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The History of the Food Refrigeration and Process Engineering Research Centre (FRPERC) and its Role in Food Refrigeration Research

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Why you should attend

- Gain an understanding of what the FRPERC has been involved with regarding refrigerated food production, storage and retail display over the years
- Review the published outcomes of many of the investigations
- Gain insights into some of the myths as well as the potential for future food refrigeration technologies

Summary

In September 1967, investigations were started on a programme of research into meat refrigeration and processing at the new Meat Research Institute (MRI) under construction at Langford near Bristol. Until July 2009 that programme, now extended to cover the refrigeration, thermal processing, and handling of all foods, continued at the same site under the auspices of the Food Refrigeration and Process Engineering Research Centre (FRPERC). In that time, the MRI having become the Institute of Food Research – Bristol Laboratory (IFR-BL) in 1985 until closure in 1990 and FRPERC having been established in January 1991 at the University of Bristol. This programme of experimental and theoretical studies covered many aspects of the chilling, freezing, thawing, tempering, refrigerated storage, refrigerated transport, refrigerated retail display, domestic handling and refrigerated storage, cooking, pasteurisation and reheating, decontamination, hygienic processing, robotics, automation, and cutting of foods. FRPERC's activities at the University of Bristol ceased in 2009 and at the end of July 2009 some members of the centre moved to the Grimsby Institute to re-establish FRPERC at Grimsby. In April 2023 FRPERC ceased activities at Grimsby. This presentation reviews and celebrates our research carried out between 1967 to 2023 on Food Process Engineering.

These studies have resulted in over 1000 publications, far too many to review in any detail in a few pages. In 2002 we published a book on meat refrigeration [1] covering all the early meat refrigeration studies and in 2009 a review [2] of all our studies between September 1967 to July 2009. In this current review we have therefore outlined some of the more important studies carried out prior to 2009 and reported in more detail on work carried out between 2009 and 2023.

Primary chilling

Chilling is the first and probably the most important process in the cold chain. In 1967 the meat industry required reliable data on the effect of air temperature, velocity, and relative humidity on the cooling rate of and evaporation from beef sides of different weight and fat cover. An Industrial scale refrigeration pilot plant was constructed at Langford and was used to chill over 200 whole beef sides. The comprehensive results of the investigations were presented to the Institute of Refrigeration (IOR) in 1976 [3] and 1977 [4]. For ease of use, the main data were presented as four design charts. Each chart was in the form of a plot of the logarithm of temperature against time at a defined position within the carcass. Another major consideration of industry was weight loss. High accuracy balances (±20 g, over a range from 0 to 250 kg) were used to measure the weight of the beef sides during chilling. Data could therefore be provided on the influence of different chilling and carcass conditions on weight loss. In subsequent years, the same methodology was used to provide similar design charts for goat [5], mutton [6], pig [7], and chicken [8] chilling.

An important result of the studies was that pork could be toughened (cold shortened) during rapid chilling [9]. While a recognised problem with beef and lamb, pork was less prone to cold shortening. But it was show to occur if rapidly chilled. The comprehensive body of work on meat chilling has formed the backbone of meat chiller design over the past 40 years. It provides peer reviewed data sets relating rates of temperature reduction in carcasses over wide weight ranges to the chilling conditions used i.e. air velocity, temperature and RH. It also provides data on the weight loss/yield under different regimes and energy extraction rates required. This was demonstrated in a recent legal dispute in 2022 where experts on both sides relied on the data to support their opinions. Key points in the dispute on the performance of a new carcass chilling system were, 1) was there a testable process design specification, 2) was all the required data on the conditions required available and taken into account when it was designed, 3) could a maximum weight loss be guaranteed, 4) did the operational conditions substantially exceed those in the specified design.

Freezing

Meat has been commercially frozen since the 1880s and our early studies looked at commercial performance and the problems in meeting European Economic Community (EEC) freezing requirements. Later studies at Langford looked at conventional, air, immersion, plate and cryogenic freezing of beef quarters, beef blocks, mutton carcasses, offal, meat products and ready meals.

