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PRESERVATION OF MEATS BY STERILIZING DOSES OF IONIZING RADIATION

by

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Tenth European Meeting of Meat Research Workers, Roskilde, Denmark, 10-15 August 1964

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SUMMARY

Preservation of meats by sterilizing doses of ionizing radiation has been a primary objective of the U. S. Army's Radiation Preservation of Foods Program since its initiation in 1953. By approval of radiation sterilized bacon for unrestricted use, the Food and Drug Administration, U. S. Department of Health, Education and Welfare (FDA), with the concurrence of the Meat Inspection Division, U. S. Department of Agriculture, has recognized the technological feasibility of the process and the wholesomeness of the product. The 12D concept suggested 4.5 Mrad as a safe sterilizing dose for uncured meats. Study of meat packs inoculated with the most radiation resistant strains of Cl. botulinum has indicated that a lower dose may suffice, particularly for cured meats. This possibility is being investigated further. Data from studies conducted by the Army Medical Service indicate that with the exception of one or two areas which require further study, meats irradiated to 5.58 Mrad are wholesome and are comparable in nutritional adequacy to conventional heat processed meats. The technology of radiation sterilization of pork, chicken, hams and pork sausage is advancing. Encouraging results have been obtained by irradiating beef in the frozen state. Large scale feeding tests have shown a variety of radiation-sterilized meats to be suitable as components of regular meals. Tin plated metal cans with an oleoresinous lining have been established as a reliable package for all radiation sterilized meats. Significant progress has been made towards applying flexible materials to in-package radiation sterilization of meats, but fulfillment of the exacting requirements for such containers remains one of the most difficult tasks of the entire program. The processing cost for radiation sterilized canned meats has previously been estimated to be from one to six cents per pound, suggesting that the cost of irradiation processed meats may be competitive with that of thermally processed or freeze-dehydrated meats. Study of the economic aspects of irradiated foods is in progress to appraise data based upon the most recent scientific and technological advances.

With FDA approval of radiation-sterilized bacon, and the approval anticipated within the next few years for pork, poultry and ham, the list of approved radiation-sterilized meats should be sufficiently inclusive to stimulate the interest of the meat industry in this new process. Considering the advantages radiation-preserved meats offer in the economics of storage, transportation and marketing, they should have a bright future.

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INTRODUCTION

The interest of the U.S. Army in the preservation of meats by sterilizing doses of ionizing radiation is very practical. Meat is a highly favored component of the rations. In garrison feeding, there is no problem in supplying excellent, fresh-tasting meat. In field operations, fresh meat is out of the question, and only preserved forms of meat can be used. But preserved meats have their limitations, and the Army has long been in the business of seeing what can be done to make them more appealing. The purpose of this paper is to describe the contributions of radiation preservation to the solution of this problem.

The Army's attack on this problem has been remarkably thoroughgoing. Initiated in 1953[20,35] the Army's Radiation Preservation of Foods Program addressed itself to determining the feasibility of preserving ration items by this revolutionary process[13,15,29,30]. Leading scientists and technologists across the nation were enlisted in the project[35]. The program was painstakingly organized, carefully coordinated, and so fully reported that few food research organizations in the

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U.S. and for that matter in the world, were unaware of its existence, purposes, and progress. The program has been marked by successes and failures, by excessive optimism as well as excessive doubt, but it has persisted through the years and has survived scrutinizing and criticism - most of it constructive.

In view of the long and sometimes rough road that the program has travelled, it is not surprising that the 8th of February, 1963, is a historic date. On that day, the world's first meat item preserved by a sterilizing dose of ionizing radiation, irradiated fresh canned bacon, was cleared by the U.S. Food and Drug Administration, Department of Health, Education and Welfare(FDA) - with the concurrence of the Meat Inspection Division, U.S. Department of Agriculture - for unrestricted public consumption in the United States[40]. This action by the FDA represents a recognition of both the technical feasibility of the radiation process and the wholesomeness of the product. Based on the accumulated evidence at hand, it is reasonably assured that other radiation-sterilized meats will win approval.

A few other facts deserve mention. For many years the Army's Radiation Preservation of Foods Program was conducted by the Quartermaster Food and Container Institute in Chicago. Since July 1962, it has been conducted by the Food Division at the U.S. Army Natick Laboratories in Natick, Massachusetts, an agency of the Army Materiel Command[30,34].

Research on wholesomeness aspects of radiation preserved foods has been conducted by the Army Medical Service. The present home of the program is the U.S. Army Radiation Laboratory, one of the finest facilities in the world for the study of radiation preservation of foods. With such facilities, new vistas of research and development progress have been opened.

The work on meat and the other assigned commodities is conducted in a well-equipped laboratory with these features: a food preparation area, a nuclear-radiation laboratory complex, and a modern taste-test kitchen for the preparation and serving of radiation processed foods. Photographs and other detailed descriptive material of the Laboratory have been published elsewhere(5,14,21). The radiation facilities consist of a 1.0 megacurie cobalt-60 source and 24-Mev linear accelerator cell, both being the largest known food radiation sources of this kind in the world. Food technologists, engineers, microbiologists, chemists, physicists, and food acceptance specialists work closely together here to advance the radiation program for developing, improving, and testing radiation processed foods.

STATUS AND FUTURE OUTLOOK FOR RADIATION STERILIZED MEATS

What is the present status of our knowledge regarding the radiation sterilization of meats and what is the future outlook?

The answers to be reported here are based on the results of studies made either in-house or under contract agreements with various academic, research, commercial, and governmental agencies. The studies conducted since July 1962 in the Radiation Laboratory at Natick will be given chief emphasis since earlier achievements in the field, both those of our group and those of investigators under contract, are summarized in available official publications(29,30).

The topic covered in this paper are those which have received from the onset the greatest concentration: the problem of radiation dosage, wholesomeness, chemical and sensory changes, enzyme inactivation and texture, packaging, product development, and acceptance. In keeping with the title of the paper, meats will be the commodity given primary attention, although the Army's Radiation Preservation of Foods Program covers other foods as well(15,29,42,46).

The Problem of Radiation Dosage

Determining the radiation dose required to destroy food-spoilage microorganisms is no simple matter. There are, to begin with, several types of ionizing radiation which can be used, such as gamma rays from a cobalt-60 source and electron beams from an electron linear accelerator. Both of these sources are used at the U.S. Army Radiation Laboratory, although most of our research work so far has been conducted with gamma radiation. Based on evidence available today(29,38), it can be concluded that both types of ionizing radiation have essentially the same bactericidal action.

