

PATHOGEN CONTAMINATION OF CATTLE AND BEEF; CHALLENGES AND OPPORTUNITIES IN PROCESS CONTROL

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Abstract

Social fears and economic losses occasioned by contamination of beef with foodborne pathogens (e.g., *Escherichia coli* O157:H7, *Salmonella* spp., *Listeria monocytogenes*) have prompted global concerns, threatened world trade, and generated challenges and opportunities in process control. Industry, government and academia have investigated minimizing pathogen contamination of cattle and beef from "farm to fork," in preharvest, harvest and postharvest sectors. Science has failed to elucidate on-farm factors associated with carriage and shedding of *E. coli* O157:H7 and *Salmonella* spp., so no critical control points have been identified for the preharvest sector but Good Production Practices (manure handling; bird/vermin control; cleanliness of water, feedstuffs, pens) and transport in clean vehicles lessen contamination of slaughter cattle. Chemical dehairing, before slaughtering/dressing, will be operational in the first U.S. beef packing plant by early 2001. Harvest sector control of pathogen contamination includes industry activities (Pre-Requisite Programs, GMPs, QA/QC Programs), government mandates (HACCP; Pathogen Reduction Systems) and Multiple-Hurdle Carcass Decontamination Programs (sequential interventions including steam vacuuming, organic acid rinsing and thermal pasteurization). Postharvest sector control of pathogen contamination includes interventions during carcass fabrication; maintenance of the cold-chain during transportation, distribution and retail handling; Food Safety Programs (HACCP-like) of supermarkets and food-service operations; and consumer education programs (e.g., Fight BAC! Campaign). Control of *Listeria monocytogenes* in ready-to-eat products includes environmental audits, GMPs, bacteriostatic ingredients and post-processing interventions (e.g., organic acids, thermal treatments). Challenges and opportunities in process control remain, because no "silver bullet" has emerged for precluding beef pathogen contamination in the preharvest, harvest or postharvest sectors.

Consumer Concerns About Food Safety

Contamination of beef with foodborne pathogens has prompted social fears and global concerns, threatened world trade, caused economic losses, and generated challenges and opportunities in process control concepts. In the USA: (a) 80% of consumers are as concerned about food safety as they are about safe drinking water, crime and health, (b) 75% would alter their food consumption based on negative media stories, and (c) 88% are "Very Concerned" about bacteria like *Salmonella* (Drovers Journal, 2000). "Product Safety" is "Very Important" in food selection (FMI, 2000) ranking 4th in FMI TRENDS reports in 1992, 1993, 1994 and 1995, and 3rd in 1991, 1996, 1997, 1998, 1999 and 2000 (Smith, 2000a). De Becker (1997) reported that: (a) The 5th biggest fear of USA consumers was "Food Poisoning From Meat" (36% of respondents), (b) The 7th biggest fear was "Pesticides On Food" (34%), and (c) The 2nd most often cited "Precaution I have taken in the past year, for safety reasons" was "Avoiding Certain Foods" (35%). Of respondents to a Newsweek (1997) poll: (a) 44% thought the U.S. food supply was less safe than 10 years ago (19% thought it was more safe). (b) 45% thought the government was not ensuring food safety. (c)

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62% thought the government should spend more on food inspection. In 1997, 29% of consumers said foodborne illness caused by home cooking was “somewhat” common while 30% thought it was “not very” or “not at all” common; in 2000, 43% thought it was “somewhat” common and 21% thought it was “not very” or “not at all” common (FMI, 2000).

Costs Of Foodborne Illness In The USA

Human foodborne disease causes 24 to 81 million cases and costs \$5 to \$17 billion each year (Oblinger, 1988). Pathogens associated with meat and poultry may cause, each year, 7 million foodborne-illness cases and 7,000 deaths (FSIS, 1995a) or 5.35 million cases, 4,600 deaths (3,348 from *Salmonella*, 480 from *Campylobacter jejuni/coli*, 423 from *Listeria monocytogenes*, 349 from *E. coli* O157:H7) and cost \$4.8 billion (FSIS, 1995b). Broder (1997) quoted CDC as saying “Pathogens carried in food are responsible for 9,000 deaths a year.” Wilson (1998) questioned the “9,000 deaths” when he learned that CDC attributed 1,000 of those postulated deaths to trichinosis, when, in fact, CDC had reported only one death due to trichinosis in the USA in the preceding 10 years. Challenged with the Wilson (1998) report, a CDC spokesperson, admitted, “Until we do good analysis, I would say we don’t know for sure” (NMA, 1998). Nevertheless, Buzby *et al.* (1999) repeated that foodborne illness causes 9,000 deaths each year.

In the USA, government reaction to, and press coverage of, foodborne-illness incidents differ dramatically among foods. On August 13, 1997 and August 15, 1997, media reports described foodborne-illness incidents involving ground beef and 16 cases (Wheeler, 1997) and alfalfa sprouts and 70 cases (Associated Press, 1997), both caused by *E. coli* O157:H7. Extensive press coverage and unprecedented media coverage caused the offending beef company to go out of business; essentially no press coverage and no reported government action occurred in the case of the contaminated sprouts (Smith *et al.*, 1998).

Cases Of Foodborne Pathogen Illness In The USA

Reported cases (per 100,000 people) of *E. coli* O157:H7 infection were 2.7, 2.3 and 2.8 in 1996, 1997 and 1998, respectively (NMA, 1999c) while, from 1996 to 1998, cases of *Salmonella enteritidis*, other *Salmonella* spp. and *Campylobacter* dropped 44%, 13% and 15%, respectively. CDC attributed: (a) the increase in reports of *E. coli* O157:H7 outbreaks, to widespread use of PFGE by health departments to subtype strains and link them to outbreaks (NMA, 1999a) and (b) the decrease in reports of outbreaks of other foodborne pathogens, to new inspection and HACCP programs (NMA, 1999c). Case-rate (per 100,000 people) for the 9 disease-causing agents tracked by CDC was 51.2 in 1996 vs. 40.7 in 1999 while *Salmonella* infections rose from 12.3 in 1998 to 14.8 in 1999 because of outbreaks in 1999 linked to unpasteurized orange juice, mangoes and uncooked sprouts (Bachman, 2000). Case-rate of *Campylobacteriosis* (the most widespread cause of food poisoning) fell from 25.2 in 1997 to 17.3 in 1999; *Shigella* and *E. coli* O157:H7 cases dropped 44% and 22% from 1996 to 1999 (Bachman, 2000).

CDC attributed 22.2%, 21.5%, 4.3%, 6.7% and 10.7% of *E. coli* O157:H7 illnesses to beef in 1994, 1995, 1996, 1997 and 1998, respectively; the highest incidences of *E. coli* O157:H7 illnesses in 1996, 1997 and 1998 were attributed to apple juice (18.6%), alfalfa sprouts (36.2%) and cole slaw (22.5%), respectively (NMA, 1999a). Of foodborne illness outbreaks in the 1990s, CSPI traced 1 of 5 to meat and poultry; three-fourths of food poisoning outbreaks stemmed from food subject to inspection by the FDA (e.g., eggs, fruits, vegetables, seafood, wild game) and

one-fourth from meat and poultry which are inspected by USDA (Maixner, 1999). CDC reported that illnesses caused by food contaminated with foodborne pathogens have declined 19% since 1997; Dr. Patricia Griffin (CDC) said “There have been mandated changes in meat and poultry processing plants causing industry to make lots of changes and there has also been increased attention to good agricultural practices on farms” (NMA, 2000a).

Source Of Food Safety Problems

When asked “Where do you think food safety problems are most likely to occur?,” respondents (Food Processing, 1997) said: (a) Processing plants (37% of those interviewed), (b) Restaurants (22%), (c) Warehouses (13%), (d) Homes (10%), (e) Supermarkets (10%), and (f) Farms (3%). CDC (1994) discussed “Location Of Food Mishandling” in relation to outbreaks of foodborne illness, reporting that 77% of mistakes occur at food-service sites (including restaurants and delicatessens), 20% in the home, and 3% at processing plants. In response to the question “Where do you think food safety problems are most likely to occur?,” supermarket shoppers (FMI, 2000) replied: (a) Food Processors/ Manufacturers, 27%; (b) Restaurants, 24%; (c) At Home, 14%; (d) During Transport, 8%; (e) Supermarkets, 7%; (f) Other, 7%; (g) All, 5%; and (h) On Farm, 2%.

In answer to the question “As far as you are personally concerned, who do you rely on the most to be sure that the products you buy in your supermarket are safe?,” the shopping public (FMI, 2000) responded: (a) Yourself, As An Individual, 37%; (b) Manufacturers/Food Processors, 17%; (c) Food Stores, 22%; (d) Government Institutions Or Agencies, 21%; (e) Consumer Groups/Organizations, 7%; (f) All/Everybody, 7%; (g) Farmers, 4%; (h) Not Sure, 2%; and (i) No One, 1%. In response to the question “What do you think is the single most important source of food poisoning?,” supermarket shoppers (FMI, 2000) answered: (1) Mishandling, 27% (of which 18% was due to mishandling/improper handling, and 9% was because of poor sanitation/not washing hands/dirty silverware); (2) Spoiled Food/Expired Food, 19%; (3) Improperly Cooked Food, 18%; (4) Germs/Bacteria, 13% (of which non-specific bacteria was 7%, *Salmonella* was 4%, and *E. coli* was 2%); and (5) Specific Food, 7% (of which chicken was 3% and beef was 2%).

Industry Investment In Beef Safety Prior To The 1993 Outbreak Of *E. coli* O157:H7

Morgan and Smith (1992) quantified the food-safety investment by the USA beef packing industry to prevent foodborne illness, in 1991 as \$1.1295 billion (\$4.34 per USA consumer; \$42.62 per beef carcass). Of that, \$553 million was for Packaging, \$12 million was for Carcass Rinsing, \$484 million was for Refrigeration, \$25 million was for In-House Quality Control Programs, \$39 million was for Third-Party Quality Control Programs, \$29 million was for Sanitation, and \$8 million was for Heating of Water for Cleaning and Sterilization. Interestingly, expenditures during that same period (calendar year 1991) by FSIS to police the safety of meat and poultry was \$.5 billion--less than half as much as was spent by the beef industry to keep its products safe.

Chronology Of Events: *E. coli* O157:H7

The chronology of events related to an outbreak of *E. coli* O157:H7 in the USA is as follows: (a) An outbreak of foodborne illness in 1993, because of undercooking of ground beef patties that contained *E. coli* O157:H7, caused hundreds of illnesses and four children died (Bell *et al.*, 1994). (b) Concern arose in 1993-1994 among those in the consuming public, media, and U.S. Congress that FSIS and industry were not satisfactorily monitoring status and minimizing pathogens microbiological counts on red meat and poultry (Savell and Smith, 1998). (c) FSIS first responded

by strictly enforcing “Clean Meat Programs,” including “Zero Tolerance” policy which required knife-trimming of all soil (fecal material, ingesta and udder contents) from beef carcasses prior to washing and chilling them (Smith *et al.*, 1994). (d) Beef packers interacted with those in government, universities and allied industries to develop/research decontamination techniques (e.g., steam/hot-water vacuuming) and microbiological-intervention treatments (e.g., spray-washing and/or rinsing treatments employing water of different temperatures, organic acids and steam) for use on carcasses (FSIS, 1996a). (e) USDA meat and poultry inspection was modernized (FSIS, 1996b) with passage (July, 1996) of the Pathogen Reduction; Hazard Analysis and Critical Control Point Systems; Final Rule (PR;HACCP;FR). Sanitation Standard Operating Procedures and Generic *E. coli* Testing, went into effect in all USA plants in January, 1997; Salmonella Testing and implementation of In-Plant HACCP Systems, had effective dates of January 1998, 1999 or 2000, respectively, for large, medium or small plants (Savell and Smith, 1998).

Five to ten years earlier, most USA beef packers had emphasized Pre-Requisite Programs, GMPs, and sanitation and operational SOPs to improve microbiological quality of their products and some USA beef packers had created and implemented “Scientific HACCP Programs.” Following passage PR;HACCP;FR, packers developed “Regulatory HACCP Programs” to comply with new meat inspection regulations. As beef packing plants initiated efforts to comply with regulatory requirements in the PR;HACCP;FR, research studies, like those of Sofos *et al.* (1999a,b,c), proved beneficial to government officials and packing plant personnel, especially as they related to meeting *Salmonella* and *E. coli* testing criteria. Since implementation of the PR;HACCP;FR, packers have used HACCP, decontamination techniques and microbiological interventions to produce beef carcasses that are dramatically cleaner and safer than they were a decade ago (Smith, 1998).

During the first year after HACCP was implemented in the 312 largest processing plants in the USA, the prevalence of *Salmonella* went down almost 50% in broilers, more than one-third in ground beef, 27% in ground turkey and more than 25% in pork, and percentages of plants meeting “Performance Standards” for *Salmonella* were 96% for broilers, 71% for swine, 90% for ground beef, and 91% for ground turkey (Meat Processing, 1999a). In March 2000, FSIS-USDA reported that results of two years of testing in large plants under HACCP showed a nearly 50% decrease in *Salmonella* prevalence in chicken and swine carcasses (compared to pre-HACCP baseline results), more than 20% in ground beef and more than 30% in ground turkey (Food Technology, 2000). Results of one year of testing in small plants showed decreases in *Salmonella* prevalence of more than 40% in ground beef, nearly 20% in chicken carcasses, and 15% in cow and bull carcasses, but an increase in swine carcasses; since HACCP implementation, 90% of large plants and 84% of small plants have met *Salmonella* performance standards (Food Technology, 2000).

Elder *et al.* (2000) reported that: (a) Of lots, at least one EHEC O157 positive was found in 72% of fecal, 38% of hide, 87% of preevisceration, 57% of postvisceration and 17% of postprocessing samples. (b) Prevalence of EHEC O157 in feces, hides, preevisceration, postvisceration and postprocessing samples was 28%, 11%, 43.4%, 17.8% and 1.8%, respectively. Reduction in prevalence from preevisceration to postprocessing suggests that plant sanitary procedures were effective. (c) EHEC O157 was recovered from 45.5% of carcasses. (d) Fecal and hide prevalence were significantly correlated with carcass contamination ($P=0.001$), indicating a role for control of EHEC O157 in live cattle on the farm. The USDA scientists told Brasher (2000a) that calves can pick up the bacteria during the birth process while other cattle get it from manure and that changes

in feeding methods and transportation can reduce the incidence, and told Lundeen (2000) that cross-contamination of carcasses may occur in plants through: (a) direct contact with personnel, knives or equipment. (b) Direct contact among carcasses. (c) Airborne and water-borne sources.

