

AN APPROACH TO THE CENTRALIZED
CUTTING OF FRESH RED MEATS

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ABSTRACT

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By

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This work was undertaken to develop a procedure which could be applied by the meat packing industry to enable the complete centralized preparation of consumer cuts of fresh red meats at production centers remote from retail outlets, and requiring a two to three week or longer salable life extension. The proposed procedure is believed to provide a satisfactory integrated solution to the major technical hurdles presently obstructing packer level centralized preparation of consumer cuts essentially unchanged in appearance and other characteristics from those available under present marketing practices.

The proposed procedure consists of the following components:

1. Treatment of the fresh meat with condensed phosphates (e.g., sodium tripolyphosphate) to reduce

fluid exudation (drip) and to aid in providing normal fresh red meat color during retail display.

2. Bulk vacuum packing of individual cuts for wholesale handling and distribution to protect against pigment and lipid oxidation during the period between cutting and retail display.

3. Use of either a constant 28°-30°F holding temperature throughout the cutting-to-retail sale marketing period, or, use of a pasteurizing dose (ca., 50-150 Krad) of ionizing radiation in combination with conventional refrigeration (ca., 35-42°F) to sufficiently retard microbial outgrowth and spoilage.

4. Removal of the cuts from the bulk vacuum containers to allow them to undergo normal red color (bloom) development in air before placing the cuts in the display case.

5. Display for sale in refrigerated display cases for periods up to three days.

In working out the overall procedure storage studies were conducted employing total microbial plate counts, presumptive qualitative assessment of the microflora, meat pH measurements and appearance and odor observations to evaluate various treatment and handling parameters. Also, a number of individual-cut packaging and multi-cut bulk packing tests were performed to evaluate potentially useful methods and materials, and to develop packaging and bulk packing guidelines. Finally, a number of sensory evaluation tests were executed in an attempt to assess the influence of important treatment and handling parameters on certain eating quality attributes, and on overall eating quality.

Major findings were (a) either a constant 28-30°F holding temperature or the combination of radiation plus conventional refrigeration can satisfactorily delay microbial spoilage; (b) the outgrowing microflora under the conditions of the procedure is dominated by harmless acid producing species which ultimately cause an acid type of spoilage; (c) beside reducing fluid exudation, phosphate treatment aids considerably in achieving satisfactory

color results; (d) entrapped air in contact with the meat after individually prepackaging and bulk vacuum packing must be avoided as this can lead to surface pigment oxidation; and (e) untrained taste panels indicated that, in general, irradiated, stored beefsteaks and freshly cut beefsteaks are of comparable eating quality.

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INTRODUCTION

Since the advent of the self-service meat department in retail food outlets in the United States some twenty to thirty years ago there has been a desire on the part of the meat industry to centralize the preparation of consumer cuts of fresh meats. The goal is to deliver fresh meat cuts to the retail outlets in individual packages ready to be placed into the display cases for sale. This would eliminate the cutting room now in the retail store, and with it any further participation in the manufacturing operation. This final evolutionary step in meat product distribution has already been accomplished completely with cured and processed meats, and to a large extent with poultry (e.g. frozen turkeys; "dry-pack" or "Chill Pak"* broiler operation) and red meats for the Hotel-Restaurant-Institutional (H-R-I) trade (e.g., portion controlled frozen units).

Among the compelling reasons for a shift to complete centralized preparation of consumer cuts of fresh red meats are: a) anticipated savings in building, equipment

* Holly Farms - Wilkesboro, N.C.

and labor costs; b) better control over the entire manufacturing operation; c) better distribution of meat cuts according to market preferences; d) more uniform and efficient cutting; e) better control of overhead costs; f) advantages of quantity purchases; g) a better market for carcass by-products; h) savings in shipping costs; and i) more efficient utilization of skilled meat cutters who are now in short supply. Although non-technical obstacles such as labor union resistance, deeply entrenched merchandising practices and industry inertia have contributed significantly to the fact that this goal has not yet been achieved, the principal reason is that a fully satisfactory solution to all of the technical problems inherent in the necessary post-cutting salable life extension has not yet been worked out. Several possible solutions are under study and/or development at meat industry, government and institutional laboratories.

Regardless of which approach is ultimately adopted by the industry as a technical basis for the centralized preparation of consumer cuts of fresh red meats, the principal technical problems associated with needed salable life extension must be overcome in a manner acceptable to

packers, wholesalers, retailers and consumers. These technical problems are microbial outgrowth and spoilage, fluid exudation (drip), pigment oxidation, and the possibility of an objectionable degree of lipid oxidation. It is believed that the integrated approach presented in this thesis adequately solves these problems, and will provide retail cuts for upwards of three weeks or longer after cutting having essentially the same form, appearance and other characteristics as fresh red meat cuts retailed under present marketing practices.

Work performed by the author in the development and study of this procedure is reported in this thesis; and it is suggested that this procedure is an effective approach to solving the technical problems associated with the centralized cutting of fresh red meats, particularly when consumer cuts are to be completely prepared at slaughtering locations remote from retail markets in large metropolitan areas.

REVIEW OF LITERATURE

The recent upsurge in the movement toward centralized cutting of fresh red meats is being manifested in a number of ways. Vacuum bagged primal and sub-primal wholesale cuts have recently been introduced into the marketing system chiefly by certain innovative smaller packers (Kunstler, 1969; Monfort, 1969; Anon., 1969 a). Iowa Beef Packers and Wilson & Company presently break about one-third of their beef carcasses into primal cuts which are wholesaled in vacuum bags to the H-R-I and retail markets (Meyers, 1969; Anon., 1968 a). While this system represents a large step in the direction of the ultimate goal, some cutting and all of the individual-cut packaging remain the function of the retail outlet.

Retailers have become increasingly interested in preparing primal and sub-primal cuts, and possibly even consumer sized cuts themselves at strategically located centers from which a number of retail outlets may be supplied. A few regional chains have already taken this step (Anon., 1968 b; Anderson, 1968; Cannoles, 1968; Davis,

1969). Conceivably, packer and retailer centralized cutting could be combined through a system in which packers ship vacuum-bagged primals and sub-primals to retail chain distribution centers for final fabrication into packaged consumer cuts which are delivered to local retail outlets.

Although the primal and sub-primal partial solution to centralized cutting appears to be gaining in popularity it has also met with some disfavor. One report cites considerable resistance among retailers with regard to costs and flexibility, although it concludes that packer primal operations have resulted in real productivity gains from a total industry viewpoint (Yankelovich, 1968, p. 56). The vice chairman of one large regional chain cites cost and profit disadvantages which have not as yet been solved. His view is that it is advantageous to break beef carcasses into vacuum bagged primals at company owned divisional meat warehouses rather than purchase them from packers (Davis, 1969).

There are some differences of opinion among retailer and packer executives as to which of the two should carry out the centralized preparation of consumer cuts of red meats and which method or methods to use. While centralized cutting and prepackaging at the retailer level would

be less complex with respect to technical complications, labor union resistance and changes in merchandising practices, it is generally conceded that it would be best to do it at the packer level if the means were available (Anon., 1966; Brody, 1968; Cannoles, 1968; Yankelovich, 1968, pp. 48-49, 115-116). Retailers strongly desire that centrally prepared meat be essentially unchanged from meat as presently sold, and they are generally quite negative toward frozen consumer cuts of red meats. Packers, on the other hand, generally favor freezing, especially cryogenic freezing, as the ultimate method for achieving packer level centralized cutting and prepackaging for the retail as well as the H-R-I trade (Leach, 1966, p. 30; Howell, 1969; Meyers, 1969, p. 136; Yankelovich, 1968, pp. 21, 24, 59-63, 73, 80-86, 109).

An earlier attempt at marketing frozen red meat cuts failed chiefly because of consumer resistance to the form and cost. The view is held by some that consumer acceptance of frozen cuts still remains questionable (Anon., 1966; Cheney, 1969; Yankelovich, 1968, pp. 21, 62-63, 80-86). Those who presently favor freezing feel that previous failures with frozen consumer cuts of red meats were due to unfortunate timing and poor planning, and they are

optimistic that this time the marketing of frozen cuts will be properly approached and carried out. They express the view that the consumer presently buys fresh meat only to freeze much of it at home, and therefore they merely need to convince the consumer that a superior frozen product will be provided if the packer does the freezing. Swift and Company and Needham Packing Co. and other packers, and even a few retailers are presently testing the freezing approach with caution and guarded optimism (Anon., 1968 a; Anon., 1969 b, c, d, e, f, g; Meyers, 1969).

Besides freezing, a few other approaches to salable life extension are in various stages of study and development. These are: 1) improved sanitation and refrigeration. This is felt to be capable of providing salable life extension sufficient only for regional supermarket chain centralized cutting (Bernholdt, 1967; Yankelovich, 1968, pp. 68, 118-121); 2) controlled atmosphere or controlled environment. This imprecise concept usually refers to reduced oxygen tension achieved by means of a vacuum or by substitution of one or more other gases such as nitrogen and carbon dioxide, the latter having bacteriostatic properties. This approach is frequently discussed in conjunction

with containerization and total environmental control (temperature, relative humidity and atmosphere). Swift and Company is conducting perhaps the most thorough exploration of this concept at the Fort Worth, Texas pilot plant centralized meat cutting facility where cryogenic freezing investigations are being carried out along with market testing and economic studies (Bernholdt, 1967; Anon., 1968 b; Little, 1968, p. 39; Yankelovich, 1968, pp. 49, 92-95); 3) radiation pasteurization, a subject of this thesis, and 4) individual vacuum packaging. This approach of vacuum packaging consumer size units is widely used for processed meat items and it is used to some extent with ground beef. While it has its advocates for consumer cuts of fresh meats, there is essentially no interest in this approach within the meat industry largely because of packaging costs and the unfamiliar purple meat color of reduced myoglobin (Yankelovich, 1968, pp. 87-91).

It is certain that one or more of the foregoing approaches will be employed if and when the industry moves to complete centralized preparation of consumer cuts of fresh red meats. As pointed out in the introduction centralized preparation of poultry has attained noteworthy

success with the use of freezing (e.g. turkey), and the "dry-pack" "Chill Pak" broiler operation. Complete centralized preparation of fresh red meat cuts is well established in Europe; however this is considered a "showcase" operation in a completely different meat economy from that of North America where the small amount of centralized preparation of red meats is almost exclusively for the H-R-I trade (O.E.C.D., 1964; Anon., 1968b; Little, 1968).

When discussing centralized cutting one important consideration that should not be overlooked is the possibility of future large scale air transport of fresh red meats from remote slaughter-cutting locations to large metropolitan areas several hundred or more miles distant. The tremendous volume of fresh meat that is shipped interstate and unfavorable economics have been cited in the past as deterrents to air shipment. Presently air transport of fresh meat is employed to a very minor extent in special situations, but future widespread usage in tandem with packer level centralized cutting and containerization is forecast. Of great importance is the fact that air-transport would reduce salable life extension requirements by up to several days compared with surface transport time when long

distance shipping is involved (Walrath and Konicek, 1967; Yaeger, 1968).

The remainder of this literature review is addressed to technical aspects and complications inherent in approaching centralized cutting with the aim of (a) providing the consumer with fresh red meat cuts essentially unchanged in appearance and other characteristics from those available under present marketing practices, and (b) providing a two to three week or more salable life extension beyond the usual three day post-cutting life.

Color change is frequently cited as the principal technical obstacle to packer-level centralized cutting (Anon., 1966; Lawrie, 1966, p. 279; Yankelovich, 1968, pp. 80-82, 87, 112, 116). Consumer preference studies indicate that the color of the lean is the most important factor influencing the purchase of consumer cuts of fresh red meats (Rickansrud and Henrickson, 1967; Bailey, 1968; Little, 1968, p. 56). Although the sarcoplasmic protein, myoglobin, is the principal red meat pigment a significant color role has been attributed to the oxygen carrying blood pigment hemoglobin as well (Fox, 1966; Solberg, 1968). Both heme proteins have a similar high proclivity toward auto-oxidation, particularly at low oxygen partial pressure.

To the consumer, extensive pigment oxidation is recognized as brown surface color, and perhaps undesirable appearance. Naumann (1968) and others have demonstrated that pigment oxidation can be accelerated by, but will take place in the absence of bacterial outgrowth, and that a holding temperature of 30°F markedly delays browning. The latter effect is attributed to a slowdown of bacterial growth and oxidation promoting processes at the low temperature. There is considerable disagreement in the literature as to the effect of display case lighting and other light upon red meat color (Solberg, 1969). When an effect is reported, assuming it is real, it is not always clear whether the effect is due to the light itself, or to heat generated by the light source, or to both.

The oxidized or ferric heme form of both pigments (metmyoglobin and methemoglobin) can undergo an enzyme mediated reduction in vivo and in situ back to the desirable oxygen-binding ferrous state. The rate of metmyoglobin reduction in vacuum packaged red meat cuts is higher as the refrigerated holding temperature is increased due to accelerated enzyme activity in the meat tissue (Solberg, 1968). It is reported that metmyoglobin reduction proceeds only in absence of oxygen and that the rate and extent of

reduction varies greatly between meat samples. The variability is attributed to a wide variation in the supply of substrates and co-factors for the enzymes which mediate the transfer of electrons to the oxidized pigment in the absence of oxygen. A number of factors including the 'freshness' and acidity of the meat cause the variability in reducing potential (Saleh, 1967; Fox, 1968). Greene (1966) observed that vacuum packaged beef undergoes metmyoglobin reduction only when there is sufficient enzymatic reducing capacity present. Also, pasteurizing doses of ionizing radiation (below one Mrad) do not diminish reducing capacity, and antioxidants substantially protect pigment as well as lipid from oxidation in ground beef.