In the 1990s the need for environmentally friendly food freezing systems focussed our freezing studies on air cycle refrigeration. In operation our first open cycle pilot plant far exceeded expectations and was shown to achieve minimum temperatures of -84°C and hot temperatures of between +40 to +70°C. Further studies resulted in a fluidised bed air cycle freezer and an integrated, rapid heating and cooling system for the food industry.

When moving to Grimsby we inherited a Cells Alive System (CAS) freezing system, a novel freezing system which claimed to improve quality at a time when there was a growing worldwide interest in novel freezing research. CAS claimed to improve food quality by effecting how ice crystals are formed by vibrating water molecules in the food during freezing utilising oscillating magnetic fields. Most if not all the novel freezing studies are based on the belief that freezing is detrimental to the quality of the food being frozen and that the main cause of this detriment is large ice crystals. We had just published a paper comparing rapid and slow freezing of aged beef steaks with unfrozen control samples [10]. In the study trained taste panels found no difference in eating quality between slow, fast, and unfrozen steaks. A small change in the final temperature of the cooked steak had a far larger effect on eating quality than freezing or freezing rate.

While carrying out experimental studies we carried out two comprehensive reviews on novel freezing [11] and dehydrofreezing [12] of food. We found that many of the publications on novel freezing start with the premises that the freezing process is detrimental to food quality, ‘fresh being better than frozen’, and the quality of frozen is detrimentally affected by the development of large ice crystals in the frozen food. Fast freezing rates are advocated to produce small ice crystals, as do the novel techniques of electo/magnetic or sonic excitation which promote super-cooling and/or limiting nucleation and ice crystal growth. Ours and other reviews, however, provide very little reliable information that taste panel or consumers can detect any difference in the eating quality of cooked previously frozen food that can be related to ice crystal size in the frozen raw material. Further FRPERC studies on electromagnetic excitation during freezing failed to show any quality advantages with garlic [13], pork loin [14], and apples and potatoes [15]. Few of the recent novel freezing publications actually look at eating quality of the product at the point of consumption so there is no real proof that novel systems produce any marked commercial advances.

One exception is some of the developments in dehydrofreezing (partial dehydration of the raw material before freezing). These appear to be able to produce some frozen fruits and vegetables with eating qualities that are very close to fresh products after thawing.

Thawing and Tempering

Interestingly, investigations on meat thawing at Langford preceded those on freezing. Factories that produce pies, pasties, burgers, or other canned, frozen, or chilled meat products require regular supplies of raw material. To take advantage of cheaper raw material arising from seasonal fluctuations in availability and to provide for scarcities, meat is often purchased, frozen and stored until needed. Thawing such material presents difficulties in obtaining consistent reproducible times, bacteriological condition, physical appearance, and loss of weight. Initial studies on pork legs were rapidly expanded to meet other industrial demands for data on thawing systems for beef quarters, lamb and mutton carcasses, meat blocks and cook-freeze catering packs [2]. A key aspect of the thawing studies was the use of finite difference mathematical modelling techniques to augment and expand the range of experimental conditions investigated. Its use became an essential aspect of all the subsequent refrigeration studies [16].

Frozen food is defined as “tempered” when its temperature is raised from that of a solidly frozen condition to some higher temperature, still below the initial freezing point, at which it is still firm but can readily be further processed. In other cases, unfrozen, chilled meat can benefit from “tempering” (partial freezing) to aid processing. At different temperatures in the frozen state, the relative proportions of ice and unfrozen water in food vary. As the percentage of water that is ice decreases, the mechanical properties of the food change and it becomes less hard and brittle. This allows further processing, for example flaking, grinding, or dicing. Our studies showed that conventional air tempering of 25kg meat blocks could take anything between 10s of hours and a week, while an even temperature of between -5 and -2°C could be achieved in 3 to 7 minutes using microwaves at a frequency of approximately 900 MHz [17].