Minimizing Pathogens On Beef Using Singular Microbiological Interventions

Scientists have investigated: (a) Sanitizing solutions (e.g., chlorinated water, organic acids, hydrogen peroxide, trisodium phosphate, ozonated water, etc.), (b) Spray-washing, (c) Hot water application, (d) Steam-vacuuming, and (e) Conventional knife-trimming plus washing, to determine their efficacy in decontamination of carcasses (Anderson *et al.*, 1977; Barkate *et al.*, 1993; Gorman *et al.*, 1995a,b; Hardin *et al.*, 1995; Kochevar *et al.*, 1997; Powell and Cain, 1987; Reagan *et al.*, 1996; Sofos and Smith, 1998). Dickson and Anderson (1992) and FSIS (1995c) believe a decontamination step during the slaughtering process can improve shelf-life and safety, and, thus, should be an essential part of the slaughtering/dressing process. In general, washing and sanitizing agents have been effective in reducing bacterial counts (1 to 3 logs) and presence of pathogens on carcasses (Reagan *et al.*, 1996; Gorman *et al.*, 1995a,b; Dickson and Anderson, 1992).

Smith *et al.* (1994) presented results of the “Wash/Trim Studies” (Gorman *et al.*, 1995a,b; Reagan *et al.*, 1996) at the Meat Industry Research Conference (San Francisco, California, USA) and, a month later, FSIS approved the commercial use of hot water (74°C) spray-washing of beef carcasses. Additional studies (Cabedo *et al.*, 1996, 1997; Gorman *et al.*, 1997; Graves Delmore *et al.*, 1997a) demonstrated efficacy of hot-water spray-washing for decontaminating beef carcasses. The largest beef packing plants in the USA use either hot-water spray-washing (thermal pasteurization) or steam pasteurization to improve microbiological quality of beef carcasses.

Gorman *et al.* (1995a,b) reported that spray-washing more effectively reduced bacterial counts and visible fecal contamination when pressure and temperature of the water were 16.89 bar and 74°C, respectively. Hot water applications result in 1 to 3 log reductions in microbiological counts (Acuff *et al.*, 1997; Barkate *et al.*, 1993; Gorman *et al.*, 1995a; Graves Delmore *et al.*, 1997; Powell and Cain, 1987; Reagan *et al.*, 1996). FSIS (1996a) approved use of solutions of acetic, lactic and citric acids at 1.5 to 2.5%, chlorinated water (20-50 ppm), trisodium phosphate (12%), hot water (>74°C) sprays and steam pasteurization (Dickson *et al.*, 1997; Dorsa, 1997; Dorsa *et al.*, 1997; Cutter *et al.*, 1997; Nutsch *et al.*, 1997; Phebus *et al.*, 1997; Sofos and Smith, 1997, 1998).

Steam (or hot water) vacuuming was approved by FSIS in 1996 based upon studies by IBP, Inc., Kochevar *et al.* (1997) and Dorsa (1997). Steam vacuuming is used in plants processing more than 80% of USA fed cattle, saving more than \$200 million a year in reduced trim losses (Beef Today, 1997). Steam pasteurization lowers bacterial counts on beef tissues (Phebus *et al.*, 1997) and beef carcasses (Nutsch *et al.*, 1997) and is used in several U.S. beef slaughter plants. Delmore *et al.* (1999, 2000) demonstrated efficacy of hot water and steam or solutions of acetic acid, lactic acid, or trisodium phosphate for decontaminating beef offals.

Minimizing Pathogens On Beef Using Sequential Microbiological Interventions

Incidence of *E. coli* O157:H7 on beef carcasses (FSIS, 1994) was 0.2% (1 of 500) in 1993-1994. Doyle (1991) reported that 2 to 4% of ground beef contained *E. coli* O157:H7. Smith *et al.* (1995) and Sofos and Smith (1995) investigated sequential applications of microbiological “interventions” in “multiple hurdle” strategies, like those used for processed meat (Leistner, 1992; Leistner and

Gorris, 1995), to lessen the odds of *E. coli* O157:H7 or other foodborne pathogens surviving slaughtering/dressing/chilling operations. Minimizing airborne and/or condensate contamination (Worfel *et al.*, 1995, 1996) might result in a ten-fold decrease (1 of 5,000) in odds of presence of *E. coli* O157:H7 on a finished beef carcass while chemical dehairing of cattle (post-stunning) (Bowling and Clayton, 1992; Schnell *et al.*, 1995; Castillo *et al.*, 1998) involves three bacteriostatic/bactericidal steps (sodium sulfide, hydrogen peroxide, lactic acid) which might further reduce the odds to 1 of 5,000,000. Add to those, interventions like pre-evisceration carcass washing (acetic acid), final carcass washing (74°C water) and spray-chilling of carcasses (chlorine dioxide) and—theoretically—the odds of finding *E. coli* O157:H7 on beef carcasses can be made practically zero, provided that no contamination is introduced at steps following slaughter (Smith *et al.*, 1995).

Combinations of antimicrobial treatments can more effectively reduce bacterial contamination on carcasses and cuts than individual treatments (Anderson *et al.*, 1977; Dickson and Anderson, 1992; Graves Delmore *et al.*, 1998; Hardin *et al.*, 1995; Phebus *et al.*, 1997; Castillo *et al.*, 1998). Graves Delmore *et al.* (1998) identified sequences of decontamination treatments (spray-washing/rinsing with warm water, acetic acid solution and/or hot water) that reduced *E. coli* counts of beef tissue (inoculated to 7.4 log CFU/cm²) by 4.3 logs and total coliform counts of beef tissue (inoculated to 3.7 log CFU/cm²) by 1.7 logs. ConAgra, Inc. used Graves-Delmore *et al.* (1998) results to devise a “Chain Of Beef Safety™” consisting of: (a) Steam-vacuuming; (b) Pre-evisceration washing (90°F water) and rinsing (2% acetic acid in 120°F water); (c) Thermal-pasteurization (165°F water), and; (d) Final-carcass washing (90°F water) and rinsing (2% acetic acid or lactic acid in 125°F water). Bacon *et al.* (1999) confirmed the effectiveness of the four-step, “Chain Of Beef Safety™” multiple-hurdle microbiological intervention sequence in the eight ConAgra, Inc. plants, achieving reductions of 4.5, 3.7 and 3.2 log CFU/cm², respectively, in total plate counts, total coliform counts and *E. coli* counts, on chilled carcasses.

The pathogen control process to be used by Future Beef Operations in their first USA plant consists of eight steps [(1) Sodium sulfide dehairing, (2) Hydrogen peroxide neutralization of sodium sulfide, (3) Steam vacuuming, (4) Lactic acid rinsing, (5) Hot subcutaneous fat removal, (6) Thermal pasteurization, (7) Acetic acid rinsing, (8) Competitive exclusion, using *Lactobacillus delbrueckii*, on cuts and trimmings; Bowling (1999) says it will reduce the probability of a pathogen being present on a carcass from 1 in 55 to 1 in 2.75 billion.

Microbiological Testing

Data collected by 12 packing plants (1 sample per 300 carcasses) and analyzed by Bacon *et al.* (2000) showed that *E. coli* O157:H7 was present on hides of 3.56% of 2,245 animals and on 0.44% of 2,248 carcasses after hide removal, but was not present (0.00%) on 2,248 carcasses or in 1,342 samples of trimmings for ground beef. AMIF (2000a), from these findings, concluded that: (a) Data support the efficacy of sanitary hide removal and carcass microbial treatments as effective means of reducing pathogens. (b) Testing for process control verification would be more effective if the testing were done before carcass fabrication and distribution. (c) If carcass testing was used, carcasses testing positive for pathogens could be removed from the raw beef food supply before reaching the consumer and appropriate process reviews could ensure that the food safety system is working effectively. USDA scientists have successfully tested an instrument that uses specific wavelengths or colors of light to electronically determine if fecal matter is present on a carcass; if so, the carcass is further sanitized (SMA, 2000a).

Microbiological testing for indicator bacteria can be used to validate or verify slaughter procedures (QC, HACCP programs, etc.) and/or carcass decontamination interventions for reducing/eliminating meatborne pathogens, but planned testing for pathogens like *E. coli* O157:H7 that are of low, infrequent and non-random (unpredictable) incidence with the objective of process monitoring or product safety assurance or verification is not effective and is not recommended by AMSA (1999), AAM (1999), Bacon (2000) or Gill (2000). Smith De Waal (2000), on the contrary, believes that pathogen testing is an essential weapon in the government's arsenal against foodborne illness and that testing at many levels (USDA should add mandatory testing of carcasses and trimmings at slaughterhouses) and for more pathogens (*Listeria monocytogenes* and *Campylobacter jejuni/coli* should be added) is needed to maximize consumer and public health protections.

AMIF (2000c) reported that a new genetic fingerprinting method developed by Andy Benson (University of Nebraska) shows that there are two genetically distinct *E. coli* O157:H7 populations in cattle. One population appears to be associated with fatal foodborne illness in people while the other is not commonly isolated from foodborne disease cases; the population most commonly found in cattle is either incapable of causing disease or is not easily transmitted to humans (AMIF, 2000d) and these results help explain why only about 20,000 cases of human infection with *E. coli* O157:H7 are reported each year when you would expect a much higher number, given the number of cattle infected (Western Livestock Journal, 2000). Itoh *et al.* (1999) reported that both Shiga toxin-producing *E. coli* O157:H7 and Shiga toxin-non-producing *E. coli* O157:H7 coexist in cattle. Acheson (2000) said the current policy in the USA is to examine ground beef for *E. coli* O157:H7 only, but restricting the focus to O157 will miss other important human Shiga toxin-producing *E. coli*. These three studies reinforce the futility of testing carcasses or beef for *E. coli* O157:H7.

Carcass contamination after application of decontamination treatments will depend on facility design, sanitation, hygiene, process control and Good Manufacturing Practices; without this foundation, even the best decontamination technologies will fail (Sofos and Smith, 1997). Because it is so difficult (and so extraordinarily expensive) to try to find foodborne pathogens on beef by use of microbiological sampling, and because not all carcass sampling protocols provide the same estimate of contamination (Krizner, 1998; Ware *et al.*, 1999; Gill, 2000), a more rational approach to lowering incidence of foodborne pathogens like *E. coli* O157:H7 on beef, is to use sequential, multiple-hurdle applications of bacteriostatic/bactericidal technologies (Smith *et al.*, 1995; Graves Delmore *et al.*, 1997b,c, 1998; Bowling, 1999; Bacon *et al.*, 1999, 2000) and to validate or verify (by testing for indicator bacteria) that the process is under control.

In 1999, after having USDA inspection pulled from its processing plant because of three consecutive failures to meet *Salmonella* performance standards, Supreme Beef (Dallas, Texas, USA) filed suit against USDA in U.S. District Court. At issue in the Supreme Beef case (NMA, 2000b) were whether: (a) FSIS can enforce its performance standard for *Salmonella* at a point where the processor has access to no control measures to comply with the standard. (b) FSIS enforcement of the *Salmonella* performance standard at beef grinding plants contradicts and undermines the basic principles and credibility of the HACCP program. (c) USDA has exceeded its authority under the law by the manner in which it has implemented the performance standard for *Salmonella* testing. (d) The standard fails to take into account geographical and temperature factors

that affect the prevalence of *Salmonella* and the significant differences between results from USDA vs. third-party laboratories. On May 25, 2000, a federal judge in Texas struck down the USDA's inspection standards for meat-processing plants saying they do not fairly measure sanitary conditions, they measure the quality of the meat brought into a plant but not necessarily the conditions of the plant, and federal law did not give the government the authority to close a meat processing plant based on bacterial tests (Burros, 2000). The standards, and the laboratory tests used to enforce them, were the foundation of a four-year-old government effort to limit meat and poultry contamination by *Salmonella*; USDA Secretary Dan Glickman said the agency (FSIS) would take "whatever legal steps are necessary" to overturn the ruling (Burros, 2000).

Responsibility Of The Preharvest Sector

From 1993 through 1996, the National Cattlemen's Beef Association (NCBA) spent more than \$5 million on food safety research studies of *E. coli* O157:H7 and *Salmonella* (Beef Today, 1997) with most of those expenditures directed toward research in the harvest portion of the "farm-to-fork" sequence and with little effort to study the preharvest or postharvest sectors. *E. coli* O157:H7 was first recognized as a human pathogen in 1982 following major outbreaks of hemorrhagic colitis in Michigan and Oregon (Riley *et al.*, 1983) and while *E. coli* O157:H7 is not host-specific (Armstrong *et al.*, 1996; Besser *et al.*, 1997; Dargatz *et al.*, 1997; Kudva *et al.*, 1997a; Hancock *et al.*, 1998a) it is most frequently found in ruminants, particularly cattle (Reimann and Cliver, 1998). CAST (1994) stated "Pathogens or their toxins may be controlled by preventing their entry into the food, by reducing the amount present, or by destroying that which is present." Crider (1997), Clapp (1997) and Suther (1997) insisted that farm-to-table HACCP plus all the pathogen kill-steps that science can provide must be used to reduce incidence of *E. coli* O157:H7 on beef.

Sugarman (1997), Wheeler (1997), Labudde (1997) and Effertz (1997) believed recurring outbreaks of *E. coli* O157:H7 occurred because no one eliminated the source of contamination at the ranch, feedlot or packing plant. Maday (1995), AMSA/NCBA (1997), Meat Processing (1997a), Kester (1997), Bryan (1997), Suther (1997), Meat and Poultry (1997b) and Murphy (2000) believe control of *E. coli* O157:H7 contamination and on-farm prevention deserved the most attention because, if farmers and ranchers could: (a) identify and cull carriers, (b) investigate production/management practices which influence growth, shedding and spread of *E. coli* O157:H7 in the environment, (c) improve on-farm sanitation and develop manure management strategies, (d) prevent this bacteria from infecting live animals (perhaps, by use of antibacterial agents), and (e) minimize cattle entering the packing plant with *E. coli* O157:H7 on or in their bodies, it would help prevent its spread further into the food production chain.