McLoughlin (1969) points to basic relationships between the live meat animal and post-mortem glycolysis and the color, water holding capacity and texture of fresh meat. His view is that it is feasible to influence and, to an extent, control these properties by controlling post-mortem glycolysis through suitable methods of ante-mortem handling, slaughtering and chilling of the carcass. He feels that this is likely to assume greater importance in the future as centralized cutting increases. Essentially the same views were expressed by Scott

(1968). In a similar vein Patton (1969) discusses the role of ante mortem treatment and methods of slaughtering and chilling in favorably influencing the quality of fresh and cured pork. He cites red meat color as being the most important quality characteristic to the housewife at the time of purchase. According to Enfield (1968) meat color is a moderately heritable trait in most populations and could likely be improved genetically through selective breeding, and perhaps by working at the gene level.

The great shift to prepackaged red meat cuts during the 1940's which made possible the self-service meat departments awaited the development of a meat wrapping material possessing adequate gas transmissibility and satisfactory moisture barrier properties. With a shift to complete centralized preparation involving an in-package salable life extension of upwards of three weeks or more, packaging takes on considerable new importance, especially if normal red meat color is to be provided in the display case. The details of a large scale centralized prepackaging operation for fresh red meats will have to be worked out on both the individual cut level and the multi-cut bulk container level (Little, 1968, pp. 31-32). In view of the accelerated rate of oxidation of meat pigment at low partial pressure of

oxygen, Fox (1966) emphasizes the need for highly oxygen-permeable red meat wrapping films. For a large scale centralized operation a film should be suitable for use with high speed automatic packaging equipment, and perhaps may need to be more rugged and durable than is necessary for a supermarket back-room meat wrapping operation (Little, 1968, pp. 29-32). This may be in conflict with high gas transmissibility (e.g., solution diffusion mechanism) which is inversely related to film thickness. There is always the possibility of a radical departure from conventional film-tray fresh meat packaging; for example, opaque packaging such as with "Chub" packaged ground beef, or one of the spray or dip coatings under development. Edible coatings still require an outside package, however (Little, 1968, pp. 33-35).

Bulk, multi-cut packing will be a critical part of a centralized operation, particularly with regard to the need to avoid mechanical pressure and related stresses on the individual cuts (Little, 1968, p. 64). Stresses such as can be caused by improper packaging and bulk packing and handling could aggravate the fluid exudation problem. Besides being a factor in declared net weight, excessive drip accumulation results in unsightly, sometimes unsalable

packages. Fluid exudation has been a very difficult problem to cope with, and in some cases so discouraging that packer centralized prepackaging has been abandoned due to the cost of a bulk carton which would not induce drip loss (Leach, 1966, pp. 42-43). Several workers have reported the "bloom extending" effect of holding red meat cuts under hyperbaric oxygen. Other workers cite anaerobic packaging as the best means of promoting metmyoglobin reduction and/or preventing pigment oxidation (Solberg, 1968). Since this work is premised on the objective of providing conventionally appearing consumer cuts, any manipulation of the atmosphere in contact with the meat during holding and transit must make use of the bulk containers, which may be rigid, semi-rigid or flexible or a combination of these. This places an extra demand upon the individual-cut packages since the contents must be in equilibrium with the imposed outside-the-package atmosphere, and a rapid and complete response may be required (e.g., such as with evacuating or flushing the bulk container, and subsequently exposing the packages to the atmosphere to generate bloom).

While holding consumer cuts of red meats under a high partial pressure of oxygen would extend the bloom life, eventually the presence of oxygen would likely lead to

gradual pigment oxidation during a two to three week period. Further, the oxygen would be expected to give rise to accelerated lipid oxidation, more so if ionizing radiation were to be employed (Lea, et.al., 1960; Lawrie, 1966, pp. 186-190; Little, 1968, p. 55). Based upon her results, Greene (1966) recommends an antioxidant treatment and/or anaerobic packaging to protect meat lipid from the damaging effects of aerobically applied irradiation and extended aerobic holding, in addition to protecting against pigment oxidation and promoting metmyoglobin reduction. Once re-exposed to oxygen, however, oxidative processes affecting lipid and pigment would commence (Belo, 1968). It has been demonstrated by several workers that anaerobically held red meat cuts become bright red upon re-exposure to the atmosphere as long as the pigment is in the reduced (purple) form while in vacuum (Ordal, 1962). Under a centralized prepackaging system involving oxygen permeable film for the individual cut packages and anaerobic bulk packing of the individual packages, it would be essential to assure that the individual packages are such that the pigment at the cut surfaces of the meat readily oxygenates upon removal of the packages from the bulk containers at the retail outlets.

Aging and tenderization of fresh meat is an incompletely understood, complex process, partially enzymatic and partially non-enzymatic, involving connective tissue, myofibrillar and sarcoplasmic proteins as well as other muscle tissue constituents. The process extends well beyond rigor, proceeds faster as temperature is increased, and has a considerable effect upon the texture, flavor and general eating quality of meat. It is much more critical with beef than with pork and lamb, but some aging is desirable with all meat including poultry (Briskey, et.al., 1966; Lawrie, 1966; Motoc and Bann, 1968; Scott, 1968; Kahn, 1969; Lawrie, 1969; McLoughlin, 1969; Patton, 1969). Beef is customarily aged or conditioned by hanging the carcass in a cooler for anywhere from a few days up to two weeks or longer. Considerable aging is also done 'on the rail' as sides, etc. move from production to consumption areas. Accelerated aging (e.g., holding at higher than usual temperature, ante-mortem and post-mortem enzyme injection) is also widely practiced. Vacuum bagged primals and sub-primals are usually cut and bagged within 48 hours after slaughter, and they undergo aging in the vacuum bags during holding and transit. This has the major added advantage of essentially eliminating shrinkage loss (Davis, 1969; Kunstler, 1969).

Scott (1968) reports that if rigor is allowed to proceed to completion before chilling, the meat is more tender and flavorful than meat from a carcass rapidly chilled immediately after slaughter. Bouton (1968) and others express the view that if beef is boned out pre-rigor the meat is much less tender than if rigor were first allowed to proceed to completion. Bouton reports that various muscles of the hindquarter, held in vacuum bags for two to three weeks at 35-36°F, show a very significant increase in tenderness which varies somewhat among muscles. He recommends fourteen to sixteen days at 32-36°F, or seven to nine days at 41-45°F for optimum aging of small and large cuts of vacuum bagged beef, starting immediately after normal chilling. Thus it is rather well established that primal and sub-primal cuts and intact muscles will undergo a normal aging and tenderization under suitable conditions. The need, then, is to assure that centrally prepackaged consumer cuts will be satisfactorily aged and tenderized before and/or after cutting. With the trend toward the addition of commercial tenderizers, flavorings and flavor enhancers, the natural process could conceivably be relegated to a role of increasingly minor importance.

In order to provide good quality conventional fresh red meat cuts in the retail meat display cases two to three weeks or more after cutting microbial growth must be slowed or eliminated, pigment and lipid oxidation must be kept below objectionable levels and excessive fluid exudation in the individual cut packages must be avoided (Urbain, 1965, 1966). The effectiveness of treatment with a polyphosphate solution in improving water holding capacity and reducing drip loss from fresh meat cuts has been demonstrated (Belo, 1968; Urbain, et.al., 1968, 1969). As previously indicated pigment and lipid oxidation is perhaps best avoided through anaerobic conditions during the period between centralized preparation and retail display. On the microbial side control or elimination of psychrophilic fresh meat spoilage bacteria, chiefly the Pseudomonas and related genera, is essential to achieving the above objective.

Holding fresh poultry and red meat cuts at just above the freezing point can delay the onset of spoilage two to three weeks or longer (Dawson and Stadelman, 1960; Elliott and Michener, 1965). Since gram positive fresh meat bacteria are quite sensitive to tetracycline antibiotics and the gram negatives are highly sensitive to

ionizing radiation, it has been proposed to combine the two in order to increase the refrigerated storage life of fresh meats (Niven and Chesbro, 1957). Since regulatory agencies presently rule out antibiotics as preservatives for fresh meats this would tend to leave constant holding just above the freezing point and ionizing radiation (assuming eventual approval by F.D.A.) plus conventional refrigeration as the two major contending approaches to salable life extension. The constant low temperature approach (combined with good sanitation) is presently being successfully employed with chicken ("dry-pack" or "Chill Pak"). In addition to greatly slowing microbial growth, a 28-30°F holding and distribution temperature would markedly retard fluid exudation and all chemical processes as well. Possible disadvantages might be costs and difficulty in maintaining the required low temperature throughout the red meat distribution and marketing chain.

A pasteurizing dose (ca. 50-500 Krad) of ionizing radiation has long been recognized as an effective means of delaying microbial spoilage of fresh red meats through the virtual elimination of fast growing psychophilic aerobes and a marked reduction in the numbers of the more radiation resistant fresh meat microorganisms such as the

lactobacilli, and micrococci (Wolin, et.al., 1957; Thornley, 1962; Niven, 1963; Thornley, 1963). It has been proposed to utilize the microbicidal effect of ionizing radiation in the centralized preparation of consumer cuts of fresh red meats and poultry (Brownell, et.al., 1954; Urbain, 1965, 1966). Opinions differ somewhat as to the needed radiation dose. This would depend upon a number of factors including (a) the types and amounts of the microorganisms on the meat; (b) the length of the desired salable life extension; (c) the temperature(s) at which the meat is held; (d) the nature of the packaging (e.g., aerobic or anaerobic); and (e) the kind of meat and its state (e.g., beef, pork or lamb; organ or muscle meat; ground or intact). It is of course desirable to employ no higher dose than is necessary to achieve the objective.

While a pasteurizing dose of ionizing radiation is highly effective against the usual fresh meat spoilage bacteria, side effects can become objectionable if precautions are not taken. Depending upon the dose and temperature of the meat, fluid exudation can be induced during the radiation treatment (Rhodes, et.al., 1967). In his review, Lawrie refers to reports that a trained taste panel can detect flavor changes in fresh beef after 50 Krad, and symptoms of

accelerated fat oxidation between 25 and 100 Krad. Damage to proteins and amino acids has been shown to be insignificant even at sterilizing dose levels (Lawrie, 1968). Holding fresh meat anaerobically during and after irradiation essentially eliminates fat oxidation and lessens the effect of irradiation on flavor (Rhodes and Shepherd, 1966; Rhodes, et.al., 1967). Anaerobic packaging of refrigerated radiation pasteurized fresh meats would be expected to inhibit surviving strict aerobes leaving the way open for outgrowth of the more radioresistant facultatively anaerobic, mainly gram positive bacteria, notably the acid producing species (Pierson and Ordal, 1969). At conventional refrigeration temperatures this would eventually lead to a sour type of spoilage (Ingram, 1962; Sharpe, 1962; Thornley, 1963; Lawrie, 1966, p. 262). The combination of refrigerator temperatures (e.g., 42°F or lower) and sufficient harmless bacterial radiation survivors to dominate the outgrowing flora, eventually causing recognizable spoilage would likely be an adequate safeguard against food poisoning or pathogenic species should any be present (Ingram and Roberts, 1966).

From the nutritional viewpoint it is generally agreed that thiamine is the most important nutritional loss

from irradiating meat (Lawrie, 1968). Thiamine is rather easily destroyed by both heat and radiation, and the degree of destruction is a function of the amount of thermal or ionizing energy applied. In meat irradiation thiamine destruction is of concern chiefly with high dose sterilization of pork in the unfrozen state. Only modest thiamine destruction occurs when fresh meats are irradiated to a pasteurizing dose, for example 250 Krad or less (Groninger and Tappel, 1957; Wilson, 1959). Thus it is perhaps safe to conclude that from the microbiological and nutritional viewpoints the combination of radiation pasteurization and conventional refrigeration poses no health hazard.

MATERIALS AND METHODS

The work described herein is divided into the three following sections: 1) storage studies comparing various levels of irradiation, phosphate treatment vs. no treatment, storage in air vs. storage under vacuum vs. storage under hyperbaric oxygen, and various storage temperatures as to the effect on the total microbial count, the nature of the dominant outgrowing flora and the type of spoilage produced, meat color and overall appearance, and, estimated salable life extension; 2) packaging tests in which various potentially useful individual-cut packaging and multi-cut bulk packing materials and methods were evaluated with particular regard to the color and appearance of the cuts during simulated retail display at the end of three weeks refrigerated holding; 3) sensory evaluation tests designed to determine the effect of selected treatment and handling parameters upon specific eating quality attributes as well as on overall eating quality. In all cases the meat used was beef from the top, bottom and knuckle of rounds obtained from the Michigan State University central food store. USDA

Choice Grade was used for sensory testing only, all other work being done with USDA Commercial Grade beef. Irradiation was accomplished with a ^{60}Co Cobalt research gamma irradiator housed in the Food Science Building.

