Food Preservation by Irradiation

U.S. ATOMIC ENERGY COMMISSION / Division of Technical Information

The Understanding the Atom Series

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

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Food Preservation by Irradiation

by Grace M. Urrows

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By Grace M. Urrows

HARVEST-FRESH FOOD

Oranges as sweet and juicy as if just picked—strawberries firm and free of mold—yet all many miles and weeks away from harvest. How is it possible? They've been radiation "pasteurized"—exposed to low levels of nuclear radiation.

Bacon, ham, and chicken that haven't been near a refrigerator in months are fed to hundreds of soldiers who find them the equal of normal fresh meat. How? They've been radiation "sterilized"—exposed to levels of radiation high enough to kill bacteria.

On February 8, 1963, the Food and Drug Administration of the U. S. Department of Health, Education and Welfare ruled that bacon preserved by radiation is safe and fit for unlimited human consumption. With that ruling a new chapter began in man's agelong battle to preserve his food from spoilage.

The striking effect of radiation in preserving foods is demonstrated in this photographic comparison. The bottom potato was exposed to 20,000 rads of gamma radiation; the top one was not treated. Both potatoes were stored for 16 months and then these photographs were taken. The irradiated potato was still firm, fresh-looking and edible, and had no sprouts.

The FDA has also approved the use of radiation for sprout inhibition of white potatoes and disinfestation of wheat and wheat flour in this country.

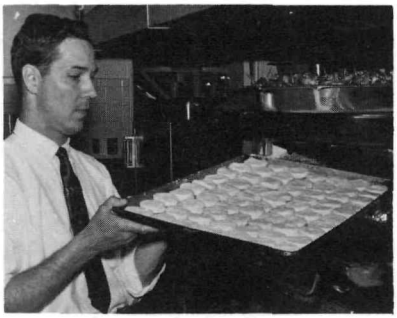
Losses from insect damage to wheat run to millions of dollars annually. Chemical pesticides can control adult insects, but their eggs remain in the wheat and hatch when the temperature rises. Exporters believe radiation is a most effective way of destroying the eggs without harming the grain.

Radiation-processed foods aren't for sale in the United States yet but in the past few years intensive research and testing has been done and more is planned, to hasten general use of the technique.

INTEREST IS WORLDWIDE

Interest in radiation processing of food is worldwide. Up to 30% of food harvests are lost in some parts of the world because of animal pests and microorganisms. Nuclear techniques can help reduce and extend the shelf life of these foods. All in all, some 55 countries now have food irradiation programs.

An example of the worldwide interest in radiation preservation of food is the fact that 200 scientists, representing 25 countries and 4 international organizations, attended an International Symposium on Food Irradiation held in Karlsruhe, Germany, in 1966. The scientists discussed radiation sources, wholesomeness of irradiated food, chemical and physical effects of radiation, status of various commodities, such as meat, poultry and eggs, grain, seafood, fruit, and vegetables, as well as programs in operation, economics, and national legislation for clearances of irradiated items.



These rolls, prepared for a radiation preservation of food meeting in Oak Ridge, Tennessee, were made with wheat flour that had been processed with radiation to ensure freshness and purity. They were part of a banquet menu that also included radiation-processed bacon and potatoes.

An international project on the radiation preservation of fruit and fruit juices is being conducted at the Institute of Biology and Agriculture in Seibersdorf, Austria. These commodities were chosen because (1) their constituents are similar to those in most other foods; (2) these constituents can be divided simply; (3) yeast, the microorganism that spoils most fruits, has been studied extensively; and (4) fruits have economic value. The countries participating are Canada, Denmark, the Federal Republic of Germany, France, Italy, Japan, Spain, Switzerland, and the United States.

PRESERVATION OF MAN'S FOOD

The history of man is the history of his search for food and of his attempts to preserve some of his harvest for the lean part of the year. Before man knew what caused his food to spoil, he was busy trying to prevent it. Over the centuries he has devised many plans for keeping edible food on hand—drying, salting and smoking, dry and cool storage, fermentation and pickling, canning, refrigeration and freezing, making sugar concentrates (like jam and jelly), and using chemical preservatives.

Even cooking and use of spices are short-term ways of preserving food. Many of our basic foodstuffs originated in attempts to keep food. Butter and cheese, for instance, are ways of extending the life of milk.

The use of radiation is the most recent step in this activity. Let us look at some of the main events in this progression.

Drying

Drying is an ancient method (still widely used) of preserving food. The sun, which sustains man in so many other ways, dries cereal grains and some vegetables before they are harvested. This natural process is so efficient that no help from man is needed. Even prehistoric farmers knew, however, that rain or cloudy periods would rot these staples in the fields; so they brought some of their crops into their caves to dry.

As the world's population grew, man could not depend solely upon sun-dried food for all his needs. Nonetheless, until the late 1700s attempts to assist nature were relatively simple and consisted of placing foods near the fire, spreading them more thinly to dry in the sunlight, and sheltering them from rain. About 1795, however, two Frenchmen, Masson and Challet, made an important improvement. They built a dehydrator in which air at about 105° F was blown over thinly sliced vegetables. Since that time more efficient dehydrators with huge capacities have been developed.

Chemical and biological forces are at work in all stages of food growth. After foods are harvested, these processes tend to cause deterioration rather than produce maturation. The chemical forces can be controlled by chemical additives, and biological activity can be stilled by blanching (quick exposure to moist heat) or drying. This is why drying always has been an important food process.

Fermentation

There are more microorganisms on earth than any other living thing. And, although most food preservation systems aim at destroying microorganisms, or at least inhibiting their growth, a few foods are formed by action of the tiny organisms. One of these processes is wine-making, which is probably as ancient as the caveman and certainly has been familiar in all known civilizations.

A yeast, *Saccharomyces ellipsoideus*, is the agent that creates alcohol from sugar. Usually this is present on grapeskins; when yeast cells have access to sugar in the juice, through bruises or breaks in the skin, fermentation takes place. The process of fermentation is one of decomposition of carbohydrates; it is easily distinguished from putrefaction, which results from the action of microorganisms on protein materials. In modern wine-making man crushes the grapes purposely, heats the juice to kill contaminating organisms, and reinoculates it with pure wine yeast to control the fermentation process.

Fermentation also is involved in preparation of beer, cottage cheese, buttermilk, cheese, sauerkraut, bread, and many other foods.

Canning

The French made another major contribution to food preservation. All 18th century soldiers were hampered by diets of putrid meat and other inferior foods. So in the 1790s Napoleon offered a prize of 12,000 francs for the invention of a method of food preservation for his fighting forces. A confectioner named Nicolas Appert observed that food cooked in sealed bottles remained unspoiled as long as the container didn't break. He didn't know why this happened (nor did any scientist of the day), but the process

worked. Appert won the prize in 1809, and canning came into use.

By 1820 the first commercial canning plants were operating in the United States and by 1840 canning was common throughout the country. But the mechanism of food spoilage and the reasons why canning prevented it were still mysteries. In 1864 Louis Pasteur reported to the French Academy of Sciences that the cause of a disease then ravaging the beer and wine industries of France was a microscopic vegetation and that, when the wine contained no living microorganisms, it remained unspoiled. Wine or beer heated to 135° F and sealed in jars did not sour. Here was the explanation of Appert's success of 55 years earlier. Many improvements in techniques, materials, and sanitation have been made since Pasteur's day. Canning has changed the eating habits of the Western world, but we still do not completely understand how microorganisms die. Unlike dehydration, canning is not an improvement on a natural process, but represents man's first attempt to control Nature for the preservation of food.

Freezing

Freezing, a more recent technique in food preservation, had scattered users and advocates long before its commercial exploitation. Patents for freezing fish, for instance, were issued to H. Benjamin in England in 1842. Cooling with natural ice or in caves had been known for centuries. Mechanical refrigeration, developed in the late 1800s, allows foods to be stored at temperatures of about 40° F. It caused enormous changes in the food habits of the more developed countries of the world and remains an important way to preserve raw foods for a limited time.