Bacon can have an initial freezing point as low as -11°C due to its high salt content. Optimal high-speed slicing of bacon requires the bacon to be presented to the blade at a very controlled temperature that ensures the correct amount of ice is present to ensure the optimum texture. The temperature depends on the salt and water content and a few °C of error can significantly reduce cutting yield. FRPERC developed a two-stage tempering system for bacon middles which was commissioned by a large retailer who claimed that the

£250,000 cost was recovered in its first year of operation due to increased yield of high-quality slices [18].

Secondary chilling

Meat is chilled immediately after slaughter, ideally to between 0°C and 4°C. Most of the subsequent operations in the cold chain are designed to maintain the temperature of the meat. Cooking is a very common operation in the production of many meat products and operators appreciate the importance of rapidly cooling the cooked product. However, any unit operation such as cutting, mixing, tumbling will add heat to the meat and increase its temperature. A secondary cooling operation is then required to return its temperature to near to 0°C. Over the years, studies were carried out at Langford on many aspects of secondary cooling of large and small individual items, solid/liquid mixtures, and sauces [19].

In the UK the Department of Health Cook-chill Guidelines (1989) recommended maximum cooling regimes and the use of special equipment to reduce product temperatures rapidly after cooking. These guidelines have been widely adopted and are still used across the food industry. Our investigations into air blast cooling of Bolognese meat sauce in metal trays of different depths but the same lateral dimensions showed that, if surface freezing was to be avoided and a simple single stage operation used, only 10 mm depth of product could be chilled within the Guidelines [20].

Chilled and frozen storage

Early Langford storage studies concentrated on improving industrial and commercial profitability by reducing weight loss during chilled and/or frozen storage. The conclusions of our comprehensive reviews of frozen storage life were that much of the underlying data had been gathered from practical experience backed up by a relatively small number of controlled scientific experiments. Much of the scientific data dated back to the time when meat was either stored unwrapped or in wrapping materials that are no longer generally used (such as waxed paper). It was thus not surprising, when consideration was made of the changes in packaging and handling methods over the last century, that there is a considerable scatter in published data on storage lives for similar products.

Much of our work on cold store performance has been confidential, however, Defra have funded two LINK research projects looking at different aspects of cold-store use. In one project a predictive program, 'ColdRoom', was developed to allow cold-storage operators, contractors, and manufacturers to specify and design cold rooms to keep food at optimum temperatures under actual working conditions, and users to rapidly predict the effect of operating conditions and loading patterns on performance and identify how they can avoid unacceptable food temperatures [21].

A separate project looked at air entrainment through cold-store entrances. In cold-stores energy is wasted due to air infiltration into the room during loading and unloading and other instances when the barrier between the cold and warm environments is removed.

In 2018 we were funded by the Meat & Livestock Australia (MLA) to look at the long term frozen storage life of commercially produced lamb and beef. In most of the previous published long term frozen storage life studies, small carefully replicated samples of lean meat, with a known pre freezing history, were stored in laboratory freezers at different temperatures and sampled at set times. In our study commercially produced frozen export lamb and beef (boxed loins and boxed trim) was sourced in Australia. The meat was shipped by sea (beef) or air (lamb) to the UK under commercial conditions and stored in large conventional freezer rooms prior to sampling.