It was learned many years ago that the sensitivity of various bacteria to radiation differed widely. Vegetative forms of bacteria (and also yeasts, molds, and parasites) of significance in food preservation, generally require radiation doses of less than 1.0 million rads. Bacterial spores may require doses several fold higher. The most radiation-resistant of these of importance in food preservation, are the spores of Clostridium botulinum, an unhappy situation for the meat specialist since this organism seems to grow well in anaerobically packaged meats and is often found in meats. According to the present 12D concept, the sterilization requirement for this microorganism in low-acid foods, such as uncured meats, is 4.5 million rads (4.5 Mrad)(8,32). There is a disconcertingly high dosage. Brightening the picture, however, are recent microbiological findings. Using inoculated bacon and chicken meats, it was found that this value may be too high. The inoculated pack studies completed so far on bacon have shown that the experimental radiation sterilizing dose was 2.0 Mrad and the dose based on the 12D concept was 2.5 Mrad(8). Preliminary inoculated pack studies on chicken indicate a sterilizing dose of about 3.5-4.0 Mrad.

A very limited study on the sterilization dose requirement for ham revealed no toxic spoilage beyond 1.5 Mrad, although viable spores were recovered after treatment at a dose level of 3.0 Mrad.

Additional work on inoculated meat packs will be conducted to establish the minimum sterilizing dose of radiation (with a reasonable safety margin) for each major meat item. At present, a confirmatory study on inoculated chicken pack is in progress. The future plan provides for completion of the studies on inoculated ham in 1965, with pork, beef, and other meat products to follow.

In our present development work on radiation-sterilized meat items, the 12D concept will be used as the criterion for safety and hence clearance by the U.S. Food and Drug Administration. However, we are hopeful that our current research efforts will lead to a better criterion for microbiological safety so that newer and better radiation sterilized meat products can be realized in the ruture.

Wholesomeness of Irradiated Foods

The wholesomeness part of the program is a crucial one. Naturally, a new process of this nature deserves the utmost scrutiny with regards to its effects. The Army Medical Service conducts the work on wholesomeness, the aim being to furnish regulatory agencies the evidence needed to establish irradiated foods as safe for human consumption. From this work comes the experimental data required for the FDA clearances of irradiated foods for unrestricted consumption by both military personnel and the civilian population.

Procedures for establishing wholesomeness for FDA clearance are meticulous. The various foods studied were first subjected to short-term (eight weeks) subacute toxicity feeding tests. Of the 40 foods that have now cleared these short term tests, 21 have been selected for long-term toxicity studies. Among the meat items selected were, bacon, ground beef, beef stew, pork loin, chicken, and chicken stew[30]. These investigations were rigorous. The tests were run over a two-year period of four generations of the experimental animals, and during that time, the effects of irradiated diets on growth, reproduction and lactation, hematology, life span, histopathology, and carcinogenicity were studied in two animal species selected from rats, dogs, chickens, and monkeys[4].

The feeding phases of the program have been completed except for a few instances in which repeat runs were required as a result of inconclusive data. The Army Medical Service has concluded that with the exception of one or two doubtful areas which require further study, foods irradiated to 5.58 Mrads are wholesome. Their nutritional adequacy is comparable to conventional heat-processed foods[4,30].

Laboratory studies have shown that radiation processing is detrimental to some vitamins but does not significantly affect essential amino acid content. The vitamins affected are the ones which are also sensitive to heat treatment. The metabolizable energy value of a diet composed of irradiated foods was the same as that of a corresponding nonirradiated diet. No significant difference was noted in the biological value of proteins from irradiated or nonirradiated foods[28]. Digestion of fats by alimentary lipase was depressed by irradiation[4,30].

Feeding experiments were conducted also with human volunteers at the U.S. Army Medical Research and Nutrition Laboratory. Human subjects were divided into groups of five which alternated between control and irradiated diets. The maximum period for any subject on irradiated foods was 15 days. The irradiated foods constituted up to 100 percent of the total caloric intake. Clinical and laboratory tests before and after the feeding periods failed to reveal any evidence of toxic effects[30].

The study of induced radioactivity in foodstuffs produced by either electron or gamma irradiation is closely related to wholesomeness. Theoretical considerations and experimental data have shown that irradiation with gamma from cobalt-60 and cesium-137 does not produce any radioactivity in food constituents. Electrons with energy less than 10 Mev are below the threshold for most (γ,n) and (γ,p) reactions which could cause food elements to become radioactive[27,38]. Except for radioisotopes with half-lives so short that they are of no significance in food processing, induced radioactivity in food does not become detectable until the electron energy is above 15 Mev[22,26]. The Army is studying induced radioactivity, wholesomeness and micronutrients in beef, bacon, ham, and pork processed with electrons at the 4.5 Mrad dose and at energies up to 24 Mev.

Chemical and Sensory Changes

In food irradiation research, one of the most difficult tasks is to determine just what are the radiation process requirements for specific foods.

Radiation process requirements are determined by the need to insure sterility in the processed food and to achieve an acceptable product. With respect to the product's acceptability, it is necessary to study the radiation induced chemical and physical changes in foods and food components in relation to changes of sensory characteristics such as flavor, texture, color and overall appearance of the foods.

Changes in flavor is the most pronounced effect of meat irradiation. The degree to which a foreign flavor develops depends not only on the amount of radiation used, but also on the type of meat. Beef is most sensitive to flavor changes; pork, ham, bacon, and poultry meat are less sensitive. The chemistry of sensory changes has not yet been completely elucidated although it has been under investigation for several years.

All of the components of the meat are subject to chemical reactions resulting from the impact of ionizing radiation. The effects may be direct or indirect, depending upon whether they result from impact upon the substrate or from ionizations in the wake of the impacting particles. The reactions of water, a major component, are well characterized. It is sufficient to note that all possible ions and free radicals of oxygen and hydrogen, alone and in combination, have been reported. These ions and radicals may interact with each other, producing both inert and reactive compounds, and with other components in foods. In all probability the majority of radiation-caused reactions in meat components are of the indirect type - that is, are reactions with ions and radicals from the water.

Degradation of proteins is considered the principal cause for undesirable sensory changes in irradiated meats, particularly the degradation of sulfur containing amino acids(17,19). Irradiation of simple amino acid model systems revealed deamination and carbonyl formation at the alpha carbon. Products formed included ammonia, hydrogen, carbon dioxide, formaldehyde, formic acid, the parent fatty acid, the fatty acid of one less carbon, the amino acid of one less carbon, and the alpha keto acid.

In peptides, deamination of N-terminal amino acids occurs, but the major effect is chain scission with the production of equivalent amounts of amide terminal and alpha keto acid terminal fragments.