Mechanical refrigeration provided the base, but not the impetus, for the frozen-food industry, too, but it was not until about 1940 that frozen foods became important competitors for fresh, canned, and dried foods. Quick-freezing processes and equipment developed by Clarence Birdseye and others helped to promote frozen foods as a consumer item.

Because of their high water content, most foods freeze solidly at temperatures between 25 and 32° F. Although each food has a specific freezing point, quick freezing takes place in 30 minutes or less. If freezing is rapid, many small ice crystals are formed, and the changes in the food tissues are reversible. Slow freezing, according to a theory of ice crystal damage, permits large, uneven crystals to build up. These puncture the food cells as they grow, and, when the food is thawed, it will be mushy.

Although the factors in successfully freezing food are well under control, the complex physical, chemical, and biological changes involved are still not completely understood. In freezing, as in canning, Nature is controlled, even though man is not always quite sure why.

HOW FOOD SPOILS

For maximum nutrition, food plants and animals should be eaten as near to the harvest or slaughter as possible. Once a plant or animal is dead, decomposition begins and nutrients are lost.

Food spoils because of physical, chemical, or biological deterioration and by the activities of microorganisms and insects. How a particular food spoils depends on its composition, the way it is stored, and the type of microorganisms that attack it. Microorganisms specialize in the kind of organic matter they decompose; only a few consume more than one kind of food. The result is, however, pretty much the same: All living tissues ultimately decay to the minerals, water, carbon dioxide, and ammonia from which their complex organic molecules are made.

When a strawberry is bruised in picking, for example, it is invaded by mircoorganisms on the hands of the picker or in the soil. Its juice is slightly acid, and so it is a happy feasting ground for molds and yeast. The molds destroy one cell after another, obtaining energy from the fruit's sugar. The yeast attacks the sugar, converting it by fermentation into alcohol, which attracts fruit flies carrying vinegar bacteria on their feet. In the fermenting tissue the vinegar bacteria burn up the alcohol. The strawberry is soon demolished.

Food Poisoning

Although people around the world do not agree on what constitutes spoiled food—consider the variety of tastes in cheese, for instance—food that is truly spoiled makes anyone who eats it sick. Most cases of food poisoning come from intestinal infections caused by bacteria.

The most common type of bacterial food poisoning is caused by *Staphylococcus aureus*, a common bacterium found on the skin and in the nose and throat. This kind of illness typically begins suddenly. Victims usually recover after several days' illness. It can be prevented by cleanliness, proper cooking, and refrigeration of foods.

Other forms of food-borne illness result from *Salmonella* and *Shigella* bacteria often found in eggs, insects, and the intestines of animals and man. These organisms normally have a longer incubation period than the *Staphylococci,* and the effects are not felt until 12 to 24 hours after the food has been eaten. Again, these usually are not serious illnesses, and patients soon recover. They never occur where there is rigid cleanliness in food preparation and eating areas, sterilization of utensils, and proper cooking and refrigeration of foods.

Another kind of food-borne illness can come from the parasite *Trichinella spiralis,* which is often found in pork products. Trichinae, or larvae of the parasite, are destroyed by cooking pork well or keeping it below freezing temperature for 20 days. This infestation is common; often it is not serious enough to cause sickness, but it can be dangerous.

Fatal Toxin

A most serious, but quite rare, form of food poisoning, fatal to 70% of its victims, is botulism. It comes from a poison formed in food by the bacterium *Clostridium botulinum.* This organism lives in the soil and is not itself harmful to man, but, when it multiplies in food under anaerobic conditions (without air), it produces a potent toxin. If that toxin is consumed, even in minute amounts, botulism will result. The only known treatment for botulism is an antitoxin, but frequently the disease is not diagnosed soon enough for antitoxin to be obtained, and the patient dies.

Botulism is more common in home-canned foods than in commercial products. Prevention of botulinum toxin formation is important in all food preservation.

RADIATION—A NEW TECHNIQUE

Except for canning, radiation processing is the only original—that is, nonnatural—method of preserving food developed since the dawn of history. Quickly, economically, and safely, without raising internal temperatures more than a few degrees, ionizing radiation can preserve foods by inhibiting or destroying bacteria and other microorganisms.

Ionizing Radiation

An atom is conceived of as a nucleus with a positive electrical charge around which revolve negatively charged electrons; the whole atom is electrically neutral. If an atom is bombarded by radiation having sufficient energy to strip the electrons away, the neutral atom is converted to a positively charged particle or *ion.* Radiation speeding through food ionizes some atoms in its path and causes an alteration of vital macromolecules (large molecules) in bacteria and other microorganisms and these are destroyed.

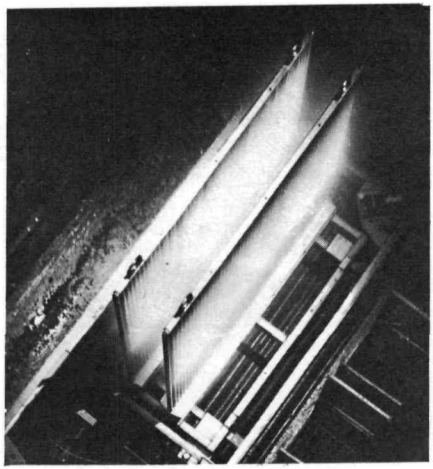
If food atoms are ionized, they suffer no harmful effects. The food does not become radioactive, and with low doses of radiation there is less loss of vitamins than in canning, freezing, or drying. Some vitamins are lost if higher radiation doses are applied, but they can be replaced, as they sometimes are in other processed foods.

Radiation preservation of food is accomplished in two ways: *Pasteurization,* which is accomplished with low dosages, and *sterilization,* which requires higher levels. Food can be irradiated by bombarding it with beta particles or with gamma rays.*

Gamma rays are used because of their penetration range; high-energy particles, such as electrons from an accelerator, are usually as penetrating and their direction can be

*For more information about ionization, atomic energy, and various forms of radiation, see *Our Atomic World,* a companion booklet in this series.

better controlled.* The radiation dose is usually expressed in terms of the *rad,* defined as that quantity of ionizing radiation which results in the absorption of 100 ergs of energy per gram of irradiated material.



The cobalt-60 source at the Army's Radiation Laboratory in Natick, Massachusetts, glows like a neon sign at the bottom of a 25-foot storage pool. (See pictures on pages 30 and 31.)

The amount of radiation to be delivered depends upon the food itself and the result desired. If the goal is prolongation of shelf life, or storage time, a pasteurization dose, generally from 200,000 to 500,000 rads, is sufficient. If the aim is to sterilize food for long-term storage without refrigeration, the required dose is between 2 and 4.5 million rads. (This dose range can also be expressed as 2.0 to 4.5 megarads or Mrads.)

At even lower doses, radiation can perform effective preservation chores. A dose of 4000 to 10,000 rads applied to potatoes or onions is highly effective as a sprout inhibitor. At 20,000 to 50,000 rads, grains and cereals can be disinfested of insects. At 50,000 rads, it is also possible to sterilize the larvae of insects that lodge inside fruits.

Doses of 200,000 to 400,000 rads are highly effective in extending the refrigerated storage life of fresh fish up to 30 days. Bacon and other pork products, chicken, and beef

*"Spent" reactor fuel elements also were used in food irradiation research for some time but were abandoned as unsatisfactory radiation sources for this purpose.

can be packaged and then irradiated at 4.5 Mrads, resulting in sufficient preservation to permit a year's storage at room temperatures.

For several years both the Army and the Atomic Energy Commission (AEC) have been testing methods of irradiating food, the "keeping" quality of foods after irradiation at various dose levels, and the nutritional value and esthetic appeal of irradiated products.