Our aim being to duplicate as carefully as possible a normal cold chain for Australian frozen lamb and beef. There were three overall objectives for this research project: (1) To determine the shelf-life of frozen Australian beef and lamb loin (strip loin and eye of loin, respectively), beef trim of 65CL, 85CL, and 95CL, and lamb trim of 65CL, 85CL, and 90CL (Chemical Lean - a mandatory AUS-MEAT Ltd measurement of the amount of lean red meat compared to the amount of fat in a meat sample);(2) To determine the correlation of frozen end of shelf-life (determined by taste panel) to any measurable parameters, such as oxidative rancidity (PV and TBARS); (3) To determine the rate of oxidation or development of rancidity in frozen Australian beef and lamb meat stored at -12°C, -18°C (Control), and -24°C. After an initial 2 years of storage at either -12, -18 or -24°C the organoleptic and taste panel results showed no marked deterioration, so storage was extended for a further year. Clear changes with time were found in chemical rancidity that could be related to meat composition, packaging, and storage temperature. However, these changes do not appear to correlate clearly with the taste panel results in this study. Whereas the PV and TBARS levels show a clear relationship with storage temperature over time at different holding temperatures, this does not appear to be reflected in the mean taste panel results. While some sensory degradation, small decreases in mean sensory scores, occurred over time in all meat this did not appear to be affected by storage temperature, but occurred at all storage temperatures, and the meat remained palatable after 38 months.

While -18°C has become the standard temperature for the storage of frozen foods, red meat of the type examined appears able to be stored successfully for many months or years at a temperature warmer than this threshold. Providing the meat is of sufficient hygienic quality when frozen and handled under controlled hygienic conditions, no food safety hazards exist with frozen meat that has been held at, or reached, a temperature between -10°C and -18°C. Sensory degradation occurs only slowly at these temperatures and no food safety hazards arise. It is interesting to note that a presentation to the Institute of Refrigeration (IOR) in 1974 [22] reported that UK frozen meat at the time was transported and stored typically at -9 to -10°C, and had been for years. The practices were only changing due to the requirements of regulations for 'intervention freezing' and the increasing use of general food cold stores rather than dedicated meat cold stores. While -18°C has become the standard temperature for the storage of most frozen foods, red meat of the type examined appears to be able to be stored successfully for many months or years at a temperature warmer than this threshold. The results of our study are currently being prepared for peer reviewed publication.

Super-cooling

Super-cooling is an alternative process with the potential to extend shelf-life in comparison with chilling without the damage that happens with super-chilling or freezing. Super-cooling is the physical phenomena where the temperature of a substance can be reduced below its freezing point without ice crystallization occurring. While the mechanism in pure liquids, such as water, is attributed to the lack of a seed crystal or nucleus around which a crystal can form during freezing it is less clear how super-cooling occurs in more complex liquids and solids, such as foods. Research begun at Langford and continued at Grimsby has looked at the super-cooling of liquid and solid foods. Initial studies [23] showed that garlic bulbs and cloves could be super-cooled and stored well below their freezing point (of -2.7°C) at -6°C. Further research by us has looked at super-cooling in fruits, vegetables, meats, fish, and other foods [24] and a current continuing research project is looking at how super-cooling can be implemented in the fresh fish industry.

Although the literature often states that super-cooling is unstable in solid foods, we have found (in unpublished work) that retail packed beef and fish can be held in super-cooled state for at least 35 and 20 days, respectively. Other independent studies have also demonstrated stable super-cooling in other foods. While we have seen stable super-cooling without any assistance there is also some evidence that technologies such as magnetic fields may help maintain super-cooling in different products.

Transportation

Early transportation studies at Langford focused on the problems of poor temperature control during road transportation of both chilled and frozen meat. We found that there are substantial difficulties in maintaining the temperature of chilled foods transported in small, refrigerated vehicles that conduct multi-drop deliveries to retail stores and caterers. The vehicles must carry a wide range of products and operate under diverse ambient conditions. During any one delivery run, the chilled product can be subjected to as many as fifty door openings, where there is heat ingress directly from outside air and from personnel entering to select and remove product. The design of the refrigeration system must allow for extensive variation in load distribution, which is a function of different delivery rounds, days of the week and the removal of product during a delivery run. A refrigeration system's ability to respond to sudden demands for increased refrigeration is often restricted by the power available from the vehicle. All these problems combine to produce a complex interactive system.

