



RADIATION PRESERVATION:
ITS TECHNOLOGY AND POTENTIAL
FOR BEEF PROCESSING

by

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PREFACE

This thesis involves a study of irradiation preservation and its potential as a method for beef processing. No attempt is made to consider the many potential applications of irradiation to the entire field of food processing.

Rather, an attempt is made to explain the technology and potential of irradiation in the field of beef processing. An attempt is also made to project the effects that irradiation processing, once it is perfected, will have on the distribution and merchandising of beef in supermarkets.

The writer, having been a supermarket manager and planning to make a career of supermarket merchandising and management, is interested in determining the potential effect irradiation processing will have on the sale of beef through supermarkets. Since beef is a high tonnage item for supermarkets, any technological development that will reduce the cost of distributing it or increase total sales volume should be of interest to persons throughout the industry.

Although very little work has been done on the commercial application of irradiation to beef processing, the extensive amount of research conducted in an effort to improve military rations has provided much valuable information concerning the effects of irradiation on beef. This paper is a consolidation of some of the information gained from this

research in a manner that should be helpful to supermarket management in formulating policies that will allow them to realize the full potential of irradiation processed beef once it is commercially available.

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No thesis is the product of one individual. Many persons provided research material or revealed sources of information of which the writer was unaware. He is grateful to all those who have assisted in any way.

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INTRODUCTION

Spoilage of foods by micro-organisms has always been a serious problem. Throughout the ages, man has devised various methods for prolonging the storage life of perishable foods. Many methods of food processing have been designed to prevent or delay microbial spoilage, such as drying, salting, canning, cooking, fermenting, and freezing. As a result of extensive research, observation and practical experience in these various methods of processing, the commercial food packers can preserve most foods today for an almost indefinite period without seriously affecting either their quality or palatability. However, the problem of extending the storage life of fresh meat, poultry, and fish while retaining sensory properties of fresh products is yet to be solved.

The conventional methods of food preservation produce many undesirable changes in fresh beef. Those methods that produce the least undesirable changes in the beef have other limitations. Freezing, for instance, requires continuous application of the process or the food decomposes. Pickled products are but temporarily preserved. Chemical additives, by the nature of the additive itself, in most instances are objectionable additions to the diet. Radiation may enjoy a special position in preserving, disinfecting, and stabilizing man's beef and its products.

The Problem

Fresh beef accounts for a major portion of the meat department sales in the average supermarket today. Any technological development that will extend the storage life, reduce distribution costs, or enlarge the market area for this high volume product is of extreme interest to members of the food industry. Supermarket management must keep abreast of technological developments in order to utilize these developments in retail store operation. The specific problem of this paper is to analyze the potential of irradiation as a means of achieving more economical sales of beef in supermarkets.

Objectives

Distribution costs continue to rise in the food retailing industry. The physical handling and risk of loss due to perishability in the marketing of beef, a high tonnage item, are significant contributors to these costs. The objectives of this study are to determine: (1) The technical feasibility, (2) the economic potential, (3) the chief restrictions to implementation, (4) the most likely application, and (5) the possible effect irradiation preservation of beef may have on the distribution of beef through supermarkets.

Hypothesis

Realizing that much additional work must be done before irradiation is commercially applicable to beef processing, it is hypothesized that irradiation will have its most immediate

application through the use of pasteurization dosages to extend the storage life of the fresh product under refrigerated conditions. It is further hypothesized that irradiation pasteurization, once perfected, will be an aid to central meat cutting operations of supermarket chains.

Approach

The limited number of books that have been written on irradiation preservation of food were reviewed to establish the technology of the process. The most prolific sources of information were current periodicals and reprints of progress reports issued by various research groups that have performed research for the Quartermaster Corps. In addition, the Quartermaster Corps and the Atomic Energy Commission supplied much valuable information gathered from their extensive research projects.

An attempt has been made to consolidate a large amount of technical material into a paper that can be read and understood by laymen. For this reason the main text of the paper is void of detailed analysis of specific experiments. Results of specific experiments are contained in the appendix and even these are concerned more with end results than with the technicalities of conducting the experiments.

Limitations of the Study

Research is limited by the quantity of available information relating to the scope of the study. Although research on irradiation has been underway for a number of years and

beef has received more emphasis than most other food products, much more detailed research is needed before irradiation treatment of beef is commercially adaptable.

Material contained herein is an agglomeration of bits of information secured from a variety of sources plus a measure of personal speculation. The author bears full responsibility for any shortcomings and opinions expressed.

CHARACTERISTICS OF BEEF IMPORTANT TO THIS DISCUSSION

Marketing

The job of supplying beef for 135 million consumers is the business of 3½ million farmers and ranchers and thousands of marketing agencies. The production and marketing process is indeed complex. It consists of many different and necessary jobs to move beef from the farms into the hands of consumers at the time and place and in the form they desire.¹

Any technological development that will aid in supplying the consumer with a product as good or better than is now available, at a competitive price, should be welcomed by the various marketing agencies and producers.

Definition of Beef

Beef is described as "the edible portion of the muscle of cattle."² The term "fresh" is used to describe meat which has not been preserved with any additive or cooked in any way.³

¹"Meat," Collier's Encyclopedia, 1955 ed., Vol. XXIII, p. 287.

²Lloyd B. Jensen, Meat and Meat Foods (New York: Ronald Press Company, 1949), p. 10.

³Morris B. Jacobs, The Chemistry and Technology of Food and Food Products (New York: Interscience Publishers, Inc., 1951), p. 201.

Composition

The principal constituents of beef are water, protein, fat, and minerals. Small quantities of glucose, glycogen, and lactic acid are also present. Lean beef is a highly nutritious human food containing approximately 25 per cent high-quality protein and the necessary B vitamins and minerals. Higher grades of beef have a lower percentage of protein due to their higher fat content.¹

Color

Beef is usually thought of as having a brilliant red color. This color is due to the presence of two basic molecular pigments--hemoglobin and myoglobin. Myoglobin acts in the living animal as a storage mechanism for oxygen while hemoglobin acts as a transport mechanism.²

Oxygenation, forming a bright red pigment, occurs when meat is cut and exposed to the air. As time passes iron atoms present in the meat oxidize and form Fe_2O_3 , changing the color from deep purplish red to brown within about 72 hours. This oxidization makes the meat less eye appealing to potential customers although it does not affect the quality in any way.³

¹"Beef," McGraw-Hill Encyclopedia of Science and Technology, 1951 ed., Vol. II, p. 561.