A dietician prepares servings of irradiated baked ham for taste testing by volunteers at the Army Quartermaster Food and Container Institute.

Research History

The possibility of radiation preservation of foods was recognized in general terms in the early 1900s. Research in the mid-1940s revealed the potential of the process, as well as determining some of the problems. In the early 1950s, the AEC was looking for ways to use radioactive products from nuclear reactor operations and began a limited investigation of possibilities in food protection. In August 1953, the Army also began modest research (since greatly expanded) in food preservation by irradiation.

By 1959 the Army had decided to concentrate its attention on several meat items (ham, pork, chicken, and beef), with the objective of developing them for combat rations through high-dose radiation (sterilization). Responsibility for low-dose (pasteurization) research was assumed by the AEC, believing this process would be of more direct benefit to civilian consumers. The goal in each program is to bring the techniques to the point of technical and economic feasibility so that private industry can apply them commercially.

Testing for Wholesomeness

Ionizing radiation inhibits bacteria by killing them outright or slowing their metabolism or reproductive rate. The exact way it does this is not entirely known. Since the same radiation that will kill a bacterial cell also will destroy some of the cells in the tissues of the food product, extensive testing has been undertaken to learn the effects of radiation on food wholesomeness.

Certainly no food processing method in use today has been as thoroughly studied as radiation. Over 400,000 animals have been involved in Army feeding programs to establish the wholesomeness of irradiated foods. Although the first long-term feeding studies seemed to produce some abnormalities in experimental animals, additional research showed that these often resulted from poor experimental procedures. Unrealistic diets (such as feeding rats almost nothing but oranges) and undue strain (keeping dogs mostly in isolation cages) proved to be at fault rather than the irradiated food. (Subsequent feeding tests showed that radiation caused neither abnormalities related to vitamin destruction nor some other abnormalities that were unexplained at the time. However, a few have not been completely explained, so research continues.)

Short-term feeding of irradiated foods to human volunteers and army personnel over periods of several weeks also has demonstrated the wholesomeness of foods that were processed by radiation. The broad program of testing for wholesomeness has included:

Long-term animal feeding experiments (2 years) to investigate the possibility of chronic toxicity.

Nutritional adequacy experiments on heat-processed and radiation-processed foods to determine comparative effects on nutrients.

Carcinogenicity experiments to determine whether consumption of radiation-processed food by animals will result in formation of tumors.

Blood and tissue enzyme research to discover if feeding irradiated foods to experimental animals alters metabolic processes in the animals' cells.

Histopathology examinations—postmortem microscopic studies of the tissues of experimental animals that had been fed irradiated food for long periods of time.

Samples of cooked fish preserved by radiation are tasted and compared with cooked but nonirradiated fresh fish.

Alteration of food proteins and other special problems also have been studied by several biological and chemical tests.

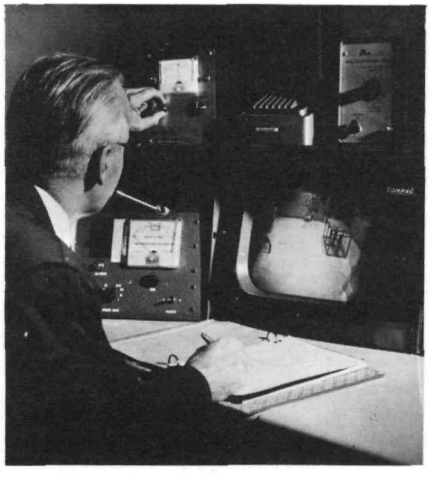
Government Clearance

The Food and Drug Administration (FDA), which has the responsibility for deciding whether a particular radiation-processed food is fit for human consumption, requires that extensive wholesomeness data accompany each application for clearance of a food. Investigators consult with FDA officials for guidance on wholesomeness data and how the tests should be made. The Meat Inspection Division of the Department of Agriculture also has responsibility for reviewing petitions for clearance of irradiated meats.

Pasteurization requires only about one-tenth as much radiation dosage as sterilization. Foods that have been proven safe for consumption after radiation sterilization are generally assumed to be safe if lesser pasteurizing doses are administered. However, because pasteurizing doses do not kill *all* bacteria, it is necessary to perform studies on microbiological safety of such products.

The first radiation-sterilized food approved in the United States, as mentioned before, was bacon that had been subjected to 4.5 Mrads from a radioactive isotope (cobalt-60) radiation source. The use of cesium-137, which also emits gamma rays, has also been approved for sterilizing bacon, wheat, wheat flour, and potatoes.

In August 1963, the FDA approved the sterilization of bacon by machine-accelerated electrons having an energy not greater than 5 Mev, which results in an absorbed dose to the bacon of 4.5 to 5.6 Mrads.* At the same time it approved disinfestation of wheat and wheat flour by irradiation with 20,000 to 50,000 rads from a cobalt-60 source. In June 1964, radiation was approved as a sprout inhibitor for potatoes. These clearances moved radiation pasteurization and sterilization programs nearer to the goals of commercial development and marketing.



Closed-circuit television is used to monitor experimental food processing at the Army's Radiation Laboratory in Massachusetts.

Appearance and Taste

Organoleptic or acceptability problems—alterations in color, taste, or odor—that plagued early radiation processing attempts, have been solved for the most part by more recent research. Meats, in particular, had suffered alteration in odor, flavor, texture, and color. These changes have been eliminated or substantially reduced by irradiation at very low temperatures, application of adsorbents as odor scavengers, skillful use of spices and condiments, and appropriate cooking practices.

It has been found that if irradiation is done at ultralow temperatures, from −32 to −78°F, off-flavors are mark-

*For more information about such sources of radiation, see *Accelerators*, another booklet in this series.

edly reduced. Chicken, precooked and then irradiated at −78°F, has been evaluated by a trained taste panel as having little, if any, detectable irradiation flavor. Off flavors and odors that developed in irradiated beef with early experiments have now been virtually eliminated. Sterilized cooked hamburger held at room temperature for over a year does not appear to differ from fresh-cooked hamburger. Results are much the same with pork, shrimp, chicken, ham, and bacon.

Packaging

Packaging is of importance in radiation sterilization because food to be preserved indefinitely must be protected from recontamination. Cans, used successfully in heat preservation of food, are also acceptable for irradiated food. Plastic packages, however, have advantages in terms of weight and storage space, important to the armed forces. Research to find suitable packaging materials, therefore, is underway. Since the food is irradiated after it is in its container, the effects of radiation upon the packaging and the interrelation between the radiation, the packaging, and the food must all be considered. The resistance of packages to perforation during storage and handling also is tested.

The packaging problems with radiation-pasteurized foods are different. The bacteria are decreased by 99%, but not eliminated; so the packaging material must not provide conditions that might encourage bacterial growth.

Packaging also has to be attractive in order to compete with other food packages in retail markets. It seems likely that a variety of packages will be necessary to meet all the needs of product protection and sales appeal.

On August 14, 1964, a regulation was issued by the Food and Drug Administration allowing the use of nine packaging materials or materials classes when in contact with food being irradiated. On March 8, 1965, the FDA approved the use of a vegetable parchment paper wrapping, and in the summer of 1967, two other packaging material petitions were approved. Other packaging material petitions, for processes using either radioisotopes or electrons, are either pending before the FDA or planned.