Knowledge Base For Developing Preharvest Microbiological Interventions

Most cattle producers agree (Smith *et al.*, 1998) that: (a) We do not have an adequate base of research knowledge to mandate microbiological interventions in the preharvest sector. (b) If preharvest microbiological interventions are needed, they should start with Good Production Practices (GPPs) and then proceed to HACCP systems if preharvest Critical Control Points are ever identified. (c) Preharvest microbiological interventions should be incorporated into the voluntary NCBA, BQA programs rather than dictated through government regulations.

Research has documented the presence of *E. coli* O157:H7 in cattle feces; and, human illnesses due to this pathogen have not been traced to animals other than cattle (Dean-Nystrom *et al.*, 1997). Beef

and dairy cattle are known reservoirs for *E. coli* O157:H7 (Borczyk *et al.*, 1987; Wells *et al.*, 1991; Chapman *et al.*, 1993, 1997; Hancock *et al.*, 1994a, 1997b; Zhao *et al.*, 1995; Besser *et al.*, 1997). Of 100 outbreaks of *E. coli* O157 since 1982, 52% were associated with foods from cattle (WHO, 1997). Chapman *et al.* (1997) detected *E. coli* O157:H7 in the feces of 14% of culled dairy cows and of 13% of pasture-reared youthful cattle. Based on fecal samples from 100 feedlots in the top 13 cattle feeding states: (a) 1.61% of the samples of fresh feces in the pens contained *E. coli* O157:H7 and that 63% of the feedlots had one or more positive samples (NAHMS 1995a; Dargatz *et al.*, 1997), and (b) 5.5% of the samples of fresh feces in the pens contained *Salmonella* and that 38% of the feedlots had one or more positive samples (NAHMS, 1995b).

NAHMS (1997), Dargatz *et al.* (1997) and Hancock *et al.* (1997a) reported that: (a) Pens of cattle on-feed less than 20 days were 3.39 times more likely to have a positive sample of *E. coli* O157:H7 than those on-feed for longer times. (b) Pens of cattle fed vs. not fed barley in their current diet were 2.75 times more likely to have a positive sample of *E. coli* O157:H7. (c) Pens of cattle with entry weights of 700 lb or more were less likely to have positive samples of *E. coli* O157:H7. (d) Pens of at least 85% heifers were less likely to have positive samples of *E. coli* O157:H7. (e) Shedding of *E. coli* O157:H7 was not related to current feeding of antibiotics, coccidiostats, ionophores, probiotics, urea or other feed additives. (f) Shedding of *E. coli* O157:H7 was not associated with general health of the cattle in the pen or of animal density in the pen. (g) *E. coli* O157:H7 prevalence among USA feedlots was not different among geographical regions. NAHMS (1995b) concluded that (a) Cattle on-feed longer were more likely to shed *Salmonella*. (b) Sample prevalence of *Salmonella* within feedlots appeared to be highly variable and was very low to zero (not detectable) in about two-thirds of feedlots. (c) Shedding by cattle, of *Salmonella* spp. serotypes commonly associated with human illness occurred infrequently.

Hancock *et al.* (1994a,b; 1996; 1997a,b,c; 1998a,b), LeJuene *et al.* (1997), Garber *et al.* (1995a,b; 1999), Lynn *et al.* (1998), Besser *et al.* (1996, 1997) and Herrott *et al.* (1998) concluded that *E. coli* O157:H7: (a) exists—at least intermittently—on a majority of cattle farms, (b) is distributed across the USA in both dairy and beef cattle, (c) prevalence is not affected by the size of a cattle herd, (d) is detectable in the feces of less than 5% of cattle, (e) is found in feces from cattle, deer, sheep, dogs, horses, flies and birds, (f) if it has a long-term reservoir species, that species has not been identified, (g) colonizes in cattle in short duration (1 to 2 months) but long-term carriers have not been identified, (h) prevalence rates in cattle recently arrived in the feedlot are threefold higher than in those in the feedlot for several months, (i) is not associated with any recognizable disease in cattle, but instead appears to behave as transient *E. coli* “normal flora,” (j) can colonize a minority of cattle at low doses (<250 CFU) and these animals amplify the infection and transmit *E. coli* O157:H7 to other cattle, (k) is more prevalent in growing cattle (3 to 18 months of age) than in either younger (suckling) calves or adult cattle, (l) prevalence in a herd may (Hancock *et al.*, 1994b) or may not (Hancock *et al.*, 1997) be associated with manure application to grazing land, (m) prevalence in a herd is eight times as likely on dairy farms where alleyways are flushed with water as opposed to being cleaned by other methods, (n) sheds in a typical pattern in a herd followed over time as “epidemics of shedding” (mainly during warm weather) interspersed with longer periods with rare or no shedding animals, (o) can multiply prolifically in cattle feeds when moisture is added, as commonly occurs in mixed rations, (p) will not grow in total mixed rations containing a silage naturally high in propionic acid, (q) can replicate in a variety of feeds at temperatures found on farms during summer months, (r) has been found in water troughs on numerous farms and can

persist at least 4 months in water-trough sediments (thus water troughs could be a long-term reservoir which maintains *E. coli* O157:H7 in herds during periods of low infection prevalence), (s) persists on particular farms as a specific strain for at least 2 years, and (t) is regionally transmitted, because indistinguishable strains have been found in herds less than 500 km apart.

E. coli O157:H7 occurs in all regions of the USA (Garber *et al.*, 1995a) and prevalence fluctuates, from undetectable to detectable, depending partially upon season (Hancock *et al.* 1997a,b,c, 1998b). Fecal shedding, risk of cattle contamination and risk of human outbreaks (Riley *et al.*, 1983; Rodrique *et al.*, 1995) are highest in Spring and Summer (Hancock *et al.*, 1994a; Van Donkersgoed *et al.*, 1999; Chapman *et al.*, 1997). *E. coli* O157:H7 shedding is greater in cattle fasted before harvest (Rasmussen *et al.*, 1993). *E. coli* O157:H7 shedding was not related to rumen fill, body condition, type, gender or distance traveled to the packing plant, in a study of slaughter cattle by Van Donkersgoed *et al.* (1999). Jordan and McEwen (1998) reported that an abrupt change in diet slightly reduced shedding of *E. coli* Biotype I in feedlot cattle while Kudva *et al.* (1995, 1997b) increased shedding of *E. coli* O157:H7 in feces of sheep by shifting their diet from grain to forage.

Buchanan and Doyle (1997), citing their work (Zhao *et al.*, 1995; Meng *et al.*, 1995; Brown *et al.*, 1997) and that of others detailing “Reservoirs and Sources of *E. coli* O157:H7” reported that: (a) Young animals carry *E. coli* O157:H7 more frequently than adults, (b) Prevalence of fecal excretion varies substantially among positive herds, (c) Reported incidence among cattle varies widely, in part because of differences in sensitivity of procedures used for detecting *E. coli* O157:H7, (d) Results of two major USA surveys indicated that 3.2% of dairy calves and 1.6 to 2.0% of feedlot cattle were positive for *E. coli* O157:H7. (e) *E. coli* O157:H7 in calf feces ranged from $<10^2$ to 10^5 CFU/g, (f) Fecal shedding of *E. coli* O157:H7 frequently is intermittent and of short duration, i.e., several weeks to months, (g) Strains of *E. coli* O157:H7 with indistinguishable PFGE genomic DNA profiles can be isolated from calves in different states or farms, (h) More than one strain of *E. coli* O157:H7 can be isolated from feces of the same animal or different animals within the same herd, (i) *E. coli* O157:H7 is not pathogenic to calves; inoculation with 10^{10} CFU did not induce significant clinical disease, (j) *E. coli* O157:H7 shed in feces decreased dramatically during the first 14 days postinoculation (e.g., from 10^4 to 10^6 CFU/g after 48 hr to $5-10^2$ CFU/g at 14 days, (k) *E. coli* O157:H7 is confined to the gastrointestinal tract, with the forestomachs (rumen, omasum, reticulum) and distal sites (distal ileum, proximal cecum, spiral colon, descending colon) as principal sites of localization, (l) Fasting increases the levels of *E. coli* O157:H7 shed in the feces of some animals, but not in most, (m) *E. coli* O157:H7 did not form attaching and effacing lesions and did not colonize mucosal surfaces, and (n) The ability of *E. coli* O157:H7 to persist in and reinfect cattle that have a strong immune response is likely to contribute to the introduction and persistence of infection in herds.

E. coli O157:H7 has unusual tolerance to environmental stresses such as acidic and dry conditions (Arnold and Kaspar, 1995). *E. coli* O157:H7 survived in cattle manure for 79 days (Wang *et al.*, 1996) and in a manure pile for 21 months (Kudva *et al.*, 1998). A waiting period between manure application and allowing cattle to graze that field is recommended by Hancock *et al.* (1994b). Gunnerson (2000) reported that Cornell University scientists discovered that adding sodium carbonate plus sodium hydroxide to manure kills most of the *E. coli* bacteria. The worst outbreak of *E. coli* O157:H7 in North America (6 deaths in Ontario, Canada) was caused by contamination of the municipal water supply, perhaps because flooding from rains

washed animal feces into the town water supply (Cohen, 2000). While house flies and fruit flies have been thought to be simply mechanical vectors of enterohemorrhagic *E. coli* O157, Iwasa *et al.* (1999), Kobayaski *et al.* (1999) and Janisiewicz *et al.* (1999) proved otherwise, demonstrating that the organism is ingested by flies, lives in their mouth and crop, is excreted for several days and, thus, is disseminated via their spittle. Smith *et al.* (2000) used combination of draining/refilling, brush-scrubbing and 15 min. exposure to a 1:32 (sodium hypochlorite:water) solution and concluded that routine cleaning or disinfection may not, by itself, reduce the likelihood of transmitting coliform bacteria to cattle through feedlot water tanks. Doyle (1992) considers *Campylobacter jejuni*, *Listeria monocytogenes*, and Enterohemorrhagic *E. coli* O157:H7 important foodborne pathogens. Siragusa *et al.* (1993) reported incidences of *Listeria monocytogenes* in six studies of bovine feces of 0%, 19%, 52%, 11%, 7% and 18% (52% in mature cows) and of 1.0 to 1.3% in feces from healthy feedlot beef cattle.

Attempts To Manipulate The Gastrointestinal Tract To Control Pathogens

Newman (1996), Stern *et al.* (1996), Spring (1995), Scheoni and Wong (1994), Miles (1993) and Scheoni and Doyle (1992) described nutritional or microbiological manipulation of the gastrointestinal tract to prevent colonization or eliminate pathogens in chickens and/or pigs; such manipulation, using oligosaccharides or bacteria (lactic acid bacteria, *Bacillus cereus* and competitive exclusion cultures), though not 100% effective, have been shown to decrease populations of *Salmonella* and *Campylobacter* (Newman, 1996). Cannell *et al.* (1997) administered a feed additive combining a mannanoligosaccharide plus lactic-acid secreting bacteria to growing dairy heifers for 28 days but found no differences in Total Coliform Counts or Generic *E. coli* Counts in the feces of control vs. treated cattle. NMA (1997) and Meyer (1997) reported that Michael Doyle (University of Georgia) had isolated 18 beneficial strains of bacteria from cattle gastrointestinal tracts and droppings which, when added to cattle feed, virtually eliminated *E. coli* O157:H7 in two or three weeks and that this discovery might lead to a product that eliminates the microorganism before cattle are sent to slaughter or keep *E. coli* O157:H7 from invading cattle that do not have it.

Diez-Gonzales *et al.* (1998) reported that: (a) The gastric stomach of humans is a barrier to foodborne pathogens, but *Escherichia coli* can survive at pH 2.0 if it is grown under mildly acidic conditions. (b) Cattle are a natural reservoir for pathogenic *E. coli*, and cattle fed mostly grain had lower colonic pH and more acid-resistant *E. coli* than cattle fed only hay. (c) On the basis of numbers and survival after acid shock, cattle that were fed grain had 10⁶-fold more acid-resistant *E. coli* than cattle fed hay; but, a brief period of hay feeding decreased the acid-resistant count substantially. (d) Cattle could be given hay for a brief period immediately before slaughter to significantly reduce the risk of foodborne *E. coli* infection. Keen *et al.* (1999) determined that an abrupt ration change from a corn-based concentrate to 100% alfalfa hay greatly decreased fecal EHEC O157 shedding from 50% to 18% within 7 days of ration change (vs. no change for grain-fed cattle); however, hay-fed cattle lost about 0.8 lb per day (vs. 2.6 lb per day gain in grain-fed cattle). Scott *et al.* (2000) manipulated finishing diets of cattle by limit-feeding, altering dietary ingredients in a finishing ration and feeding alfalfa hay *ad libitum* for five days. Manipulation of finishing diets did not reduce shedding of acid-resistant *E. coli* in feces; however, short duration hay feeding reduced acid-resistant *E. coli* shedding in the feces (Scott *et al.*, 2000).

Programs For Preharvest Microbiological Interventions In Livestock

Campbell *et al.* (1982, 1984) and Mallinson *et al.* (1995) reported that risk of *Salmonella* contamination on processed turkey and broiler carcasses is reduced when the carcasses originate from farms with lower levels of *Salmonella*. The *Salmonella enteritidis* Pilot Project (SEPP) started in 1992 and evolved into the Pennsylvania Egg Quality Assurance Program (PEQAP) in 1994; included in both programs were microbiological interventions (chick/pullet testing, rodent control, cleaning/disinfection between flocks occupying the houses) that could be implemented by producers. White *et al.* (1997) concluded that the on-farm risk-reduction management practices of SEPP and PEQAP had reduced *Salmonella enteritidis* infections.