The storage studies were set up and conducted in the following manner. Tops, bottoms, or knuckles of beef rounds were separated into component muscles which were trimmed of loose fat and either cut into small chunks for grinding or cut into steaks. Phosphate treated cuts were immersed in a chilled water solution of 10% food grade sodium tri-polyphosphate for 45 seconds and then allowed to drain for several minutes on a wire screen. Samples to be irradiated and/or stored in vacuum were individually vacuum packaged in gas-water vapor impermeable flexible transparent pouches. Samples to be irradiated and stored in air were individually sealed inside transparent flexible pouches made from fresh meat wrapping films having high gas and low moisture transmissibility. Samples to be stored under hyperbaric oxygen were packaged in the same manner and, after irradiation, were loosely packed in modified pressure-canners which were sealed, evacuated, and backfilled with two atmospheres (30psia) of pure oxygen. Samples were stored either in a

conventional 38°F laboratory refrigerator or in special constant temperature boxes controllable to $\pm 1/2^\circ\text{F}$.

Periodically samples were withdrawn from storage and evaluated as follows: Color, odor and general appearance of each sample was observed upon opening each pouch. Vacuum held samples were additionally observed for rate and extent of blooming upon re-exposure to the atmosphere. A 30 to 40 gram portion of each sample was then aseptically removed and placed in a separate tared, sterile stainless steel blender jar. After mincing for ten seconds sufficient sterile distilled water was added to each blender jar to give an initial 1:10 dilution. After blending for three minutes the samples were immediately pour-plated in sterile plastic petri dishes. Decimal dilutions were made by pipetting 1 ml. of the blended 1:10 dilution into 99 ml. of sterile half-strength nutrient broth (0.15% beef extract, 0.25% peptone) in milk dilution bottles from which further dilutions were made in the same manner. Duplicate plates were prepared by pipetting either 0.1 ml. or 1.0 ml. from the thoroughly shaken dilution bottles to the dishes, and pouring over and mixing with sterile plate count agar (Difco) which was tempered at 112°F. After solidifying, the plates were inverted and incubated at room temperature

(70-75°F). Incubating duplicate sets of plates at 86°F was discontinued after it became obvious that counts on these were no different than on the plates held at room temperature. After three days of incubation the number of colonies on countable plates were counted using a Quebec dark field colony counter. The counts were recorded as total aerobic plate counts per gram of sample. Colony appearance and morphology was noted before picking representative colonies for gram staining, and microscopic observation for cell type and staining reaction under oil immersion. Occasionally samples were surface scraped, the scrapings shaken in a dilution blank from which they were streaked on tripticase soy agar (BBL). Representative colony types from the streak plates were also picked, smeared onto micro-slides, gram stained and observed under oil immersion for cell morphology and staining reaction. Further, representative isolates from the pour- and streak plates were tested for acid production in litmus milk when acid-producing species were suspected.

These presumptive tests plus pH of the blended 1:10 sample dilutions gave considerable insight as to the nature of the dominant outgrowing flora under each set of conditions without having to attempt rigorous positive identification

of the flora to the specie level. The pH of the blended 1:10 dilution of each sample evaluated at each withdrawal time was taken immediately after pipetting the required amount for plating and/or further dilution so as not to allow time for significant outgrowth to occur in the blended sample. In most cases vacuum packaged samples were evaluated both at the time of their withdrawal from vacuum storage and after an additional 3 or 4 days of storage in air at the same temperature. The additional storage in air was intended to simulate a real commercial situation in which anaerobic holding and distribution would be followed by a 1 to 4 day period of retail display (and post-sale holding) in air prior to consumption.

The packaging tests: Three highly oxygen permeable fresh meat wrapping films were used, both with and without polystyrene meat trays, for individual cut packaging. The films are (1) the widely used nitrocellulose-coated fresh meat cellophane, (2) one of the new plasticized stretch polyvinylchloride (PVC) films which are presently dominating retail fresh meat wrapping and (3) a new ethylene-vinyl acetate copolymer heat shrinkable fresh meat wrap film. Large gas impermeable transparent bags made from a saran-mylar-polyethylene three layer flexible film, and rigid

multi-quart modified pressure canners were used as bulk vacuum containers. Both phosphated and nonphosphated, irradiated and nonirradiated samples were used with each packaging variable except where indicated otherwise. Evaluation was by visual observation for noticeable differences in color and overall appearance of the samples, and the degree of drip accumulation in the individual packages and in the bulk containers as a result of the various packaging and bulk packing methods. Also, where appropriate, the odor of the meat samples was noted. The following packaging and bulk packing investigations were conducted:

A. There are two basic approaches to the bulk vacuum packing of consumer cuts of fresh red meats; loosely bulk vacuum packing individually prepackaged cuts, and tightly bulk vacuum packing bare (unwrapped) cuts. The first can be considered the method of choice since it incorporates centralized cutting and prepackaging, while the second is only a partial solution to complete centralized preparation since it provides for centralized cutting only, leaving the individual-cut packaging to the retailer. The two basic approaches were compared in several tests carried out as follows: Beefsteaks to be individually prepackaged were placed in polystyrene trays and overwrapped with one

of the three oxygen-permeable fresh meat films which were heat tacked under the trays. These were loosely packed and vacuum sealed in both rigid modified pressure canners and large gas impermeable transparent flexible bags. Other steaks from the same round muscles were tightly packed, without pre-wrapping, into other rigid and flexible bulk vacuum containers (the rigid containers hold about 25 lbs., and the flexible bags about 15 lbs. of tightly packed meat). After irradiation (100 Krad) and/or three weeks vacuum storage at 38°F the bulk vacuum containers were opened and, after noting initial color and odor, the packaged and non-packaged cuts were laid out in the air to bloom. Rate and extent of bloom regeneration was noted. Individual-cut packages, and the bulk containers were observed for drip accumulation. Upon removal from the bulk vacuum containers some prepackaged steaks were unpackaged, and some bare, unpackaged steaks were then packaged as the prepackaged steaks had been, before being set out in the air to bloom. Also, some prepackaged steaks were both unwrapped and then immediately rewrapped in new film of the same type. This was done to determine the effect, if any, of the presence of a packaging film, and the time of individually packaging upon color and bloom regeneration.

B. The three gas-permeable fresh meat wrapping films were compared with one another, and with no film at all with respect to beef color after three weeks of refrigerated bulk holding under vacuum, and during three additional days refrigerated storage in air. All beef steaks were from the same top and bottom round, and all were placed in individual polystyrene trays. The steaks were randomly divided into four equal groups, three of which were wrapped, each with one of the three films. The fourth group remained not wrapped. Four rigid bulk containers were loosely packed, each with the four packaging variables, after which they were sealed, evacuated, irradiated and stored. Evaluation of samples was done as described in (A).

C. The same four individual cut packaging variables compared in (B) were used in this test. This time two of the bulk vacuum containers were alternately evacuated and nitrogen flushed five times before drawing the final vacuum while the other two containers were merely evacuated. Irradiation, storage and sample evaluation were conducted as in (B). Of particular interest in this test was whether or not the multiple evacuation and flushing improved color results over simple evacuation which frequently resulted in some discoloration in individually prepackaged bulk vacuum packed cuts.

D. This group of three tests was designed to compare color results yielded by prepackaging conventionally in a tray with film over-wrap (substantial free air space within each package), and by packaging individual cuts in "skin-tight" film pouches (no free air space within each package), and from merely placing in trays with no film overwrap. It was felt that this comparison would shed some light on whether or not trapped air in bulk vacuum packed conventionally prepackaged cut packages was the cause of pigment oxidation with cuts so packaged and stored. Because they can be easily made into pouches, fresh meat cellophane and the ethylene-vinyl acetate copolymer films were used for the conventional and the "skin-tight" packaging. Steaks from the same round of beef were used. After packaging, the steaks were loosely bulk vacuum packed into rigid containers which were handled and stored as usual. The variables were two films, and air space vs. no air space within the individual packages. Steaks were evaluated for color immediately upon removal from refrigerated vacuum storage, and during post-vacuum bloom regeneration in air. As was done in (A), some prepackaged steaks were both unwrapped, and unwrapped and immediately rewrapped with new film of the same kind at the end of vacuum storage.

Also, some nonwrapped steaks were wrapped at this time, before blooming in air could proceed to any noticeable degree. Again, this was done to determine what, if any, effect the presence of a film, and the time of wrapping has upon bloom regeneration.

E. The effect, if any, upon color of two widely used types of meat wrap film coatings, a common plasticizer and a common anti-fogging agent, were tested under the proposed storage and handling conditions because such film additives can potentially migrate into the meat and interact with meat constituents. It was believed worthwhile to check this possibility although it is unlikely that there is sufficient leaching, if indeed there is any significant leaching at all, to cause so gross an effect as noticeable color change. To check the antifogging agent two ethylene-vinyl acetate films, identical except that one does not have an antifogging agent, were made into pouches in which steaks from the same bottom round of beef were sealed to give a "skin tight" fit. Some of each were irradiated to 0 and 100 Krad before storing in air at 38°F, and the rest were sealed in a bulk vacuum container which was irradiated and stored for three weeks at 38°F at which

time the samples were inspected and then allowed to bloom in air. Initial color, and rate and extent of blooming was noted.

To check the plasticizer beefsteaks were packaged in the following three ways. All steaks were cut to exactly fit petri dish bottoms with about one eighth inch of steak above the top rim of the dishes. One third of the dishes of steaks was loosely packed, not wrapped, in a modified pressure canner. Another third was placed in the same bulk container after covering the top of each steak first with two thicknesses of plasticized PVC film and then with a plate glass disc, each unit tightly wrapped with masking tape so that the film and glass disc would press down on the meat. This insured anaerobic conditions and a tight, uniform contact between film and meat surface. The last third of the dishes of steaks was handled in the same manner except that the PVC film was excluded and the meat was in direct contact with the dichromate-cleaned glass discs. The bulk container was sealed, evacuated, irradiated (100 Krad) and stored for three weeks at 38°F, after which the container was opened and the contents inspected visually for color differences, and differences in the rate and extent of bloom regeneration.

Sensory evaluation tests employed untrained panelists to judge cooked samples for color, odor, flavor, texture, juiciness, and overall quality on a 1-9 acceptability scale. For each test all of the Choice Grade beefsteaks were cooked simultaneously on the same large rack in a forced air oven operating at 325°F. Each steak was uniformly surrounded by the hot air, and the cookout juices dripped into a shallow pan below the rack. Each sample served to the panelists was cut to about 1-1/2 inches square and the panelists received all samples (three to four per test) together on one large paper plate. All samples were at approximately the same "medium doneness." No embellishments of any kind (e.g., salt, etc.) were put on or served with the samples. The method of conducting the tests was such that differences between samples were accentuated and masking of differences was avoided. Thus the samples served in the tests were being evaluated under the most revealing conditions. Controls were either freshly cut steaks or, in one test, untreated steaks cut from the same piece of meat as the treated steaks. Both top-round and eye-of-the-round (semitendinosus) steaks were used. Care was taken to insure that each panelist received a set of samples all of which were cut from the same muscle

because a single muscle could not provide enough samples for all panelists in a given test. The "overall quality" scores of each test were subjected to analysis of variance and multiple range testing to determine significance of difference in overall quality between variables at the 95% confidence level, as is done in preference/acceptance testing with the "hedonic" 1 to 9 rating scale. The following tests were conducted:

(1) Effect of phosphate and irradiation, separately and in combination, on eating quality of beefsteak stored for twenty-one days in vacuum at 29°F followed by an additional three days in air at 29°F. The low storage temperature made it possible to use phosphated and nonphosphated nonirradiated steaks taken from the same muscles as were the phosphated and nonphosphated irradiated (100 Krad) steaks. Phosphate treatment was carried out as previously described. Steaks were immersed for 45 seconds in a 10% tripolyphosphate solution and allowed to drain several minutes before packaging. All steaks used in the three tests comprising this set were individually vacuum packaged in gas impermeable flexible pouches from which they were transferred to trays with oxygen permeable film overwrap for the final three days of storage.

(2) Effect of irradiation (100 Krad) with and without prior phosphate treatment on eating quality of beefsteaks stored for twenty-one days in vacuum at 40°F plus an additional two days in an oxygen permeable wrap at 40°F. This test was identical to (1) except that 40°F storage temperature was used, and, as a result, the control steaks were cut from a fresh beef muscle the day before each of the four replicate tests was conducted.

(3) The effect of treating with salt plus phosphate, as compared to treatment with phosphate only and to no treatment on the eating quality of irradiated (100 Krad) beefsteaks. Since a tripolyphosphate-salt synergism with respect to improvement of tissue water holding capacity has been reported by several investigators it was thought to be of interest to determine the effect, if any, of this combination on flavor in particular. Four tests were conducted comparing the foregoing variables. Nonphosphated, nonirradiated freshly cut controls were employed in two of the four tests. Salt plus phosphate treated steaks were immersed in a water solution of 10% sodium tripolyphosphate and 2-1/2% culinary grade sodium chloride for 45 seconds and drained for several minutes before packaging. Steaks treated with 10% tripolyphosphate only were immersed and

drained as well. Three choice grade beef top rounds were used and one-third of the steaks from each of the three rounds was treated in each of the three ways. The steaks for each variable were tightly bulk vacuum packed, not wrapped, in separate large impermeable flexible bulk bags. After irradiation to 100 Krad all bags were stored for twenty-one days at 38°F in vacuum plus two additional days in air at 38°F before cooking. Freshly cut control steaks were used in only two of the four tests.