Table I FOOD IRRADIATION ITEMS APPROVED BY THE FOOD AND DRUG ADMINISTRATION AS OF AUGUST 1967

Product and purpose of irradiation	Radiation source	Dose (permissible range) (megarad)	Petitioner	Date of FDA approval
Bacon, sterilization	Cobalt-60	4.5 to 5.6	Army	Feb. 8, 1963
	Electron beam (5 Mev)	Same	General Electric Co.	Aug. 23, 1963
	Cesium-137	Same	AEC	Jan. 30, 1964
	X rays from electron beam (5 Mev)	Same	Radiation Dynamics Inc.	Dec. 15, 1964
	Electron beam (10 Mev)	Same	Army	Apr. 15, 1965
Wheat and wheat flour, insect disinfestation	Cobalt-60	0.02 to 0.05	Private citizens	Aug. 21, 1963
	Cesium-137	Same	AEC	Oct. 2, 1964
	Electron beam (5 Mev)	Same	High Voltage Engineering Corp.	Feb. 18, 1966
White potatoes, sprout inhibition	Cobalt-60	0.005 to 0.010	Army	June 30, 1964
	Cesium-137	Same	AEC	Oct. 2, 1964
	Cobalt-60 and cesium-137	0.005 to 0.015	Army	Nov. 1, 1965
Packaging materials, food contactants for use in radiation preservation of prepackaged foods	Gamma emitters	1 maximum	AEC	Aug. 10, 1964
Vegetable parchment paper, food contactants for use in radiation preservation of prepackaged foods	Cobalt-60	6 maximum	Army	Mar. 8, 1965
	Cesium-137	Same	Same	Same
	X rays from electron beam (5 Mev)	Same	Same	Same
Kraft paper	Cobalt-60 and cesium-137	0.05	Army	July 19, 1967
Packaging materials, food contactants for use in radiation preservation of prepackaged foods	Same	6 maximum	Army	June 10, 1967

Table II

FOOD IRRADIATION ITEMS PENDING BEFORE THE FOOD AND DRUG ADMINISTRATION AS OF AUGUST 1967

Product and purpose of irradiation	Radiation source	Dose (recommended range) (megarads)	Petitioner
Packaging materials, food contactants for use in radiation preservation of prepackaged foods	Cobalt-60 and cesium-137	1 maximum	AEC
Nylon film, food contactant for use with prepackaged foods	Same	Same	AEC
Fish, shelf-life extension	Cobalt-60, cesium-137, electron beam (5 Mev), X rays from electron beam (5 Mev)	0.10 to 0.20	Joint Army/AEC
Ham, sterilization	Cobalt-60 and cesium-137	3.5 to 5.6	Army

TESTING PROGRAMS AND DEVICES

Although the potential of irradiation was long recognized, serious development work awaited the availability of sources of radiation after World War II. These can be either radioactive isotopes, such as cobalt-60 or cesium-137, or machine-accelerated electrons. Radioactive cobalt-60 is produced in nuclear reactors* by neutron bombardment. The radiation strength of a source such as ^{60}Co is measured in terms of curies, 1 curie being equivalent to the radiation from 1 gram of radium, or 37 billion atomic disintegrations per second.

The United States' program for radiation processing of foods has two distinct but parallel efforts. The AEC is developing radiation pasteurization techniques that will extend the shelf-life of fresh foods, such as fruits and marine products, by reducing the spoilage rate. The Department of the Army is concerned with sterilizing meats so that they can be held indefinitely without refrigeration. Cobalt-60 and cesium-137 are primarily used as the radiation sources by the AEC, while the Army uses both cobalt-60 and an electron accelerator.

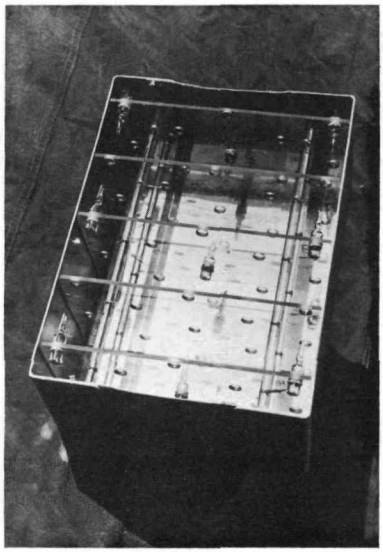
AEC Irradiators

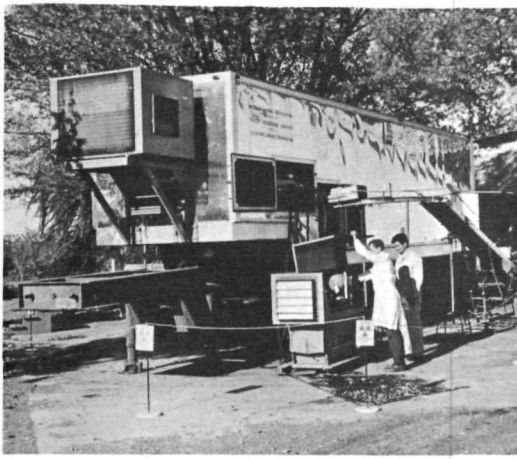
Food irradiators, using a gamma source of approximately 30,000 curies of ^{60}Co and capable of irradiating 75 pounds of food with a dose of 1 Mrad per hour, have been operated at a number of research sites. These devices essentially are deep tanks filled with water to shield operating personnel from radiation. The radioisotope sources are placed at the bottom in two rectangular plaques. A control system lowers the food in watertight containers to a point between or adjacent to the sources. Irradiation can be performed automatically by presetting the length of time the sample is to be exposed. (See page 21.)

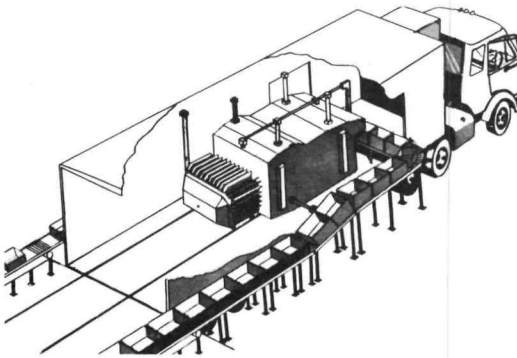
*For more information about reactors, see *Nuclear Reactors*, another booklet in this series.

MOBILE GAMMA IRRADIATOR Mobile irradiators have particular value for preservation of fruits; the nearer to the harvest-point radiation pasteurization can be achieved, the greater the benefits in preserving quality and taste and reducing spoilage. Transportable radiation units have the added advantage of being able to follow crop harvest crews as they move through a region.

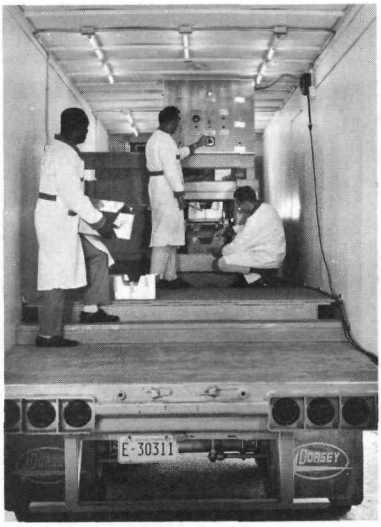
In 1966, the MGI began operation. This original 100,000-curie ^{60}Co irradiator, mounted in a truck, is used by the University of California at Davis under typical field conditions to demonstrate on a large scale the ease and feasibility of radiation processing of fruit during actual harvest. The MGI can be used for large-scale processing of fruit and vegetables.

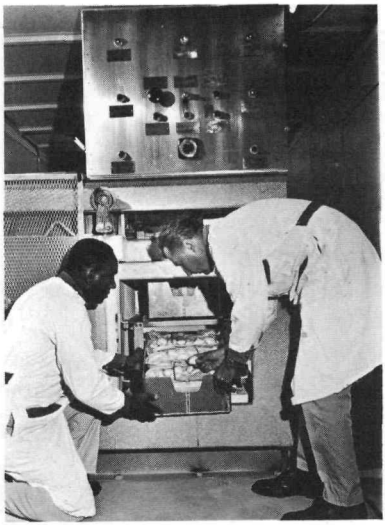






Right, top, a box of fruit (above the men) moves on a conveyor belt into the MGI processing unit. Sketch shows the interior of irradiator van. Above is an empty carrier box showing how dosimeters are placed among the product units so that the exact radiation dose can be calibrated.