To assure safety of ruminant-animal foods, Gangarosa *et al.* (1994) recommended that: (a) Each segment of the food chain identify its responsibilities (based on risk, and implemented by HACCP) for the maintenance of food safety and product quality assurance. (b) Quality Assurance Programs of commodity organizations should encompass considerations of fecal contamination of feed, water and hair coats; pathogen-free feeds; control of birds and rodents; potential chlorination of water and pasteurization of feedstuffs; and, minimizing animal stress to reduce shedding rates of pathogens. (c) Research be conducted on ecology/epidemiology of foodborne pathogens to establish appropriate critical controls in on-farm HACCP programs. (d) Preharvest food safety education programs are needed for producers, farm laborers and veterinarians. (e) A system of food safety data-bases should be developed. (f) Total Quality Management programs should be implemented that include general on-farm sanitation, cleaning/disinfecting of transport vehicles and handling of animals with minimal stress. (g) A unique animal identification system that is electronically-based should be established. (h) A traceback system should be considered but—with foodborne pathogens—a traceback system to the source, with the intent of eliminating risk at the source, is unlikely to work. (i) Specialized slaughter facilities producing only a cooked product should be established to accommodate animals identified as having a foodborne pathogen.

Grandin (1994), Hancock and Dargatz (1995) and Besser (1995) discussed potential methods of preharvest control of *Salmonella*, *Campylobacter* and *Listeria* in livestock: (a) *Trace-back* is not realistic because about 70 to 80% of farms, ranches and feedlots have cattle that are shedding *E. coli* O157:H7 and the organism is also shed by sheep and deer. (b) *Universal-testing* of all cattle going to slaughter is not realistic because about 1 in 40 slaughter cattle have *E. coli* O157:H7 in their gastrointestinal tract and many more (perhaps 10 times as many) cattle carry the organism on their hair than actually shed it in their feces. (c) *Farm visits* by FSIS or APHIS officials is not realistic inasmuch as not enough is known to allow government personnel to provide meaningful advice. (d) *Vaccination* is being studied but with not much promise of success. (e) *Preslaughter measures* such as elimination of preslaughter fasting, dietary measures to minimize colonization levels (prevalence and dose) and washing of live animals to remove feces and soil may prove efficacious for lowering the odds of finding pathogens on the outside of cattle. (f) *Ecological measures, competitive exclusion* or *niche engineering* by modifying nutritional and/or environmental variables found to be important in susceptibility to colonization, level of exposure, or maintenance of the reservoir in the herd, reduced feed contamination (5 to 20% of livestock feeds contain *Salmonella*; one-third of feeds may contain Generic *E. coli*) and using probiotics in the feed and/or inoculating the rumen with “good” bacteria that will compete with pathogens—is probably the best approach for lessening occurrence of *E. coli* O157:H7 and other pathogens in and on slaughter cattle.

Archer (1995) suggested that: (a) Soil protozoa could act as Trojan Horses for pathogenic bacteria, shielding them from disinfectants, facilitating their travel, and influencing their virulence in humans. (b) Microbial ecology at the farm level must be elucidated. (c) Potential sources and niches for *E. coli* O157:H7 at the feedlot must be identified. (d) Pathogens try to survive under the adverse conditions of the farm or feedlot and develop resistances as well as niches (e.g., water troughs, standing water) for their survival. (e) A potential decrease in the acidity of the rumen, as well as protection by protozoa, may allow survival of *E. coli* O157:H7.

Labudde (1997) recommended the following GMPs as solutions to preventing *E. coli* O157:H7 contamination on beef: (a) Cattlemen can test herds for the presence of *E. coli* O157:H7 and forego selling positive animals to packers. (b) Ranchers and feeders should wash manure off animals before sending them to market; USDA inspectors should reject unclean animals before they enter a packing plant. (c) Ranchers, feeders and packers should withhold feed from animals between 8 to 16 hr before slaughter because a two-fold to ten-fold reduction in contamination can be accomplished by withholding feed as the gut will not become bloated and burst as easily during evisceration. Crider (1997) suggested producers use these GMPs: (a) Maintain stored feeds free of bird and rodent contamination; bird feces commonly contains *Salmonella* and also has *E. coli* O157:H7; rodents commonly carry *Salmonella* and other pathogens. (b) Manage feed bunks so that refusal is minimized and residue removed frequently; *E. coli* O157:H7 and *Salmonella* can grow to very high levels in some mixed feeds. (c) Clean water troughs frequently enough to prevent visible accumulation of sediments and biofilms, or slimy scum, because pathogenic bacteria, including *E. coli* O157:H7 and *Salmonella*, live there.

Targeted research to reduce pathogens on cattle and carcasses (Smith, 1996, 2000b; Sofos *et al.*, 1998; Smith *et al.*, 1998) should include: (a) Ecology/epidemiology of pathogens on the farm, including reservoirs and life cycles. *E. coli* O157:H7 are found in deer, antelope, elk and flies and *Salmonella* is found in birds; the role of wildlife, flies, birds and rodents as reservoirs and in the life cycle of pathogens must be determined. (b) Determination of how pathogens reproduce in livestock and how/why they move into the feces. Research is needed to determine if production/management practices, stress during handling and long transportation and holding times increase shedding and transmission of *E. coli* O157:H7 and *Salmonella* from the gastrointestinal tracts of slaughter cattle. (c) Identification of potentials for changing feedstuffs or manipulating the flora in the gastrointestinal tract for decreasing pathogens in feces or for changing acid-resistance of pathogens that are shed. Competitive exclusion or inhibition should be investigated as means for enabling non-harmful bacteria to out-compete, and reduce incidence of, pathogenic bacteria like *E. coli* O157:H7 and *Salmonella*. Changing forage:concentrate ratios in the diet to make the *E. coli* O157:H7 that are shed less resistant to acid (making them less apt to survive the acidic conditions of the stomachs of humans who ingest them). (d) Evaluation of cattle cleaning systems and chemical dehairing, immediately prior to hide removal, during harvest. Most contamination comes from the hair or skin of cattle; removing the hair of cattle and cleaning them before they proceed to dehiding and dressing may be the most comprehensive and effective approach to reducing risk of contaminating meat with pathogenic bacteria. The packing plant is the first “point of concentration” for all slaughter cattle; cattle cleaning or chemical dehairing is a more practical method for reducing contamination on slaughter cattle than would be development of HACCP plans for every farm, ranch, auction market or feedlot that sends a bovine animal to a packing plant. (e) Determination of sources of farm-to-carcass contamination via conduction of longitudinal studies (replicated seasonally and geographically). Samples of bird droppings, old fecal pats, feed rations from bunks,

water in troughs, fresh fecal pats, dung-locks at feedlots and auction markets, trucks (sideboards) before (at the feedlot) and after (at the packing plant) use for transportation of cattle, gastrointestinal tract feces, dung-locks at packing plants and chilled carcass surfaces should be collected, tested for *Salmonella* and *E. coli* O157:H7, and, if present, DNA fingerprinted (via RFLP analysis and profiles by PFGE or Ribotyping) for strain identification and clustering of isolates to trace sources and/or vehicles of infection of cattle with pathogens. (f) Using information from research conducted in parts “a” through “e,” above, evaluate implementation of Good Production Practices (e.g., water ozonation, on-farm truck cleaning, pen scraping/bedding, bird and rodent control, diet manipulation, stress reduction) for reducing contamination in and on slaughter cattle.

Hussein (2000) summarized the present status of on-farm factors that can decrease risk of *E. coli* contamination as follows: (a) In the past 20 years, *E. coli* O157:H7 has surfaced as an emerging foodborne pathogen causing illness in humans. (b) The pathogen has been traced, in most cases, to the consumption of contaminated cattle products that are raw (i.e., milk) or undercooked (i.e., beef). (c) Research has identified methods to decrease post-harvest contamination of beef with *E. coli* O157:H7; a combination of these methods and preharvest (on-farm) control methods would be effective in reducing the risk of *E. coli* O157:H7 contamination of beef. (d) Preharvest control measures are based on manipulation of cattle management practices, manure handling, drinking water and dietary ingredients to decrease fecal shedding of the pathogen. (e) Although recent research addressing these control measures has shown promise, the on-farm factors associated with the carriage and shedding of *E. coli* O157:H7 by cattle remain to be elucidated.

Attempts To Characterize Farm-To-Fork Microbiological Interventions

FSIS (1993) presented a “Farm-To-Table Continuum Of Responsibility For Food Safety” that consisted of the following discussion points: (a) Producers should provide “healthy” animals (via: probiotics, GMPs, QA/QC, recordkeeping, trace-back, education); “healthy” means free of human pathogens, drugs, environmental contaminants and pesticides, (b) Transporters of cattle must minimize contamination and stress, (c) Slaughterers must use education, “process control” and/or HACCP, (d) Food-service should develop and use training and HACCP, (e) Consumers should be better educated (via: schools, television, print media) and better informed (via: “safe handling” labels); but, the consumer must not be assigned all or even most of the responsibility of safe meat, and (f) Government’s role should be HACCP verification, process-control oversight, compliance guarantees and consumer education.

National Live Stock and Meat Board (1994) developed a blueprint for industry action for solving the *E. coli* O157:H7 problem that included: (a) Preharvest—Research on host:pathogen relationships; reservoirs; ecology; interventions, (b) Carcass Conversion—Clean hide before removal; use anti-microbial washes (use HACCP), (c) Carcass Break-Up; Trim Generation—Prevent recontamination and temperature abuse (use HACCP), (d) Ground Beef Processing—Prevent pathogen growth; use interventions (use HACCP), (e) Food Service—Require suppliers to use HACCP and train employees. (f) Retail—Require suppliers to use HACCP and train employees, (g) Public Health/Consumer Education—conduct a national consumer awareness campaign, (h) Intervention Strategies—Research irradiation and other strategies, and (i) Regulatory Opportunities/Challenges—Move to risk-based analyses and verify HACCP.

Postharvest Microbiological Interventions

There are microbiological interventions that should occur during distribution and storage (Smith *et al.*, 1998). Meat & Poultry (1997a) described “Transportation and storage critical control points,” of FSIS-USDA (Transportation Analysis Group) as follows: (a) Inspect the truck and trailer before loading, (b) Ensure the temperature of the product to be loaded is not above 40°F, (c) Properly configure the load, (d) Ensure maintenance of 40°F temperature while awaiting additional product to be loaded, (e) Maintain proper temperature of the food during transit, and (f) Maintain inside temperature of the food during unloading and movement to storage.

There are microbiological interventions that could be used at supermarkets (Smith *et al.*, 1998). Sofos and Smith (1994) said retail meat markets need Sanitation Standard Operating Procedures, time/temperature controls, avoidance of cross-contamination and at least two Critical Control Points: (a) CCP1—Receiving at the warehouse; check temperature and condition of incoming product, and (b) CCP2—In the cutting room, assure pre-operation sanitation, personal hygiene, temperature, time and condition of wholesale/retail cuts are within accepted tolerances. Peter Rojack (A&P Stores) said supermarkets should: (1) Buy Safe Food (via buying specifications); (2) Maintain The Cold-Chain (via HACCP checks); (3) Eliminate Cross-Contamination (via training/controls and in-store discipline); (4) Assure Effective Sanitation (A&P does this via their “Sparkle” program); and (5) Partner With The Customer (via consumer education in special kiosks in stores) (Smith and Morgan, 1999). Nancy Donley (Safe Tables Our Priority) described things that supermarkets should do to help prevent consumer illness due to foodborne pathogens on meat and poultry, as: (1) Have HACCP programs in all stores. (2) Build microbiological control into supplier agreements. (3) Conduct unannounced visits to suppliers to assure that their sanitation standards are met. (4) Maintain species-specific areas for cutting and grinding. (5) Stop using rework. (6) Sell meat/poultry thermometers and educate people in their use. (7) Double-wrap all meat cuts to minimize contamination from drip. (8) Have plastic gloves or bags at meat counters to prevent consumer cross-contamination of other foods. (9) Separately bag meat/poultry at the checkout counter. (10) Incorporate pictures of the faces of previous innocent victims of food poisoning in numerous places to increase employee awareness of the problem in relation to their own children’s vulnerability (Smith and Morgan, 1999).

Microbiological interventions have been described by fast-food companies (Smith *et al.*, 1998). Salvage (1996) characterized food-safety activities of fast-food companies as follows: (a) Jack In The Box—HACCP-based program; *E. coli* O157:H7 control program; ServSafe training program (with National Restaurant Association); HACCP system in restaurants. (b) Arbys—HACCP-based program covering each element of receiving, manufacturing, storage, distribution, product cooking and restaurant/sandwich preparation. Burger King—HACCP-based program; unannounced audits of raw-material suppliers and meat processors; HACCP system in restaurants. AMS-USDA may require all ground beef suppliers for the National School Lunch Program to operate under a HACCP program, to have microbiological intervention steps, to test end-product for pathogens, and to test uncooked product for *E. coli* O157:H7 (Meat Processing, 1997b). FSIS-USDA may expand its efforts beyond slaughtering and processing plants to include: (a) Monitoring of retail food stores, restaurants, commercial kitchens, hotels and other institutions, and (b) Random reviews of distributors, warehouses, retail stores, restaurants/caterers, animal food processors, transporters and renderers (Smith and Morgan, 1999).

Kain *et al.* (1999) studied microbial counts on beef carcasses, wholesale cuts and retail cuts to assist those in the fabrication, distribution and retailing sectors to deliver safe beef to retail consumers. Beef at six packing plants was followed to six retail stores and bacterial counts and incidences of *Salmonella* spp., *Listeria* spp. and *Listeria monocytogenes* were determined; counts/incidences of bacteria/pathogens were higher on wholesale and retail cuts than on the carcasses from which they originated in 3 to 5, of 6, comparisons. A study of a multiple-hurdle microbiological intervention sequence for use during fabrication of beef carcasses into subprimal cuts and beef trimmings (Smith *et al.*, 1999) will be completed in late 2000. Kain *et al.* (1999) reported that more than 9% of consumers intercepted at supermarkets took more than 2 hr. to refrigerate or freeze beef purchases in the home.

