device should be small, independent of an external power source, able to withstand immersion and mechanical shocks, and be sufficiently cheap for occasional losses to be tolerable. An instrument of that type, capable of taking 2000 readings at intervals

specifiable between 1.875 and 255x1.875 min. over the range -20 to +40°C, with an accuracy of ± 0.25°C and a resolution of 0.25°C, was developed for monitoring of product temperature history during storage and transport (Phillips and Gill, 1986). The device was simply modified, by provision of an external probe, for monitoring product temperatures during processing. Enhanced models of that equipment are now commercially available (Tru-Test, Aukland, New Zealand) and in commercial use for process temperature monitoring.

Models of the variation of bacterial growth with temperature

For a temperature function integration assessment to be valid, it is obviously essential that the models relating bacterial growth response to temperature closely approximate real bacterial behavior. The Arrhenius equation has traditionally been applied for the description of the dependence of bacterial growth on temperature, but it is now recognized to be unsatisfactory (Reichardt and Morita, 1982; McMeekin et al., 1988), as also is the simple formula proposed by Spencer and Baines (1964), originally for relating the growth of fish spoilage floras to temperature (Daud et al., 1978).

Three further models have since emerged to describe the dependence of bacterial growth on temperature. The model proposed by Broughall et al. (1983) applies a non-linear modification of the Arrhenius equation that was developed by Schoolfield et al. (1981) for application to biological systems; that of Davey (1989) involves an alternatively modified Arrhenius equation, of a form used originally to describe spore destruction (Davey et al., 1978); while a simple relationship between the square root of growth rate and temperature was discerned by Ratkowsky et al. (1982). Although very different in form, all three models are similar to the extent that they are empirical, applicable to description of both lag and generation time, and capable of being modified to encompass other growth-affecting factors in addition to temperature. Good fits to published growth and lag phase data have been demonstrated for all three models, at least for the temperature range below the optimum for growth of individual organisms, and it is suggested that all models may be extrapolated beyond available data (Ratkowsky et. al., 1983; Broughall and Brown, 1984; McMeekin et al., 1987; Davey, 1989). However, it is apparent that all models tend to deviate from observed growth data towards the upper and lower limits of the growth temperature range, and that the square root relationships inevitably predicts growth below the minimum temperature for growth. It is therefore unlikely that one of these models will be superior to the others for all applications, and all are likely to be erroneous in some circumstances. Thus, the best choice of model must depend on the circumstances in which it is to be applied.

For evaluating the hygiene of raw meat cooling processes, the growth models required are few and simple, as consideration is given to growth of only one indicator organism unrestricted by any factor other than temperature. Consequently, it should be possible to collect sufficient data to empirically define all the relevant growth/temperature relationships over the full growth temperature range without significant resort to extrapolation. The models can therefore be of any convenient form that

encompasses all of an adequate number of data points.

Assessment of Offal Cooling Processes

Hygiene assessment of cooling processes by temperature function integration was first applied to the cooling of livers and other offals.

Offal cooling processes are an area of general hygienic disaster. The widespread belief that offals are inherently prone to rapid spoilage is erroneous as, when treated properly, their storage life can exceed that of carcass meat (Gill and DeLacy, 1982). The poor keeping quality observed with commercial product is due entirely to extensive temperature abuse during usual collection and packing processes. The warm temperatures to which offals are exposed during such operations allow rapid proliferation of spoilage organisms and mesophilic enterobacteria, notably E. coli but presumably including salmonellae (Gill and Penney, 1984). These undesirable circumstances have been pointed out (Hinson, 1968 a; b; Oblinger, 1983; Gill, 1984), but largely ignored, despite there being no possible justification for such hazardous mishandling of food.

Offals are commonly bulk packed while still warm, and such material generally requires several hours to cool to chiller temperatures. With diverse handling procedures both before and after packing, simple inspection does not readily reveal undesirable practice. Even product temperature monitoring may not be too enlightening, as apparently similar cooling curves may have substantially different microbiological consequences. However, these consequences can be revealed by appropriate temperature function integration analysis of temperature histories.