RESULTS AND DISCUSSION

Storage Studies

In the first study packaged ground beef was subjected to seven radiation doses and three storage atmospheres. The top, bottom and knuckle from a Commercial Grade round of beef were trimmed of surface fat and cut into chunks which were first coarsely ground and thoroughly mixed, and then put through a fine grind and thoroughly mixed again to give a homogeneous batch. The ground beef was then sealed in fresh meat cellophane pouches, 175 grams per pouch. One-third of the pouches of meat was vacuum sealed in gas-impermeable film pouches. The two packaging variables were each divided into seven equal lots. One lot of each remained nonirradiated and the other lots were treated with 50, 100, 150, 200, 300 and 500 Kilorads of gamma radiation. All of the vacuum packaged samples and half of the aerobically (fresh meat cellophane) packaged samples were stored in a 38°F refrigerator to await evaluation. The other half of the aerobically packaged samples was placed in a large modified pressure

canner which was sealed, evacuated, and immediately back-filled with two atmospheres (30 psia) of pure oxygen in which the samples were stored at 38°F. Evaluation was carried out as described under "Materials and Methods," and the data and observations are summarized in Table 1.

It was observed that vacuum-packaged samples underwent surface browning immediately upon vacuum sealing in the impermeable pouches. This was not surprising since the pigment is more labile to oxidation in ground beef than it is in the intact tissue. It was also observed that during irradiation at all of the doses the brown surface color reverted to purplish, which is consistent with the fact that irradiation of biological material under vacuum generates reducing conditions which can result in reduction of oxidized pigment and lipid peroxides, etc. The initial (one day) plate count data indicate approximately the same degree of total count reduction during irradiation in vacuum as occurred during irradiation in air. Oxygen pressure storage had a temporary protective effect against discoloration but fell short of providing the desired two to three week salable life extension color-wise. Moreover, an intense stale tallowy odor was observed at 12 days, and at 23 days when the samples under oxygen

TABLE 1.--Total plate count, pH, color, odor and appearance of irradiated and nonirradiated ground beef, stored in air, under oxygen and under vacuum at 38 F.

Variable	S T O R A G E T I M E (days)					
	1			9		
	Total count	pH	Observations	Total count	pH	Observations
A0	4×10^5	5.60	Bright red	4.2×10^8	6.20	Discolored, spoiled odor & slime
A50	5×10^3	5.72	Sl. dark red	2.6×10^7	5.51	Discolored, slight off-odor
A100	3×10^3	5.60	Sl. dark red	1.3×10^6	5.55	" "
A150	1×10^3	5.63	Purplish red	1×10^4	5.52	" "
A200	4×10^2	5.62	" "	$< 10^3$	5.63	" "
A300	$< 10^2$	5.65	" "	$< 10^3$	5.67	Discolored, moderate off-odor
A500	$< 10^2$	5.65	" "	$< 10^3$	5.68	" "
Days 12						
Variable	Total count	pH	Observations			
00	6.3×10^8	5.50	Brown-red, stale musty odor			
050	7×10^7	5.52	" "	"	"	"
0100	2.2×10^6	5.52	" "	"	"	"
0150	1.6×10^4	5.57	" "	"	"	"
0200	4.6×10^3	5.55	" "	"	"	"
0300	$< 10^2$	5.58	" "	"	"	"
0500	$< 10^2$	5.60	" "	"	"	"

Note: All 0 samples were severely discolored and oxidized at 23 days and were discarded.

All A samples became severely desiccated during the third week of storage and were discarded.

Initial counts for variables stored under oxygen are identical to those of the corresponding variables stored in air.

Code: A = Stored in Air
 0 = Stored under two atmospheres of pure oxygen
 V = Stored under vacuum
 0, 50, 100, 150, 200, 300, and 500 are doses in Krad.

TABLE 1 - Continued

Variable	S T O R A G E T I M E (days)					
	1			9		
	Total count	pH	Observations	Total count	pH	Observations
V0	4×10^5	5.60	Brown	4.5×10^6	5.70	Brown, good odor
V50	8×10^3	5.55	Purple, became red in air	4.5×10^5	5.72	Purple, "
V100	3×10^3	5.80	" "	2×10^4	5.72	" "
V150	3×10^3	5.70	" "	3×10^3	5.68	Purple, trace off-odor
V200	5×10^2	5.68	" "	5×10^2	5.70	Purple, sl. off-odor
V300	$< 10^2$	5.62	" "	$< 10^2$	5.70	" "
V500	$< 10^2$	5.62	" "	$< 10^2$	5.69	" "
Days	23			28*		
V0	4.2×10^8	5.44	Brown, slight spoiled odor	3×10^8	5.22	Brown, spoiled odor
V50	1.7×10^8	5.60	Brown-purple, sl. off-odor	1.2×10^8	5.60	Brown, slight stale odor
V100	2.6×10^7	5.58	" "	4.6×10^7	5.58	Dark red, slight stale odor
V150	1.4×10^7	5.63	" "	5.5×10^7	5.57	" "
V200	3.5×10^6	5.68	" "	1.8×10^7	5.62	" "
V300	$< 10^3$	5.64	" "	$< 10^3$	5.64	" "
V500	$< 10^3$	5.68	" "	$< 10^3$	5.64	" "
Days	40**					
V0	--	--	--			
V50	3×10^8	4.90	Brown, spoiled odor			
V100	1.8×10^8	5.20	" "			
V150	7.8×10^7	5.40	Brown, trace spoiled odor			
V200	2.5×10^7	5.61	Brown-purple, sl. off-odor			
V300	$< 10^3$	5.63	" "			
V500	$< 10^3$	5.65	" "			

*28 day V samples were exposed to the air at 23 days and remained so for the five subsequent days.

**Held in vacuum until plated at 40 days.

were discarded without further analysis. The oxidative odor was so strong that it completely masked any indications of spoilage from the nonirradiated samples at 12 and at 23 days, and it rendered all oxygen stored samples indistinguishable with respect to odor and appearance regardless of the radiation dose. All oxygen stored samples had unsalable color at 12 days. As expected, all samples stored in air were very discolored after 9 days although microbial spoilage was evident only on the non-irradiated samples.

Vacuum packaged irradiated samples remained reasonably satisfactory during 23 days in vacuum plus an additional few days in air. Upon re-exposure to the air at 23 days the samples bloomed from purple to bright red within one-half hour. The bright red bloom faded gradually during the ~~five~~ additional days in air until at 28 days color of the 100 Krad and higher dose samples was dark red with traces of brown. The 0 and 50 Krad samples were brown and exhibited signs of microbial spoilage. A slight stale odor was noted on the 28th day indicating mild oxidation during the five days in air. The pH data indicate that, while aerobically held fresh meats normally undergo an increase in pH during spoilage, vacuum packaged nonirradiated and

radiation-pasteurized fresh meats undergo a pH reduction during a recognizable spoilage process of a different nature from that in air. The total plate count data, and odor and color observations support the view that the 50 to 150 Krad dose range in combination with vacuum holding can yield the two to three week or more needed salable life extension at conventional refrigeration temperatures.

The flora of nonirradiated samples held in air was overwhelmingly dominated by a gram-negative rod which produced large, smooth, pale, creamy, spreading surface colonies on total count plates, no doubt a *Pseudomonas* specie. Only a very few of this type were isolated from the 50 and 100 Krad samples, and none at all from the higher dose samples. Interestingly, none was isolated from nonirradiated samples held under oxygen. This may be explained by the fact that strict aerobes in particular can lose viability and outgrowth potential under hyperbaric oxygen. Two subsurface colony types dominated the outgrowing flora on irradiated and nonirradiated samples held under vacuum. One was a gram positive rod and the other a gram positive cocci, and both produced acid in litmus milk. In the dose range of interest (50-150 Krad) they accounted for a sour type of spoilage and a drop in pH, all of which points to

an innocuous spoilage process involving production of short chain organic acids (e.g. lactic acid). Regarding the dose requirement, indications from this study on perishable ground beef are that 150 Krad or less is adequate to provide needed salable life extension and yet leave sufficient harmless micro-organisms remaining to produce a detectable spoilage under refrigerated vacuum holding.

In the following two storage studies the effects of tripolyphosphate dip, storage temperature and anaerobic storage followed by aerobic storage on the salable life of fresh beefsteaks were investigated. In each of the studies three Commercial Grade top-rounds were employed. Half of the steaks from each of the top-rounds was dipped for 45 seconds in a 10% solution of sodium tripolyphosphate and drained. All of the steaks were individually vacuum packaged, and half of each of the phosphate treated lots, and half of each of the nontreated lots was irradiated to 100 Krads. Each of the treatment variables was divided into three storage temperature lots which were placed in constant temperature storage cubicles. The samples from each of the top-rounds used were labeled so that all of the samples tested at each withdrawal period were from the

same top-round (i.e. samples analyzed at the 8 day withdrawal were all from round no. 1, etc.). After aseptically removing a 30-40 gram portion, steaks withdrawn from vacuum storage were placed in trays and overwrapped with gas permeable PVC film. They were immediately returned to the storage cubicles from which they came for the additional four days aerobic storage after which they were again analyzed. The data and observations, and the variable codes are shown in Table 2 and in Table 3.

On the average, dipping in 10% TPP increased meat pH 0.65 unit in the first study, and about 0.50 unit in the second. A pronounced pH decrease occurred during 50°F storage, especially with the irradiated samples. The same trend occurred at 40° and at 35°, but to a lesser extent than at 50°. There was also a tendency toward a slight rise in pH of nonirradiated samples during the four day post-vacuum storage holding period in air following the pH decline during vacuum storage. A probable explanation is that acid producing species dominated during vacuum holding while aerobic meat spoilage types still present in large numbers because the samples were not irradiated, grew out during aerobic holding and exerted their normal pH raising effect. Only one set of ~~samples~~ of those held at 29°F

TABLE 2.--Effect of phosphate, radiation, temperature and anaerobic storage followed by aerobic storage on quality of fresh beefsteaks.

Variable	Zero time evaluation	
	pH	TPC/gm
Round 1, O-0	5.53	2.0×10^4
" O-I	5.57	4.0×10^3
" P-0	6.25	6.1×10^4
" P-I	6.20	1.4×10^3
Round 2, O-0	5.52	8.2×10^3
" O-I	5.58	5.0×10^2
" P-0	6.17	2.0×10^4
" P-I	6.35	3.8×10^3
Round 3, O-0	5.53	3.2×10^4
" O-I	5.55	2.2×10^3
" P-0	6.20	3.3×10^4
" P-I	5.98	6.0×10^2

Code:

O-0 = No dip, no irradiation.

P-0 = 10% TPP dip, no irradiation.

O-I = No dip, 100 Krad.

P-I = 10% TPP dip, 100 Krad.

29, 40 and 50 are constant storage temperatures in °F.

TABLE 2 - Cont'd

	8 days in vacuum		
Variable	pH	TPC/gm	Observations
O-0-29	5.53	4.5×10^4	Phosphate treated samples were more purplish than the untreated. Samples stored at 50°F had slight off-odor. Samples stored at 29 and 40°F had good odor.
P-0-29	6.32	7.2×10^4	
O-I-29	5.48	1.5×10^3	
P-I-29	6.23	5.0×10^3	
O-0-40	5.45	1.0×10^7	
P-0-40	6.12	1.3×10^7	
O-I-40	5.42	1.5×10^5	
P-I-40	6.15	1.7×10^5	
O-0-50	5.23	7.0×10^7	
P-0-50	5.83	8.2×10^8	
O-I-50	5.45	7.1×10^7	
P-I-50	5.95	3.0×10^8	
	8 days in vacuum plus 4 days in air		
O-0-29	5.58	2.5×10^5	Brown red, good odor
P-0-29	6.20	1.4×10^5	Bright red, " "
O-I-29	5.62	1.8×10^4	Brown red, " "
P-I-29	6.13	1.2×10^4	Bright red, " "
O-0-40	5.40	2.2×10^8	Brown red, spoiled odor
P-0-40	7.00	7.9×10^8	Red + green, " "
O-I-40	5.40	1.7×10^7	Brown red, good odor
P-I-40	5.73	8.0×10^7	Bright red, " "
O-0-50	These 50°F samples were extremely spoiled and dis-		
P-0-50	colored at this time and were discarded.		
O-I-50	"	"	" "
P-I-50	"	"	" "