A “U.S. Cold Temperature Evaluation” survey (AMIF, 2000b) revealed that product temperatures rose 8 to 10°F during the typical summer shopping excursion, and 15 to 20°F for the worst 5% of shopping conditions. Percentages of household refrigerators above 41°F (the maximum recommended by FDA’s Food Code), 45°F and 50°F were 27, 8 and 2, respectively; comparable percentages, in retail cases, were 27, 9 and 1 for fresh meat, 71, 42 and 14 for deli meats and 60, 34 and 11 for pre-packaged lunch meat. To help keep food cold, American Meat Institute Foundation (2000b) recommended that consumers: (1) Ask grocery store staff to pack cold foods together in paper, not plastic, bags. (2) Take foods home from the grocery store promptly. (3) Place perishable foods in the car near the air conditioning vents or use a cooler or ice packs between store and home. (4) Keep home refrigerators and freezers at or below 41°F and 0°F, respectively.

A Recent *Listeria monocytogenes* Outbreak In The USA

In August 1998, CDC observed deaths and illnesses related to a rare strain of *Listeria monocytogenes*; the contaminated product (hot dog and deli meat products) was traced to a specific processing plant (Meat Marketing & Technology, 1999b). By March 1, 1999, 20 deaths—14 adults and six miscarriages/stillbirths—and at least 97 illnesses had been traced to the products (Meat Marketing & Technology, 1999b). Although turkey meat in contaminated hot dogs and deli products was originally believed to be the source of the *Listeria monocytogenes* (serotype 4b), FSIS-USDA since identified construction dust entering the plant through an air conditioning system as the source of the foodborne pathogen that was introduced after the products had been pasteurized (Meat Marketing & Technology, 1999c).

Recalls of processed meat products are soaring (Associated Press, 2000) because of: (a) stepped-up government testing for *Listeria monocytogenes*, and (b) refusal of processors to delay shipments of products until the results of the tests are known; 23 recalls were issued between October 1, 1999 and May 15, 2000, for hot dogs, deli meats and products that may be contaminated with *Listeria monocytogenes*. The National Advisory committee on Meat and Poultry Inspection recommended that FSIS officials include *Listeria* for finished product testing as part of the HACCP verification program and that FSIS explore use of existing and new, developmental methods of post-packaging pasteurization for ready-to-eat products (SMA, 2000b). President Bill Clinton announced on May 6, 2000 that the USA government will propose (by August 2000) requiring that companies that produce hot dogs, deli meats and cold cuts test for *Listeria monocytogenes* and related bacteria on equipment, floors and other areas of their plants; such tests will be designed to warn of sanitation problems that could lead to meat contamination and are intended to reduce illnesses caused by *Listeria monocytogenes* by one-half over five years (Brasher, 2000b).

Microbiological Interventions Through Consumer Education

Researchers at FDA and CDC have found that consumers could benefit from food safety education (NMA, 1999b). Based on a survey of almost 20,000 adults, it was found that 25% of men and 14% of women do not routinely wash their hands with soap after handling raw meat or poultry; half of the respondents reported eating undercooked eggs during the previous year. And, overall, when it comes to handling and eating food safely: (a) men take more risks than women, (b) younger people take more risks than older ones; (c) whites take more risks than blacks, and; (d) those with higher incomes are not as careful as those with lower incomes.

The most probable cause (Sofos and Smith, 1993) of the 1993 outbreak of hemorrhagic colitis caused by *E. coli* O157:H7 was undercooking of ground beef. In 1995, an FSIS spokesperson said, "Perhaps we've done too good a job of convincing U.S. consumers that we have the safest food supply in the world, because now they abuse it with temperature" (Smith, 1995). To minimize occurrence of foodborne pathogen illness (Smith, 1995) government, industry and university personnel must emphasize consumer education. Osterholm (1997) said that well-publicized outbreaks represent only a very small part of the problem nationwide, *E. coli* O157:H7 infections have been traced to: (a) Undercooked hamburger, (b) Consumption of unpasteurized milk, (c) Contact with farm animals, (d) Transmission in day-care settings, and (e) Fruits and vegetables. "The Hudson Foods recall unfortunately reinforces the impression that government can fully protect us against contamination of our food supply and that when problems do occur, they'll be quickly fixed, while the truth is quite the opposite!" (Osterholm, 1997).

At food-service sites and in the home, the biggest problems of food mishandling are: (a) Cross-contamination, (b) Temperature abuse, and (c) Undercooking (CDC, 1994). CDC (1996): (a) Identified "where the mishandled food that caused a foodborne illness was eaten" as restaurant/deli (33%), home/residence (20%), camp/picnic/church (6%), unknown (5%), school (4%) and all other (32%), (b) Determined that the largest number of foodborne illness outbreaks are linked to improper handling of foods at the point of preparation, and (c) Concluded that 97% of foodborne illnesses could be prevented with basic hygiene and improved food handling practices. Three simple means for minimizing foodborne illness include: (a) Thoroughly cook foods to destroy foodborne pathogens, (b) Keep raw and cooked foods separate and (c) Refrigerate cooked foods promptly in shallow containers (Sofos *et al.*, 1993). For fresh beef sold at supermarkets, consumers must be educated to: (a) Cook ground beef to 71°C (measured with a thermometer or t-stick) and (b) Refrigerate or freeze beef as soon after purchase as possible. While ground beef should be cooked to an internal temperature of 71°C, steaks and roasts can be safely served if cooked "medium rare" (63°C internal) because surface bacteria will be destroyed (Food and Nutrition News, 1997).

Ten common food safety mistakes identified by Food and Nutrition News (1997) are: (1) Countertop thawing, (2) Leftovers left on the counter, (3) Unclean cutting board, (4) Room-temperature marinating, (5) Store-to-refrigerator lag time, (6) Same platter for raw and cooked meat, (7) Restaurant "doggie-bag" delay, (8) Stirring-and-tasting spoon, (9) Shared knife for raw meat and vegetables, and (10) Hide-and-eat Easter eggs. Morganthau (1997) presented the following guidelines for "Making The Kitchen Safe": (a) Wash your hands (20 seconds); (b) Wash the dishes (within 2 hours); then air-dry; (c) Clean dish-rags and sponges (use bleach); (d) Clean the counter (bleach, not detergent); (e) Clean the cutting board (after each use); (f) Pop it in the fridge (within 2 hours after cooking); (g) Keep the fridge cold (40°F or colder); (h) Defrost in the fridge, microwave

or cold water (30 minute changes of the water); (i) Don't eat the batter or raw eggs; and (j) Cook the red out (71°C in the center) (Morganthau, 1997).

Partnership For Food Safety Education (a coalition of industry, government and consumer groups) developed a "Fight Bac™" campaign (FMI, 1998) with four key principles: (a) Wash Hands And Surfaces Often, (b) Prevent Cross-contamination, (c) Cook Foods To Proper Temperatures, and (d) Refrigerate Promptly. "Fight Bac™" addresses critical points in everyday food handling where improper practices can lead to foodborne illness and educates the public because consumers are the last line of defense in the food safety chain (FMI, 1998). USDA has launched a new food safety education campaign to promote the use of food thermometers in cooking meat, egg and poultry dishes; the campaign theme "It's safe to bite when the temperature is right!" is spouted by a cartoon food thermometer named "Thermy™" (SMA, 2000c).

Consumers were willing to pay a modest price increase for measures associated with beef safety—including irradiation, steam pasteurization and hot-water rinsing—in a Kansas State University (1999) study. Survey participants would pay 34 cents per pound premium for steam-pasteurized beef if it was 99% free of *E. coli* and 29 cents per pound premium for hot-water rinsed beef if it was 90% free of *E. coli*. If the price for beef treated with interventions was equal, the majority of respondents chose the irradiation option (Kansas State University, 1999).

Will Irradiation Be Used To Destroy Foodborne Pathogens In USA Ground Beef?

Use of irradiation (more appropriately termed "electronic pasteurization") on fresh pork, poultry and beef for sale to consumers has been approved by both the FDA and USDA (most recently, for beef, on February 13, 1999 by USDA) but there are concerns (Smith and Morgan, 1997) with use of irradiation that may delay its adoption by the beef industry. These concerns include: (1) Expense—Application of this technology is costly because of the expense to construct or access irradiation facilities and the comparatively high costs for special packaging materials. (2) Consumer Acceptance—Many end-users, especially those in foreign markets, are reluctant to purchase and consume or sell to consumers, meat or poultry that has been exposed to radiation; intentional exposure of a food to radiation seems incongruous to many food purchasers. (3) Incidence Of Odd Odor/Flavor—To some people, and in certain instances, irradiation generates "odd," "off" or "undesirable" tastes and smells in end-products.

Colorado Boxed Beef, IBP, Inc. and Excel, Inc. (Meat Processing, 1999b; Associated Press, 1999) were the first meat companies in the USA to commercially use irradiation technology. In March 1999, McDonald's Corporation announced that it has suspended testing of ground beef treated with irradiation because "the irradiated meat did not measure up to the chain's organoleptic standards" (Meat Marketing and Technology, 1999a). The first irradiated hamburgers, sold in the USA (Minneapolis/St. Paul; May 2000) sold so fast that distributors immediately expanded sales into four other states (Manning, 2000). The burgers were irradiated using electronic pasteurization after the beef was processed, formed as patties, wrapped, frozen and packaged; electronic beam pasteurization (Surebeam; Titan Corporation) is more acceptable to consumers than processes that expose food to radioactive material such as cobalt⁶⁰ (Manning, 2000).

Of supermarket shoppers asked the question “How Likely Would You Be To Buy Food Products Like Strawberries, Poultry, Pork Or Beef If They Had Been Irradiated to Kill Germs And Keep It Safe?”, 38% said they were “Very Likely” or “Somewhat Likely”—down substantially from the 69% in 1996 and from the 56% in 1999 who said that, while 36% replied “Not Very Likely” and 20% said “Not At All Likely.” Interestingly, more women than men, those with a high school education or less and single persons (rather than those with families) are more likely to say they would purchase irradiated products (FMI, 2000).

REFERENCES

AAM. 1999. Food safety: Current status and future needs. Report based on an AAM colloquium (August, 1998; Nashville, Tennessee, USA). Ed. Stephanie Doores. American Academy of Microbiology, Washington, DC, USA.

Acheson, D.W.K. 2000. How does *Escherichia coli* O157:H7 testing in meat compare with what we are seeing clinically? *J. Food Prot.* 63:819-821.

Acuff, G.R., A. Castillo and J.W. Savell. 1997. Hot water rinses. *Proc. Recipr. Meat Conf., American Meat Science Association, Chicago, Illinois, USA.* 49:125-128.

AMIF. 2000a. AMIF study shows pathogen interventions in beef plants are effective against *E. coli* O157:H7. *American Meat Institute Foundation News.* (March Issue) Volume 2, Issue 1, pages 1-6.

AMIF. 2000b. AMIF survey shows foods often kept too warm to ensure food safety. *American Meat Institute Foundation News.* (March Issue) Volume 2, Issue 1, pages 1-5.

AMIF. 2000c. DNA fingerprinting of *E. coli* O157:H7. *American Meat Institute Foundation News.* (March Issue) Volume 2, Issue 1, page 5.

AMSA. 1999. The role of microbiological testing in beef food safety programs: The scientific perspective. *AMSA Symposium* (January 1999; Chicago, Illinois, USA). Co-Chairs: C.R. Calkins and M. Koochmaria. American Meat Science Association, Kansas City, Missouri, USA.

AMSA/NCBA. 1997. Beef safety symposium. Emerging beef pathogens. American Meat Science Association and National Cattlemen’s Beef Association. (December 3-4; Chicago, IL) National Cattlemen’s Beef Association, Englewood, Colorado, USA.

Anderson, M.E., R.T. Marshall, W.C. Stringer and H.D. Naumann. 1977. Combined and individual effects of washing and sanitizing on bacterial counts of meat—A model system. *J. Food Protection* 40:688-670.

Archer, D. 1995. The Food Microbiology Division Lecture. Institute of Food Technologists Annual Meeting (Anaheim, California, USA). *IFT Book of Abstracts:* 34.1.

Armstrong, G.L., J. Hollingsworth and J.G. Morris, Jr. 1996. Emerging foodborne pathogens: *E. coli* O157:H7 as a model of entry of a new pathogen into the food supply of the developed world. *Epidemiol. Rev.* 18:29-51.

Arnold, K.W. and C.W. Kaspar. 1995. Starvation and stationary-phase-induced acid tolerance of *E. coli* O157:H7. *Appl. Environ. Microbiol.* 59:2364-2368.

Associated Press. 2000. Heightened testing hikes meat recalls. (May 15 Release).

Associated Press. 1997. Sprouts tainted by *E. coli*. *The Denver Post*. (August 15 Issue) page 23.

Bachman, J. 2000. Foodborne diseases. Associated Press. (March 17 Release).

Bacon, R.T., J.N. Sofos, K.E. Belk and G.C. Smith. 2000. Incidence of *Escherichia coli* O157:H7 on beef animal hides, carcasses and trimmings in twelve commercial slaughtering facilities. *Dairy, Food and Environmental Sanitation* (Submitted for publication).

Bacon, R.T., J.N. Sofos, K.E. Belk, J.O. Reagan and G.C. Smith. 1999. Commercial evaluation of multiple-sequential interventions for decontamination of beef carcasses. Annual Meeting, International Association of Milk, Food and Environmental Sanitarians, 86:T3.

Barkate, M.L., G.R. Acuff, L. Lucia and D.S. Hale. 1993. Hot water decontamination of beef carcasses for reduction of initial bacterial numbers. *Meat Science* 35:397-401.

Bean, N.H., J.S. Goulding, M.T. Daniels and F.J. Angulo. 1997. Surveillance for foodborne disease outbreaks—United States, 1988-1992. *J. Food Protection* 60:1265-1286.

Beef Today. 1997. Safe Food “From Farm To Fork.” *Beef Today*. (April Issue) page 34.

Bell, B.P., M. Goldoft, P.M. Griffin, M.A. Davis, D.C. Gordon, P.I. Tarr, C.A. Bartleson, J.H. Lewis, T.J. Barrett, J.G. Wells, R. Baron and J. Kobayaski. 1994. A multistate outbreak of *Escherichia coli* O157:H7—Associated bloody diarrhea and hemolytic uremic syndrome from hamburgers. *The Washington Experience. JAMA* 272:1349-1353.