A predictive program was developed from individual modules that were verified either using a static vehicle body in our processing halls or on the road. The resulting program, called 'CoolVan' was a unique tool for vehicle operators and manufacturers. Much effort was put into making the program very user friendly and easy to use resulting in very favourable feedback from the many companies involved, and the program was released subsequently as a commercial product [25].

Retail display

The retail display of refrigerated food has long been considered one of the weakest links in the cold chain. Controlling the temperature of an individual retail pack is far more difficult than that of a bulk pack or pallet load of product. In addition, the display cabinet must cater for the marketing requirement for a minimal barrier between the customer and the product. Studies on delicatessen cabinets for unwrapped food showed that colour changes due to surface desiccation was the factor limiting display life and the RH in the cabinet the key controlling parameter [26].

Projects have also looked into the use of environmentally friendly refrigeration systems, especially the use of the air cycle, for retail display. The application of air cycle to retail display resulted in prototype chilled and frozen display cabinets with temperature control, noise and energy levels that were as good as, if not better than, conventional cabinets [27].

While FRPERC and others have produced much data on the performance of retail display cabinets under controlled conditions there is very little data on the temperatures in cabinets in real retail stores, particularly data on performance over weeks of operation. In a recent study we monitored temperatures in frozen retail display cabinets in four branches of a major UK supermarket chain, ranging from a medium size outlet to a large hypermarket [28]. Two types of cabinets were monitored which were: (1) combined frozen top doored and open bottom (well) cabinets (ISO classification RYF3) and (2) vertical frozen glass doored cabinets (ISO classification RVF4). The results showed that while cabinets may run at the required overall temperature(s), some frozen products in those cabinets can spend a substantial amount of time, up to 45 %, above -12°C, at sub-optimal temperatures. While this will have no effect on the safety of the food, it is likely to have a detrimental impact on quality.

Domestic handling

The past decades have seen a considerable increase in legislation defining maximum temperatures during the production, distribution and retailing of chilled food. However, as soon as the food is purchased by the consumer, it is no longer covered by any of these legislative requirements.

After a chilled product is removed from a retail display cabinet it is outside a refrigerated environment whilst carried around the store and transported home for further storage. In the home it may be left in ambient conditions or stored in the refrigerator until required. FRPERC carried out its first survey of the performance of domestic refrigerators in UK homes in the late 1980s [29] and we published our last review on the performance of fridges in 2017 [30]. The overall mean temperature inside a domestic refrigerator has remained at approximately 6°C throughout that period with only a small proportion reliably keeping chilled food within the optimal temperature quality range.

Energy

While many of our projects looked at multiple aspects of the cold-chain at the same time, one particular project encompassed energy usage in the complete cold-chain. In the UK there is increasing pressure on government and industry to make significant reductions in carbon emissions. In the UK 11% of electricity is consumed by the food industry and in some sectors a substantial portion of site energy, up to 90%, is consumed by refrigeration systems. Starting in June 2006, Defra funded a project to "identify, develop and stimulate the development and application of more energy efficient refrigeration technologies and business practices for use throughout the food chain whilst not compromising food safety and quality". This project, led by FRPERC, was a collaboration between 4 top UK University research groups, an industrial steering group, and hundreds of stakeholders from the food and refrigeration industries. The first important findings of this project were presented to the IOR in February 2009 [31]. The research programme concentrated on three topics: (1) Mapping of energy use; (2) Identifying new technologies; and (3) Feasibility studies on promising technologies. In the mapping exercise, we identified and ranked the top 10 food refrigeration operations in terms of the potential to achieve the greatest total reduction in energy usage. We identified large energy savings that can be achieved with current knowledge and the barriers to their uptake. Clear gaps were identified in 'real' energy data and in current knowledge in areas of technology, equipment, management, maintenance, and overall understanding. We critically reviewed all the 'new/alternative' refrigeration technologies in terms of their potential to save energy in a food refrigeration operation and their probable development timescale before they are likely to enter commercial use. Finally, in silico (computer-based) studies resulted in a powerful tool to optimise the energy consumption of a total 'food refrigeration' process. This was used to direct further experimental studies, provide case histories, and identify further research needs.