TABLE 2 - Cont'd

Variable	16 days in vacuum		Observations
	pH	TPC/gm	
O-0-29	5.42	5.5×10^4	Brown, good odor
P-0-29	6.02	3.5×10^4	Purple, " "
O-I-29	5.50	1.0×10^3	Brown, " "
P-I-29	6.24	1.4×10^3	Purple, " "
O-0-40	5.28	1.5×10^7	Brown-purple, sl. off odor
P-0-40	6.02	1.2×10^8	Purple, " "
O-I-40	5.46	1.1×10^6	Brown-purple, good odor
P-I-40	6.08	6.0×10^6	Purple, " "
O-0-50	5.10	1.6×10^8	Brown-purple, sour odor
P-0-50	6.07	1.4×10^9	" " " "
O-I-50	5.10	1.0×10^8	" " sl. off-odor
P-I-50	5.78	3.2×10^8	Purple, " "
16 days in vacuum plus 4 days in air			
O-0-29	5.60	6.0×10^5	Brown, good odor
P-0-29	6.12	8.0×10^5	Bright red, good odor
O-I-29	5.50	7.0×10^4	Brown, " "
P-I-29	6.28	4.2×10^4	Bright red, " "
O-0-40	5.41	3.1×10^8	Brown + green, spoiled
P-0-40	6.28	2.2×10^9	" " "
O-I-40	5.43	1.0×10^7	Brown, sl. off-odor
P-I-40	5.98	1.2×10^8	Red, " "
O-0-50	Samples stored at 50°F were extremely spoiled and discolored and were discarded.		
P-0-50			
O-I-50			
P-I-50			

TABLE 2 - Cont'd

Variable	24 days in vacuum		Observations
	pH	TPC/gm	
O-0-29	5.42	4.1×10^5	Brown, good odor
P-0-29	6.14	1.5×10^6	Purple + brown, good odor
O-I-29	5.42	2.0×10^3	Brown, good odor
P-I-29	6.05	6.0×10^3	Purple, " "
O-0-40	5.25	1.8×10^8	Brown, spoiled
P-0-40	5.94	4.3×10^8	Purple + brown, spoiled
O-I-40	5.37	9.0×10^6	Brown, sl. off-odor
P-I-40	6.18	9.5×10^7	Purple, good odor
O-0-50	5.23	5.2×10^8	Poor color and odor
P-0-50	5.83	6.5×10^9	" " "
O-I-50	5.00	1.2×10^8	" " "
P-I-50	5.58	4.5×10^8	" " "
24 days in vacuum plus 4 days in air			
O-0-29	5.50	1.8×10^6	Brown, good odor
P-0-29	6.18	3.0×10^6	Bright red, good odor
O-I-29	5.48	7.5×10^4	Brown, " "
P-I-29	5.90	5.0×10^4	Bright red, " "
O-0-40	5.25	2.3×10^8	Brown + green, spoiled
P-0-40	5.72	6.0×10^8	Red + green, "
O-I-40	5.38	1.3×10^8	Brown, sl. off-odor
P-I-40	5.97	4.7×10^8	Bright red, sl. off-odor
O-0-50	Discarded		
P-0-50	"		
O-I-50	"		
P-I-50	"		

TABLE 3.--Effect of phosphate, radiation, temperature and anaerobic storage followed by aerobic storage on quality of fresh beefsteaks

Variable		Zero time evaluation	
		pH	TPC/gm
Round 1,	O-0	5.48	1.2×10^5
"	P-0	6.12	1.0×10^5
"	O-I	5.49	7.0×10^3
"	P-I	5.92	2.2×10^4
Round 2,	O-0	5.56	1.3×10^5
"	P-0	6.03	1.5×10^5
"	O-I	5.51	1.8×10^3
"	P-I	5.82	2.0×10^4
Round 3,	O-0	5.39	5.0×10^4
"	P-0	5.97	2.3×10^4
"	O-I	5.41	2.7×10^3
"	P-I	5.97	1.0×10^3

Code:

O-0 = No dip, no irradiation.

P-0 = 10% TPP dip, no irradiation.

O-I = No dip, 100 Krad.

P-I = 10% TPP dip, 100 Krad.

29, 35 and 40 are constant storage temperatures in °F.

TABLE 3 - Cont'd

Variable	8 days in vacuum		Observations
	pH	TPC/gm	
O-0-29	5.43	1.3×10^5	Brown, good odor
P-0-29	5.87	5.6×10^5	Purple, " "
O-I-29	5.50	1.5×10^3	Brown, " "
P-I-29	5.98	5.0×10^3	Purple, " "
O-0-35	5.45	1.2×10^6	Brown, " "
P-0-35	5.98	6.2×10^6	Purple, " "
O-I-35	5.46	1.5×10^3	Brown, " "
P-I-35	5.87	3.5×10^3	Purple, " "
O-0-40	5.56	8.8×10^6	" " "
P-0-40	5.86	3.0×10^7	" " "
O-I-40	5.46	1.4×10^5	" " "
P-I-40	5.92	1.6×10^6	" " "
8 days in vacuum plus 4 days in air			
O-0-29	5.52	1.2×10^6	Red-brown, good odor
P-0-29	5.78	9.3×10^6	Bright red, " "
O-I-29	5.54	7.0×10^3	Red-brown, " "
P-I-29	6.02	8.5×10^4	Bright red, " "
O-0-35	5.44	2.0×10^7	Brown-red, " "
P-0-35	5.88	1.9×10^8	Red, " "
O-I-35	5.51	1.1×10^5	Brown-red, " "
P-I-35	5.92	2.1×10^6	Bright red, " "
O-0-40	5.65	1.3×10^9	Brown + green, spoiled
P-0-40	5.92	1.6×10^9	Red-brown + green, "
O-I-40	5.46	2.0×10^7	Red-brown, sl. off-odor
P-I-40	5.75	4.1×10^8	Red, " "

TABLE 3 - Cont'd

Variable	16 days in vacuum		Observations
	pH	TPC/gm	
O-0-29	5.43	6.2×10^5	Brown, good odor
P-0-29	6.08	5.8×10^6	Purple, " "
O-I-29	5.40	2.0×10^4	Brown, " "
P-I-29	5.90	8.6×10^4	Purple, " "
O-0-35	5.44	1.0×10^7	Brown, " "
P-0-35	5.82	2.6×10^7	Purple, " "
O-I-35	5.42	4.6×10^5	Brown, " "
P-I-35	6.02	5.5×10^6	Purple, " "
O-0-40	5.47	6.6×10^7	Purple-brown, trace off-odor
P-0-40	5.82	2.1×10^8	Purple, " "
O-I-40	5.43	9.3×10^6	Brown, " "
P-I-40	5.90	9.0×10^7	Purple, " "
16 days in vacuum plus 4 days in air			
O-0-29	5.47	1.8×10^6	Red-brown, good odor
P-0-29	5.97	2.2×10^7	Bright red, " "
O-I-29	5.43	3.9×10^5	Brown, " "
P-I-29	5.88	7.2×10^5	Bright red, " "
O-0-35	5.51	2.3×10^8	Brown-red, sl. spoiled odor
P-0-35	5.79	6.6×10^8	" " " " "
O-I-35	5.45	1.3×10^7	" " , good odor
P-I-35	5.96	5.0×10^7	Bright red, " "
O-0-40	5.62	3.0×10^9	Brown + green, spoiled odor
P-0-40	5.82	4.2×10^9	" " " "
O-I-40	5.38	3.3×10^8	Brown-red, sl. off-odor
P-I-40	5.87	1.0×10^9	" " " "

TABLE 3 - Cont'd

Variable	24 days in vacuum		Observations
	pH	TPC/gm	
O-0-29	5.42	2.2×10^6	Brown, good odor
P-0-29	6.03	2.7×10^7	Purple, " "
O-I-29	5.60	2.0×10^5	Brown, " "
P-I-29	5.98	2.1×10^5	Purple, " "
O-0-35	5.38	4.9×10^7	Brown, " "
P-0-35	5.91	1.5×10^8	Purple, " "
O-I-35	5.46	6.5×10^6	Brown, " "
P-I-35	5.98	8.3×10^7	Purple, " "
O-0-40	5.30	1.3×10^8	Brown, spoiled odor
P-0-40	5.88	1.0×10^9	Purple, " "
O-I-40	5.52	8.5×10^7	" sl. off-odor
P-I-40	5.92	2.5×10^8	" " "
24 days vacuum plus 4 days in air			
O-0-29	5.51	1.2×10^7	Brown, good odor
P-0-29	5.90	1.3×10^8	Bright red, good odor
O-I-29	5.67	1.4×10^6	Brown, " "
P-I-29	6.03	1.3×10^6	Bright red, " "
O-0-35	5.40	9.0×10^8	Brown-red + green, spoiled
P-0-35	6.00	7.0×10^8	" " " "
O-I-35	5.55	2.5×10^7	Red-brown, good odor
P-I-35	5.80	3.0×10^8	Red, " "
O-0-40	5.42	2.7×10^9	Brown, spoiled
P-0-40	6.00	1.3×10^9	Brown-red, "
O-I-40	5.52	8.3×10^8	" " sl. off-odor
P-I-40	5.97	9.8×10^8	" " " "

(phosphate-treated and nonirradiated) reached a total count in excess of 10^8 per gram, and this wasn't until 24 days in vacuum plus four days in air. No signs of spoilage were evident at any time with samples held at a constant 29°F, nor were there any with 35° samples so long as they remained under vacuum. At 35°F rapid outgrowth and spoilage took place within a few days after removing samples from vacuum and placing them in air; and the data and observations indicate that radiation is necessary to achieve a three week or more salable life at this temperature under the conditions employed. At 40°F, 100 Krad appeared barely adequate to provide in excess of three weeks salable life from a microbial standpoint. A 150 Krad dose would likely have provided a significant additional margin at this fairly high temperature. At a constant storage temperature of 50°F all samples became spoiled during a few days storage in air following eight days in vacuum. In agreement with published information about enhanced metmyoglobin reduction at higher temperatures, it was observed that metmyoglobin reduction of vacuum packaged nonirradiated samples which had browned was greatest at 50°F. A dose of 100 Krad is clearly insufficient for a constant 50°F holding temperature

which, in a commercial situation, would represent temperature abuse and improper handling.

As in the first study, the outgrowing flora on all samples while under vacuum was dominated by a few gram positive species which produced acid in litmus milk besides causing the reductions in meat pH. There were no qualitative differences in the outgrowing flora at the various temperatures; there were merely more of the same, and sooner, at the higher temperatures, especially at 50°F. Gram-negative *Pseudomonas* types were present in significant numbers on nonirradiated samples at all temperatures, but their outgrowth was greatly depressed under vacuum. Their numbers did, however, increase sharply during post-vacuum holding in air. This was most noticeable with non-irradiated samples held at 29°F at which temperature the acid producing species increased in numbers relatively slowly, and with the higher temperature nonirradiated samples at the earlier withdrawal periods before the acid producers became overwhelmingly dominant. A small but noticeable general enhancement of outgrowth due to phosphate treatment occurred with both irradiated and non-irradiated samples at all temperatures. This was probably largely due to the higher pH which favors the outgrowth of

the common meat bacteria. This slight, apparently unimportant negative effect of phosphate treatment is more than offset by the beneficial effects upon water holding capacity and color retention.

Although the phosphate treatment was intended specifically as a drip controlling measure, color observations lead one to conclude that phosphate treatment is probably necessary to attain satisfactory color as well under the proposed conditions. The striking beneficial effect of phosphate treatment on color may or may not be entirely a pH effect as well, but it could be considered at least as important (if not moreso) as the drip reducing effect. While untreated samples occasionally became partially or completely brown immediately upon vacuum packaging (probably due to a combination of residual oxygen and low metmyoglobin reducing capacity meat) this was never observed to occur with phosphate treated samples, even when they were from the same muscle as the discolored untreated samples. Further, untreated samples often became brown (if they were not already) rather than blooming very soon after re-exposure to the atmosphere following vacuum storage. This has not been observed to occur with phosphated samples. Retention of bloom during post-vacuum holding was enhanced

by low temperature (29°F) holding, as well as by radiation pasteurization when the higher holding temperatures were employed. The radiation effect is probably due to (1) reducing conditions brought about by irradiation in vacuo, and (2) the reduction in the number of micro-organisms and resulting delay in microbial spoilage. Thus it appears that to achieve the objective, phosphate treatment and vacuum holding are needed with a temperature just above freezing, and radiation (or some equivalent treatment) must be added at conventional refrigeration temperatures.

Packaging Tests

Since the packaging and bulk packing tests were evaluated by qualitative observations for gross differences which do not lend themselves to graphic or tabular representation, the results are presented here entirely in the form of a discussion of each of the five tests (A through E) in the order in which they are described under "Materials and Methods."

A. The aim of this group of tests was to compare the two basic approaches to bulk vacuum packing: 1) the method of choice, that of loosely bulk vacuum packing

individually prepackaged consumer cuts such that they can be shipped in bulk containers under anaerobic conditions without having the individual cut packages undergo any physical damage (e.g., one layer of packages pressing upon another) during handling and shipment, and 2) the partial approach to complete centralized preparation, that of tightly bulk vacuum packing bare (nonwrapped) consumer cuts for shipment, and leaving the individual-cut packaging to the retailer. The two approaches were compared solely from a technological viewpoint although there are important, perhaps overriding non-technical aspects (e.g., merchandising) involved. Upon opening the bulk containers and before removing the contents a mild "confinement" odor was noted in all cases. It was stronger and of a slightly different nature from irradiated containers than from non-irradiated containers, but it rapidly disappeared in both cases. Nonwrapped, tightly bulk vacuum packed cuts were consistently uniformly purple in color, and all cuts so packed, phosphated and nonphosphated, irradiated and non-irradiated, bloomed to a desirable red shortly after laying out in the air whether or not they were first wrapped with oxygen permeable film before blooming. The nonirradiated samples had a sour spoilage odor and they did not maintain

the bloom as well as the irradiated. Phosphate treatment and/or irradiation resulted in markedly better bloom retention during aerobic holding. Discoloration usually did not become objectionable with the irradiated until the third day at the earliest after three weeks of vacuum holding.