Besser, T.E. 1995. Means for lessening/preventing occurrence of *E. coli* O157:H7 in cattle populations. Proc. Conf. On New Technol. To Improve Food Safety (April 12, 1995; Chicago, IL) Food Safety and Inspection Service, USDA, Washington, DC, USA.

Besser, T.E., D.D. Hancock, L.C. Pritchett, E.M. McRae, D.H. Rice and P.I. Tarr. 1997. Duration of detection of fecal excretion of *Escherichia coli* O157:H7 in cattle. *J. Infect. Dis.* 175:726-729.

Besser, T.E., D.H. Rice, D.D. Hancock and B. Richards. 1996. Colonization of calves with *Escherichia coli* O157:H7: Infectious dose and direct contact transmission. *App. Environ. Microbiol.* 60:1328-1335.

Borczyk, A.A., M.A. Karmali, H. Lior and L.M.C. Duncan. 1987. Bovine reservoir for verotoxin-producing *E. coli* O157:H7. *Lancet* 1:98.

Bowling, R.A. 1999. Future Beef Operations: A farm-to-fork beef supply chain. Presented at the Rosenthal Lecture Series, Texas A&M University (College Station, Texas, USA).

- Bowling, R.A. and R.P. Clayton. 1992. Method for dehairing animals. U.S. Patent 5,149,295.
- Brasher, P. 2000a. Study: *E. coli* rates in cattle higher; USDA considering tighter controls. Associated Press. The Denver Post. (March 1 Issue) page A-9.
- Brasher, P. 2000b. Clinton targets *Listeria* in latest food-safety plan. Associated Press. The Coloradoan. (May 7 Issue) page 5.
- Broder, J.M. 1997. Food safety push on tap. The Denver Post. (December 28 Issue) page 13A.
- Brown, C.A., B.G. Harmon, T. Zhao and M.P. Doyle. 1995. Experimental *Escherichia coli* O157:H7 carriage in calves. Appl. Environ. Microbiol. 63:27-32.
- Bryan, J. 1997. The war against a pathogen. Farm Journal. (October Issue) page 34.
- Buchanan, R.L. and M.P. Doyle. 1997. Foodborne disease significance of *Escherichia coli* O157:H7 and other Enterohemorrhagic *E. coli*. Food Technology 51:69-76.
- Burros, M. 2000. Meat plant standards struck down. The Denver Post. (May 26 Issue) page 29.
- Buzby, J.C., T. Roberts, C.T. Jordan, C.T. Lin and J.M. MacDonald. 1999. Bacterial foodborne disease, medical costs and productivity losses. Agricultural Economic Report No. 741. Economic Research Service, U.S. Department of Agriculture, Washington, DC, USA.
- Cabedo, L., J.N. Sofos and G.C. Smith. 1997. Attachment of *Escherichia coli* and other bacterial cells grown in two media to beef adipose and muscle tissues. J. Food Protection 60:102-106.
- Cabedo, L., J.N. Sofos and G.C. Smith. 1996. Removal of bacteria from beef tissue by spray-washing after different times of exposure to fecal material. J. Food Protection 59:1284-1287.
- Campbell, D.F., R.W. Johnston, M.W. Wheeler, K.V. Nagaraja, C.D. Szymanski and B.S. Pomeroy. 1984. Effects of evisceration and cooling processes on the incidence of *Salmonella* in fresh dressed turkeys grown under *Salmonella*-controlled and -uncontrolled environments. Poultry Science 63:1069-1072.
- Campbell, D.F., S.S. Green, C.S. Custer and R.W. Johnston. 1982. Incidence of *Salmonella* in fresh dressed turkeys raised under *Salmonella*-controlled and -uncontrolled environments. Poultry Science 61:1962-1967.
- Cannell, R.C., J.H. Killen, J.N. Sofos, T.P. Karnezos, R.L. Lewis and G.C. Smith. 1997. Use of lactic-acid secreting bacteria and mannanoligosaccharide to reduce pathogens in cattle preharvest. Final Report to Alltech, Inc. Colorado State University, Fort Collins, Colorado, USA.
- CAST. 1994. Foodborne Pathogens: Risks And Consequences. September, 1994. Des Moines, Iowa, USA.

Castillo, A., J.S. Dickson, R.P. Clayton, L.M. Lucia and G.R. Acuff. 1998a. Chemical dehairing of bovine skin to reduce pathogenic bacteria and bacteria of fecal origin. *J. Food Prot.* 61:623-625.

Castillo, A., L.M. Lucia, K.J. Goodson, J.W. Savell and G.R. Acuff. 1998b. Comparison of water wash, trimming and combined hot water and lactic acid treatments for reducing bacteria of fecal origin on beef carcasses. *J. Food Prot.* 61:823-828.

CDC. 1996. Foodborne illness outbreaks by location—Where the mishandled food was eaten. *Morbidity and Mortality Weekly Reports (MMWR)*, October 25. Centers For Disease Control, U.S. Department of Health and Human Services, Atlanta, Georgia, USA.

CDC. 1994. Location of Food Mishandling. *Morbidity and Mortality Weekly Reports (MMWR)*, November 1. Centers For Disease Control, U.S. Department of Health and Human Services, Atlanta, Georgia, USA.

Chapman, P.A., C.A. Siddons, A.T. Cerdan Malo and M.A. Harkin. 1997. A 1-year study of *E. coli* O157:H7 in cattle, sheep, pigs and poultry. *Epidemiol. Infect.* 119:245-250.

Chapman, P.A., C.A. Siddons, D.J. Wright, P. Norman, J. Fox and E. Crick. 1993. Cattle as a possible source of verocytotoxin-producing *E. coli* O157:H7 infections in man. *Epidemiol. Infect.* 111:439-447.

Clapp, S. 1997. Speakers note HACCP limits. *Meat & Poultry*. (November Issue) page 10.

Cohen, T. 2000. Canada water plant knew about *E. coli* bacteria. *Associated Press*. *The Denver Post* (May 26 Issue) page 6.

Crider, J. 1997. No longer just a packer problem. *Drovers Journal*. (October Issue) pages 24-26.

Cutter, C.N., W.J. Dorsa and G.R. Siragusa. 1997. Parameters affecting the efficacy of spray washes against *Escherichia coli* O157:H7 and fecal contamination of beef. *J. Food Protection* 60:614-618.

Dargatz, D.A., S.J. Wells, L.A. Thomas, D.D. Hancock and L.P. Garber. 1997. Factors associated with the presence of *Escherichia coli* O157:H7 in feces of feedlot cattle. *J. Food Protection* 60:466-470.

Dean-Nystrom, E.A., B.T. Bosworth, W.C. Cray and H.W. Moon. 1997. Pathogenicity of *E. coli* O157:H7 in the intestines of neonatal calves. *Infect. Immun.* 65:1842-1848.

De Becker, G. 1997. Conquering what scares us. *USA Weekend magazine* (August 24 Issue). Report of "What Americans Fear/Taking Precautions" consumer survey, pages 4-6.

Delmore, Jr., R.J., J.N. Sofos, G.R. Schmidt, K.E. Belk, W.R. Lloyd and G.C. Smith. 2000. Interventions to reduce microbiological contamination of beef variety meats. *J. Food Protection* 63:44-50.

- Delmore, Jr., R.J., J.N. Sofos, K.E. Belk, W.R. Lloyd, G.L. Bellinger, G.R. Schmidt and G.C. Smith. 1999. Good manufacturing practices for the improvement of the microbiological quality of beef variety meats. *Dairy Food and Environmental Sanitation* 19:742-752.
- Dickson, J.S. and M.E. Anderson. 1992. Microbiological decontamination of food animal carcasses by washing and sanitizing systems. A review. *J. Food Protection* 55:133-140.
- Dickson, J.S., M.D. Hardin and G.R. Acuff. 1997. Organic acid rinses. *Proc. Recipr. Meat Conf., American Meat Science Association, Chicago, Illinois, USA* 49:129-131.
- Diez-Gonzalez, F., T.R. Callaway, M.G. Zizoulis and J.B. Russell. 1998. Grain feeding and the dissemination of acid-resistant *Escherichia coli* from cattle. *Science* 281:1666-1668.
- Dorsa, W.J. 1997. New and established carcass decontamination procedures commonly used in the beef-processing industry. *J. Food Protection* 60:1146-1151.
- Dorsa, W.J., C.N. Cutter and G.R. Siragusa. 1997. Effects of acetic acid, lactic acid and trisodium phosphate on the microflora of refrigerated beef carcass surface tissue inoculated with *Escherichia coli* O157:H7, *Listeria innocua*, and *Clostridium sporogenes*. *J. Food Protection* 60:619-624.
- Doyle, M.P. 1992. A new generation of foodborne pathogens. *Dairy, Food and Environmental Sanitarian* 12:490-492.
- Doyle, M.P. 1991. *E. coli* O157:H7 and its significance in foods. *Int. J. Food Microbiol.* 12:289-302.
- Drovers Journal. 2000. Consumers prioritize food safety. (January Issue) page 18.
- Effertz, N. 1997. What to do about beef's bad bug. *Beef Today*. (October Issue) pages 8-9.
- Elder, R.O., J.E. Keen, G.R. Siragusa, G.A. Barkocy-Gallagher, M. Koohmaraie and W.W. Laegreid. 2000. Correlation of enterohemorrhagic *Escherichia coli* O157 prevalence in feces, hides and carcasses of beef cattle during processing. *PNAS* 97:2999-3003.
- FMI. 2000. TRENDS IN THE UNITED STATES--Consumer Attitudes & The Supermarket 2000. Food Marketing Institute, Washington, DC, USA.
- FMI. 1998. TRENDS IN THE UNITED STATES--Consumer Attitudes & The Supermarket 1998. Food Marketing Institute, Washington, DC, USA.
- Food and Nutrition News. 1997. Food safety perspectives. National Cattlemen's Beef Association. Volume 69, Number 1, Spring Issue. Chicago, Illinois, USA.
- Food Processing. 1997. Safety measures. (Report of an FDA/USDA consumer survey) *Food Processing magazine* (June Issue) 58:88.

Food Technology. 2000. HACCP programs result in substantial reductions in *Salmonella*. 54(5):30.

FSIS. 1996a. Achieving the zero tolerance performance standard for beef carcasses by knife trimming and vacuuming with hot water and steam; Use of acceptable carcass interventions for reducing carcass contamination without prior agency approval. Notice of Policy Change. Federal Register 61:15024-15027.

FSIS. 1996b. Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) systems: Final Rule. Federal Register 61:38805-38989.

FSIS. 1995a. Backgrounder:FSIS Pathogen Reduction/HACCP Proposal. (February Issue) page 2. FSIS-USDA, Washington, DC, USA.

FSIS. 1995b. Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems. Code of Federal Regulations 9:308-381. FSIS-USDA, Washington, DC, USA.

FSIS. 1995c. Comparison of methods for achieving the zero tolerance standard for fecal, ingesta and milk contamination of beef carcasses; Notice of conference. Federal Register 60:49553-49564.

FSIS. 1994. Nationwide beef microbiological baseline data collection program: Steers and heifers—October 1992 to September 1993. FSIS-USDA. Washington, DC, USA.

FSIS. 1993. Discussion points—continuum of responsibility (farm-to-table). Proceedings of the FSIS Conference on the Regulatory Program of the Future (November; College Station, TX), FSIS-USDA, Washington, DC, USA.

Gangarosa, E.J., C.V. Kimberling, G.A. Mitchell, B.I. Osburn, M.E. Potter, G.C. Smith, P.H. Sparling, H.F. Troutt and J.C. Whittier. 1994. Final Report, Ruminant Animal Production TAG for USDA, FSIS and APHIS. Information Data Systems. Silver Spring, Maryland, USA.

Garber, L., S. Wells, L. Schroeder-Tucker and K. Ferris. 1999. Factors associated with fecal shedding of verotoxin-producing *E. coli* O157 on dairy farms. J. Food Prot. 62:307-312.

Garber, L.P., S.J. Wells, D.D. Hancock, M.P. Doyle, J.A. Shere and T. Zhao. 1995a. *E. coli* O157:H7 in dairy heifers: Results of a case-control study. J. Am. Vet. Med. Assoc. 207:46-47.

Garber, L.P., S.J. Wells, D.D. Hancock, J. Tuttle, J.A. Shere and T. Zhao. 1995b. Public veterinary medicine: Food safety and handling—Risk factors for fecal shedding of *E. coli* O157:H7 in dairy calves. J. Am. Vet. Med. Assoc. 207:48-49.

Gill, C. 2000. Microbiological testing and safety of beef: Summary of the Task Force's conclusions. pages 1-4. International Livestock Congress (Houston, Texas, USA).

Gorman, B.M., S.L. Kochevar, J.N. Sofos, J.B. Morgan, G.R. Schmidt and G.C. Smith. 1997. Changes on beef adipose tissue following decontamination with chemical solutions or water of 35C or 74C. *J. Muscle Foods* 8:185-197.

Gorman, B.M., J.B. Morgan, J.N. Sofos and G.C. Smith. 1995a. Microbiological and visual effects of trimming and/or spray-washing for removal of fecal material from beef. *J. Food Protection* 58:984-992.

Gorman, B.M., J.N. Sofos, J.B. Morgan, G.R. Schmidt and G.C. Smith. 1995b. Evaluation of hand-trimming, various sanitizing agents and hot water spray-washing as decontamination interventions for beef brisket adipose tissue. *J. Food Protection* 58:899-907.

Grandin, T. 1994. Preharvest pathogen control. *Meat & Poultry*. (January Issue) pages 62-64.

Graves Delmore, L.R., J.N. Sofos, G.R. Schmidt and G.C. Smith. 1998. Decontamination of inoculated beef tissue through application of sequential spraying treatments. *J. Food Science* 63:890-893.

Graves Delmore, L.R., J.N. Sofos, J.O. Reagan and G.C. Smith. 1997a. Hot-water rinsing and trimming/washing of beef carcasses to reduce physical and microbiological contamination. *J. Food Science* 62:373-376.