²"Foods," Kirk and Othmer Encyclopedia of Chemical Technology, 1952 ed., Vol. VIII, p. 325.

³American Meat Institute Foundation, The Science of Meat and Meat Products (San Francisco: J. H. Freeman and Company, 1960), pp. 33-34.

Other Characteristics

Other than a pleasing color, beef must have other attributes, such as freshness, palatability, and nutritional value to make it a desirable food. Freshness basically means that decay caused by bacteria has not caused putrefaction. Palatability and nutritional value are factors described in terms of tenderness, taste, moistness, flavor, and those qualities of vitamins, minerals, and other body-building values.¹

Distribution Costs

Slaughtering the beef steer, processing and wholesaling the beef carcass, and retailing the fresh beef carcasses constitute the major distribution expenses encountered in the marketing of fresh beef. The costs of marketing beef are related to the channels through which the animals move, and to the marketing services provided.

U. S. Choice grade beef accounts for about half of the total U. S. supply of block beef for which adequate statistical data are available for study. Only approximately 25 per cent of all beef is sold as processed meat; therefore, the marketing costs for beef sold in fresh form are very significant factors in the beef industry.

About 59 pounds of carcass beef are obtained from 100 pounds of live steer of U. S. Choice grade and about 80 per cent of the U. S. Choice grade carcass is saleable retail cuts.

¹Frank E. Halleck, "Factors Affecting Quality of Pre-packaged Meat," Food Technology (June, 1958), p. 305.

The remaining 20 per cent of the carcass represents fat, suet, bone, and trim which does not move over the retail counter. Retail composite prices are derived from the prices obtained from individual retail cuts of beef. Since only about 46 or 47 pounds of saleable retail cuts of beef are obtained from 100 pounds live weight of U. S. Choice grade steer, additional losses in weight and value of the product resulting from spoilage can be very significant.¹

The additional losses in weight and value of the product from spoilage and salvage selling are not actually known. The USDA estimated them at 3 to 5 per cent of retail sales in a study involving beef marketing margins and costs in 1956.² If only half of these thousands of pounds of fresh beef which are lost due to spoilage every year were saved by the use of irradiation treatment, the farmer, the processor, the retailer, and the consumer would all benefit.

¹It takes approximately 2.16 pounds of Choice grade live cattle to yield one pound of U. S. Choice grade beef at the retail store.

²U. S., Department of Agriculture, Beef Marketing Margins and Costs, Agriculture Marketing Services (Washington: U. S. Government Printing Office, February, 1956), No. 710, p. 15.

TECHNOLOGY OF IRRADIATION PRESERVATION

Introduction

Until the advent of radiation, no new method of preserving foods had appeared since the discovery of canning in the early 19th century.¹

Various speculations were made during pre-war years that ionizing radiations might be used for preserving foods. The French filed a patent as far back as 1929. Only since 1947, however, has research been intensive. The majority of research has been done by or in conjunction with government agencies in the United States, Canada, and Great Britain.²

Irradiation preservation is still in the developmental stage and although beef has received more attention than any other meat, much additional research is necessary before beef preserved by irradiation treatment will be available for retail selling in the supermarkets. The present status of irradiation preservation is reviewed and some of the major problems inherent in its implementation are discussed in the following pages.

¹Norman W. Desrosier and Henry M. Rosenstock, Radiation Technology in Food, Agriculture, and Biology (Westport, Connecticut: The AVI Publishing Company, Inc., 1960), p. 257.

²R. S. Hannan and M. J. Thornley, "Radiation Processing of Foods," Journal of American Dietetic Association, XXXII (1958), p. 457.

Definition

Irradiation preservation makes use of the ionizing effects of fast moving sub-atomic particles or electromagnetic waves which are energetic enough to strip electrons from the atoms or molecules of matter. Ionizing radiation is produced in three different classes of naturally radioactive materials: (1) Alpha particles, (2) beta rays, and (3) gamma rays which like the better known X-rays are highly energetic electromagnetic waves. Protons, the ultimate units of gamma rays or of X-rays have energy levels in the range of one Mev (one million electron volts), compared to the binding forces of valence electrons in atoms or molecules which are of the order of only 10 electron volts.¹

It is the electrically charged particles that produce the overwhelming preponderance of the acts of energy-transfer which give ionizing radiations their significance in technology. When swiftly moving electrons, alpha particles, protons or deuterons penetrate matter, the molecules near which they pass are subjected to an intense electrical force which is devastating.²

In contrast to the process of life involving relatively low turn-overs of energy and a high degree of self-regulating harmony, ionizing radiation conveys huge packets

¹Ferdinand P. Mehrlich, The Current Outlook for Radiation Processed Foods. A speech presented at the 15th annual meeting of the Research and Development Associates, Richmond, Virginia, April 4, 1961.

²R. L. Plazman, "What is Ionizing Radiation?" Scientific American (March, 1951), p. 75.

of energy and upon interaction with living matter provokes anarchy. In every case the ultimate damage arises from injury done to the individual cell. Such injury causes lethal malfunctions through destruction of the permeability of cellular membranes permitting the interaction of enzymes and substrates in unwanted ways. This undesirable interaction produced by ionization leads to the destruction of microorganisms and can also render enzymes ineffective, thus extending the product life for a longer period.¹

Measurement of Radiation Dose

Two types of units are in common use for measuring radiation used in food preservation: (1) Electron-volts--a measure of the intrinsic energy of each particle of the radiation. The significance of radiation treatment is seen most easily with this measurement since, in effect, it indicates the velocity of each particle and hence its penetration. Energy for food processing is limited to about 10 Mev if induced radioactivity is to be avoided. (2) Rad--the quantity of radiation energy absorbed by a medium in any given time. A rad corresponds to an absorption of 100 ergs per gram of material. Another unit of measurement, the rep (Roentgen equivalent physical), was widely used until recent years. Because rep has different meanings to people of different countries, and because it is similar to rad, it has lost its

¹A. Hollaender and G. E. Stapelton, "Ionizing Radiation and the Living Cell," Scientific American (March, 1953), p. 95.

popularity as a unit for measuring radiation dosage.¹

Electron-volts, abbreviated ev, and rad will be used throughout this paper when referring to dosages.