The portable cesium-137 irradiator undergoes a final check at Brookhaven National Laboratory before leaving on a nationwide demonstration program. Food in special aluminum trays is cycled in and out of the inner irradiation chamber for pretimed exposures up to 30 minutes.

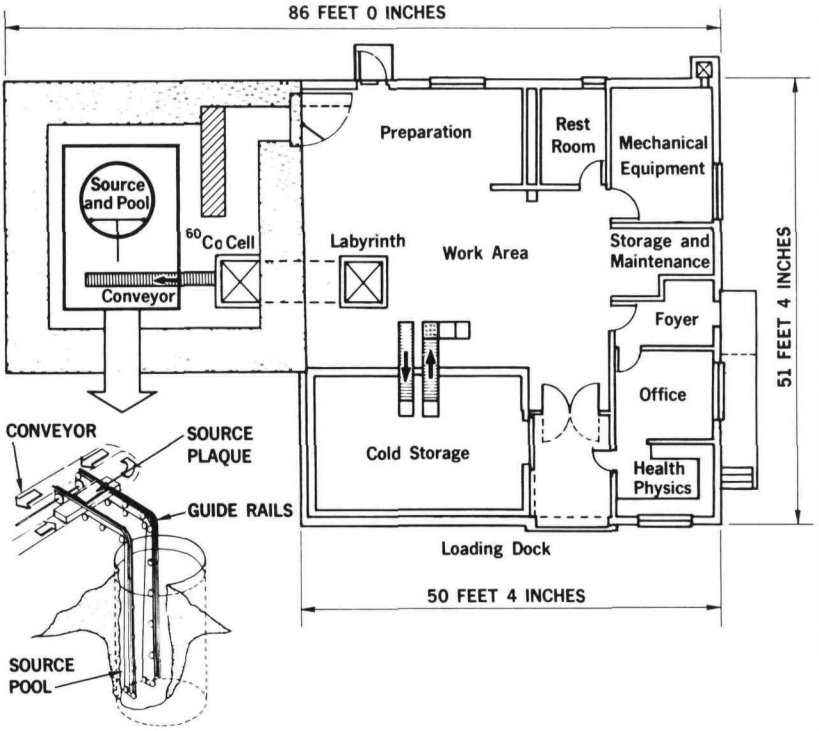
PORTABLE CESIUM-137 IRRADIATOR The purpose of this irradiator is to acquaint members of the food industry with radiation technology and to allow them to evaluate the process at their own plants. Following a brief tour to 4 states and 12 companies, the initial 170,000-curie unit has, since October 1967, been in the State of Washington where it has been used by more than 40 companies. These companies provide the location and the produce and conduct and finance the test program, while the AEC furnishes the irradiator and the operator without charge. The test data are then turned over to the AEC.

Wheat and wheat flour, potatoes, tomatoes, onions, oranges, mushrooms, mink feed (mainly fish), and seeds are the products that are being irradiated. Several tons of irradiated Washington potatoes have been shipped by rail and ship to Chicago and Honolulu to demonstrate the possibility of lowering spoilage in transit and also of lowering icing and refrigeration costs.

The food moves in two aluminum containers, one above and one below the radiation source, where it is exposed to gamma rays for a preset time. Except for operation of the outer door, the entire cycle is automatic.

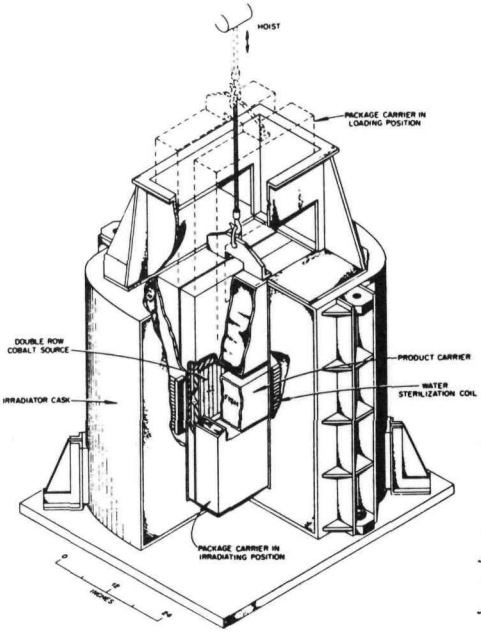
MARINE PRODUCTS DEVELOPMENT IRRADIATOR The Marine Products Development Irradiator (MPDI) at Gloucester, Massachusetts, has been built to provide marine products for large-scale shipping, storage, and distribution tests, to obtain a better understanding of the economics of radiation processing, and to assist the fishing industry in commercializing the process. This stationary facility was built with a 250,000-curie ^{60}Co source to process 2000 pounds of food per hour with a 250,000-rad dose. Packages of fish fillets weighing 10, 20, and 30 pounds pass over and under a rectangular-shaped source. The MPDI can also process containers weighing up to 100 pounds.

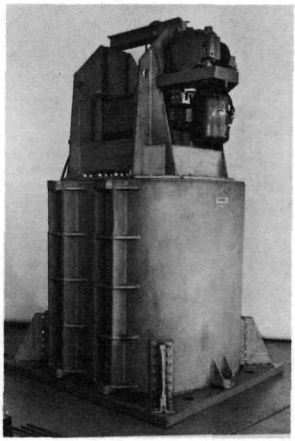
The MPDI is operated for the AEC by the Bureau of Commercial Fisheries Laboratory of the Department of the Interior.



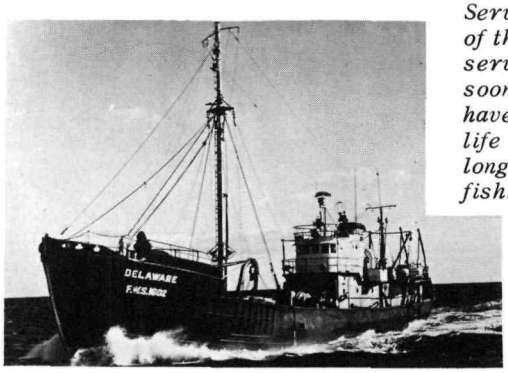
SHIPBOARD IRRADIATORS Since radiation preservation should be done as soon after harvest as possible, the development of shipboard irradiators is another important aspect of the AEC program.

Three such irradiators, each weighing 17 tons and using an initial 30,000-curie ^{60}Co source, are in operation. These safe, simple, easily transported units can process many different marine products. One was on a Department of the Interior vessel, the *Delaware,* working off the coast of Massachusetts, while a second, which irradiated shrimp





Above is the irradiator before it was installed aboard the Delaware, *a research fishing vessel operated by the U. S. Fish and Wildlife Service of the Department of the Interior. Fish, preserved through irradiation soon after they are caught, have a refrigerated storage life two or three times longer than nonirradiated fish.*

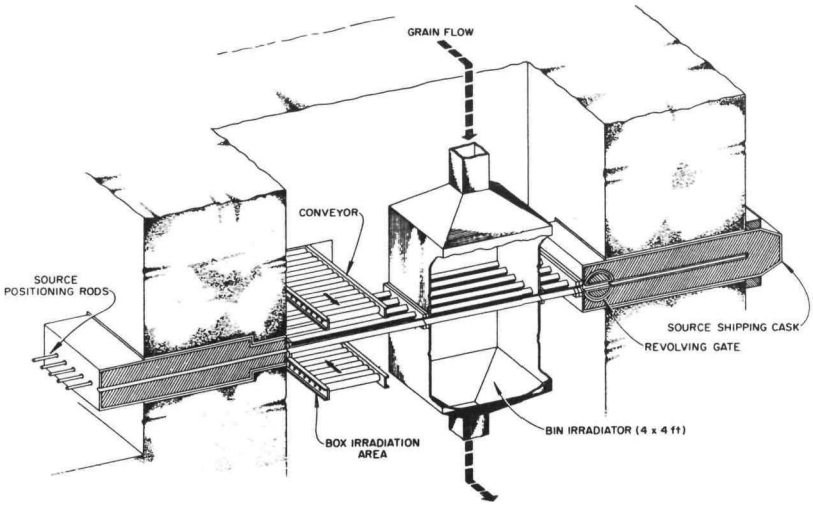


and other fish caught in the Gulf of Mexico, was on another Interior ship, the *Oregon.* Although the capacity of these irradiators is much less than that of the MPDI, they are valuable for intermediate volume irradiation. These two units are now on international loan.