Routine assurance of the hygiene of fresh meat processing must involve personnel of widely differing capabilities. It is obviously desirable that as many as possible be able to readily comprehend the basis of any assessment technique that is employed. Therefore, for the purposes of hygiene assurance in meat works, the simplicity of the basic square root relationship must be an attractive feature of that model. Fortunately, a modified square root model can be applied to the offal-cooling situation.

At the warm temperatures of freshly excised offals, any lag will be rapidly resolved, while anaerobic conditions will obtain at the centre of a product mass. In commercial circumstances, temperature monitoring can only begin after the offals are packed. The model need therefore describe only the change of growth rate with temperature for E. coli growing under anaerobic conditions (Gill, 1984). A square root plot of anaerobic growth rate against temperature gives a straight line relationship over much of the growth temperature range. However, a distinct change of slope occurs above 30°C, while at 44°C, the growth rate declines from the maximum value observed at 40°C. For computational purposes, a plateau can be assumed for rates between 40 and 45°C and the simple three phase plot terminated at maximum and minimum temperatures of 45 and 7°C.

That model of E. coli growth allowed calculation, from temperature history data, of increases in E. coli numbers on livers that were in close agreement with the increases in the natural E. coli population directly determined by enumeration on agar plates. Calculations by hand, from average growth rates for 5°C temperature intervals between 5 and 45°C, or by computer, for average temperatures in sequential 3.75 minutes periods,

gave similar results.

Further work with a variety of offals being cooled under commercial circumstances gave similar correspondence between observed and calculated increases in E. coli numbers, establishing a reasonable validity of the model for assessing offal cooling processes, and showing that temperature function integration assessment could be applied in commercial circumstances (Gill and Harrison, 1985).

Application of temperature function integration assessment to processing of carcasses.

The application of temperature function integration to carcass processing requires some definition of the purpose and practice of product temperature monitoring in the meat plant environment.

Temperature function integration must evaluate the hygienic efficiency of a process; it cannot be used to assess the absolute hygienic status of individual units leaving the process. However, processing 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 causes of hygienic inadequacy must be controlled by other means.

As the purpose of the relatively intense regulatory inspection during carcass dressing is to assure hygienic adequacy, an assumption of the hygienic adequacy of carcasses leaving the dressing line would seem warranted. Thereafter, time temperature monitoring should commence as soon as practically possible.

Any meat cooling procedure will consist of an alternating sequence of relatively short periods, when product is being modified, and commonly longer periods, when product is being stored. Temperature monitoring can take place only during storage periods, as it is inconvenient or impossible during the times that product is being modified. However, each unmonitored modification period can be incorporated in the assessment by making "worst case" assumptions for the unmonitored time, and by restricting the maximum duration of each non-monitored period. The worst case assumptions will be hygienically conservative, as they will tend to overestimate the adverse hygienic effects of unmonitored periods, provided that the duration of unmonitored period are sufficiently short for the worst case conditions to be reasonably deduced from the recorded temperature history.

All processes start with a period of product modification; slaughter of the animal and dressing of the carcass. The duration of those operations for each stock unit will rarely exceed 30 min., even when throughput is slow. However, peculiarities of plant layout and practice may delay probe placement for temperature monitoring for some time after dressing is completed. To encompass the variability of the dressing operation, it is therefore necessary to allow a 1 hour maximum for that period of product modification.

At the temperatures of freshly killed carcasses, the lag phase of E. coli will resolve within 1 h (Smith, 1985). Therefore, the hygienic effect of the unmonitored dressing period can be encompassed by the assumption that

any lag in E. coli growth has been resolved before monitoring commences, although that would not actually be so for stationary phase organisms deposited toward the end of the dressing period.

To monitor carcass cooling, the probe must be placed to allow temperature to be recorded from the slowest-cooling area of the carcass surface. This is achieved by fixing, with a plastic staple, a metal disc to the longissimus dorsi muscle where it passes under the external oblique abdominal muscle, the metal disc having a central slot to retain a temperature probe. That slowest-cooling area of the beef carcass surface has long been known from the work of Scott and Vickery (1939). At some 75% of other surface sites, calculated proliferation is likely to be less than 25% of the value obtained for the warmest site on the same carcass.