The volatile compounds of beef, as would be expected, are of great interest in the search for substances contributing to off-flavor. More than forty compounds - hydrocarbons, alcohols, aldehydes, ketones, sulfur, and nitrogen - have been identified[11,44], using a concurrent radiation-distillation technique. Many of these are also present in unirradiated beef. Apparently methional and hydrocarbons are unique constituents of irradiated beef, whereas n-alkanals and alkanols are components of both non-irradiated and irradiated beef.

After six months of storage of enzyme-inactivated irradiated beef, methional disappears nearly completely and n-alkanals are apparently reduced to n-alkanols[45]. These results, when considered with the finding that stored irradiated beef exhibits only weak irradiation odor, indicate that methional, hydrocarbons, and n-alkanals are important contributors to irradiation off-odor.

In an attempt to relate these substances more directly to the off-odor characteristic of beef, raw beef to which a number of these compounds had been added, was submitted to trained panels. The nearest identifications of the irradiation off-odor was obtained with mixtures containing at least a carbonyl compound, a nitrogenous base, and a sulfur compound.

Studies are continuing (a) to complete the identification of volatile substances in irradiated beef, (b) to determine the amounts of each produced by the irradiation treatment, (c) to specify the effects of temperature during irradiation on the kinds and amounts produced, and (d) to determine the contribution of each to the typical off-odor.

Lipoproteins are less susceptible to damage than are their constituent proteins. Lipids undergo oxidation, decarboxylation, hydrogenation and dehydrogenation in the radiation process[16]. Radiation degradation of lipids appears to be less conducive to off-flavor development, however, than does the degradation of protein. Furthermore, lipid oxidation can be controlled to a great extent through the exclusion of oxygen by vacuum sealing of foods prior to irradiation. Oxidations also occur in the myoglobin[1].

Many stratagems have been employed to suppress off-flavor development. The use of low temperature during irradiation (irradiation in frozen state) was effective in retarding off-flavors and off-odors in radiation-sterilized beef. Skillful use of spices, condiments, barbecue sauce and appropriate culinary practices have resulted in greater acceptance of radiation sterilized meat products.

Enzyme Inactivation and Texture Problem

A major concern with regard to radiation sterilized meats is the inactivation of enzymes. Irradiation at the level used for destruction of microorganisms does not accomplish total enzyme inactivation. Storage tests under non-refrigerated condictions on meats irradiated at levels of 4.5 Mrad or less show evidences of enzyme activity as production of off-flavors and bitter taste[6,29]. The growth of tyrosine crystals on the surface of the meats has also been observed as objective evidence of enzyme activity. Proteolytic activity in irradiated raw meats during long term storage at non-refrigeration temperatures results in a most undesirable effect - a mushy and friable texture. A study has been conducted to gain a better understanding of the reaction mechanisms of the naturally-occurring proteolytic enzymes in beef and the possibility of their control by non-thermal means. So far, the results are not very encouraging. Changing the pH of the product has had some effect. Partial inhibition of beef cathepsins is achieved by lowering the pH of the product to 4.0 or increasing it to pH 6.5-7.0. The addition of tolerable amounts (1 to 3%) of salt or citric acid-sodium citrate buffer (meat pH 4.5 to 5.6) resulted in a small inhibitory effect also. What appears to be needed is a whole new approach to the problem of non-thermal-enzyme inactivation. Any ideas as to what this new approach should be will be welcomed.

Until such a new, effective method can be found, blanching of meats to internal temperatures of 160 to 180°F. (71°-82°C) will have to be used to make products shelf-stable at non-refrigerated temperatures for a long period of time. Different forms of mild heat treatment (blanching) of meats have been investigated. In general, independent of the kind of meat, short-time, high-temperature blanching methods have yielded the most acceptable products.

An excessive degradation of connective tissue, responsible for the friability of meat fibers, has been observed in irradiated beef subjected to long-time, low-temperature blanching methods to achieve enzyme inactivation. An example in this respect is given in Table 1. Two grades of beef were blanched in a smokehouse until the meat had reached 170°F. internally. By regulating the temperature and relative humidity in the smokehouse, a long-time, low-temperature (180°/20 hours) or a short-time, high-temperature (192°/6 hours) blanching condition was obtained. Degradation of connective tissue of the beef before and after irradiation was then determined by extracting with water or with 10 percent calcium chloride solution the decomposed fractions of collagen from the connective tissue, followed by determination of hydroxyproline (an index for connective tissue) in the extracts[47]. As the data in Table 1 indicate, blanching of beef by the long-time, low-temperature blanching method caused an excessive degradation of the connective tissue, particularly in irradiated U.S. Choice grade beef.

However, some progress has been made in this area. Excessive physical softening and friability of enzyme inactivated beef tissue on irradiation can be minimized by using beef of lower grades(31). It has been observed that irradiation at 4.5 Mrad can cause a tenderization of low-grade beef, such as U.S. Commercial, with corresponding improvement of the product.

Irradiating beef in the frozen state has also been beneficial to texture(31). Such texture defects as mushiness and friability have been greatly reduced by irradiating enzyme inactivated beef at low temperature (31,48). Low temperature irradiation offers an opportunity for developing acceptable radiation sterilized beef items. A higher dose of radiation might be required for radiation sterilization of beef in the frozen state. However, exploratory studies conducted on radiation resistance of Cl. botulinum spores over the temperature range of -320°F. to 194°F. (-196°C. to 90°C) revealed that the dose increase might not be great. For example, in an inoculated beef pack experiment in which 5 x 10^4 spores per can (100 g. meat) was used, an increase of about 0.9 Mrad in the sterilization dose level was required between 0 and -196°C. The sterilizing dose level increased from 2.7/3.0 Mrad (spoilage/no spoilage) at 0°C. to 3.6/3.9 Mrad at -196°C.

Packaging Problems

Initial efforts in the packaging of irradiated foods were concentrated on tin-plated steel cans because of their reputation as rugged dependable containers. It was found that certain types of steel, tin coatings, internal enamels, and end-sealing compounds are suitable for use with irradiated foods[29,30]. Long-term studies (up to 25 months) of irradiated meats and other foods have proven that tin plated steel cans are reliable both for withstanding irradiation and protecting their contents against rough handling and non-refrigerated storage. Enameled aluminum containers are satisfactory for irradiated foods that can be sealed under low vacuum or under inert gases.

Studies have been initiated to determine the nature and origin of hydrogen and other gases produced during irradiation and storage of meat and fish products irradiated in metal cans. This problem of gas formation must be solved. Presently, vacant headspace is left in the cans to compensate for gas products and thus prevent the cans from appearing to be swellers.

Considerable progress has been reported on developing flexible packaging materials for in-package radiation treatments of foods[30,39,46,50]. The requirements for flexible packaging materials in this phase of the program are that they:

1. Must be resistant to changes in protective characteristics such as heat sealability, resistance to rough handling and creasing, permeability, stress, cracking, etc.