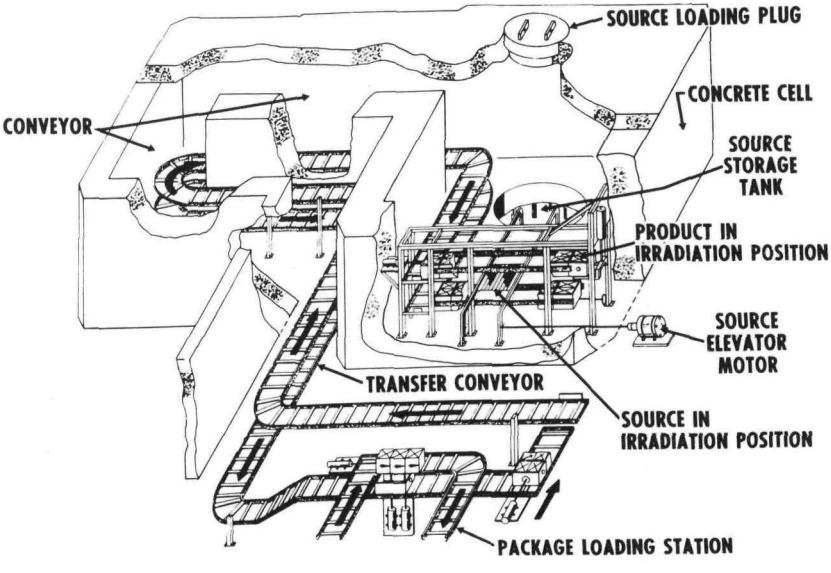
A third irradiator is in use aboard a Department of the Interior vessel, the *Miller Freeman,* in Seattle, Washington.

GRAIN PRODUCTS IRRADIATOR Disinfestation of grains, milled flour, or other packaged wheat products also is easily accomplished by irradiation. The AEC and the Department of Agriculture have a cooperative research program using a stationary Grain Products Irradiator (GPI) at the Entomological Research Center in Savannah, Georgia. This irradiator, utilizing an original 25,000-curie ^{60}Co source, is capable of handling 5000 pounds of bulk grain or 2800 pounds of packaged products per hour at a dose of 25,000 to 50,000 rads.

The GPI began operation in 1966 and is available for limited commercial testing by private industry, as is the MPDI. It was originally intended only for insect disinfestation of grains, but when processors of packaged mixes, cereals, and flours asked for test irradiations of their products, the design was modified to accommodate these uses.



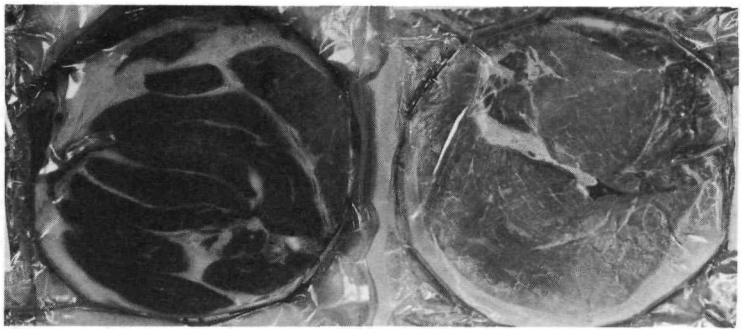
HAWAII DEVELOPMENT IRRADIATOR The HDI was completed in the spring of 1967 and can irradiate near-production quantities of Hawaiian fruits, such as papaya and mango, and other foods. It is located in Honolulu and is operated by the Hawaiian Department of Agriculture under contract to the AEC. The original 250,000-curie ^{60}Co source can process 4000 pounds of food per hour at 75,000 rads.



Source Selection

The best radiation source for any particular operation is determined by the kind of food to be processed, its quantity, the size of the package, and the amount of time it must stand in the presence of the radiation. Gamma rays from ^{60}Co have great penetrating power and assure thorough application. Simplicity and reliability make cobalt an excellent source. A multiple-pass machine, which presents both sides of the package to the radiation, cuts the exposure time, ensures full distribution of the dose, and increases the capacity and efficiency of the plant.

Accelerators that produce electrons also serve as radiation sources. They are especially efficient in treatment of thin packages, such as those containing steaks or fillets.

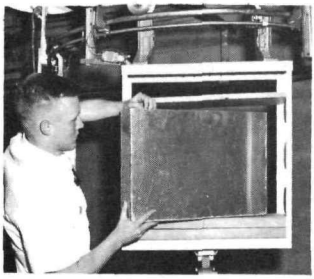


The smoked ham slice at right was not irradiated, while the other one received 2.7 Mrads. After 9-months storage at room temperature, the irradiated slice is fresh and has retained its color, and the other one is gray, obviously not fresh.

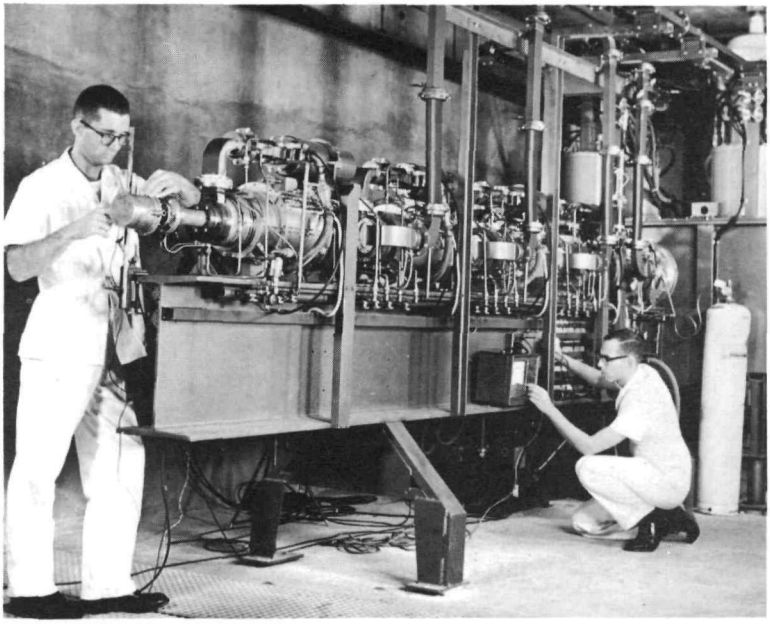
Electrons from a 5-Mev machine will penetrate about 1 inch. An advantage in use of accelerators is that the direction of the electron beam can be controlled.

By a process called X-ray conversion, electron accelerators can be made to produce high-energy X rays by bouncing accelerated electrons off a target made of a heavy element. The electrons release energy as they are slowed down or displace orbital electrons in target atoms. Energy given up in this manner is in the form of X rays, which are very much like gamma rays. Since they are so similar to gamma rays, are partially directional, and are produced in the machines at a high rate, their use for food processing is most promising.

Historically, use of ^{60}Co was emphasized by the AEC because the isotope was available and machines for commercial use were not at the time. Now both methods are available, and each potential user chooses whichever is suitable for his special needs.



A food container is loaded onto a conveyor for processing in the 24-Mev linear accelerator in Natick, Massachusetts.