Temperature monitoring can be ended at any convenient time after the temperature at the monitored point has fallen, and will remain, below 7°C, provided that the product will not be further modified to expose warmer tissue or generally raise the product temperature. However, if carcasses are broken down while deep tissues are still warm, or meat from chilled carcasses are subjected to treatments, such as grinding, that will raise the product temperature, then monitoring must be continued with the further-processed product.

For such circumstances, the probe must be removed from the carcass and replaced with product derived from the carcass with the shortest possible time. Twenty minutes appears to be an adequate maximum time to allow between probe removal and replacement. For the time that the probe is not with product, the warmer of the temperatures at the times of probe removal and replacement can be assumed to define the worst possible temperature history during the unmonitored period.

Such considerations, along with models of E. coli growth responses to temperature, have been incorporated into a process assurance program, for interpretation of process temperature history data (Gill et al. 1988). The program requires a logger to be associated with a particular type of process, defined from the form of the final product, before temperature monitoring is started. If the temperature history presented does not meet checks on critical time and temperature elements for the process type, the program will not run. The imposition of those restrictions forces use of standard procedures, and ensures that the appropriate E. coli growth response model is applied to each stage of a process. Thus, a relevant analysis can be obtained by persons having little knowledge of microbial behavior, and the analysis can be accepted by other parties, such as regulatory authorities, as an unambiguous description of the behavior of a product unit in a particular process.

A Temperature Function Integration Criterion for Meat Cooling.

Attempts to base meat cooling criteria on theoretical considerations alone have led to impossibly stringent requirements (USDA, 1970; EIS, 1986). To avoid that type of difficulty, it would seem appropriate to derive criteria for meat cooling from the realities of Good Manufacturing Practice. Moreover, it would be desirable to have a single criterion for all meat cooling, rather than have a unique criterion for each type of meat cooling process.

The fundamental cooling process in meat production is chilling of whole or split carcasses. As beef provides the largest - and so presumably the slowest cooling - carcass units common in meat production, beef carcass cooling should define the acceptance limits for meat cooling processes.

The rate at which a beef side surface cools will be affected by factors both intrinsic and extrinsic to the side (Wootton, 1986). Conformation as well as weight will affect the cooling rate, while the extrinsic factors affecting air conditions at the side surface will vary within a chiller at any time, and at any point during a loading, chilling, unloading cycle.

As a wide variation in possible proliferation seems inevitable in any carcass cooling process, specification of only a maximum permissible proliferation would be inadequate to properly characterize an acceptable process. Instead, a criterion compatible with a three class attributes acceptance sample plan, such as is commonly used for decision with regard to the microbiological quality of food (Jarvis, 1989), would be more appropriate. 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.

As a first step to developing a criterion, a beef carcass cooling process was assessed by a temperature function integration technique. In that process, the average side weight was 123.6 kg, with a range of 80 to 317 kg. The average time for sides to cool to a deep temperature of 7°C was 24.6 h, with a range from 16 to 46 h. The average rate of cooling obtained was somewhat faster than the average rates reported for British and Northern Ireland chilling operations (Wootton, 1986). The process examined could therefore be considered representative of what is currently accepted as Good Manufacturing Practice. Data from that process suggested a criterion stipulating that 80% of the calculated proliferations should not exceed 10 generations, and none should exceed 14 generations. However, that form for a criterion was found to be inadequate when it was extended to a hot-boning process.

In the hot-boning process, meat was stripped from the sides within a few minutes of dressing being completed. Therefore, the meat was within cartons of uniform size during most of the cooling period, with temperatures necessarily monitored at the carton centres. The greater thermal uniformity of the product at the point of temperature monitoring reduced the range but increased the average for calculated proliferations. Thus, the maximum proliferation barely exceeded 12 generations rather than, as with the carcass cooling process, approaching 14, but about 40% of the calculated proliferations exceed 10 generations, and the average proliferation was 9.2 generations as against 6.8 generations for the carcass cooling process.

It therefore appears that a general criterion would have to stipulate a maximum average proliferation as well as defining tolerable maximum limits for individual units. The previously suggested criterion would then include an element requiring that the average calculated proliferation should not exceed 7 generations.

Current Application of Temperature Function Integration to Meat Processing.