2. Must not be adversely affected by radiation induced changes in the food.

3. Must not transmit adverse odors or flavors to the food.

4. Must not transmit toxic or potentially toxic migratory substances to the food.

5. Must be fabricated into packages of such size and shape as to utilize the radiation energy most efficiently.

The research work to evaluate packaging materials is subdivided into two phases:

1. Determine the extractives and other fragmentation compounds of various food packaging polymeric materials produced by ionizing radiation.

2. Develop flexible containers that will have the chemical, physical, and protective characteristics necessary to meet the overall requirements.

Extractives studies have been completed on 16 packaging materials while in contact with standard food simulating solvents[9,36,50]. Some of the data obtained from this research are given in Table 2. The data indicate that irradiated samples containing medium density polyethylene, polyvinyl chloride, and polychlorotrifluoroethylene plastics, used as the food contacting materials, produced extractives in the amounts below the minimum requirements set by the FDA for food packaging materials[41]. Low extractives were also obtained from polyester (Mylar), polystyrene, high-density polyethylene, and polyamide (Nylon-6) plastic films. The extractives data are being used in preparation of a petition to the FDA proposing the issuance of a regulation for the safe use of several packaging materials for in-package radiation sterilization of meats. An investigation is in progress on six flexible materials, vacuum packed with bacon, ham, and pork chops and irradiated at 4.5 Mrad, to determine their functional performance and non-refrigerated storage life.

Inasmuch as the conventional polyethylenes produce off-odors on irradiation, a research study has been initiated to synthesize a superpolymeric, odor-free, radiation resistant polyethylene.

Prospects for plastic materials are promising even though many problems remain unsolved. Future research will be concentrated on developing acceptable flexible packages (laminated pouches) for radiation sterilized meats. The most radiation resistant plastic films will be used as the food contacting materials in the packages.

Product Development

There is no easy generalization that can be made regarding radiation sterilized meats. The status of each is dependent on its own product characteristics, and in many instances is a composite of the degrees of progress made in solving problems of flavor, odor, color, texture, and enzyme inactivation.

All products discussed here were packaged in metal cans with "C" enamel lining, sealed under 20-25 inches vacuum, and irradiated with cobalt-60 gamma radiation. With the exception of the products irradiated in the frozen state, all other products were chilled to 35°F. (1-2°C.) (internal) prior to irradiation.

Much of the information to be presented has been published recently or is in press[12, 31, 43, 46, 49].

The organoleptic data given in the accompanying tables refer to preference scores which were obtained by using the 9-point hedonic scale method of Peryam and Pilgrim for measuring food preference[23]. The test subjects were asked to record their preference on a numerical scale, shown below:

Preference	Score
Like Extremely	9
Like Very Much	8
Like Moderately	7
Like Slightly	6
Neither Like nor Dislike	5
Dislike Slightly	4
Dislike Moderately	3
Dislike Very Much	2
Dislike Extremely	1

The method gives useful results with people who are totally inexperienced in food testing as well as with subjects who have had food testing experience. Its usefulness has been proven in preference testing of various foods used in the U.S. Armed Forces[10]. In the case of meat products, the score of 5 indicates marginal acceptability. A rating of 7 indicates a highly acceptable product. For the meat preference ratings, tables 3 and 6-14, inclusive, the least significant difference of the meat values at the 95% confidence level is about 0.5 point.

Irradiated Bacon.- The preference study of irradiated bacon during 25 months of nonrefrigeration storage has shown that the product is acceptable (Table 3). The product retains good quality for a period of at least two years at 70°F.(21°C.) and at least 16 months at 100°F.(38°C).

Clearance of irradiated canned bacon for unrestricted consumption by the U.S. public has not brought the research and development work on irradiated bacon to completion. Additional research is under way to make a better quality product and to assure production of a consistently high quality product.

There are variations in acceptability of bacon obtained from separate commercial lots (Comm.#1 and Comm.#2) and procured under U.S. Government specifications (GI-bacon)(Table 3). This may be due to raw material and/or processing variables. Therefore, the effect of curing variables on the irradiated product is under investigation; extreme care being taken to assure that the raw material and smoking conditions are as uniform as possible for all experimental bacon lots.

In another experiment (Tables 4 and 5) a commercial brand of bacon was irradiated at 2.5 and 4.5 Mrad doses and evaluated for organoleptic and chemical changes during 12-month storage at 72 and 100°F. (22 and 38°C); nonirradiated controls were stored at -20°F.(-29°C). The control samples were acceptable for 12 months, but signs of oxidative rancidity were evident. The irradiated bacon samples, whether stored at 72 or 100°F, were acceptable organoleptically without detectable rancidity (43). Among the chemical indices investigated (moisture, fat, salt, protein, pH, free fatty acids (FFA), nonprotein nitrogen(NPN), and peroxide and TBA values), only FFA and TBA values were slightly increased as a result of irradiation. During storage, FFA and NPN showed an increase; however, no consistant trend was evident in the case of NPN after 6 months of storage (Table 5). TBA values showed a decrease during the storage period; however, variations among the samples did not permit observing a consistant trend with the storage time. In contrast to the irradiated bacon samples, the nonirradiated controls showed more than a tenfold increase in the TBA values after 12 months storage at -20°F. (Table4). The increase in FFA and NPN during storage suggests incomplete enzyme inactivation in the commercially processed bacon used in this experiment. An experiment on radiation-sterilized bacon to determine the heat treatment needed during smoking for enzyme inactivation is in progress.

The Army has filed a petition with the FDA requesting approval at an absorbed dose between 4.5 and 5.6 Mrad for electron beam radiation of canned bacon with energy levels not to exceed 10 million electron volts from an electron linear accelerator source. The General Electric Company, using Army data, has received clearance from the FDA for electron irradiation of bacon at 5 million electron volts, with the absorbed dose between 4.5 and 5.6 Mrads.

It is also noteworthy that a limited production purchase description (LPPD) for canned bacon, irradiated with 4.5 - 5.6 megarad of gamma radiation, has been prepared. It is planned to procure irradiated bacon under this document later this year to ascertain its adequacy as a procurement document and to generate an interest in production on a commercial scale by bacon processors.

<u>Irradiated Uncured Pork.</u>- Uncured pork products, such as pork loins, steam cooked or oven cooked to an internal temperature of 160°F.(71°C) are promising meat items which can be preserved by 4.5 megarads of ionizing radiation. As shown in Table 6, pork products so treated received preference scores of 6.4 to 6.7 after 20 months storage at 70°F(21°C) and were considered acceptable. Similar results were obtained with irradiated pork chops after 25 months storage.

The effect of activated charcoal, in the amount of 0.5 to 2.0 percent of the meat weight, as an odor scavenger in irradiated chicken, bacon, ham, pork and beef items, has been inconclusive[12].