Sources of Energy

There are two methods for securing radiation energy for use in food preservation. First, electrical devices may be used to produce X-rays or cathode rays. Several types of machines have been designed, the linear accelerator generating an electron beam, being the most suitable for securing appreciable penetration. Ample electrical power can be delivered by these machines for treatment of food in quantity. Most of the present commercial models have a power output sufficient to treat about one ton of food per hour with pasteurizing doses and higher powered models are under development. Second, naturally radioactive materials, such as spent fuel rods or radioisotopes such as Cobalt-60, may be used for securing gamma and beta rays. Since the intensity of radiation from these materials declines rapidly, the preferred source for industrial use is obtained by the chemical extraction of nuclear fission products in used fuel rods to give the isotope, Cesium-137. Cesium-137 has a long half life, over 30 years, and emits a penetrating radiation.²

Construction of an elaborate extraction plant is

¹Hannan and Thornley, "Radiation Processing of Foods," p. 457.

²Ibid., p. 459.

necessary to secure Cesium-137. The complex operation of the extraction facility requires a large number of technically trained personnel. These factors make the use of naturally radioactive materials more costly than machine produced radiation at the present time.¹

Regardless of the source used, ample protection must be provided for operators working with high energy radiations. Machine produced energy has a definite advantage in this respect, since the machine can be turned off and rendered harmless when not in use.

The above sources are similar in their application to food processing except for differences in penetrating ability of the various rays as shown in Table 1.

TABLE 1

USEFUL PENETRATIONS ACHIEVED WITH DIFFERENT
IONIZING RADIATIONS USING TYPICAL
IRRADIATION SOURCES

	Irradiation Source	Useful Penetrations in Inches	
		Irradiation from one side	Irradiation from both sides
Gamma rays	Cobalt-60	4.0	16.0
X-rays	50 kev	0.05	0.2
Cathode rays	1 Kev	0.1	0.3
	5 kev	0.7	1.7
	10 kev	1.5	3.4
Beta rays	Strontium-90	0.05	0.1

Source: R. C. Hannan and H. J. Thornley, "Radiation Processing of Foods," p. 452.

¹Ibid.

The deeper penetrating ability of high energy gamma rays and X-rays make them suitable for treating foods of considerable thicknesses, such as beef in either wholesale or retail cuts.

Application of Ionizing Radiation to Beef Processing

Ionizing radiation can be utilized in beef processing in two principal ways: (1) Sterilization--the destruction of all spoilage micro-organisms present, leading to a sterile product that may be stored for extended periods of time without refrigeration; (2) pasteurization--the destruction of a sufficient number of spoilage micro-organisms to produce an extension of product life under specified conditions such as refrigeration.¹

The amount of radiation required to produce sterility is not known with a high degree of preciseness at this time. It is known that the radiation sensitivity of various bacteria is different. In general, spores are much more radiation-resistant than are vegetative forms. Apparently, the most radiation-resistant micro-organism commonly occurring in meat is Clostridium botulinum. The best estimate for the sterilization requirement for this micro-organism using radiation alone in a non-acid, low-salt medium, such as fresh beef, is 4.8 million rads.²

¹W. W. Urbain, Irradiation for the Meat Industry. A speech presented at the Tenth Research Conference sponsored by the Research Advisory Council of the American Meat Institute at the University of Chicago (March 27-28, 1958).

²Ibid.

The use of salt, spices, and additives and improved techniques both in irradiation and measurement of dosage indicate that the sterilizing dose for non-acid materials may be 20 per cent lower than previously assumed. The real value then appears to be approximately 3.6 to 3.8 megarads.¹ Regardless of what figure is finally settled on as the sterilization requirement of beef, one can state at the present time with reasonable certainty that a substantial amount of irradiation will be needed. This is significant in that ionizing radiation induces certain changes that affect the sensory properties of beef so treated. The most notable change is a change in flavor and beef is apparently more sensitive to this change than are other fresh meats. It has been found that the degree of foreign flavor varies in proportion with the amount of radiation used.²

A major area of concern for sterilized beef is the inactivation of the enzymes. It has been shown that very large amounts of radiation are required to produce complete destruction of micro-organisms and even larger amounts are required to inactivate enzymes. It is generally conceded that irradiation cannot be used to produce enzyme inactivation because of the undesirable changes in sensory properties resulting from the large radiation dose. Storage

¹Mehrllich, The Current Outlook for Radiation Processed Foods, pp. 10-11.

²Urbain, Irradiation for the Meat Industry, p. 9.

tests on meats irradiated with quantities sufficient to destroy only the micro-organisms have shown evidence of enzyme activity in the production of off-flavors and in the growth of crystals of the amino acid, tyrosine, on the surface of the meat. Present thinking is that heat will be required to inactivate enzymes leading to the immediate conclusion that sterilized beef will probably be cooked beef.¹

Because of the undesirable changes in the sensory properties of beef sterilized by irradiation treatment, pasteurization treatment requiring a lesser dosage appears more feasible. As with sterilized foods, one of the most important pieces of information to be determined for pasteurized products is the dose requirements. This appears to be better known, although it is necessary to specify the intended use and life of the product in order to be able to specify precisely what dosage is required.

The major spoilage micro-organisms present in fresh beef are Pseudomonas reticulata. Although some substance present in meat juices partially protects this micro-organism against gamma radiation, it is still relatively sensitive to radiation. Because of the sensitivity of these micro-organisms to irradiation, it appears that approximately 100,000 rads is a useful dose on fresh meat.²

¹Ibid.

²Doty, Schweigert, Niven, and Kraybill, *Ionizing Radiations for Meat Processing* (Chicago: American Meat Institute Foundation, January, 1956), p. 13.