In 2010 we produced a review on the relationship between the cold chain and climatic change [32]. This and a further book chapter [33] have become some of our most referenced publications. Food refrigeration is a major user of energy throughout the world and any increase in ambient temperatures will increase the energy consumption of refrigeration systems. However, the growing of crops and rearing of animals requires considerably more energy than refrigeration and this is imbedded in the food. If this food is wasted rather than consumed, then the energy loss is substantial. Chilling and freezing food can considerably extend the storage life of all perishable foods i.e. meat, fish, fruits and vegetables, prepared food and grains. Our conclusions were that increasing the amount of food efficiently refrigerated would substantially increase the overall sustainability of worldwide food production even after considering climatic change.

Other research interests

FRPERC were one of the first food engineering groups to look at the use of robots in food processing in the late 1980s. An initial study was carried out on the application of robotics to poultry processing which revealed seven potential areas for the application of robotics in poultry processing, hanging of live birds, evisceration, grading, trussing, portioning, giblet packaging and further processing. Later FRPERC, in conjunction with European project partners, implemented robotic butchery systems to separate a pork carcass into the major sections (known as primals) in Norway and Spain. This resulted in a commercially viable robotic pork primal cutting robot system.

The work on robotic butchery illustrated a lack of fundamental understanding of food cutting and separation processes. The majority of industrial cutting systems to date having been developed on an iterative experimental basis or by application of a closest match to existing processes. A MAFF LINK funded project into the fundamentals of food fracture and separation showed that food separation situations are complex where interacting 2-D shear stresses can combine to perform cutting more effectively. Initial work developed experimental equipment to measure interrelationships of temperature, cutting type, feed speed and cut parameters in example products such as cheese, beef, and bacon. Cheese was taken to be a homogeneous material but proved not to be so during our trials. The effects of blade friction and effects of temperature on the material properties of cheese had a bigger influence than any other cutting tool or cutting process parameter studied [34].

Further work on robotics and automation in food refrigeration [35] and meat processing [36] continued after moving to Grimsby.

It is interesting to note that some of the first work of the group at Langford was on carcass decontamination. After a hiatus of a decade or so, work on this subject began again in the early 1990s at FRPERC and was expanded to look at many aspects on reducing microbial contamination and improving food safety during primary processing of foods of animal origin and other foods, a number of which looked at the role of temperature. Much of this work (over 30 projects and 70 publications) was funded initially by MAFF and then the UK Food Standards Agency. Many of these projects were carried out in collaboration initially with the Division of Farm Animal Science (DFAS) at the University of Bristol and after moving to Grimsby with the National Centre for Food Manufacturing (NCFM) at the University of Lincoln. Recent and continuing work has been looking at how aspects of the food chain from farm-to-fork may impact on antimicrobial resistance (AMR). Addressing the public health threat posed by AMR is a national strategic priority for the UK. We have recently carried out critical reviews of the evidence on the impact of heat treatments of food on antimicrobial resistance genes and their potential uptake by other bacteria [37] and biocide and metal use during food animal production [38], and further work on AMR is continuing.

Conclusions

Since moving to Grimsby FRPERC produced 107 publications (34 chapters, 18 papers, 40 presentations, 7 articles, and 8 official reports). We worked on 25 publicly funded research projects with 15 centered on food refrigeration. In addition, we continued to carry out many confidential projects for individual refrigeration and food companies, locally, nationally, and internationally; organised training sessions on all aspects of food refrigeration; and carried out legal expert witness activities.