Barbecued pork has also received acceptable organoleptic ratings (Table 7). Similar results were obtained with irradiated barbecued chicken and beef. Barbecued meats, preserved by sterilizing doses of ionizing radiation, are in the process of further technological development.

Present research on irradiated uncured pork items is concentrated on improving the texture, selecting the best blanching methods for enzyme inactivation, and the most convenient and efficient way of packaging the product prior to radiation.

Irradiated Ham.- 4.5 Mrad irradiated commercial hams have not always given a product which was acceptable after nonrefrigerated storage. Research is underway to determine the effect of various curing ingredients, smoke, internal temperature, and irradiation dose of 1.0, 1.5, 2.5, and 4.5 Mrads on postirradiation storage stability, chemical changes, and acceptance of the irradiated product. Since ham is a cured pork product, it may not require 4.5 Mrad for sterilization, as indicated in the case of bacon. Research underway can be expected to provide additional information on this point.

A few hams, irradiated at levels of 1.0 and 2.0 Mrad were tested after 18 months of nonrefrigerated storage. The hams were highly acceptable and contained no surviving anaerobes. Elevating the pH of commercial hams by FDA approved chemicals other than condensed phosphates reduced the irradiation flavor intensity in 4.5 Mrad irradiated samples. This is an encouraging finding and we are exploring it further.

Another finding of much interest resulted from experiments with "honey-glazed" hams. The honey-glaze mixture (honey, sucrose, and brown sugar) has certain inhibitory effects on the development of irradiation flavor and off-flavors in hams irradiated at 4.5 Mrad. However, preference tests run with oval canned hams, irradiated at 4.5 Mrad, resulted in higher ratings for smoked canned hams than for the honey-glazed item (Table 8). Apparently, the panelists did not like the slightly sweet taste of the product. The experiment will be repeated, but the smoked and honey-glazed hams will be served to panelists with a sweet raisin or pineapple sauce.

Much technological work is presently in progress on 2.5 Mrad irradiated hams. Commercial hams obtained from different producers vary in preference ratings after irradiation. For example, the so-called "Fully-Cooked Smoked Hams - Water Added" showed low acceptability after irradiation and storage (Table 9), although the non-irradiated controls all were rated acceptable. Research in progress on hams processed with six different curing mixtures should yield data to explain these differences in preference ratings.

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Irradiated Pork Sausage.- Prefried, canned pork bulk sausage patties irradiated with a 2.5 Mrad dose, received acceptable ratings by organoleptic taste panels after 6 months of nonrefrigerated storage (Table 10). The product irradiated at 4.5 Mrad had a low acceptance one week and 3 months after irradiation. Acceptance of all samples improved after 6 months storage. The experiment is still in progress.

Prefried pork sausage links were preferred by the taste panel members over the bulk sausage type. The 2.5 Mrad samples were comparable with the nonirradiated control one week after irradiation and after 2 months storage at 70°F(Table 11). The 4.5 Mrad irradiated pork sausage links had a slight irradiation off-odor, which disappeared at 2 months storage, resulting in an increase of the preference scores (Table 11).

Irradiation of pork sausage links at -40°F(-40°C) has a marked beneficial effect on acceptability of 4.5 Mrad samples one week after irradiation when compared with radiation at +35 and -10°F. The benefit of -40°F. irradiation on acceptance for the 2.5 Mrad treated product was not as pronounced. However, this beneficial effect of 4.5 Mrad irradiation was not noted after 2 months storage, whereas the acceptance of the +35 (1.7°C) and -10°F. (-23°C) irradiated samples increased by 1.0 point on the hedonic scale (Table 11). Further storage study of the product will provide additional data which should allow more definite conclusions regarding the advantages of -40°F irradiation temperature.

Although present data for radiation-sterilized pork sausage are limited, our experience with other pork products gives us confidence that irradiated pork sausage will be another meat item capable of being preserved by sterilizing doses of ionizing radiation.

Irradiated Chicken.- Development of enzyme-inactivated chicken parts (breast and thighs) is nearly completed. Results of a storage study (21 months at 70°F. and 100°F.) have confirmed previous results that chicken can be preserved by ionizing radiation and stored without refrigeration for a long period of time (Table 12).

Our current research has the objective of establishing the best blanching methods for chicken parts prior to packaging and irradiation. Results obtained so far indicate that any of the following short-time, high temperature blanching methods (to internal temperature of 180°F. (82°C) are satisfactory: low pressure steamer, autoclave, micro-wave oven; deep fat frying. The minimum vacuum requirements during can-closing, temperature during irradiation, the use of odor scavengers, controlled head space, etc., are other technological factors under investigation.

A petition to the FDA proposing clearance of 4.5 Mrad irradiated chicken parts, vacuum packed in "C" enameled metal cans will be submitted, according to present scheduling, in 1965. The inoculated chicken pack study now being conducted will complete the research necessary to petition the FDA.

Radiation-Sterilized Beef.- Investigations, both contractual and in-house have been directed toward obtaining acceptable irradiated beef items. It must be recognized that the development of acceptable irradiated beef still presents a problem. Irradiation of beef at 4.5 Mrad without temperature control during radiation treatment causes undesirable changes in texture, color, flavor, and appearance.

Recent work has indicated, however, that acceptable beef products can be achieved through low temperature irradiation(31). Texture deterioration during storage of irradiated beef caused by the action of proteolytic enzymes (cathepsins) has been prevented by thermal processing to an internal temperature of 170°F.(77°C). Irradiated low grade beef, such as U.S. Commercial, resulted in better products than high grade beef, such as U.S. Choice, particularly in texture.

Irradiation flavor intensity can also be decreased by employing proper technological measures. Addition of barbecue sauce was mentioned previously as a means of decreasing irradiation flavor. Additions of nitrite and nitrate also depress irradiation flavor. Unfortunately, the resulting product is pink, the characteristic color of corned beef, and hence use of nitrite and nitrate has its limitations.

Blanching beef in a smokehouse and in an electric oven, followed by irradiation in a frozen state (-40° and -60°F)(-40° and -51°C), has resulted in acceptable products (Commercial grade roast beef and beefsteak).

The products so treated received average preference scores in the acceptable range (6.1 to 6.9) on the 9-point hedonic rating scale. This rating indicates good acceptability. Some of our recent results on acceptability of irradiated beef items are given in Table 13.