Bacterial growth will be sufficiently impeded by a dosage of 100,000 rads so that, at the end of two or three weeks, microbial spoilage has not occurred. This amount of radiation is sufficiently small to impart little or no off-flavor. Consequently, off-flavor problems with pasteurized meats are at a minimum. However, the objective is to obtain a product stability with respect to all desirable properties. It has been found that discolorations, in particular, occur at refrigerator temperatures in a matter of a few days. This fact so limits the life of the product from a saleability standpoint that such pasteurized fresh meats have little commercial value at the present time. It may be that, by using radiation in combination with other treatments, the desirable properties of fresh meats can be maintained for a sufficiently long period so that utility exists.¹

¹Urban, Irradiation for the Meat Industry, p. 10.

THE FEASIBILITY OF USING IRRADIATION IN BEEF PROCESSING

Introduction

Before any technological development can be promoted commercially, its technical and economic feasibility must be determined. In the case of irradiation, such factors as sources of radiation energy, facilities for performing the treatment, the expected cost of the process, and the effect the process has on the sensory properties of the beef must be considered. The following pages contain a general analysis of all these factors. For a more detailed review of specific experiments and the effect on sensory properties, see the appendix.

Availability of Energy Sources

The United States' program for the radiation processing of food was an outgrowth of nuclear reactor development. The availability of large amounts of radiation from fission by-products resulted in a search for possible utilization of this otherwise unused energy. In 1957, a United States Atomic Energy Commission sponsored survey indicated that a successful process for preserving food by irradiation would provide an important outlet for such products and improve

the nutritional and public health characteristics of the diet.¹

The commercial use as sources of gamma radiation of fuel elements during their "cooling" period will, in part, depend on the availability of sufficient quantities of these in steady supply. Although the supply appears plentiful at the present time, supplies of the future will be governed by other uses for reactors, probably the generation of electric power. The utilization of reactors designed specifically for food irradiation, either in whole or part, awaits technological advances as well as economic justification.²

With fresh fuel elements a few days after they are removed from a reactor, it is possible, with a suitable array, to sterilize a 6-by-7 inch package of beef with ionizing radiations in a matter of minutes. A steady stream of such packages could be processed. A half carcass of beef in a suitable container that would prevent post treatment contamination could be sterilized in a similar time provided that the array of elements of sufficient activity and configuration is accumulated. For pasteurization dosages the process could be speeded up considerably and fuel elements

¹Paul C. Aebersold, The USA Research Program on Low Dose Radiation Processing of Food. A speech presented at the Symposium on Isotopes Applications, Tenth Pacific Science Congress, Honolulu, August 30, 1961, p. 2.

²Urbain, Irradiation for the Meat Industry, p. 3.

of lesser activity could be used.¹

Another and presently more economical energy source is available from high voltage electron-beam generators. There are three basic types of generators which can be considered: (1) the resonant transformer, (2) the Von de Graff generator, and (3) the linear accelerator. As mentioned earlier, the linear accelerator appears to possess the greatest potential because of its ability to produce the much higher voltages necessary for greater penetration. There are electron-beam generators available today which can be built or selected for the type of radiation process contemplated in any particular instance.

Availability of Irradiation Processing Facilities

No commercial facilities are available presently and cannot be expected until many technical problems inherent in irradiation processing have been solved. Numerous irradiation research facilities have been erected for purposes of studying these problems and refining the irradiation processes. The largest of these, the Quartermaster Radiation Facility, is scheduled for completion at Natick, Massachusetts, by August, 1962.²

Once the technical problems have been solved and irradiation processing becomes economical, commercial facilities

¹Norman S. Desrosier, The Technology of Food Preservation (Westport, Connecticut: The AVI Publishing Company, Inc., 1959), p. 365.

²Sherrill, The Current Status of Food Irradiation Processing, p. 14.

of various types can be constructed to satisfy specific requirements. A study has been made and additional studies are being conducted relative to the design requirements of transportable irradiators as well as central plant facilities.¹

Results of Tests to Date

The results of work to date were thoroughly covered by Walter M. Urbain of Swift and Company as follows:²

1. Radiation can destroy micro-organisms responsible for spoilage.
2. With the allowances for differences in penetration and absorption, electron beams and gamma radiations or X-rays have similar if not identical action.
3. The amount of radiation required to control a particular spoilage agent varies with the agent over a wide range from about 10,000 to 1,500,000 rads. With regard to control of spoilage by bacteria, two areas of application exist: (a) destruction of all organisms present (sterilization) and (b) partial destruction (pasteurization), the former leading to essentially unlimited preservation and the latter to limited extension of product life.
4. The amounts of radiation to inactivate enzymes exceed by a substantial margin those needed for any other spoilage agent of a biological nature, and, from a practical viewpoint are too great to allow the use of radiation as a means of control.
5. Radiation can produce changes in taste, appearance, and texture of the food. The exact effect depends upon the amount of radiation and the conditions of treatment.

¹Heberfeld, The USA Research Program on Low Dose Radiation Processing of Food, p. 9.

²W. M. Urbain, Progress and Problems in Radiation Processing of Food. A speech presented at the Nuclear Engineering and Science Conference, New York, April, 1960, pp. 3-4.

6. While inadequately evaluated at present, the consumer acceptance of foods irradiated at sterilization levels may be considered to be generally low. At less than sterilization levels, however, many foods are acceptable.
7. Certain levels of energy of both electron beams and gamma rays can induce radioactivity in foods; on the other hand it is possible to select useful limits which avoid this effect.
8. Based on information available, wholesomeness of irradiation foods appears to be satisfactory.
9. Nutritive value seems to undergo small alterations, certainly none that has importance in the normal use of foods.