Above, adjustments are made on the Army's Natick accelerator. Below is the complete machine.

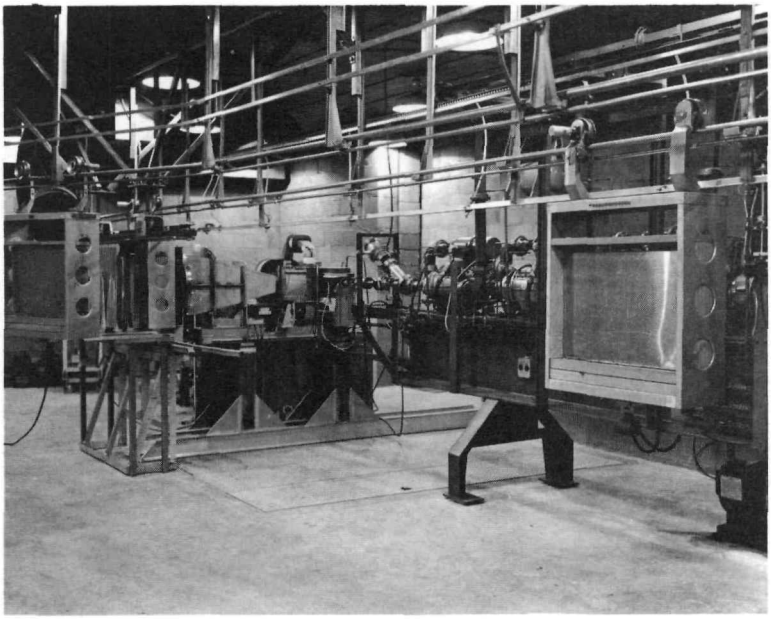
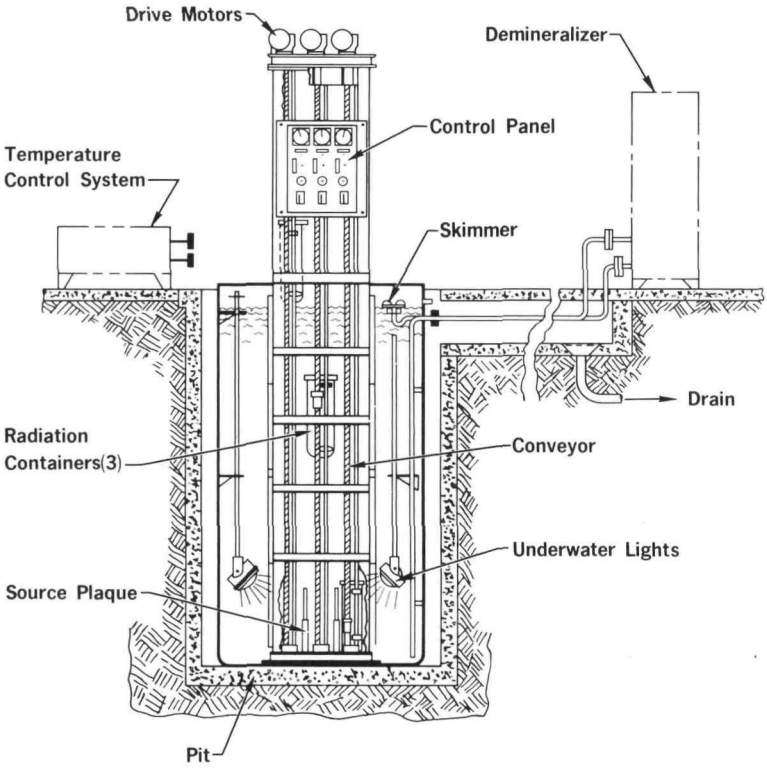


Table III

AEC FOOD IRRADIATORS

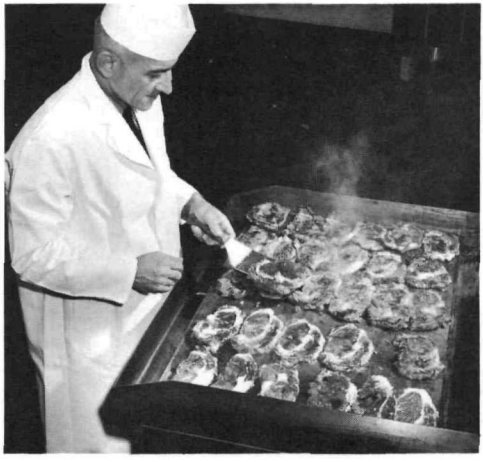
Irradiator	Purpose	Location	Description
Research irradiators (4 total)	Immediate irradiation service for contractors in food irradiation program	M.I.T.; U. of Calif. (Davis); U. of Wash.; U. of Fla.	35,000-curie ^{60}Co source; capacity: 75 pounds per hour at 1 megarad dose, underwater irradiation in closed containers
Marine Products Development Irradiator (MPDI)	Semicommercial seafood irradiation; cooperative industry program	U. S. Dept. of Interior, Technological Lab., Gloucester, Mass.	250,000-curie ^{60}Co source; capacity: 2000 pounds per hour at 250,000 rads
Grain Products Irradiator	Disinfestation of bulk grain or packaged products	U. S. Dept. of Agriculture, Entomological Research Center, Savannah, Ga.	25,000-curie ^{60}Co source; capacity: 5000 pounds per hour bulk grain or 2800 pounds per hour packaged product at 25,000 to 50,000 rads
Mobile Gamma Irradiator (MGI)	Large-scale demonstration of feasibility of irradiation processing of fruits at harvest locations	U. of Calif. (Davis) (headquarters)	100,000-curie ^{60}Co source; truck-mounted, 60-ton unit; capacity: 1000 pounds per hour at 200,000 rads
Shipboard Irradiators (3)	Seafood irradiation on fishing vessels immediately after catch	U. S. D. I., Seattle; the other two units, which were at Louisiana State University and Gloucester, Massachusetts, are presently on international loan.	30,000-curie ^{60}Co source; transportable 17-ton unit; capacity: 150 pounds per hour at 100,000 rads
Hawaii Development Irradiator	Semicommercial irradiation processing of tropical fruit	Honolulu	250,000-curie ^{60}Co source; capacity: 4000 pounds per hour at 75,000 rads
Portable ^{137}Cs Irradiator	Research support for food processing industries	On site at industry locations	170,000-curie ^{137}Cs source; portable, trailer-mounted, 18-ton unit; capacity: 200–300 pounds per hour at 200,000 rads



Four research irradiators, like the one in the drawing, are providing radiation support to food projects at the Massachusetts Institute of Technology, the University of Florida, and the University of Washington. On the left scientists load lemons into the irradiator at the University of California.

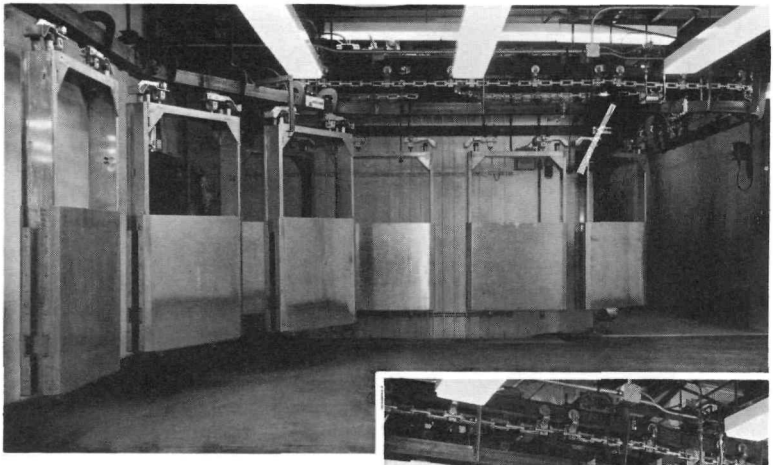
U. S. Army Radiation Laboratory

The Army Radiation Laboratory at Natick, Massachusetts, is the most complete food irradiation research facility in the nation. It contains the largest known source of ^{60}Co (initially rated at 1.3 million curies), a complete food preparation area, a physics and microbiology section, an experimental kitchen, and a taste-panel room. In addition, a 24-Mev linear electron accelerator is being used to study effect on foods subjected to high-energy electrons. Although the Natick laboratory is capable of processing large quantities of food, there is no intention that it will become a production facility.