Freezing of enzyme inactivated beef to -40 to -60°F prior to irradiation, followed by radiation treatment at room temperature in the Cobalt-60 cell while the product remained in the frozen state, improved the product significantly in comparison with the counterpart samples which were only chilled to +35°F. prior to irradiation. The large cobalt-60 source in the Radiation Laboratory (4.0 Mrad/hour dose rate) makes it possible to achieve a 4.5 Mrad absorbed dose before the food thaws. Additional improvement was achieved when the temperature during irradiation (-40 to -60°F) was controlled[31]. Present development work on beef is concentrated on determining an optimal subzero temperature for radiation treatment of beef to obtain acceptable products without an undue increase in process costs. The temperature range from +35° to -320°F (+2 to -196°C) is being investigated. Additional research in the field comprises such factors as beef grades and cuts, blanching methods, modification of pH, smoke application, use of various additives, and radiation processing of beef items after thermal treatment for enzyme inactivation below 170°F internal temperature.

We are confident that acceptable radiation-sterilized beef items can be obtained. It is recognized that much research and development work lies ahead before the technology and radiation-sterilization requirements for beef irradiated in frozen state will be fully worked out.

Acceptance Testing of Irradiated Foods

The primary objective of field testing and evaluation of irradiated foods thus far has been to determine relative consumer preference for items processed by this method.

At the beginning of the Army radiation project, acceptance testing of irradiated meats was confined mainly to small panels. Limited field testing of eight 4.5 Mrad irradiated foods (meats tested: bacon, pork, chicken, chicken stew) was conducted in 1958. The irradiated meats tested were judged as comparable in appeal to the corresponding fresh or frozen items. Beginning in June 1963, consumer preference tests of radiation-sterilized (4.5 Mrad) bacon, pork, and chicken, were conducted. All irradiated foods tested had been stored at room temperature for 4 to 5 months. Preference ratings for the experimental items were sufficiently high for all irradiated food items tested to be considered acceptable as components of standard meals. Prior knowledge that irradiated food items were being served had no effect on the consumer preference ratings. Irradiated bacon was slightly less acceptable than standard issue bacon. This difference, however, was thought to be partially due to high fat content in the lot of the irradiated bacon used in the test. A more rigid quality requirement in regard to the lean-fat ratio in bacon to be used for irradiation should eliminate these differences in the preference scores of irradiated versus standard bacon.

The effect of repetitive feeding of radiation-sterilized chicken parts was investigated under garrison mess-hall feeding conditions.

The test revealed that the consumer preference ratings for irradiated chicken and standard chicken were not significantly affected by the repeated consumption of these items once a week over a period of a month. It was concluded that the preference ratings for the irradiated chicken are sufficiently high for this product to be considered acceptable as a component of standard meals. Analysis of the data showed that the method of preparation had no significant effect (5 percent probability level) on the acceptability of either the irradiated or the standard chicken.

Another consumer feeding test was conducted using 2.5 Mrad radiation treated bacon and ham after 4 and 9 months of storage at ambient temperatures. Although the nonirradiated controls were preferred, the ratings for both the irradiated bacon and the irradiated ham were sufficiently high for both items to be considered acceptable as components of standard meals (24).

A consumer preference test for 4.5 Mrad irradiated pork sausage and beef was conducted. The sausage was of a bulk type, served as oven-fried sausage patties. Both the irradiated and nonirradiated sausage patties received low preference scores (25). Apparently, this kind of pork sausage has in general lower acceptance than sausage links. In future tests irradiated pork sausage links will be used instead. The irradiated beef which was served with a barbecue sauce on a bun was considered acceptable as a component of standard meals (25).

The results of the acceptance tests of irradiated meats are summarized in Table 14. These consumer tests on a variety of irradiated meats place firmly on record the fact that acceptable radiation-sterilized meats can be produced.

Our future plan provides for similar consumer tests on different radiation-sterilized meats during the next 5 years with emphasis on beef items irradiated in frozen state at controlled temperatures during irradiation. Additional tests will be run also on all meat items which received the average preference ratings of only 5 to 6 on the 9-point hedonic scale (Table 14). This will be done following additional development work on the products.

Economic Aspects and Commercial Adoption

Not withstanding technical feasibility the commercial feasibility must rest on economic considerations.

In June 1960, a comprehensive study was undertaken by the Operations Research Office of the John Hopkins University on the economic aspects of radiation-processed foods. The report on this study, published in August 1961 (29), indicates the estimated cost of radiation processing as being competitive with the cost of thermal canning, freezing, and freeze-dehydration processes. The processing cost for radiation sterilized canned meats was estimated to be from 1 to 6 cents per pound. The same researchers estimated the processing costs of other preservation methods. For thermally processed canned meats, they estimated a cost of 0.8 to 5 cents per pound, for frozen foods 2 to 3.5 cents per pound, and for freeze-dried foods 2 to 8 cents per pound. They also pointed out the additional economic advantage of irradiated foods over perishable fresh and frozen foods through lowered costs during storage, transportation and marketing because of savings in refrigeration.

The savings which might be achieved by eliminating or reducing the need for refrigeration could exceed processing costs. Refrigeration facilities, particularly at home, are not available or are inadequate in many countries of the world, even in some highly industrialized countries. For such countries, radiation sterilization of meats and other foods offers a challenging opportunity for preventing great losses of foods during seasons when they are most abundantly available. The radiation process could be the means for providing people with more and better quality foods throughout the entire year independently of the seasonal variations in the supply of raw food material. Therefore, the economic aspects of the radiation sterilization of meats should not be considered from the processing cost alone.

The economic data embodied in the Operations Research Office report were based upon a number of assumptions and predictions in the absence of processing data on a commercial scale. Among the factors considered were the projected cost and availability of radioactive isotopes such as cobalt-60 and cost and reliability of machine sources such as electron linear accelerators.

In the United States, both the Army and the Atomic Energy Commission are pushing research in food irradiation to the point where clearances by the FDA for a wide spectrum of commodities is expected to be obtained within a few years [15,33]. The programs of the Army and Atomic Energy

Commission are closely coordinated. The Army is concerned primarily with radiation sterilization of animal products; the Atomic Energy Commission with low-dose radiation preservation (pasteurization) of fruits, vegetables, and marine products. It is our expectation that the food processing and radiation sources industries will move rapidly ahead once clearances by the FDA are obtained to establish radiation food processing on a commercial scale. Only those commodities which are best preserved by radiation and are economically advantageous to produce will find their way into the homes of consumers. Radiation-sterilized and radiation-pasteurized meat and poultry appear to meet these criteria.

The competition between isotope and machine sources should further favor the economics of the radiation process. As machine sources are simplified and made more reliable and as their costs are reduced, there is further incentive to reduce the cost of isotopes. The machine and isotope rivalry is leading to more efficient source design which should further reduce processing costs. The expectation of a large commercial market for irradiated food, both domestic and foreign, is a great incentive; as markets expand, production of isotopes and machines will be increased, further reducing the cost of radiation sources.