Beef treated with sterilization dosages has been subjected to various chemical studies to ascertain the chemical changes that occur during irradiation. These studies have been correlated with taste panel evaluations resulting in considerable progress in the determination of the nature of off-flavor and odor constituents. Unfortunately, however, no simple technique to prevent the occurrence of these off-flavors and odors has as yet been devised. Several factors appear to be helpful, including irradiation at low temperatures, keeping oxygen away during and after irradiation, and inactivation of proteolytic enzymes by heat prior to irradiation. Many of these undesirable odor and flavor changes can be masked by the addition of additives or by dilution.¹

In addition to flavor and odor other sensory characteristics may be altered by irradiation. Color alterations are

¹ L. S. Schweikert, "The Present Status of Irradiation of Foods in the U.S.A.," International Journal of Applied Radiation and Isotopes, June, 1959, p. 177.

frequent. At relatively low levels raw beef will be browned, but at higher levels (several million rads) the normal red color returns and may be intensified. Cooked beef, on the other hand, turns pink when irradiated in the absence of oxygen. Texture of foods may likewise be altered, becoming quite tender when exposed to several million rads.¹

Costs of Irradiation Treatment

One cannot have a discussion on irradiation without some analysis of the economics of the process. Furthermore, any potential savings on present processes realized from irradiation must be considered in connection with the costs of the irradiation treatment itself. It is possible today to calculate costs for treatment of foods with electron beams. Machines for generating these beams exist and can be purchased at known prices; their operating characteristics and costs are known.

The costs can be expressed conveniently in terms of a million rad pounds (megarad) units. Costs such as are available, however, must be considered as estimates, since actual commercial experience is lacking. Further, generator costs are based on today's prices, which may be high because of low volume production of these units. In arriving at costs, the assumption is made that efficient utilization of the equipment is possible; that is, that the process allows this, and the volume of product available to be treated

¹Urban, Progress and Problems in Radiation Processing of Food, pp. 6-7.

permits a high use factor. With such considerations one arrives at costs as low as 0.25 per cent per megarad pound and as high as 10 cents per megarad pounds, depending on the electron generator chosen. At the present time, the statement "from a fraction to a few cents per pound" is the best estimate. Actual experience with the process and the equipment in a commercial operation is needed to define costs more closely.¹

A projection of current charges for isotopes, such as Cobalt-60 and Cesium-137, to their ultimate costs, assuming large scale production, shows that costs for Cobalt-60 will be substantially higher than exist today for electron generators. Projections for Cesium-137 indicate the possibility of costs competitive with some electron generators.² Table 2 shows the cost per pound of preserving meat by various processes.

Extension of Storage Life

In its highest stage of perfection, radiation sterilization would permit the preservation of beef indefinitely, theoretically forever, without any supplementary preservatives, such as refrigeration. This would be possible providing packaging is available to prevent post-irradiation contamination and enzymes have been deactivated by either irradiation or some other means.

¹Urban, Irradiation for the Meat Industry, p. 10.

²Ibid.

TABLE 2

COMPARATIVE COSTS OF CANNING, FREEZING, AND IRRADIATING MEATS

Cost Elements	Irradiating Costs ^b , cents/lb.				Thermal Costs, cents/lb. (Standard Retorts)	Freezing Costs, cents/lb. (Flat Freezers)
	Electron Accelerator		Cesium-137			
	105 rad	300 rad	105 rad	300 rad		
Processing ^a	0.33	0.87	0.52	4.30	0.16	0.32
Packaging	0.19	2.43	2.12	2.43	2.43	2.19
Transportation ^d	1.05	1.50	1.25	1.50	1.50	2.10
Storage ^e	<u>0.34</u>	<u>0.12</u>	<u>0.30</u>	<u>0.12</u>	<u>0.12</u>	<u>0.42</u>
Total	4.05	4.97	5.15	3.99	4.26	5.05

^aProduction basis. In all cases, 45,200,000 lbs. are produced each year. Thermal and freezing costs are based on an 8-hour day, 300 days per year. Irradiation costs are based on 2,000 lbs. processed per hour, 16 hours per day, 300 days per year.

^bThe costs of radiation processing are based on the following costs per kilowatt-hour emitted from the source.

a. 2.25 kilowatt electron accelerator (105 rad dose): \$11.40

b. 63 kilowatt electron accelerator (300 rad dose): 0.95

c. 2.25 kilowatt cesium-137 source (105 rad dose): 19.15

d. 42 kilowatt cesium-137 source (300 rad dose): 5.30

Source power levels are established by assuming a 50 per cent absorption efficiency in all cases. In addition to these costs, in all cases a cost of 0.14 cents per pound (separately estimated) was added to cover nonsource direct labor and overhead and amortization of the building and conveyor system.

TABLE 2 (continued)

Thermal and freezing costs were obtained from producers in the field.
Cost of transportation is from Chicago to San Francisco.
Storage costs are estimated for private facilities.

Source: Radiation, A Tool for Industry, Report ALI-53, Office of Technical Services,
Department of Commerce, 1953, p. 3.

Pasteurization doses of approximately 100,000 rads increase the storage life of beef under refrigeration two to five fold.¹ Such extensions of storage life would curtail losses from spoilage and would enhance the use of central meat cutting facilities which in themselves could produce considerable labor and equipment savings.

Central Meat Cutting Facilities with Radiation Pasteurization

Whenever meat merchandisers and retailers get together at meetings, conventions, etc., one of the main topics of discussion is the feasibility of centralized pre-packaged meats. The United States Department of Agriculture is continuing to work on the problem of developing a workable operation. Some substantial improvement in the process is expected in the next few days as additional installations are built. Their research and actual experience of 20th Century Stores, Incorporated, show that the investment in equipment and direct labor costs can be reduced when a central cutting and pre-packaging facility is used.²

The largest centralized meat prepack operation is operated in Birmingham, England, by the Birmingham Cooperative Society. The co-op's central meat plant services 30 retail outlets, all within a 70-mile radius, with a total of approximately 30,000 packages a day. With this operation, they have

¹Hannan and Thornley, "Radiation Processing of Foods," p. 560.

²Lew Millovics, "Central Prepackage Meat Operation Holds the Line on Expenses for 3-Store Organization," Progressive Grocer, February, 1961, pp. 50-51.

been able to reduce direct labor costs by 43 per cent from that of individual retail unit cutting operations. Plans are now underway to expand the operation to a capacity of 100,000 packages daily and to extend the service to stores more distantly located from the central warehouse.¹

Both of the above described operations as well as the installations studied by the U.S.D.A. are confronted with two major problems that tend to limit the expansion of central cutting and packing operations.

1. One day of the normal three-day shelf-life of retail beef cuts is lost before the meat reaches the retail outlet. Since the short shelf-life of the product at retail stores is made even shorter, losses from discoloration and spoilage increase.
2. Retail units have less flexibility to adjust to consumer demands since the beef is received in precut, prepackaged form. The variety and size of cuts is held to a minimum to prevent excessive loss from discoloration.