Graves Delmore, L.R., J.N. Sofos, G.R. Schmidt and G.C. Smith. 1997b. Inactivation of pathogenic bacteria by the chemical dehairing process proposed for use on beef carcasses during slaughter. Proceedings of the 50th Annual Reciprocal Meat Conference, American Meat Science Association, Chicago, Illinois, USA.

Graves Delmore, L.R., J.N. Sofos, G.R. Schmidt and G.C. Smith. 1997c. Evaluation of multiple hurdles for beef carcass decontamination. Proceedings of the 50th Annual Reciprocal Meat Conference, American Meat Science Association, Chicago, Illinois, USA.

Gunnerson, T. 2000. Carbonating cow manure kills *E. coli* bacteria. Reuters Limited. Citing a study by Diez-Gonzalez *et al.* (2000); *Environ. Sci. and Research* 34:1275-1278. http://dailynews.yahoo.com/h/nm/20000428/hlmanure_1.html.

Hancock, D. and D. Dargatz. 1995. Implementation of HACCP on the farm. Presented at the HACCP Symposium of the 75th Annual Meeting of the Conference of Research Workers in Animal Diseases (November 12; Chicago, Illinois, USA) pages 1-6.

Hancock, D.D., T.E. Besser, D.H. Rice, E.D. Ebel, D.E. Herriott and L.V. Carpenter. 1998a. Multiple sources of *E. coli* O157:H7 in feedlots and dairy farms in the Northwestern USA. *Prev. Vet. Med.* 35:11-19.

Hancock, D.D., T.E. Besser and D.E. Rice. 1998b. Ecology of *E. coli* O157:H7 in cattle and impact of management practices. pages 85-91: In: *E. coli* O157:H7 And Other Shiga-Toxin Producing *E. coli* Strains (Eds. J.B. Kaper and A.B.O'Brien) ASM Press, Washington, DC, USA.

- Hancock, D.D., D.H. Rice, L.A. Thomas, D.A. Dargatz and T.E. Besser. 1997a. Epidemiology of *Escherichia coli* O157:H7 in feedlot cattle. *J. Food Protection* 60:462-465.
- Hancock, D.D., D.H. Rice, D.E. Herriott, T.E. Besser, E.D. Ebel and L.V. Carpenter. 1997b. Effects of farm manure handling practices on *Escherichia coli* O157:H7 prevalence in cattle. *J. Food Protection* 60:363-366.
- Hancock, D.D., T.E. Besser, D.H. Rice, D.E. Herriott and P.I. Tarr. 1997c. Longitudinal study of *E. coli* O157:H7 in 14 cattle herds. *Epidemiol. Infect.* 118:193-195.
- Hancock, D.D., T.E. Besser, D.H. Rice, D.E. Herriott and P.I. Tarr. 1996. Longitudinal study of *Escherichia coli* O157:H7 in fourteen cattle herds. *Epidemiol. Infect.* 118:193-195.
- Hancock, D.D., T.E. Besser, M.L. Kinsel, P.I. Tarr, D.H. Rice and M.G. Paros. 1994a. The prevalence of *Escherichia coli* O157:H7 in dairy and beef cattle in Washington State. *Epidemiol. Infect.* 113:119-207.
- Hancock, D.D., T.E. Besser and D.H. Rice. 1994b. Identification of management factors influencing farm prevalence of *E. coli* O157:H7. Proceedings of the 8th International Congress of Animal Hygiene. pages PB1-PB4. St. Paul, Minnesota, USA.
- Hardin, M.D., G.R. Acuff, L.M. Lucia, J.S. Oman and J.W. Savell. 1995. Comparison of methods for decontamination from beef carcass surfaces. *J. Food Protection* 58:368-374.
- Herriott, D.E., D.D. Hancock, E.D. Ebel, L.V. Carpenter, D.H. Rice and T.E. Besser. 1998. Association of herd management factors with colonization of dairy cattle by Shiga Toxin-positive *E. coli* O157. *J. Food Prot.* 61:802-807.
- Hussein, H.S. 2000. On-farm factors can decrease risk of *E. coli* contamination. *Feedstuffs*. (March 13 Issue) pages 18-23.
- Itoh, Y., N. Hayashi, M. Katoh, A. Yamamoto, S. Hayashi, S. Maeda and T. Ezaki. 1999. The characterization of Shiga toxin-non-producing *Escherichia coli* serotype O157:H7 isolated from carcasses of cattle at a slaughter house. *Microbiol. Immunol.* 43:699-703.
- Iwasa, M., S.I. Makino, H. Asakura, H. Kobori and Y. Morimoto. 1999. Detection of *Escherichia coli* O157:H7 from *Musca domestica* (Diptera; Muscidae) at a cattle farm in Japan. *J. Med. Entomol.* 36:108-115.
- Janisiewicz, W.J., W.S. Conway, M.W. Brown, G.M. Sapers, P. Fratamico and R.L. Buchanan. 1999. Fate of *Escherichia coli* O157:H7 on fresh-cut apple tissue and its potential for transmission by fruit flies. *Appl. Environ. Microbiol.* 65:1-9.
- Jordan, D. and S.A. McEwen. 1998. Effect of duration of fasting and a short-term, high-roughage ration on the concentration of *E. coli* Biotyp I in cattle feces. *J. Food Prot.* 61:531-534.

Kain, M.L., J.N. Sofos, K.E. Belk, J.O. Reagan, G.C. Smith, D.R. Buege, W.P. Henning, J.B. Morgan, T.P. Ringkob and G.R. Bellinger. 1999. Microbiological contamination baselines of beef carcasses, wholesale cuts and retail cuts. Annual Meeting, International Association of Milk, Food and Environmental Sanitarians, 86:P44.

Kansas State University. 1999. Consumers will pay for beef safety. Kansas Livestock Association, News and Market Report. (In: Beef. July 1999 Issue. page 40).

Keen, J.E., G.A. Uhlich and R.O. Elder. 1999. Effects of hay- and grain-based diets on fecal shedding of naturally-acquired enterohemorrhagic *E. coli* (EHEC) O157 in beef feedlot cattle. Proceedings of the Conference for Research Workers on Animal Diseases. Abstract No. 86 (Chicago, Illinois, USA).

Kester, W. 1997. Food safety:An issue on the hot seat. Beef. (August Issue) pages 26-28.

Kobayashi, M., T. Sasaki, K. Tamura, K. Suzuki, H. Watanabe and N. Agui. 1999. Houseflies not simple mechanical vectors of enterohemorrhagic *Escherichia coli* O157:H7. Am. J. Trop. Med. Hyg. 61:625-629

Kochevar, S.L., J.N. Sofos, R.R. Bolin, J.O. Reagan and G.C. Smith. 1997. Steam vacuuming as a pre-evisceration intervention to decontaminate beef carcasses. J. Food Protection 60:107-113.

Krizner, K. 1998. Incongruities in testing lead to inconsistent results. Meat Marketing & Technology. (December Issue) page 60.

Kudva, I.T., K. Blanch and C.J. Hovde. 1998. Analysis of *E. coli* O157:H7 survival in ovine or bovine manure and manure slurry. Appl. Environ. Microbiol. 64:3166-3174.

Kudva, I.T., P.G. Hatfield and C.J. Hovde. 1997a. Characterization of *E. coli* O157:H7 and other Shiga toxin-producing *E. coli* serotypes isolated from sheep. J. Clin. Microbiol. 35:892-899.

Kudva, I.T., C.W. Hunt, C.J. Williams, U.M. Nance and C.J. Hovde. 1997b. Evaluation of dietary influences on *E. coli* O157:H7 shedding by sheep. Appl. Environ. Microbiol. 63:3878-3886.

Kudva, I.T., P.G. Hatfield and C.J. Hovde. 1995. Effect of diet on the shedding of *E. coli* O157:H7 in a sheep model. Appl. Environ. Microbiol. 61:1363-1370.

Labudde, R. 1997. The facts about Hudson Foods and *E. coli* O157:H7. Meat & Poultry. (October Issue) pages 12-15.

Leistner, L.E.E. 1992. Linkage Of Hurdle-Technology With HACCP. Proceedings of the Reciprocal Meat Conference, American Meat Science Association, Chicago, Illinois, USA.

Leistner, L. and L.G.M. Gorris. 1995. Food preservation by hurdle technology. Trends In Food Science and Technology 6:41-46.

LeJuene, J., D.D. Hancock and T.E. Besser. 1997. *E. coli* O157:H7 in cattle water troughs: A possible on-farm reservoir. Proceedings of the 5th Annual Food Safety, Farm To Table Conference. Northwest Food Safety Consortium (Moscow, Idaho, USA).

Lundeen, T. 2000. Prevalence of *E. coli* greater in summer; lower after processing. Feedstuffs. (April 10 Issue) page 9.

Lynn, T.V., D.D. Hancock, T.E. Besser, J.H. Harrison, D.H. Rice, N.T. Stewart and L.L. Rowan. 1998. The occurrence and replication of *E. coli* in cattle feeds. J. Dairy Sci. 81:1102-1108.

Maday, J. 1995. Searching for pathogen control points. Drivers Journal. (June Issue) pages 17-20.

Maixner, E. 1999. Meat, poultry cause minority of food poisonings. Feedstuffs. (September 6 Issue) page 8.

Mallinson, E.T., L.E. Carr, G.W. Malone, C.J. Wabeck, D.H. Palmer, E.P. Pusey, E. Russek-Cohen and S.W. Joseph. 1995. Lower Water Activity In Broiler Litter And The Reduction of *Salmonella* On Farms And Processed Carcasses. Cooperative Extension Service Bulletin 348, University of Delaware and University of Maryland, College Park, Maryland, USA.

Manning, A. 2000. Fallout of irradiated burgers: Red-hot sales, rapid expansion. USA Today. (May 25 Issue) page D-6.

Meat & Poultry. 1997a. Transportation and storage critical control points. (August Issue) page 43.

Meat & Poultry. 1997b. Beef Safety Symposium advocates preharvest research. (December Issue) page 3.

Meat Marketing & Technology. 1999a. The Scoop: No irradiation for Ronald? (March Issue) page 19.

Meat Marketing & Technology. 1999b. *Listeria*: Government and industry take aim at a silent killer. (April Issue) page S3.

Meat Marketing & Technology. 1999c. Turkey not the culprit. (April Issue) page 11.

Meat Processing. 1999a. *Salmonella* down in HACCP plants. (April Issue) page 10.

Meat Processing. 1999b. Colorado Boxed Beef to irradiate meat. (April Issue) page 12.

Meat Processing. 1997a. Prevention is critical in *E. coli* situations. (December Issue) page 16.

Meat Processing. 1997b. HACCP coming for school lunch suppliers? (December Issue) page 8.

- Meng, J., S. Zhao, T. Zhao and M.P. Doyle. 1995. Molecular characterization of *Escherichia coli* O157:H7 isolates from raw milk, ground beef and calf feces using pulsed field gel electrophoresis and plasmid DNA analysis. *J. Med. Microbiol.* 42:258-263.
- Meyer, T. 1997. Germ that kills *E. coli* found. *The Denver Post*. (October 13 Issue) page 13.
- Miles, R.D. 1993. Manipulation of the microflora of the gastrointestinal tract; Natural ways to prevent colonization by pathogens. *Proceedings of the 9th Annual Symposium on Biotechnology in the Feed Industry*. pages 133-138. Alltech's Technical Publications, Nicholasville, Kentucky, USA.
- Morgan, J.B. and G.C. Smith. 1992. 1991 Beef Investments To Prevent Foodborne Illness. *Meat Minutes* (April Issue). Meat Science Group, Department of Animal Sciences, Colorado State University, Fort Collins, Colorado, USA.
- Morganthau, T. 1997. *E. coli* alert. *Newsweek*. (September 1 Issue) pages 26-32.
- Murphy, D. 2000. Food safety: The next stage; down on the farm. *Meat Marketing & Technology*. (April Issue) pages 52-55.
- NAHMS. 1997. Factors Associated With *Escherichia coli* O157:H7 In Feces Of Feedlot Cattle. National Animal Health Monitoring System, VS/APHIS, U.S. Department of Agriculture, Fort Collins, Colorado, USA.
- NAHMS. 1995a. *Escherichia coli* O157:H7 Shedding By Feedlot Cattle. National Animal Health Monitoring System, VS/APHIS, U.S. Department of Agriculture, Fort Collins, Colorado, USA.
- NAHMS. 1995b. *Salmonella* Shedding By Feedlot Cattle. National Animal Health Monitoring System, VS/APHIS, U.S. Department of Agriculture, Fort Collins, Colorado, USA.
- National Live Stock and Meat Board. 1994. Solving the *E. coli* O157:H7 problem. A blueprint for industry action. Blue Ribbon Task Force (July). National Cattlemen's Beef Association, Englewood, Colorado, USA.
- Newman, K.E. 1996. Nutritional manipulation of the gastrointestinal tract to eliminate *Salmonella* and other pathogens. *Proceedings of the 12th Annual Symposium on Biotechnology in the Feed Industry*. pages 37-46. Nottingham University Press, Nottingham, United Kingdom.
- Newsweek. 1997. Poll, Princeton Survey Associates. (September 1 Issue) pages 26-32.
- NMA. 2000a. Foodborne illness numbers decrease. *Herd On The Hill*. (March 30 Issue) page 3.
- NMA. 2000b. At issue in the Supreme Beef case. *Lean Trimmings*. (January 10 Issue) page 1.
- NMA. 1999a. CDC *E. coli* O157:H7 illness data for 1998. *Lean Trimmings*. (April 12 Issue) page 1.