The Army has recently initiated a study to be carried out by the U. S. Department of Commerce on the economics of radiation-sterilized meats and its prospects for commercial adoption. Similar studies on low dose treated foods, sponsored by the Atomic Energy Commission, have been conducted by the U. S. Department of Interior [18] and by the U. S. Department of Agriculture [7]. The economics of fish irradiation are reported to be favorable [18,33]. The fish industry has indicated that a radiation cost of one to three cents per pound could be tolerated and it is felt that this cost can be met [18]. Construction by the U. S. Atomic Energy Commission of a semiproduction facility, the Marine Products Development Irradiator, for radiation pasteurization with a capacity of processing approximately 1000 pounds of fish per hour, will be completed for the Bureau of Commercial Fisheries at Gloucester, Mass. this year [33].

The Atomic Energy Commission and several industrial concerns are working on designing commercial irradiators for radiation processing of various foods [2,3,5,33]. These are encouraging developments. Even so, the present semi-commercial efforts are concentrated on pasteurization of fish and fruits, insect deinfestation in grain, and sprout inhibition in potatoes. These efforts will undoubtedly be extended to radiation-pasteurization and radiation-sterilization of meats and poultry as soon as additional radiation-processed meat and poultry items receive the needed approvals from the FDA and the Meat Inspection and Poultry Divisions of the U. S. Department of Agriculture. It is planned to introduce into Army mess hall radiation-sterilized bacon in 1965, followed by radiation-sterilized chicken and ham by 1968. Civilian use of selected radiation processed meats and poultry should begin to be commonplace shortly thereafter. An educational program may be required to dispel certain prejudices consumers might have against the use of irradiated foods. The U. S. Atomic Energy Commission and the U. S. Department of Interior are planning to develop such educational campaigns (2).

All the evidence available at this time leads to the conclusion that the prospects for preserving meats, poultry, and other foods by ionizing radiations on a commercial scale are bright. It is predicted that by the end of this decade, and possibly sooner, radiation preserved meats and poultry will become abundantly available at a price the consumer will be willing to pay.

CONCLUSIONS

The U. S. Army's Radiation Preservation of Foods Program has demonstrated that processing meats and poultry with sterilizing doses of radiation is feasible. It has been demonstrated also that radiation sterilized meats and poultry are wholesome for human consumption and are well accepted when served as components of regular meals.

The clearance of the world's first radiation sterilized food, bacon, by the U. S. Food and Drug Administration for unrestricted public consumption on 8 February 1963, is a forerunner of things to come. There is now considerable assurance that other meat products and poultry sterilized by ionizing radiation will win approval from the U. S. Food and Drug Administration and the U. S. Department of Agriculture. Industrial approval - and utilization - can be predicted by the end of this decade.

We are on the threshold of a new era in food processing in which ionizing energy offers a great opportunity to improve the world food situation, particularly in the availability of animal protein, and thus the health and happiness of many millions of human beings.

In the meantime, the search for answers to unanswered questions will go on. Those working on the U. S. Army's Radiation Preservation of Foods Program are happy to have the opportunity to take an active part, along with our professional colleagues abroad, in developing further this new method of food preservation.

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TABLE 1

Effect of Blanching Conditions on Decomposition of the Connective Tissue in Beef, as Determined by the Hydroxyproline Method.-

Percent Hydroxyproline Extracted	U.S. Choice 180°/20 Hr. 17% RH	U.S. Choice 192°/6 Hr. 92% RH	Canner & Cutter 180°/20 Hr. 17% RH	Canner & Cutter 192°/6 Hr. 92% RH
(1) H_2O - Extn.				
Non-Irrad	10.2	5.1	7.9	11.0
Irradiated	44.5	15.1	33.2	10.1
(2) $H_2O + CaCl_2$ Extn.				
Non-Irrad	16.7	8.9	13.7	16.7
Irradiated	81.8	19.1	63.6	19.4

Wierbicki and Anderson (47)

TABLE 2

Extractive Data Obtained from Flexible Packaging Materials After Irradiation with 6.0 Mrad of Cobalt-60 Radiation

Material			Extractive Data (mg./sq. in.)				
No.	Composition	Treatment	Distilled Water(**) Total Solubles	Distilled Water(**) Chloroform Solubles	0.01N Acetic Acid(**) Total Solubles	0.01N Acetic Acid(**) Chloroform Solubles	n-Heptane(**) Total Solubles
1	High Density Polyethylene, 0.5 mil Aluminum Foil, 0.7 mil Low Density Polyethylene(*), 2.0 mil						
		Irradiated	0.02	0.01	0.52	0.01	1.67
		Control	0.04	0.01	0.03	0.01	0.16
		Difference	-0.02	0.00	0.49	0.00	1.51
2	29 lb. Paper Aluminum Foil, 0.3 mil Polyester and M.d. Polyethylene(*), 4.5 mil						
		Irradiated	0.02	0.01	0.49	0.01	0.47
		Control	0.03	0.01	0.02	0.01	0.25
		Difference	-0.01	0.00	0.47	0.00	0.22
3	20 lb. Paper Aluminum Foil, 0.3 mil Polyester and M.d. Polyethylene(*) 2.0 mil						
		Irradiated	0.02	0.01	0.33	0.01	0.32
		Control	0.01	0.01	0.05	0.01	0.13
		Difference	0.01	0.00	0.28	0.00	0.19
4	Polychlorotrifluorothylene(*),0.5 mil						
		Irradiated	0.03	0.01	0.45	0.01	0.12
		Control	0.02	0.01	0.02	0.01	0.01
		Difference	0.01	0.00	0.43	0.00	0.11
5	Mylar, 0.5 mil Aluminum Foil, 0.35 mil Polyvinyl Chloride(*) 2.0 mil						
		Irradiated	0.06	0.01	0.58	0.01	2.22
		Control	0.06	0.01	0.03	0.01	2.00
		Difference	0.00	0.00	0.55	0.00	0.22

(*) Food Contacting Films (M.d. = Medium Density)

(**) Neutral, acid, and fatty foods simulating solvents, respectively.