As mentioned earlier in the paper, discoloration and spoilage are the result of bacterial action on the fresh beef. Therefore, the development of a method that will prevent or retard bacterial growth on fresh products should provide a substantial boost to the adoption of central meat cutting and packaging operations by supermarket chains. There is strong indication that irradiation pasteurization will perform this function. By applying pasteurization dosages of irradiation the storage life of beef under

¹"Centralized Meat Prepack--A World Tester," Super Market Merchandising, September, 1961, p. 112.

refrigeration can be increased two to five times what is now possible. This increased storage life will permit the retail outlet to stock a wider variety of cuts without excessive loss due to discoloration and spoilage.¹

Reduction of Distribution Costs

Beef completely sterilized by irradiation would require no refrigeration in storage, transport, or in retail outlets resulting in substantial savings in distribution costs. Non-refrigerated storage facilities are less expensive to construct since no insulation or refrigeration equipment is needed. They are also cheaper to operate and entail less upkeep because of the absence of refrigeration equipment.

Special purpose refrigerated trucks and railroad cars would not be needed to transport sterilized beef. In the case of privately owned transport, this would permit savings in initial purchase of the transport equipment as well as savings in operation and maintenance. By the same token, freight rates charged by common carriers are considerably less for non-refrigerated hauls.

Considerable savings would be possible at the retail outlets in that no refrigerated storage or display facilities would be needed. Sterilized beef could be stored and displayed in much the same manner used for dry groceries at the present time.

¹Hannan and Thornley, "Radiation Processing of Food," p. 560.

Enlargement of Market Segment

Once irradiation sterilization is refined to the point of yielding a package of beef that is completely acceptable to the consumer in terms of quality and price, beef can be enjoyed by hunters, campers, and households that do not have refrigeration facilities. This would create outlets for beef that are not presently available. Such outlets would possibly increase total beef sales by a considerable amount.

Packaging of Irradiated Beef

One of the advantages of the radiation process is that the products can be sterilized in their final containers, within the limits set by the penetrating power of the energy source. Since no object can remain sterile unless protected from contamination by other micro-organisms, much of the success of radiation preservation depends upon the package being airtight, but capable of allowing gamma or beta rays to readily pass through and into the product within the container.

Tests have been conducted with numerous types of containers to determine their suitability. Standard type tin containers with diameters up to 12 inches appear to be satisfactory for irradiation with gamma rays. In processes using beta rays, the length and breadth of the package can be practically unlimited, but the depth must be restricted because of their limited penetrating power. Regardless of the energy source, the irradiation process places less stress on the can than is exerted during thermal sterilization. This

may lead to the use of thinner metal since the can needs only to be strong enough to withstand the rigors of distribution handling.¹

Two difficulties are encountered with glass containers: (1) At high dose rates glass tends to shatter, and (2) most common forms of glass turn brown following radiation. Heating of the glass prevents the latter condition, but this process would probably necessitate the heating of the contents also.²

Since radiation sterilization is effected without an appreciable rise in the temperature of the material being treated, the possibility exists of using containers, such as cardboard, fiber, or plastic film. Film containers have shown promise of becoming a major packaging material by meeting the following requirements:³

1. The package must be resistant to handling stress.
2. The film must be impermeable to oxygen.
3. The film must withstand the irradiation process. This includes damage which is immediately apparent, such as discolorations, as well as subsequent deterioration.
4. For processes which involve irradiation while frozen, the film must withstand low temperatures.

¹R. S. Hannan, Food Preservation (New York: Chemical Publishing Company, Inc., 1955), p. 55.

²Ibid.

³Ibid., pp. 136-137.

Some clear plastics become stronger following irradiation while others grow weaker. Certain films actually cause the meat to spoil. The most important problem in the use of plastics for the packaging of irradiated meat has been defined as the tendency of films to transmit oxygen, carbon dioxide, and water vapor. As yet there is no clear indication as to the degree of such transmission that is most desirable.¹

The most satisfactory film tested to date is polyethylene, though it, too, is lacking in certain requisite characteristics. The consensus is that a lamination of two or more films may be the eventual solution. A laminate of polyethylene and polyester, combining the low gas transmission of the latter with the low moisture transmission of polyethylene, is a possibility. Moisture transmission could be further reduced by adding a layer of aluminum foil.²

Scientists are still searching for a substance that possesses all of the desirable packaging attributes. Some of the materials that have been studied or are now in the testing process are polystyrene, mylar and polyethylene-mylar, laminated halogenated plastics, celloastics, and paraffin.³

Current packaging materials will probably be adapted to

¹"What to Expect in Irradiated Foods," Packaging Forum, Nov., 1957, pp. 147-148.

²Ibid.

³The Interdepartmental Radiation Preservation of Food Program, Office of Technical Services, United States Department of Commerce, Washington, D. C., February 17, 1957, p. 1.

for products receiving pasteurization dosages. However, these materials, too, must be able to withstand discoloration and deterioration during and after pasteurization treatment.

OBSTACLES TO COMMERCIAL APPLICATION OF IRRADIATION TO BEEF PROCESSING

Many problems must be solved by skillful, controlled studies before radiation preservation is ready for commercial use with beef. Control of the sensory changes is essential if we are to provide the customer with products reasonably similar to those of fresh beef. Ways must be found to overcome irradiation odors and flavors as well as color changes produced by the process. Products must have acceptable or desirable characteristics and should represent substantial quality improvement over conventional processing methods.¹

Closely associated with control of sensory changes is the problem of enzyme inactivation. As mentioned earlier, the amount of radiation required to inactivate naturally occurring enzymes appears to be several times that required for sterilization. Even minimum sterilization dosages cause undesirable changes, hence, some other process for inactivating enzymes will be needed. At this time, the most effective method seems to be heat inactivation.²

Pasteurization dosages to extend the normal shelf-life of products do not produce these sensory changes and may be

¹Urbain, Progress and Problems in Radiation Processing of Food., pp. 9-10.