In rigid bulk containers from which some 25 to 30 lbs. of tightly packed steaks were removed there was never more than a few ml. of a rather viscous, coagulated fluid exudate remaining. A probable reason is that the tightly packed bare steaks acted essentially as a single uncut large chunk of meat with a low surface to volume ratio, since the cut surfaces were pressed against one another under a slight pressure. When large flexible vacuum bags were used as the bulk containers noticeably more drip loss remained behind after removing the cuts, but this was still a relatively small amount (ca.10 ml.). Most importantly, cuts so packed never exuded more than insignificant amounts of drip during a few days holding in air after individually packaging. It seems that with this approach phosphate treatment is more important for color retention than it is for drip reduction. From every technical aspect this basic approach consistently yields highly satisfactory results.

Color and drip control successes are particularly noteworthy, and the cuts could not be distinguished appearance-wise from freshly cut steaks before discoloration in air appears, as happens with freshly cut steaks as well.

With the approach of individually prepackaging prior to loosely bulk vacuum-packing color and drip results were variable and frequently unsatisfactory. Upon removal from the vacuum containers, the cuts in trays with film overwrap were frequently somewhat discolored, and often the watery drip in the individual packages, especially at the bottom layers, was excessive. Phosphate treatment nearly always markedly improved color. While it caused a significant drip reduction it did not eliminate drip accumulation, which was sometimes excessive in spite of the phosphate treatment. Drip would probably be further reduced by a phosphate application method which does not incorporate as much added water into the meat as does dipping in solution. Prepackaged cuts which did undergo bloom regeneration during post-vacuum holding in air appeared to do so more rapidly and to a greater extent when first unwrapped and then allowed to bloom without any film. Steaks which underwent blooming while still in the packages generally discolored faster than steaks which

were unwrapped prior to blooming. All prepackaged steaks which did bloom, however, discolored faster than did the tightly bulk vacuum packed nonprepackaged steaks whether or not the latter were wrapped before being set out to bloom.

B. When the gas permeable meat wrapping films were compared with one another, and with no film at all, with regard to color and bloom regeneration as described in (B) under "Materials and Methods," the three films were found to perform equally well. When discoloration occurred it did so to about the same degree with each film. Usually the cuts in trays with no film overwrap yielded best results colorwise whether or not they were overwrapped immediately upon removal from the bulk vacuum containers. On the whole, irradiation appeared to result in somewhat improved color, and phosphate treatment markedly improved color results. In general, indications were that when cuts are loosely bulk vacuum packed in separate trays best results are obtained when there is no film overwrap, but such results are not as consistently good as when nonwrapped cuts are tightly bulk vacuum packed as in (A). When loosely bulk vacuum packed nonphosphated prewrapped and nonwrapped cuts showed severe discoloration the meat appeared to be of the

pale, watery low metmyoglobin reducing capacity type which derives the greatest benefit from phosphate treatment. Conversely, in instances where no discoloration whatever occurred during loose bulk vacuum holding, the meat appeared to be of the high metmyoglobin reducing capacity type. The two extremes can be rather easily recognized by visual examination of appearance. Also, the former usually becomes brown upon vacuum packaging in transparent pouches whereas the latter rapidly develops and maintains a deep purple color.

C. This test was a repeat of (B) except that two of the four rigid bulk vacuum containers employed were alternately evacuated and nitrogen flushed five times prior to drawing the final vacuum. In this test all samples, prewrapped and nonwrapped, nitrogen flushed and not flushed showed the same desirable purple color upon removal from vacuum. Subsequent bloom regeneration in air proceeded highly satisfactorily with all samples as well. There were varying amounts of drip up to several ml. in the individual trays. As usual, the drip was greatest in the trays toward the bottom of each container. Trays are stacked six layers deep in the containers, and despite efforts to avoid pressure on the cuts from packages above a small amount of this stress was unavoidable. It appears to be the only

possible reason for the greater amounts of drip in the bottom layers of packages. Drip was noticeably more abundant in packages from the nitrogen flushed containers. This may have been due to the suction-compression effect of the multiple evacuations and flushings. A nitrogen flushing advantage was not evident; however this test did demonstrate that very fresh meat of obviously high metmyoglobin-reducing capacity can yield good color results under the conditions employed which have often resulted in partially or completely discolored meat. Rate and extent of post-vacuum bloom regeneration appeared to be enhanced somewhat by removing the wrapping film from prepackaged cuts and either allowing them to bloom unwrapped or rewrapping them in fresh new film of the same kind prior to blooming. It may be that when film is in intimate contact with the cuts for an extended period of holding, the film may lose some of its gas transmissibility, thus possibly enhancing pigment oxidation. The meat itself does not appear to be affected, whereas cuts from the same muscle which were unwrapped upon removal from vacuum and which had not been prewrapped at all, underwent bloom regeneration in air at the same rate and to the same extent. Both bloomed more rapidly than prepackaged cuts that remain

packaged and nonwrapped cuts that are wrapped before blooming in air. The differences usually were not great, however.

D. This series was intended to compare the conventional (tray plus overwrap) and 'skin-tight' methods of individual cut packaging with the aim of determining whether or not trapped air in the packages is contributing to the discoloration due to pigment oxidation which frequently has occurred during bulk vacuum holding of conventionally prepackaged cuts. It is reasoned that, during the evacuation of the bulk containers, some air probably remains within the trayed and overwrapped packages giving rise to pigment oxidation. The observation that discoloration occurs particularly with meat of apparent low metmyoglobin reducing capacity supports this view. The results of these tests also point to entrapped air as the major cause of discoloration. Steaks packaged in 'skin-tight' pouches prior to bulk vacuum packing did not discolor to any noticeable degree whereas some of the conventionally prepackaged steaks emerged from vacuum holding showing various amounts of surface browning. In general, steaks so packaged did not bloom as well, and did not hold the bloom as long as did the 'skin-tight' packaged steaks.

In both cases phosphate treatment improved color results over those of nonphosphated steaks. Cuts packaged in the 'skin-tight' fitting pouches bloomed more rapidly and extensively when the film was removed at the end of bulk vacuum holding than when the cuts remained in their pouches. As noted in other tests, rewapping the cuts in fresh new film of the same type also improved bloom regeneration somewhat compared with leaving the cuts in their original pouches. Equally good color results were obtained with nonwrapped cuts and with 'skin-tight' packaged cuts which were unwrapped upon removal from vacuum. Not as good, but satisfactory results were obtained when 'skin-tight' packaged cuts were allowed to undergo post-vacuum bloom regeneration in the original pouches. Variable, sometimes unsatisfactory color results occurred with conventionally prepackaged cuts. Again, discoloration was apparently due to a combination of residual in-package oxygen and low metmyoglobin reducing capacity meat.

E. Tests designed to check the effect, if any, of a common film plasticizer and anti-fogging agent on surface color yielded negative results. No observable effects attributable to either film additive occurred. Samples in direct contact with plasticized film and samples in direct contact

with dichromate cleaned glass were identically purple upon removal from vacuum holding, and both sets bloomed in air at the same rate and to the same extent. Similarly, samples wrapped in ethylene-vinyl acetate film with and without an anti-fog additive performed identically color-wise. If, as indicated by these results, the film itself does not contribute to discoloration when it occurs, then residual low partial pressure oxygen, and the freshness and biological activity of the meat (e.g. its oxygen utilization - and metmyoglobin reducing potential) would appear to be the principal, and perhaps the only significant factors governing color results under the conditions used.

Sensory Evaluation Tests

The results of the three series of sensory evaluation tests are presented and discussed in the order in which they appear under "Materials and Methods."

(1) This series of three tests was designed to study the effect of phosphate and irradiation, separately and in combination, on eating quality of beefsteak stored for twenty-one days in vacuum at 29°F followed by an additional three days in air at 29°F. The next page is a

copy of the scoresheet used for all sensory evaluation tests, and the results of the three tests comprising this series are summarized in Table 4. The variable codes are as follows:

0 - 0	no phosphate, no irradiation
P - 0	phosphate treated, no irradiation
P - I	" " , 100 Krad
0 - I	no phosphate, " "

Just prior to cooking it was noted that the phosphate treated samples were generally bright red and appealing in appearance whereas those not treated with phosphate were generally dull red to brown. Upon removal from the vacuum pouches a trace of off odor could be detected from the irradiated samples, although all samples had essentially fresh beef odor with no indications of spoilage.

In PANEL 1 the relatively low texture and juiciness scores for "0-I", and the relatively low flavor score and high texture and juiciness scores for "P-I" are noteworthy.

Differences in overall quality scores are not great, and all four variables can be considered definitely acceptable.

In PANEL 2, however, the two irradiated variables were marginally acceptable, both having rather low flavor scores.

The "0-I" variable again received low texture and juiciness scores, as did the "P-I" variable in this test. In contrast,

"0-I" was the most preferred variable in PANEL 3, and "P-I"

SENSORY EVALUATION OF QUALITY FACTORS:

For each sample, please evaluate each quality factor. Score each factor with the number corresponding to the most descriptive comment. For example, a color score of 5 would indicate that you consider the sample to have an overall color of marginal quality (i.e., "on the fence" between slightly acceptable or fairly good and slightly unacceptable or fairly bad).

Sample code	Color	Odor	Flavor (Taste)	Texture	Moistness or juiciness	Overall quality	Comments

SCORING CODE:Acceptable Range:

9 = Excellent

8 = Very good

7 = Good

6 = Fairly good

5 = Marginal

Unacceptable Range:

4 = Fairly bad

3 = Bad

2 = Very bad

1 = Poor

TABLE 4. Effect of phosphate, irradiation, and phosphate plus irradiation on eating quality of beefsteaks.

Treatment	Cooked color	Odor	Flavor	Texture	Moistness or juiciness	Overall quality	Significantly different @ 95% level*
PANEL 1 (24 panelists):							
O-I	Ave 6.5	6.4	6.2	5.9	5.7	6.1	0-0
	Range 4-9	4-9	4-8	3-8	3-9	4-8	
P-0	Ave 6.2	6.1	6.0	6.2	6.1	6.0	0-0
	Range 4-8	2-8	3-9	4-8	3-8	4-8	P-I
P-I	Ave 6.3	6.3	5.8	6.8	6.7	6.2	0-0
	Range 4-8	2-8	3-8	5-9	4-9	4-8	
O-0	Ave 6.4	6.3	6.4	6.4	6.4	6.4	
	Range 3-9	4-8	3-8	4-8	3-8	4-8	
PANEL 2 (20 panelists):							
O-I	Ave 5.7	5.9	5.3	4.8	4.7	4.8	P-0
	Range 3-8	4-8	4-8	1-7	1-7	2-7.5	P-I
P-0	Ave 6.4	6.2	6.2	6.6	6.4	6.3	0-0
	Range 4-8	3-9	4-9	4-9	3-9	3-9	
P-I	Ave 5.6	5.6	5.6	5.5	5.6	5.3	P-0
	Range 3-8	1-8	3-8	2-9	3-9	3-7.5	0-0
O-0	Ave 6.8	6.5	6.4	7.2	6.9	6.6	
	Range 5-9	2-9	2-9	5-9	5-8	2-8	
PANEL 3 (31 panelists):							
O-I	Ave 6.9	5.9	5.9	6.3	6.5	6.2	
	Range 5-9	3-9	3-9	3-8	4-9	3-8	
P-0	Ave 6.2	6.2	5.9	5.9	6.0	5.8	0-I
	Range 3-8	4-8	1-8	3-8	2-8	3-8	
P-I	Ave 6.2	5.6	5.4	5.8	5.9	5.4	0-I
	Range 3-9	2-8	1-8	3-8	4-8	2-8	P-0
O-0	Ave 5.8	6.0	6.0	5.4	5.0	5.5	0-I
	Range 2-8	4-8	3-8	2-8	3-8	3-8	P-0

* Refers to "overall quality" scores only. Variables appearing in this column had significantly higher "overall quality" scores than the variables for that row.

and the control the least preferred. The control was judged to be inferior in the texture and juiciness categories, and "P-I" in the flavor and odor categories. Surprisingly, "O-I" received the highest ratings for texture and juiciness in the third panel. There appears to be an unfavorable interaction between phosphate treatment and irradiation with respect to flavor. If so, this might be attributable to increased water content due to dipping which would tend to favor increased radiation induced flavor changes (reducing the water content of foods is commonly recognized as a means of reducing radiation induced off flavors and damage due to products of water radiolysis). In most instances the range of scores among the panelists was rather broad indicating considerable disagreement among the panelists as to their responses. Comparing "P-0" and "O-0" in PANEL 3, phosphate treatment appeared to improve texture and juiciness whereas in the other two panels phosphate treatment appeared to have no effect, or possibly a slight overall negative effect. Comparing "O-I" and "O-0", and "P-I" and "P-0", there appears to be a slight negative effect of a 100 Krad dose of radiation upon flavor and odor. With a familiar, standard food item like beefsteak a detectable atypical flavor note would be expected to be graded

critically by a taste panel, but unless very pronounced, might go unnoticed in the home, especially if normal culinary practices and embellishments were used.