TABLE 3

Mean Preference Ratings for Irradiated Bacon

4.5 Mrad Bacon

Storage Time Months	Storage Temperature 70°F	100°F
0	7.2	7.0
1	7.1	7.0
4	7.0	7.0
9	7.0	7.0
16	6.9	6.6
25	6.8	6.2

2.5 Mrad Bacon

Months at 70°F	Comm. #1	Comm. #2	GI-Bacon
1	6.05	6.90	6.65
3	6.55	6.32	7.36
6	6.75	7.05	6.70

20 Panelists (Ref.12, 49).

TABLE 4

Effect of Storage on TBA Values of
Non-Irradiated and Irradiated Bacon

Storage Time (Months)	Bacon Samples			
	A	B	C	D
0	0.71	0.88	0.98	0.15
1	0.34	0.13	0.37	-
6	0.86	0.06	0.10	0.16
12	0.21	0.22	0.23	1.74

(*) Sample Variables: (applicable also to Table 5)

Sample	Irrad. Dose (Mrad)	Storage Temp. °F
A	4.5	72
B	4.5	100
C	2.5	72
D	0.0(Control)	-20

Warnecke et. al. (43)

TABLE 5

Effect of Storage on Free Fatty Acids and Non-Protein Nitrogen of Non-Irradiated and Irradiated Bacon

I. Free Fatty Acids

Storage (Months)	Oleic Acid, % Total Fat			
	A	B	C	D
0	1.33	1.36	1.39	1.22
1	1.93	2.78	2.47	-
6	6.40	9.60	4.80	0.60
12	6.37	12.43	12.46	0.88

II. Non-Protein Nitrogen

Storage (Months)	NPN, % Total N			
	A	B	C	D
0	10.3	9.7	11.2	9.7
1	10.2	16.1	10.4	9.1
6	19.2	26.5	14.6	8.6
12	12.9	14.5	15.7	8.9

Warnecke _et al_ (43)

TABLE 6

Mean Preference Ratings for 4.5 Mrad Irradiated Pork Loin.-

Months at 70°F	Preference Scores	
	Steam Cooked	Oven Cooked
0	6.4	6.6
5	6.2	6.4
10	7.4	7.3
16	7.0	7.2
20	6.4	6.7

36-40 Panelists: Heiligman (12)

TABLE 7

Mean Preference Ratings for 4.5 Mrad Irradiated Pork in Barbecue Sauce.-

Months at 70°F	Preference Scores	
	Sample A	Sample B
1	6.4	7.3
3	6.6	7.3
6	6.9	6.9
12	6.5	6,8
18	6.5	6.2

40 Panelists: Heiligman (12)
Sample A - 6 oz. barbecue sauce per 22 oz. pork
Sample B - 10 oz. barbecue sauce per 18 oz. pork

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TABLE 8

Preference Ratings for 4.5 Mrad Irradiated

Canned Hams: Smoked versus Honey-Glazed

Weeks at 70° F.	Smoked Canned Ham		Honey-Glazed Ham	
	Mean	SD	Mean	SD
2	6.38	1.46	7.00	1.90
4	7.15	1.42	7.15	1.00
12	6.18	1.80	6.76	2.00
24	7.20	0.79	5.80	2.60

17 Panelists
SD = Standard Deviation

TABLE 9

Mean Preference Ratings for 2.5 Mrad

Irradiated Hams of Three Different Commercial Brands

Weeks at 70° F.	Brand #1		Brand #2		Brand #3*	
	Mean	SD	Mean	SD	Mean	SD
1	6.79	1.39	6.84	1.51	5.21	1.59
3	6.86	1.46	6.07	2.05	5.50	1.54
6	7.47	0.77	6.07	1.54	4.53	1.31
12	6.47	1.00	7.12	1.23	3.70	1.61
26	6.85	1.35	6.95	1.50	4.10	1.62

*"Water Added" Ham
15-20 Panelists

SD = Standard Deviation

TABLE 10

Mean Preference Ratings for Prefried Irradiated Pork Bulk Sausage Patties

Commercial Product No.	Irrad. Dose Mrad	Storage at 70°F 3 Months	Storage at 70°F 6 Months
1	0.0	6.1	6.7
	2.5	6.3	7.0
	4.5	4.8	5.2
2	0.0	7.2	7.3
	2.5	5.7	7.0
	4.5	5.3	6.5

20 Panelists

TABLE 11

Mean Preference Ratings for Prefried Pork Sausage Links Irradiated at Different Temperatures

Irrad. Temp. °F	2.5 Mrad 1 Week	2.5 Mrad 2 Months	4.5 Mrad 1 Week	4.5 Mrad 2 Months
+35	7.3	7.0	5.4	6.6
-10	7.1	7.0	5.6	6.6
-40	7.6	7.2	6.4	6.7

Non-Irradiated Control

1 Week - 7.3
2 Months - 7.1

Storage Temperature:

Control Samples, -20°F

Irradiated Samples, +70°F

TABLE 12

Mean Preference Ratings for 4.5 Mrad Irradiated Chicken Parts

Months of Storage	Storage Temperature 70°F	100°F	Non-Irradiated -20°F
0	7.0	7.4	7.2
3	7.4	7.1	7.2
6	7.3	7.0	7.4
12	7.1	7.6	7.1
18	7.6	7.3	7.3
21	7.4	6.4	6.7

36 Panelists: Heiligman (12)

TABLE 13

Preference Ratings for 4.5 Mrad

Irradiated Beef Items

Sample No.	Product	Weeks at 70° to 75°F.	Number of Testers	Preference Mean	Preference SD
A	Beefsteak (with gravy)	5	33	6.9	1.8
B	Roast Beef (with gravy)	4	29	6.7	1.7
C	Roast Beef (with gravy)	6	20	6.8	1.3
D	Roast Beef (with BBQ)	4	38	6.9	1.4
E	Roast Beef (with BBQ)	5	10	6.6	-
F	Beef (Sukiyaki)	10	20	7.9	0.72

Temperature before irradiation = -60°F.
Temperature after irradiation = 28° to 32°F.

Wierbicki and Heiligman[49].

TABLE 14

Acceptance of Irradiated Foods:

Mean Preference Ratings

Food Item	Dose Mrad	Number Subjects Tested	Scores		Year
			Irrad.	Control	
Bacon:					
Oven fried	4.5	60	7.82	7.98	1958
Baked	4.5	282	5.62	6.52	1963
Baked	4.5	274	5.57	6.53	1963
Baked	2.5	586	5.59	6.02	1964
Pork:					
Roast	4.5	60	7.82	7.98	1958
Roast, BBQ	4.5	60	7.80	7.82	1958
Grilled Chops	4.5	255	7.06	7.21	1963
Grilled Chops	4.5	305	7.27	7.28	1963
Chicken:					
Stew	4.5	104	7.37	7.58	1958
Breaded-baked	4.5	101	7.38	7.95	1958
Fried	4.5	215	6.77	7.21	1963
Fried	4.5	236	6.66	7.18	1963
Southern fried	4.5	383	5.73	6.52	1963
Oven fried	4.5	397	5.55	6.65	1963
Barbecued	4.5	196	5.58	6.41	1963
Ham:					
Baked	2.5	531	6.53	7.20	1964
Pork Sausage:					
Oven fried patties	4.5	489	5.16	5.82	1964
Beef:					
Sliced BBQ beef on bun	4.5	515	6.11	6.79	1964