- NMA. 1999b. Risky food handling behaviors commonplace. *Lean Trimmings*. (April 12 Issue) page 1.
- NMA. 1999c. Cases of infection. *Lean Trimmings*. (April 12 Issue) page 2.
- NMA. 1998. Article questions USDA statistics. *Herd On The Hill*. (June 15 Issue) page 1.
- NMA. 1997. Search for methods of destroying *E. coli* O157:H7 continue. *Lean Trimmings*. (September 2 Issue) page 1.
- Nutsch, A.L., R.K. Phebus, M.J. Riemann, D.E. Schafer, J.E. Boyer, R.C. Wilson, J.D. Leising and C.L. Kastner. 1997. Evaluation of a steam pasteurization process in a commercial beef processing facility. *J. Food Protection* 60:485-492.
- Oblinger, J.L. 1988. Bacteria associated with foodborne diseases. *Food Technol.* 42:181-200.
- Osterholm, M.T. 1997. No magic bullet. *Newsweek*. (September 1 Issue) page 33.
- Phebus, R.K., A.L. Nutsch, D.E. Schaefer, R.C. Wilson, M.J. Riemann, J.D. Leising, C.L. Kastner, J.R. Wolf and R.K. Prasai. 1997. Comparison of steam pasteurization and other methods for reduction of pathogens on surfaces of freshly slaughtered beef. *J. Food Protection* 60:476:484.
- Powell, V.H. and B.P. Cain. 1987. A hot water decontamination system for beef sides. CSIRO Division Of Food Research, Cannon Hill, Queensland. *CSIRO Food Research Quarterly* 47:79-84.
- Rasmussen, M.A., W.C. Cray, T.A. Casey and S.C. Whipp. 1993. Rumen contents as a reservoir of Enterohemorrhagic *E. coli*. *FEMS Microbiol. Letters* 114:79-84.
- Reagan, J.O., G.R. Acuff, D.R. Buege, M.J. Buyck, J.S. Dickson, C.L. Kastner, J.L. Marsden, J.B. Morgan, R. Nickelson II, G.C. Smith and J.N. Sofos. 1996. Trimming and washing of beef carcasses as a method of improving the microbiological quality of meat. *J. Food Protection* 59:751-756.
- Riemann, H.P. and D.O. Cliver. 1998. *E. coli* O157:H7. pages 41-48. In: *The Veterinary Clinics Of North American Food Animal Practice: Microbial Food Borne Pathogens* (Ed. L. Tollefson). W.B. Saunders Company, Philadelphia, Pennsylvania, USA.
- Riley, L.W., R.S. Remis, S.D. Helgerson, H.B. McGee, J.G. Weil, B.R. Davis, R.J. Hebert, E.S. Olcott, L.M. Johnson, N.T. Hargrett, P.A. Blake and M.L. Cohen. 1983. Hemorrhagic colitis associated with a rare *E. coli* serotype. *New Engl. J. Med.* 308:681-685.
- Rodrique, D.C., E.E. Mast, R.D. Greene, J.P. Davis, M.A. Hutchinson, J.G. Wells, T.J. Barrett and P.M. Griffin. 1995. A university outbreak of *E. coli* O157:H7 infections associated with roast beef and an unusually benign clinical course. *J. Infect. Dis.* 172:1122-1125.

- Salvage, B. 1996. Tales from the fast-food front. *Meat Marketing & Technology*. (April Issue) pages 40-46.
- Savell, J.W. and G.C. Smith. 1998. *Laboratory Manual For Meat Science*. (Sixth Edition) pages 8-9. American Press, Boston, Massachusetts, USA.
- Scheoni, J.L. and A.C.L. Wong. 1994. Inhibition of *Campylobacter jejuni* colonization in chicks by defined CE bacteria. *Appl. Environ. Microbiol.* 60:1191-1197.
- Scheoni, J.L. and M.P. Doyle. 1992. Reduction of *Campylobacter jejuni* colonization of chicks by cecum-colonizing bacteria producing anti-*C. jejuni* metabolites. *Appl. Environ. Microbiol.* 58:664-670.
- Schnell, T.D., J.N. Sofos, V.G. Littlefield, J.B. Morgan, B.M. Gorman, R.P. Clayton and G.C. Smith. 1995. Effects of postexsanguination dehairing on the microbial load and visual cleanliness of beef carcasses. *J. Food Protection* 58:1297-1302.
- Scott, T., C. Wilson, D. Bailey, T. Klopfenstein, T. Milton, R. Moxley, D. Smith, J. Gray and L. Hungerford. 2000. Influence of diet on total and acid resistant *E. coli* and colonic pH. 2000 Nebraska Beef Report. pages 39-41. University of Nebraska, Lincoln, Nebraska, USA.
- Siragusa, G.R., J.S. Dickson and E.K. Daniels. 1993. Isolation of *Listeria* spp. from feces of feedlot cattle. *J. Food Protection* 56:102-105, 109.
- Smith, D., T. Milton, R. Moxley, J. Gray, L. Hungerford, D. Bailey, T. Scott and T. Klopfenstein. 2000. Cleaning coliform bacteria from feedlot water tanks. 2000 Nebraska Beef Report. pages 77-79. University of Nebraska, Lincoln, Nebraska, USA.
- Smith DeWaal, C. 2000. FSIS policy on *E. coli* O157:H7: Reviewing the role of pathogen testing in HACCP. pages 1-9. Center for Science in the Public Interest, Washington, DC, USA.
- Smith, G.C. 2000a. Bacteriological/Chemical Safety: Meat As A Food (2000). Presented at the Minnesota Dietetics Association Annual Conference (Minneapolis, Minnesota, USA).
- Smith, G.C. 2000b. Meat scientist urges research that could improve food safety on farms and feedlots. *Western Livestock Journal, North American Bull Guide—Section II*, pages 102-103.
- Smith, G.C. 1998. Reducing microbial contamination in the plant: Implementing HACCP and technological alternatives. *Proceedings of the 1998 World Food and Sustainable Agriculture Symposium*, University of Illinois, Urbana, Illinois, USA.
- Smith, G.C. 1996. The role of bovine practitioners in assuring the safety of beef. *American Association of Bovine Practitioners, The Bovine Proceedings*. pages 3-9.
- Smith, G.C. 1995. Food Safety. *Meat Minutes* (January Issue). Meat Science Group, Department of Animal Sciences, Colorado State University, Fort Collins, Colorado, USA.

Smith, G.C. and J.B. Morgan. 1999. Understanding today's customers and marketing to their needs; Industry trends and projections for the future; Current and future food safety issues—Staying ahead (1998-1999). Wakefern Food Corporation Seminar, Edison, New Jersey, USA (September 14-15, 1999).

Smith, G.C. and J.B. Morgan. 1997. Technology: Changing the meat you sell. Proceedings of the AMI/FMI/FDI/NGA Meat Marketing Conference (Nashville, Tennessee, USA) pages 34-52.

Smith, G.C. and J.N. Sofos. 1994. The scientist in the meat department and building a HACCP program. AMI/FMI Meat Marketing Conference (April 19; Boston, Massachusetts, USA), American Meat Institute, Arlington, Virginia, USA.

Smith, G.C., K.E. Belk and J.N. Sofos. 1999. Microbial Mapping III. Determining microbiological counts on beef cuts and trimmings during/following fabrication, with and without microbiological interventions. Colorado State University for National Cattlemen's Beef Association. Center for Red Meat Safety, Colorado State University, Fort Collins, Colorado, USA.

Smith, G.C., J.N. Sofos and K.E. Belk. 1998. Interventions From The Farm Or Feedlot To The Food Store: Minimizing Microbiological Food Safety Risks. pages 323-350. In: Passport To The Year 2000: Biotechnology In The Feed Industry (Eds. T.P. Lyons and K.A. Jacques) Nottingham University Press, Nottingham, United Kingdom.

Smith, G.C., J.N. Sofos, J.B. Morgan, J.O. Reagan, G.R. Acuff, D.R. Buege, J.S. Dickson, C.L. Kastner and R. Nickelson, II. 1995. Fecal-Material Removal and Bacterial-Count Reduction by Trimming and/or Spray-Washing of Beef External-Fat Surfaces. Proceedings of the Conference On New Technology to Improve Food Safety (April 12; Chicago IL) Food Safety and Inspection Service, U.S. Department of Agriculture, Washington, DC, USA.

Smith, G.C., J.N. Sofos, J.B. Morgan, J.O. Reagan, G.R. Acuff, D.R. Buege, J.S. Dickson, C.L. Kastner and R. Nickelson, II. 1994. Fecal-Material Removal and Bacterial-Count Reduction by Trimming and/or Spray-Washing of Beef External-Fat Surfaces. Proceedings of the Meat Industry Research Conference. pages. 1-17. American Meat Institute, Washington, DC, USA.

Sofos, J.N. and G.C. Smith. 1998. Nonacid meat decontamination technologies: Model studies and commercial applications. *Int. J. Food Microbiol.* 44(3):171-188.

Sofos, J.N. and G.C. Smith. 1997. Meat decontamination technologies: Model studies and commercial applications. Proceedings of the World Congress on Food Hygiene. page 269. The Hague, Netherlands.

Sofos, J.N. and G.C. Smith. 1995. Preliminary Studies To Initiate Development Of A Model With Multiple Hurdles For The Reduction Of The Probability Of Contamination Of Beef Carcasses With Bacterial Pathogens. A Research Project being conducted by Center For Red Meat Safety, Colorado State University, Fort Collins, Colorado, USA.

Sofos, J.N. and G.C. Smith. 1993. The new headache of the U.S. meat industry: *E. coli* O157:H7. *Meat Focus International* 2:317-325.

Sofos, J.N., S.L. Kochevar, G.R. Bellinger, D.R. Buege, D.D. Hancock, S.C. Ingham, J.B. Morgan, J.O. Reagan and G.C. Smith. 1999a. Sources and extent of microbiological contamination in seven U.S. slaughtering plants. *J. Food Prot.* 62:140-145.

Sofos, J.N., S.L. Kochevar, J.O. Reagan and G.C. Smith. 1999b. Extent of beef carcass contamination with *Escherichia coli* and probabilities of passing United States regulatory criteria. *J. Food Prot.* 62:234-238.

Sofos, J.N., S.L. Kochevar, J.O. Reagan and G.C. Smith. 1999c. Incidence of *Salmonella* on beef carcasses relating to the U.S. Meat and Poultry Inspection regulations. *J. Food Prot.* 62:467-473.

Sofos, J.N., K.E. Belk and G.C. Smith. 1998. Minimizing microbiological food safety risks: Potential for preslaughter (preharvest) interventions. A White Paper prepared for the National Cattlemen's Beef Association by Center for Red Meat Safety, Colorado State University, Fort Collins, Colorado, USA

Sofos, J.N., J.B. Morgan and G.C. Smith. 1993. Meat Safety Facts and Guide. *Meat Minutes* (September Issue). Meat Science Group, Department of Animal Sciences, Colorado State University, Fort Collins, Colorado, USA.

SMA. 2000a. Prototype provides instant *E. coli* detection. *InfoMeat*. (June 12 Issue) page 3.

SMA. 2000b. Advisory committee recommends *Listeria* testing. *Info Meat*. (May 30 Issue) page 1.

SMA. 2000c. USDA launches new food safety education campaign. *Info Meat*. (May 30 Issue) page 2.

Spring, P. 1995. Competitive exclusion of *Salmonella* using bacterial cultures and oligosaccharides. *Proceedings of the 11th Annual Symposium on Biotechnology in the Feed Industry*. pages 383-388. Nottingham University Press, Nottingham, UK.

Stern, N.J., J.S. Bailey and N.A. Cox. 1996. MCE to control *Campylobacter* in turkeys and broiler chickens. *Southern Poultry Science Society* 17:4(Abstract).

Sugarman, Carole. 1997. Building a safer burger. Critics question cattlemen's role. *The Washington Post*. (September 3 Issue) pages E1-E10.

Suther, S. 1997. The *E. coli* buck stops at your gate. *Beef Today*. (September Issue) page 3.

Van Donkersgoed, J., T. Graham and V. Gannon. 1999. The prevalence of verotoxins, *E. coli* O157:H7 and *Salmonella* in the feces and rumen of cattle at processing. *Canadian Vet. J.* 40:332-338.

- Wang, G.D., T. Zhao and M.P. Doyle. 1996. Fate of Enterohemorrhagic *E. coli* O157:H7 in bovine feces. *Appl. Environ. Microbiol.* 62:2567-2570.
- Ware, L.M., M.L. Kain, J.N. Sofos, K.E. Belk and G.C. Smith. 1999. Comparison of sponging and excising as sampling procedures for microbiological analysis of fresh beef-carcass tissue. *J. Food. Prot.* 62:1255-1259.
- Wells, J.G., L.D. Shipman, K.D. Greene, E.G. Sowers, J.H. Green, D.N. Cameron, F.P. Downes, M.L. Martin, P.M. Griffin and S.M. Ostroff. 1991. Isolation of *E. coli* serotype O157:H7 and other Shiga-like toxin-producing *E. coli* from dairy cattle. *J. Clin. Microbiol.* 29:985-989.
- Western Livestock Journal. 1999. Research reveals surprises about *E. coli* O157:H7. (December 6 Issue) page 4.
- Wheeler, S.R. 1997. *E. coli* triggers meat recall. *The Denver Post.* (August 13 Issue) page B-1.
- White, P.L., W. Schlosser, C.E. Benson, C. Maddox and A.Hogue. 1997. Environmental survey by manure drag sampling for *Salmonella enteritidis* in chicken layer houses. *J. Food Protection* 60:1189-1193.
- WHO. 1997. Prevention and control of enterohemorrhagic *Escherichia coli* (EHEC) infections. Food Safety Unit, Programme of Food Safety and Food Aid. World Health Organization, Geneva, Switzerland.
- Wilson, D. 1998. Factoid watch: Food poisonings phony figure. *Columbia Journalism Review.* (May/June Issue) pages 47-61.
- Worfel, R.C., J.N. Sofos, G.C. Smith and G.R. Schmidt. 1996. Airborne contamination in beef slaughtering-dressing plants with different layouts. *Dairy, Food and Environmental Sanitation* 16:440-443.
- Worfel, R.C., J.N. Sofos, G.C. Smith, J.B. Morgan and G.R. Schmidt. 1995. Microbial contamination of condensates formed on superstructures of wood and other materials in meat plants. *Dairy, Food and Environmental Sanitation* 15:430-434.
- Zhao, T., M.P. Doyle, J. Shere and L. Garber. 1995. Prevalence of Enterohemorrhagic *Escherichia coli* O157:H7 in a survey of dairy herds. *Appl. Environ. Microbiol.* 61:1290-1293.