(2) This series of four tests was designed to study the effect of irradiation with and without prior phosphate treatment on the eating quality of beefsteaks stored for twenty-one days in vacuum at 40°F plus an additional two days in air at 40°F. Variable codes are the same as for (1) and the data from the four tests are summarized in Table 5. In three of the four panels the control was judged to have significantly higher "overall quality" than the treated samples. PANEL 1 data suggest that the difference in overall quality between the treated-stored samples and the freshly cut control is largely if not entirely due to superior flavor of the latter. The especially low flavor score for "P-I" might possibly be due to an interaction between irradiation and added water due to the phosphate dip and/or an undesirable flavor note originating from the phosphate salt. In PANEL 2, objectionable flavor and odor appear to be the reasons for the low overall quality score given to "P-I". "O-I" and the fresh control were rated slightly lower in texture and juiciness and slightly higher in flavor and odor. In PANEL 3, "O-I" and

TABLE 5.--Effect of phosphate dip and/or irradiation and storage at 40°F on eating quality of beefsteaks.

Treatment	Cooked color	Odor	Flavor	Texture	Moistness or juiciness	Overall quality	Significantly different at 95% level*
<u>PANEL 1 (20 panelists):</u>							
Ave	6.4	5.2	4.9	6.8	7.2	5.5	0-I
P-I							0-0
Range	4-8	1-7	3-7	5-8	6-8	3-8	
Ave	6.8	6.2	6.0	6.5	6.6	6.3	
O-I							0-0
Range	5-8	3-8	4-8	5-8	5-8	4-8	
Ave	7.1	6.6	6.8	6.6	6.6	6.8	
O-0							
Range	5-8	5-8	5-8	5-8	4-8	5-8	
<u>PANEL 2 (25 panelists):</u>							
Ave	6.6	5.7	5.1	6.7	6.6	5.4	0-I
P-I							0-0
Range	4-9	3-7	3-8	3-9	4-9	3-8	
Ave	7.0	6.2	6.1	6.8	6.6	6.3	
O-I							
Range	6-9	3-9	3-8	5-9	5-8	5-8.5	
Ave	6.8	6.5	6.3	6.2	6.2	6.3	
O-0							
Range	5-9	4-8	4-9	3-8	3-8	4-8	
<u>Panel 3 (32 panelists):</u>							
Ave	6.3	6.0	5.8	6.4	6.2	5.9	
P-I							0-0
Range	4-9	3-9	3-8	4-8	4-8	3-8	
Ave	6.2	6.1	5.6	6.3	6.2	5.9	
O-I							0-0
Range	3-9	4-9	3-8	2-9	4-8	4-8	
Ave	6.9	7.1	7.0	6.8	7.0	7.0	
O-0							
Range	5-9	5-9	3-9	4-8	5-9	4-9	
<u>Panel 4 (28 panelists):</u>							
Ave	6.7	6.3	5.6	6.4	6.1	6.0	
P-I							0-I
Range	3-9	3-9	1-8	4-9	3-9	3-8	0-0
Ave	6.9	5.8	5.8	6.8	7.0	6.2	
O-I							0-0
Range	4-9	3-8	2-8	5-9	5-9	4-8	
Ave	7.0	6.6	6.8	6.5	7.0	6.7	
O-0							
Range	5-9	3-9	4-9	4-8	5-8	5-8.5	

* Refers to "overall quality" scores only. Variables appearing in this column had significantly higher "overall quality" scores than the variable for that row.

Code: P-I phosphate treated, 100 Krad
 O-I no phosphate, 100 Krad
 O-0 no phosphate, no irradiation

"P-I" have equivalent overall quality scores, both being considerably lower than that of the freshly cut control which was preferred in every respect. Flavor appears to have been the chief influencing factor. As with panels 1 and 2, PANEL 4 scores indicate that "P-I" is significantly lower in overall quality than both "I-0" and "0-0." Surprisingly, "P-I" was judged lowest in juiciness by a fairly wide margin. In general, the overall data demonstrate that beefsteaks irradiated and held for an extended period at 40°F can be judged to be of equivalent or nearly equivalent quality as freshly cut untreated steaks. As in the first series of tests, the data suggest an objectionable phosphate treatment-irradiation interaction that probably would be reduced or eliminated by a phosphate application method that incorporates a minimum of added water into the meat.

(3) This series was designed to compare the effect of treating with salt plus phosphate, phosphate only, and no phosphate on the eating quality of irradiated beefsteaks. Results of the first two panels are summarized in Table 6. The variable codes are as follows:

TABLE 6.--Effect of phosphate dip, and salt plus phosphate dip on eating quality of irradiated beefsteaks.

Treatment	Cooked color	Odor	Flavor	Texture	Moistness or juiciness	Overall quality	Significantly different at 95% level *
Panel 1 (27 panelists):							
Ave	6.5	6.2	6.3	6.8	6.8	6.3	
0-0-I							8-P-I
Range	4-8	5-9	4-8	5-9	3-9	5-8	

Ave	6.6	6.1	6.2	6.6	6.7	6.3	
0-P-I							S-P-I
Range	4-8	3-9	4-8	3-9	3-8	4-9	

Ave	7.0	6.2	6.5	6.6	6.2	6.5	
S-P-I							
Range	4-9	2-9	5-8	3-9	3-9	4-9	
Panel 2 (21 panelists):							
Ave	6.1	5.7	6.0	6.6	6.7	6.1	
0-0-I							
Range	4-8	3-7	4-8	5-8	5-9	5-8	

Ave	6.7	6.0	5.9	6.3	6.9	6.2	
0-P-I							
Range	4-8	3-8	4-7.5	4-8	4-8	4-8	

Ave	6.2	5.8	5.8	6.2	6.3	5.9	
S-P-I							0-0-I
Range	4-8	4-7	3-8	3-8	5-9	4-7.5	0-P-I

* Refers to "overall quality" scores only. Variables appearing in this column had significantly higher "overall quality" scores than the variable for that row.

0 - 0 - I	no salt, no phosphate, 100 Krad
0 - P - I	no salt, phosphate treated, 100 Krad
S - P - I	treated with salt plus phosphate, 100 Krad

No control was included in the first two tests in order to observe how the panelists, who had become accustomed to a control sample, would react to tests without a control. The panelists were not aware of the absence of a control. The results indicate that there is little if any difference in eating quality as a result of treatment with salt plus phosphate. The interaction between phosphate treatment and irradiation noted before did not appear to be a factor in this set of tests. The closeness of the scores from variable to variable may be in part a result of there being no freshly-cut control. The absence of a freshly cut control may have resulted in a slight general increase in scores for the irradiated-stored variables. All were decidedly acceptable after more than three weeks at 40°F. Under these conditions nonirradiated steaks exhibit a sour spoiled odor and flavor (they were tasted by the author but were not served to panelists). The combination of salt plus phosphate which is reported to have a synergistic effect in

improving water holding capacity did not exhibit this effect in this series of tests. There was noticeably more drip loss in the flexible bulk vacuum bag holding the tightly packed nonwrapped "S-P-I" steaks than in the bag holding the "O-P-I" steaks. Both, however, exuded much less drip than the "O-O-I" steaks. Further, dipping in salt plus phosphate solution did not have any beneficial effect upon texture and juiciness in this set of tests.

The second pair of taste panels did include a freshly cut control, from the same muscle for both tests, which was judged to be inferior in overall quality compared to the treated-stored variables. The data for this set are summarized in Table 7. The data and verbal comments indicate that the control had poor texture and was lacking in flavor, indications of insufficient ageing. The salt plus phosphate combination appears to have had a beneficial effect in the first panel study, particularly with respect to texture and juiciness scores, but no apparent effect in the second.

Looking at all of the taste panel data together, one can observe some apparent trends. Because comparable data are sometimes contradictory, however, caution must be exercised in interpretation. Written and verbal comments

TABLE 7.--Comparison of eating quality of nondipped, phosphate dipped irradiated beefsteaks and freshly cut untreated control beefsteaks.

Treatment	Cooked color	Odor	Flavor	Texture	Moistness or juiciness	Overall quality	Significantly Different at 95% level*
Panel 1 (24 panelists):							
O-I	Ave 5.9	6.5	6.0	5.4	5.3	5.8	S-P-I
	Range 4-8	5-9	3-9	2-8	4-8	3-8	
P-I	Ave 6.2	5.7	5.5	6.0	5.8	5.6	S-P-I
	Range 3-8	3-7	3-8	3-8	2-8	3-8	
S-P-I	Ave 6.4	6.1	6.0	6.6	6.3	6.3	
	Range 3-9	3-9	1-9	4-8	4-8	4-8	
Control	Ave 6.4	6.0	5.6	5.2	5.7	5.4	O-I
	Range 4-8	2-8	1-8	3-8	2-8	2-8	P-I
							S-P-I
Panel 2 (25 panelists):							
O-I	Ave 5.8	5.4	5.4	6.4	6.3	5.8	
	Range 3-9	2-8	1-8	4-9	4-9	1-8	
P-I	Ave 6.2	6.0	5.8	6.1	6.3	5.8	
	Range 4-9	4-8	2-8	3-9	4-8	3-8	
S-P-I	Ave 6.5	5.6	6.0	6.1	5.9	5.7	
	Range 2-9	3-9	3-8	3-8	3-8	2-8	
Control	Ave 6.1	6.0	5.8	4.8	5.5	5.5	O-I
	Range 3-9	4-9	3-8	2-7	2-9	3-8	P-I

* Refers to "overall quality" scores only. Variables appearing in this column had significantly higher "overall quality" scores than the variable for that row.

by several panelists together with some of the data indicate that phosphate treatment improves juiciness (and apparently texture) by increasing water content and/or by reducing cookout fluid. This logical conclusion is somewhat tempered by the fact that other of the data indicate equivalent juiciness for phosphated and nonphosphated steaks, and still other data indicate higher juiciness for the latter. One might expect phosphated steaks to be superior in juiciness than their untreated counterparts; however, a conclusion to that effect is not unequivocally supported by the data.

The flavor data generally indicate a tendency toward scoring nonphosphated-nonirradiated steaks (both freshly cut, and stored at 29°F) superior in flavor to nonphosphated-irradiated stored steaks which in turn are judged to be superior in flavor to phosphated-irradiated stored steaks. Here again, however, the data do not allow an unqualified conclusion. At best, the data indicate overall trends. This suggests that 100 Krad alone, under the conditions employed, can cause a detectable negative effect upon flavor which is enhanced somewhat by the combination of phosphate dip plus irradiation. The slight off-flavor can perhaps best be described as "aged"

or merely different, but it is not the classical irradiation flavor associated with meat processed with greater than pasteurizing doses. The panel rating differences, while real, are not large differences. The differences very likely would be greatly diminished and possibly rendered undetectable by some culinary practices.

That phosphate treatment plus irradiation plus anaerobic holding followed by aerobic holding might effect taste and odor to some degree is not an unreasonable expectation.

Some form of change associated with the period of holding the meat and not specifically related to the treatment given the meat might be expected to occur. Evaluation of the meaning of such a change in terms of consumer acceptance probably will require a large-scale consumer-type panel, possibly best employed under true marketing conditions.

SUMMARY AND CONCLUSIONS

The combination of (1) treatment with condensed phosphate solution (e.g., tripolyphosphate); (2) bulk vacuum packing followed by subsequent reoxygenation of the meat surface pigment in air; and (3) either irradiation (50-150 Krad) plus conventional refrigeration (i.e., 35-42°F), or, a constant 28-30°F holding temperature can extend the salable life of consumer cuts of fresh red meats three to four weeks, and yet provide cuts having essentially the same appearance, form and other features as freshly prepared consumer cuts. The eating quality of the treated-stored cuts is comparable to that of freshly cut meat. Irradiation to the above dose range is necessary with conventional refrigeration to sufficiently reduce the number of micro-organisms present on the cut meat so as to adequately delay microbial spoilage. With constant holding at 28-30°F, the low temperature alone is sufficient to adequately delay microbial spoilage. While the low temperature practically eliminates fluid exudation, phosphate treatment nevertheless appears necessary to guarantee satisfactory bloom

regeneration in air following lengthy anaerobic holding. At the higher anaerobic holding temperatures at which meat-borne pathogens and food poisoning micro-organisms could present at least a hypothetical risk, indications are that both irradiated (50-150 Krad) and nonirradiated fresh meat undergo the same innocuous spoilage process. The dominant outgrowing flora under such conditions appears to consist of harmless acid producing species, which ultimately cause a recognizable sour (i.e. lactic acid) type spoilage, and which would be expected to inhibit the outgrowth of organisms of public health significance should any be present. In addition to reducing the microbial load, irradiation in-vacuo was observed to have a pronounced reducing effect on oxidized meat pigment, which is most desirable.