²H. E. Robinson, "Status of Irradiation Preservation of Foods," Nutrition Reviews, September, 1959, p. 258.

more readily applicable. However, when attention is directed to products so treated it must be recognized that quality improvement, detectable to the consumer, may not result. The results are more likely to be reduction of spoilage losses, extension of the marketing period, and accessibility of hitherto unreachable markets. The value of such benefits is primarily economic and for this reason economics and not product quality improvement will determine whether or not the process is commercially applicable.¹

Any use of the process commercially depends upon its ability to fulfill a useful purpose at an allowable cost. The extension of storage life, in the case of pasteurization, for example, must produce savings equal to or greater than the costs involved in the process.

Furthermore, the commercial utilization of irradiation for preserving beef cannot become a reality until its use is approved by government regulatory bodies, specifically the United States Food and Drug Administration. Under the Food Additive Amendment of 1958, the burden of proof of safety of a food additive or process is on the one who wants to use it. The prospective user of the process, then, must convince the Food and Drug Administration that the process is safe in order to gain approval for its use.²

Other problems that must be solved are: (1) Wholesomeness

¹Urbain, Progress and Problems in Radiation Processing of Foods, p. 10.

²Ibid., p. 9.

must be established, (2) adequate sources of radiation must be available, (3) problems of packaging to prevent post-irradiation contamination must be solved, and (4) control of the process through suitable radiation dosimetry must be solved.¹

Finally, the consumer or public attitude toward irradiated beef will be a large if not dominant factor in its success. Even with the assurance of safety based on government approval for irradiation preservation, the public will act on its own confidence and understanding. Public consciousness of the hazards of potentially carcinogenic substances in beef, and its awareness of the dangers of radiation per se are bound to raise questions regarding safety. The possibilities of confusion between the effects of radiation on the human body and the consumption of irradiated beef will require education to clarify. The seller of irradiated beef will need to secure public confidence through an organized information program.²

¹ Urbain, Irradiation for the Meat Industry, p. 11.

² Urbain, Progress and Problems in Radiation Processing of Food, p. 12.

SUMMARY AND CONCLUSIONS

Summary

Because of government controls over radioactive materials, the high cost involved, and the amount of risk, present research is being conducted in the United States by two government agencies: the Atomic Energy Commission and the Army Quartermaster Corps. Research in other countries is also being handled by government agencies. In all cases many of the research projects are contracted out to industrial organizations and educational institutions, giving numerous people experience in irradiation processing of beef.

The most extensive programs being conducted, that of the Atomic Energy Commission concerned primarily with pasteurization dosages and that of the Army Quartermaster Corps concerned with sterilization dosages, are complimentary to each other. Although the Army program is primarily designed to improve the logistics and acceptability of military rations, many of the problems concerned with commercial application of irradiation sterilization may also be solved. The AEC program is designed to determine the products and processes suitable for radiation pasteurization. This program may provide many of the answers needed before radiation pasteurization of beef is commercially feasible.

The irradiation process could have a radical effect

upon distribution costs and merchandising policies of beef in the nation's food industry. Successful businesses and industries are built upon their ability to adjust to new ways of manufacturing, transporting, storing, and merchandising products that allow more economical service to the consumer.

Current research projects, therefore, have as their objectives the development of systems, processes, and products which will assure that meat items of good quality will be available to the consumer at prices competitive with other processing methods.

The following criteria should be used to determine whether or not beef preserved by irradiation is commercially feasible.

1. The beef must be acceptable, palatable, nutritious food. It should resemble very closely the original fresh product in all organoleptic characteristics.
2. The beef should retain most of the essential nutritive elements present in fresh meat.
3. The product must be stable for considerable periods of time under adverse storage conditions or the storage life must be extended under present storage conditions. No undesirable odors or flavors should develop on storage and there should be little or no loss of essential nutrients.
4. Costs of performing the process must result in competitive prices at the point of consumption. If preparation accomplished heretofore in the field is now done at the packing-house or in a related food-processing facility, it is reasonable to believe that the processed product will show a higher unit cost there than previously. Offsetting savings in transport, storage, and/or packaging would be desirable, therefore, to keep costs competitive.

Conclusions

Research and analysis of work to date tends to substantiate the hypothesis. Although no method of irradiation processing is being used commercially at the present time, all indications are that pasteurization dosages will be the most immediately applicable form of irradiation processing. Low-dose pasteurization treatment produces little or no undesirable changes in the sensory properties of the fresh product. The biggest problems remaining are refining the process to make it more economical and getting approval for its use by the Food and Drug Administration. In anticipation of these accomplishments, policies must be formulated for integrating this new process into supermarket operation and consumer education programs must be started.

From a review of the limited amount of data available on central meat cutting and packaging operations, it is evident that irradiation pasteurization of beef will aid in overcoming the major problems plaguing this type operation. This substantiates the latter part of the hypothesis, that perfection of the irradiation pasteurization process will give added impetus to the adoption of central meat cutting operations by supermarket chains. By treating prepackage retail cuts with pasteurization doses in a central cutting facility, the shelf-life of such cuts can be extended to allow the retailer to realize the potential economies of a central cutting and packaging facility without suffering increased loss from spoilage and discoloration.

Recommendations

All persons concerned with moving beef from the farm to the ultimate consumer should encourage and support continued research toward solving the many problems associated with the commercial application of irradiation to beef processing. It is suggested that more progress in the development of commercial applications may be made through the combined or co-operative efforts of research teams sponsored by equipment manufacturers, chemical companies, equipment manufacturers, government agencies, meat packers, and retail food chains.

Research must continue to:

1. Perfect the processes so that none of the sensory properties of the fresh product is altered.
2. Develop materials and methods for packaging products processed by irradiation.
3. Investigate and develop merchandising methods and policies that are applicable to irradiation processed beef.
4. Investigate and optimize methods of transportation and storage.

The commercial utilization of irradiation processing cannot become a reality until its use is approved by government regulatory bodies, such as the Federal Food and Drug Administration. The food industry should tell the story of irradiation processing in general and encourage congressional representatives to approve its use.

Consumer or public attitude toward foods processed by irradiation will be a large if not dominant factor in its success. Even with the assurance of safety based on

government approval, the public will act on its own confidence and understanding of the process plus the economic value of the end products. The consumer should be interested, provided the quality of products so processed is equal to or better than what is now available or a particular need is satisfied.