Consumer demand for reliably tender meat has required New Zealand's producers of frozen lamb to develop processes for accelerated aging of their product at warm temperatures before it is frozen. In addition, the need to contain costs has directed beef and lamb producers towards the development of hot and warm boning processes. Permitting these developments present difficulties to New Zealand's regulatory authority because, in the absence of any specific regulations or guidelines, assessment of process hygiene becomes a matter of highly uncertain subjective judgment. The possibility of introducing objectivity into assessments by applying a temperature function integration technique is therefore being actively examine in New Zealand by both the regulatory authority and the meat producers. The means of applying the technique in practice are emerging from that activity.

Any assessment must begin with a formal description of a process. The description must include identification of the facilities used for each stage of the process, specification of the operating conditions for each facility, and specification of the minimum and maximum times that product may remain within each facility. Although the institution of novel procedures is the principal reason for interest in temperature function integration assessment, the proposed new procedures must usually be integrated with existing operations. Therefore, when defining a process, consideration must be given to the product entering the process, the product leaving the process, and the type of plant used for the process. Operations both existing and novel, that are broadly similar in all three respects should be aggregated to a single process. This is particularly necessary in large meat plants, where a number of similar facilities may be used for the same operation, and handling of product can differ with circumstances.

To fully characterize any process, data must be collected over a lengthy period, so that the data provides an adequate sample of the full range of variation encountered in the process. However, before starting the routine collection of data, some outline characterization of the process is needed to direct the routine activity. For the initial characterization, it may be necessary to make some assumptions in order to describe all aspects of the process that may be relevant to its control. Any such assumptions must be clearly identified in the initial description, so that they can be verified, modified, or abandoned as adequate data against which to judge them are accumulated for the process.

To expedite the initial survey, the assumption must be made that all plant currently being used for the process can be operated to maintain adequate product hygiene. This assumption will generally be warranted, as hygienic inadequacy will more often arise from procedures inappropriate to the plant than from fundamental defects in the plant itself. Therefore, the primary objective of the initial survey is to assess process management in relation to the available plant, so that the hygienic adequacy of the process can be optimized by procedural changes before plant upgrading is considered as an option.

For the initial survey, product temperature histories should be collected for a representative portion of the process only. Preferably, ten

histories should be obtained on each of two days. The starts of recordings should be spaced approximately equally throughout the working period on each day, the first record being started within 30 min of the beginning of work. On each day of monitoring, the operating temperature of cooling facilities at the time each monitored product unit is loaded should be noted, as should the times of loading and unloading of each such unit. Any other circumstances of the day's work that may aid in assessing the data should be noted. For example, the batch size, the rate of throughput, whether the batch had an unusual predominance of very heavy or very light units, any unusual delay in processing etc.

The frequency distribution of estimated proliferation on each day should be prepared. Comparison of the two frequency distributions should show whether operation of the process segment was reasonably comparable or substantially different on the two days.

If the two frequency distributions are comparable and within the provisional specification, then routine monitoring to progressively encompass the whole process can be initiated.

If the frequency distributions are incompatible and/or exceed the provisional specification, the individual temperature histories and notes on procedures should be examined to determine the causes of inadequate cooling. Procedures likely to remedy the inadequate cooling should be adopted, and temperature histories again sampled on two days. Only when the possibility of consistently operating the representative segment within the provisional specification has been demonstrated, and the process description revised to adequately document the procedures required to achieve that objective, should routine monitoring to encompass the whole process be initiated.

Although the procedure to develop a hygienically acceptable process may appear potentially tedious, practical familiarity with the causes of excessive calculated proliferation usually allows mispractice to be rapidly identified. Remedy of mispractice may take somewhat longer, as there are few who will accept without question that their habitual activities are less than satisfactory. However, it has been found that the objective demonstration of inadequacy by product temperature history data can greatly facilitate desirable change.

At present, temperature function integration assessment is still at an experimental stage. Much remains to be done in both strengthening the theoretical underpinnings and in clarifying the practical application. However, the technique is already proving useful in commercial circumstances. It is to be hoped that the current interest in its application can continue, as it offers the only obvious means of escaping from restrictive, subjective regulation to objective evaluation of the hygienic adequacy of temperature control during raw meat processing.

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