Treatment with a 10% solution of sodium triphosphate results in a meat pH increase of from 0.5 to 1 unit. This treatment has the effect of reducing fluid exudation and generally improving pigment stability by (1) aiding in the prevention of pigment oxidation, and (2) enhancing oxidized pigment reduction, and post-vacuum holding bloom generation in air. Phosphate treatment also results in a slight overall enhancement of microbial outgrowth on irradiated and nonirradiated cuts but this effect

appears to be minor and is greatly overshadowed by the beneficial effects of phosphate treatment upon drip and color. A method of phosphate application (e.g. gas entrainment) which does not involve as much water incorporation into the cuts as does immersion into solution may likely further reduce fluid exudation.

The approach of tightly bulk vacuum packing a large quantity of bare (unwrapped) consumer cuts in a rigid or a flexible multi-cut container invariably resulted in excellent color and drip control results. This approach allows more efficient utilization of container and shipping space (maximum amount of meat per volume of space) than does the approach of loosely bulk vacuum packing individually prepackaged cuts. The latter approach often yielded unsatisfactory color and drip results, discoloration apparently being due to a combination of entrapped air within the individual packages and meat of low biochemical activity and low metmyoglobin reducing capacity. While the method of tightly bulk vacuum packing nonwrapped cuts is technically less complicated and more reliable than the prewrapping approach, the packaging remains the function of the retailer. If individual cut centralized prepackaging is a firm requirement as it well may prove to be, the package

will have to provide for rapid and complete equilibration of the contents with the atmosphere in contact with the package. Further packaging development appears necessary in order to provide a package that will meet all of the technical needs of a centralized prepackaging system, and be acceptable costwise.

Finally, the combined effects of vacuum packaging, irradiation and refrigerated holding for three weeks in vacuum followed by holding in air for a few additional days can result in a flavor and odor which is slightly but detectably different from that of untreated cuts when the cuts are cooked and rated by a sensory panel under the most revealing conditions. The differences are small, but to determine if the treated, stored meat is acceptable to the consuming public will require additional studies, probably of a test-market nature.

BIBLIOGRAPHY

- Anderson, D. L. 1968. Directions of change in meat distribution. In, Opportunities in Change, Second Meat Sci. and Dist. Conf., Ohio State U. Coop. Ext. Service/U.S.D.A. PP. 1-10.
- Anon. 1966. Is centralized packaging inevitable? Meat Magazine 32(8):33-38.
- Anon. 1968a. Triumph of Logic. Forbes 102(12):48-51.
- Anon. 1968b. Centralized processing. Meat Proc. 7(7):30-44.
- Anon. 1969a. Fabricating meat at Monfort - from kill to fill. The Nat. Provisioner 160(20):12-20.
- Anon. 1969b. More central freezing of cuts for retail. Quick Frozen Foods 31(8):130-131.
- Anon. 1969c. Instant-frozen beef. Food Technol. in Australia 21(2):80.
- Anon. 1969d. Fast freeze in Southern California. The Nat. Provisioner 160(14):20-23.
- Anon. 1969e. KSU tests acceptance of frozen lamb. The Nat. Provisioner 160(20):23.
- Anon. 1969f. Centralized frozen meat packaging to prove boon for warehousemen. Quick Frozen Foods 31(9):181-192.
- Anon. 1969g. Centralized meat cutting and freezing calls for study of consumer needs. Quick Frozen Foods. 31(10):118-19.

- Bailey, M. E. 1968. Importance of color to the meat industry. Proc. Meat Indus. Res. Conf. A.M.I.F., Chicago: PP. 1-3.
- Belo, P. S., Jr. 1968. Water-holding capacity, lipid oxidation, pigment and color changes in radiation pasteurized prepackaged fresh beef pretreated with sodium tripolyphosphate. Thesis for the degree of M.S. Michigan State University.
- Bernholdt, H. F. 1967. Environmental controlled distribution systems. Proc. Meat. Indus. Res. Conf. A.M.I.F., Chicago: PP. 94-99.
- Bouton, P. E. 1968. Ageing of beef. CSIRO Food Preserv. Quarterly 28(3-4):52-54.
- Briskey, E. J., R. G. Cassens and J. C. Trautman, eds. 1966. The Physiology and Biochemistry of Muscle as a Food. U. of Wisconsin Press, Part III.
- Brody, A. L. Meat goes to market. In, Meat Technology and Marketing. The Iowa Dev. Comm. 250 Jewett Bldg., Des Moines, Iowa.
- Brownell, L. E., J. V. Nehemias and J. J. Bulmer. 1954. Proposed new method of wholesaling fresh meat based on pasteurizing by gamma irradiation. USAEC Tech. Inf. Serv., Oak Ridge, Tenn. AECU-3043. Eng. Res. Inst., U. of Mich., Ann Arbor, 29 pp.
- Cannoles, C. M. 1968. Meat distribution centers - where are we now. In, Opportunities in Change, Second Meat Sci. and Dist. Conf. Ohio State U. Coop. Ext. Service/U.S.D.A. PP. 29-37.
- Cheney, V. L. 1969. The many sides of frozen meat. The Nat. Provisioner 160(10):98-105.
- Davis, A. D. 1969. Retail trends in meat marketing. The Nat. Provisioner 160(11):18-19.
- Dawson, L. E. and W. J. Stadelman. 1960. Micro-organisms and their control on fresh poultry meat. Mich. State U. Ag. Exp. Sta. Tech. Bull. 278. 39pp.

- Elliott, R. P. and H. D. Michener. 1965. Factors affecting the growth of psychrophilic micro-organisms in foods - a review. U.S.D.A. - A.R.S. Tech. Bull. No. 1320.
- Enfield, F. D. 1968. Problems related to the genetic analysis of differences in meat color. Proc. Meat. Ind. Res. Conf. A.M.I.F., Chicago: 4-11.
- Fox, J. B., Jr. 1966. The chemistry of meat pigments. J. Agr. Food Chem. 14(3):207-210.
- Fox, J. B., Jr. 1968. Chemico-physical properties of meat pigments as related to color. Proc. Meat. Ind. Res. Conf. A.M.I.F., Chicago: 12-20.
- Greene, B. E. 1966. Lipid oxidation and pigment changes in fresh and irradiated beef. Thesis for the degree of PhD, The Florida State Univ., Tallahassee.
- Groninger, H. S. and A. L. Tappel. 1957. The destruction of thiamine in meats and in aqueous solutions by gamma radiation. Food Res. 22:519-23.
- Howell, K. 1969. Urge meat packers to aid retail on pre-packaging. Supermkt. News., February 24, p. 35.
- Ingram, M. 1962. Microbiological principles in prepackaging meats. J. appl. Bact. 25(2):259-81.
- Ingram, M. and T. A. Roberts. 1966. Microbiological principles in food irradiation. In, Food Irradiation, Proc. Intern. Symp., Karlsruhe, 6-10 June. IAEA, Vienna, STI/Pub/127. PP. 267-85.
- Kahn, A. W. 1969. Tough meat is avoidable, NRC says. Food in Canada 29(2):33.
- Kunstler, M. 1969. Vacuum pack boon for Fearman. Food in Canada 29(2):38-39.
- Lawrie, R. A. 1966. Meat Science, Pergamon Press, Ltd.

- Lawrie, R. A. 1968. Chemical changes in meat due to processing - a review. J. Sci. Food and Agric. 19(5): 233-40.
- Lea, C. H., J. J. MacFarlane and L. J. Parr. 1960. Treatment of meats with ionizing radiations. V. Radiation pasteurization of beef for chilled storage. J. Sci. Food and Agric. 11(12):690-94.
- Leach, H. V. 1966. Economic costs and retail shelf life requirements for centralized meat distribution systems. U.S.D.A. - A.R.S. Report PPES - 66 - Feed - 4.
- Little, A. D., Inc. 1968. New Developments in Meat and Meat Packaging Technology. Report to the Iowa Dev. Comm. C-69488. (Available from Iowa Dev. Comm. or from A. D. Little, Inc.).
- McLoughlin, J. V. 1969. Relationship between muscle biochemistry and properties of fresh and processed meats. Food Mfr. 44(1):36-40.
- Meyers, H. B. 1969. For the old meat packers, things are tough all over. Fortune, February: 89-93, 134-36.
- Monfort, K. 1969. A U.S. perspective. Food in Canada 29 (2):44.
- Motoc, D. and C. Banu. 1968. Biochemical changes during the storage of beef and pork. Die Fleischwirtschaft 8:1045-50.
- Naumann, H. D. 1968. Cutting and packaging of fresh meats. Proc. Meat Ind. Res. Conf. A.M.I.F., Chicago: 157-167.
- Niven, C. F. and W. R. Chesbro. 1957. Complementary action of antibiotics and irradiation in the preservation of fresh meats. In, Antibiotics Annual 1956-57, Med. Encyc., Inc., N. Y. PP. 855-9.
- Niven, C. F. 1963. Technological aspects of the radiation pasteurization of foods. Int. J. Appl. Rad. and Iso. 14:26-29.

- O.E.C.D. 1964. The Economic Effects of Fresh Meat Pre-packaging in Member Countries of the O.E.C.D. Documentation in Food and Agric. No. 68. O.E.C.D. Publications, Paris.
- Ordal, Z. J. 1962. Anaerobic packaging of fresh meat. Proc. Fourteenth Res. Conf. A.M.I.F., Chicago: 39-45.
- Patton, J. 1969. Practical aspects of processing pig meat. Food Mfr. 44(1):41-44.
- Pierson, M. D. and Z. J. Ordal. 1969. Microbiological, sensory and pigment changes in aerobically and anaerobically packaged beef. Paper delivered at 29th annual meeting of the I.F.T., Chicago, 11-15 May.
- Rhodes, D. N. and H. J. Shepherd. 1966. Treatment of meats with ionizing radiations. XIII. Pasteurization of beef and lamb. J. Sci. Food and Agric. 17(7):287-97.
- Rhodes, D. N., T. A. Roberts and H. J. Shepherd. 1967. Treatment of meats with ionizing radiations. XV. Irradiation of beef from barley-fed animals. J. Sci. Food and Agric. 18(12):576-78.
- Rickansrud, D. A. and R. L. Henrickson. 1967. Total pigment and myoglobin concentration in four bovine muscles. J. Food Sci. 32(1):57-61.
- Saleh, B. A. H. 1967. The role of pyridine nucleotides, substrates, and intermediates in the enzymatic reduction of metmyoglobin in ground beef. Thesis for the degree of PhD. The Florida State Univ., Tallahassee.
- Scott, W. J. 1968. Technological problems of meat production and export. C.S.I.R.O. Food Pres. Quarterly 28(1-2):14-19.
- Sharpe, M. E. 1962. Lactobacilli in meat products. Food Mfr. 27(12):582-9.

- Solberg, M. 1968. Factors affecting fresh meat color. Proc. Meat Ind. Res. Conf. A.M.I.F., Chicago: 32-40.
- Thornley, M. J. 1962. Relative resistance to cobalt - 60 gamma irradiation of strains of *Pseudomonas* and *Achromobacter*. J. Appl. Bact. 25:ii.
- Thornley, M. J. 1963. Radiation resistance among bacteria. J. Appl. Bact. 26(3):334-45.
- Urbain, W. M. 1965. Radiation preservation of fresh meat and poultry. In, Radiation Preservation of Foods, Nat. Acad. of Sci. Pub. 1273, pp. 87-98.
- Urbain, W. M. 1966. Technical and economic considerations in the preservation of meats and poultry by ionizing radiation. In, Food Irradiation, Proc. Intern. Symp., Karlsruhe, 6-10 June. I.A.E.A., Vienna STI/PUB/127, pp. 397-409.
- Urbain, W. M., G. G. Giddings, P. S. Belo and W. W. Ballantyne. 1968. Radiation Pasteurization of Fresh Meats and Poultry. Annual Report to the A. E. C. C00-1689-2. Isotopes - Industrial Technology (TID-4500). 80 pp. (Available from Clearinghouse for Federal Sci. and Tech. Info., Springfield, Va.)
- Urbain, W. M., P. S. Belo and G. G. Giddings. 1969. Centralized Processing of Fresh Meat and Poultry Including Radiation Pasteurization - A Bibliography. ORNL-IIC-20. 71 pp. (Available from C.F.S.T.I., Springfield, Va.).
- Urbain, W. M., G. G. Giddings, P. S. Belo and W. W. Ballantyne. 1969. Radiation Pasteurization of Fresh Meats and Poultry. Annual Report to the A.E.C. C00-1689-5. (In Press).
- Walrath, R. L. and R. R. Konicek. 1967. Meat Technology and Transport, Iowa Dev. Comm., 250 Jewett Bldg., Des Moines, Iowa.

- Wilson, G. M. 1959. The treatment of meats with ionizing radiations. II. Observations on the destruction of thiamine. J. Sci. Food and Agric. 10(5):295-300.
- Wolin, E. F., J. B. Evans and C. F. Niven, Jr. 1957. Microbiology of fresh and irradiated beef. Food Res. 22:682-87
- Yaeger, D. 1968. Lower rates forecast for air-freight. Supermkt. News, December 16, p. 27.
- Yankelovich, Daniel, Inc. 1968. Cost benefit study of selected meats in the Atomic Energy Commission low dose food irradiation program. Report - N.Y.O.-3831-1 (Unpublished).

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