Food refrigeration centred projects	
1	Fostering the development of technologies and practices to reduce the energy inputs into the refrigeration of food (Defra)
2	Review of the risk management practices employed throughout the fish processing chain in relation to controlling histamine formation in at-risk fish species in Scotland (FSAS)
3	Research services/collaboration for investigation into the fundamentals of cryogenic freezing and the evaluation of CAS freezing technology together with its potential when combined with cryogenic freezing
4	Description of the processes used in the UK to manufacture MSM and former DSM meat products from poultry and pork and an initial assessment of microbiological risk (FSA)
5	Qualitative Risk Assessment to support a policy decision on partially eviscerated (effilé) poultry production (FSA)
6	Microbial evaluation of poultry and pork mechanically separated meat (MSM), compared to fresh cuts of meat, meat preparations and minced meat products (FSA)
7	The development of dynamic energy control mechanisms for food retailing refrigeration systems (Innovate UK)
8	Can super-cooling extend the shelf-life of seafood? (Seafish Authority)
9	Feasibility of the IoT for domestic refrigerators, food safety and waste (FSA)
10	Bacteriophage control of listeria in chilled RTE salmon products (Innovate UK)
11	The development of dynamic energy control mechanisms for food retailing refrigeration systems (Innovate UK)
12	The Greater Lincolnshire Agri-Food Innovation Platform (ERDF)
13	The shelf-life of Australian frozen red meat (MLA)
14	Development & optimisation of fresh produce supply chain and storage systems (NEWTON FUND)
15	Quantification of the controls that should be placed on meat prior to mincing (FSA)
Food safety and technology based projects	
1	Creating physical structure from disarray. Developing generic understanding and systems to assess disorder and create physical product arrangements for food industry processing (EPSRC)
2	Study into the use of anal bungs or plugs on pig carcases during processing to reduce faecal leakage
3	Study to optimise the performance and running costs of various commercial scalding systems
4	Study to evaluate decontamination options for automatic and hand scrapers and polishing equipment
5	Study to determine the effectiveness of the application of a second singe on the reduction of surface contamination
7	Exploring the potential for technology to support agency objectives in meat operations (FSA)
8	Decontamination of food: development of the microbial immobilisation treatment of cattle hides (FSA)
9	Assessing the impact of heat treatment on antimicrobial resistance genes and their potential uptake by other 'live' bacteria (FS
10	A critical review of AMR risks arising as a consequence of using biocides and certain metals in food animal production (FSA)

Since April this year the last members of FRPERC have either joined the University of Lincoln or set up an independent consultancy (Fairholme Research Ltd) to continue their activities. We continue to maintain our website FRPERC.com as a repository of much of our past work and publications.

About the authors

Stephen James

Steve joined the Meat Research Institute (MRI) when it was established in 1967 initially involved primarily in research on all aspects of meat refrigeration. He remained at the institute during its change to the Institute of Food Research – Bristol Laboratory (IFR-BL) where his role expanded to cover all foods and heating processes (cooking and decontamination). He established the Food Refrigeration & Process Engineering Research Centre (FRPERC) in 1991 at the University of Bristol when the IFR-BL closed in 1990. He took up a consultancy role at FRPERC when it moved to Grimsby Institute in 2009. He is an author/co-author of over 600 publications on all aspects of the food cold chain from primary cooling through to domestic handling. Although formally retired he still provides support and input to research projects, acts as a reviewer for many food and refrigeration journals and provides expert witness consultancy.

Christian James

Chris worked at FRPERC since graduation in 1993. When FRPERC closed at the University of Bristol in 2009 he moved with some of his colleagues to re-establish FRPERC at the Grimsby Institute. In 2023 FRPERC was closed down at the Grimsby Institute and he established Fairholme Scientific Ltd to continue his work in supporting research and consultancy for the food industry. He is also a Visiting Research Fellow at the University of Lincoln. His research and consultancy have covered many topics such as hygienic control measures during the primary processing of meat and produce, chilling and freezing (including freezing points and supercooling), thawing and tempering, conventional and microwave cooking/pasteurisation, and surface pasteurisation technologies. He has written and presented extensively on these subjects via peer-reviewed papers, conferences, lectures, and books.

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