The cost of applying the process is very small compared to the potential savings and advantages to be gained.

Whenever a new method of food preservation is discovered there is always the fear that more established methods will disappear. Consequently, resistance arises from trade unions and established processors as well as from consumers. Ultimate acceptance of irradiation processing will require a thorough educational job of all concerned and proof that the process does offer unique advantages.

It is expected that radiation processing of beef will eventually find its place among the historic processes of drying, salting, canning, and freezing. A particular product or process finds acceptance when there is unique application, through the competitive action of the market place. Much additional research is necessary, however, before irradiation processed beef is ready for this final market test.

APPENDIX

Results of specific experiments are presented below to provide deeper insight into the effects irradiation has on bacterial growth and on the sensory properties of beef.

EXPERIMENT 1

EFFECT OF GAMMA RADIATION (100,000 rep) ALONE OR IN COMBINATION WITH THE ANTIBIOTIC OXYTETRACYCLINE (10 p.p.m.) UPON THE QUANTITATIVE BACTERIAL FLORA OF BEEF ROUND HELD AT 2° C.

Treatment	Bacteria per gram ($\times 10^3$)			
	0 days	8 days	14 days	20 days
Control	90	700,000	4,000,000	--
Irradiated	0.5	100	60,000	800,000
Irradiated + oxytetracycline	0.5	1	60	2,000

Source: C. F. Niven, Jr. and W. R. Chesbro, "Antibiotics and Irradiation in Meat Preservation," Proceedings of the Eighth Research Conference, sponsored by the Council on Research, American Meat Institute, at the University of Chicago, March 22-23, 1956, p. 49.

EXPERIMENT 2

RELATIVE EFFECTS OF GAMMA RADIATION (100,000 rep) AND
THE ANTIOTBIOTIC OXYTETRACYCLINE (10 p.p.m.) UPON THE
QUANTITATIVE BACTERIAL FLORA IN GROUND BEEF OF
POOR QUALITY HELD AT 2° C.

Treatment	Bacteria per gram ($\times 10^3$)	
	0 days	6 days
Control	100,000	1,000,000
Irradiated	300	10,000
Oxytetracycline	60,000	1,000,000
Irradiated + oxytetracycline	100	100

Source: Niven and Chesbro, "Antibiotics and Irradiation
in Meat Preservation," p. 50.

EXPERIMENT 3

Boneless U. S. Choice beef rib roasts were packed in standard No. 2 tin cans and sealed under vacuum. After sealing the samples were frozen and irradiated to a level of 5 megarads with a Cobalt-60 source. The enzymes were heat inactivated in the cans by raising the internal temperature of the roasts to 165° F. The cans were stored throughout the experiment at a temperature of 76° F.

For panel testing the meat was heated to an internal temperature of 150° F., cut into small samples, coded, and presented to an 18-member untrained panel, who rated the

samples on the 9-point hedonic scale.¹

THE EFFECTS OF PRE-ENZYME AND POST-ENZYME INACTIVATION
STORAGE UPON PANEL SCORES OF IRRADIATED BEEF ROAST

Treatment	Length of storage prior to enzyme inact	Samples tested at time of inact	Samples tested after 90 days total storage
Frozen-unirradiated control	90 days (frozen)	--	7.7
Pre-irradiation enzyme inact	0 days	4.9	5.2
Post-irradiation enzyme inact	0 days	4.4	4.9
Post-irradiation enzyme inact	4 days	3.6	4.4
Post-irradiation enzyme inact	8 days	5.1	5.1
Post-irradiation enzyme inact	16 days	4.8	4.2
Post-irradiation enzyme inact	32 days	4.8	4.7
Post-irradiation enzyme inact	64 days	3.3	3.7
Means ^a		4.4	4.6

^aMeans does not include unirradiated control.

Source: A. M. Pearson and L. J. Bratzler, "The Effects of Pre- and Post-Enzyme Inactivation Storage on Irradiated Beef and Pork Roasts," Food Research XXV:6, 1960, p. 690.

¹The hedonic scale makes ratings in terms of likes and dislikes as follows: 1-dislike; 2-dislike very much; 3-dislike moderately; 4-dislike slightly; 5-neither like nor dislike; 6-like slightly; 7-like moderately; 8-like very much; 9-like extremely.

EXPERIMENT 4

THE EFFECTS OF PRE-IRRADIATION ENZYME INACTIVATION TEMPERATURES ON PANEL SCORES OF BEEF STEAKS

External inactivation temperatures	Internal meat temperatures	Unirradi- ated ^a	Length of storage ^b		
			0 months	3 months	6 months
155° F.	145° F.	6.3	2.1	4.0	3.2
170° F.	160° F.	6.2	3.7	4.4	3.9
180° F.	170° F.	6.3	4.1	6.7	4.4
212° F.	145° F.	5.8	4.5	4.6	4.8
212° F.	160° F.	6.2	3.8	5.6	4.9
212° F.	170° F.	6.1	4.3	5.4	5.4

^aTested only at 0 months storage

^bAll samples irradiated at 5×10^6 rads

Source: A. M. Pearson, L. J. Bratzler, and R. N. Costilow, "The Effects of Pre-Irradiation Heat Inactivation of Enzymes on Palatability of Beef," Food Research, XXV:6, 1960, p. 683.

EXPERIMENT 5

THE EFFECT OF LEVEL OF IRRADIATION, TEMPERATURE, AND LENGTH OF STORAGE UPON PANEL SCORES OF PRECOOKED BEEF

Treatment	Length of Storage				Means
	0 month	1 month	3 months	6 months	12 months
Control-cooked unirradiated	6.87	--	--	--	--
1.86 x 10 ⁶ rads storage @ 20° C.	4.22	5.72	4.89	4.61	6.56
2.79 x 10 ⁶ rads storage @ 20° C.	3.57	6.22	4.33	5.11	5.50
2.79 x 10 ⁶ rads storage @ 24° C.	3.57	5.78	4.67	4.28	4.44
					4.79

Source: A. M. Pearson and L. J. Bratzler, "The Influence of Level of Irradiation, Temperature and Length of Storage Upon the Level of Panel Scores for Pre-cooked Beef," Food Research, XXIV:6, 1959, p. 635.

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