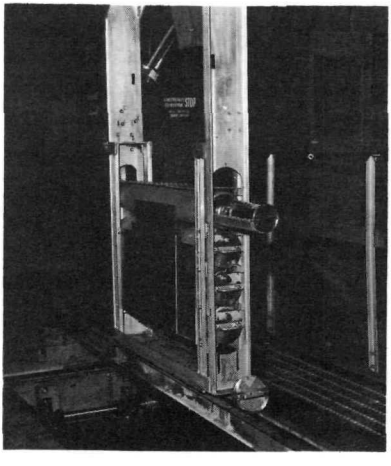
Steaks are partially cooked to destroy enzymes prior to irradiation at the Natick Laboratory.

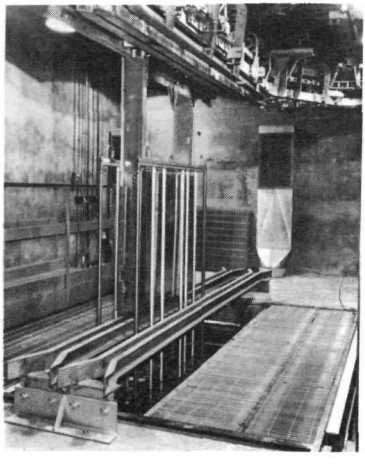
The precooked steaks are sealed in cans.



The cans are placed in aluminum boxes that are conveyed into the radiation cell.

Conveyor racks pass between raised ^{60}Co rods. (See picture on page 11.)





In 1966 when the Army wanted 30,000 pounds of sterilized bacon the processing was done in the High Intensity Radiation Development Laboratory at the AEC's Brookhaven National Laboratory in Upton, New York. This was the only facility at which such a large project could be undertaken under the stringent specifications required.

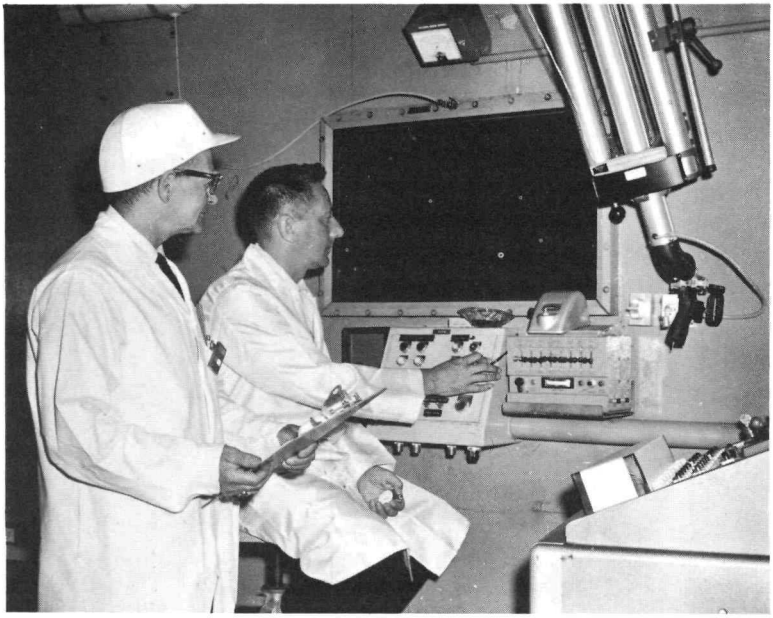
One of the cases filled with 1-pound cans of bacon that was processed at Brookhaven National Laboratory.

The uncooked but smoked bacon was canned and packed by two commercial firms. John Morrell and Company with Iso Nuclear Corporation provided 22,000 pounds, and George A. Hormel Company provided 8000 pounds.

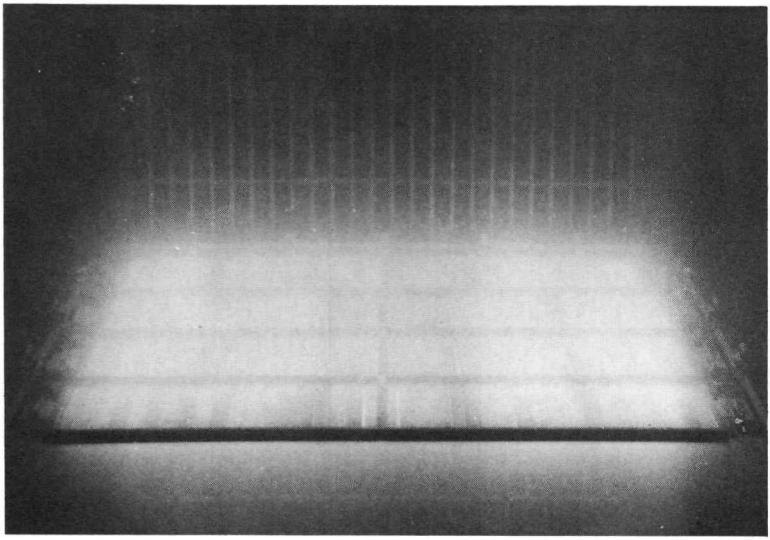
Also in 1966, 400,000 pounds of potatoes were irradiated by Nuclear Materials and Equipment Corporation and shipped to military bases for consumption. Tests were conducted to determine acceptability of the product.

The results of both these projects have been favorable.

A similar study, involving 250,000 pounds of flour, began in 1967.



The irradiation of bacon at Brookhaven is monitored through a heavy lead-glass window. Below is a fully loaded plaque of ^{60}Co, glowing in the irradiation cell. The bacon was refrigerated until irradiation; after irradiation it can be kept preserved indefinitely without refrigeration.



Pilot Plant Meat Irradiator

The Pilot Plant Meat Irradiator will be an important step between laboratory processing and commercial production. To encourage participation by private industry in the meat irradiation program, the AEC will share with industry the costs of a 3,000,000-pound-per-year irradiation facility. The Department of Defense will guarantee purchase of a minimum of 300,000 pounds of irradiated meat annually for the first 3 years, subject to availability of funds, FDA clearance, and product acceptability. The Department of Commerce is assisting as part of its continuous program to develop civilian commercial markets for irradiated foods.

The goals of the project are:

1. Construction of a facility, which would begin operation in 1969, in which laboratory techniques would be scaled-up to semi-commercial conditions.
2. Provision of sufficient radiation-sterilized foods to fulfill military needs for logistic and test purposes.
3. Determination of processing costs and economics of radiation sterilized meats and poultry.
4. Introduction of a portion of the output into the civilian economy.

After a number of food companies expressed interest in the project, the AEC invited contract proposals in December 1966. Ten proposals were received and a contract was awarded to Irradiated Foods, Inc. (IRRADCO), of Allentown, Pennsylvania, in July 1967. This company will bear engineering design and construction costs, which will result in a 1 million dollar private investment. The AEC will furnish $185,000 for procurement of the 400,000-curie ^{60}Co source, and technical assistance will be provided by the Army's Natick Laboratory and the Brookhaven National Laboratory.

Construction of the plant will begin as soon as FDA approves the Army's petition for radiation sterilized ham.

The facility is being designed to store and irradiate a wide range of prepackaged products, including all the Department of Defense procurement meats, representative meats for the civilian market, and a line of proposed pet

foods, at room temperature and at refrigerated temperatures as low as $-80°C$. The plant's flexible design will also make it simple to expand from pilot to full-commercial scale.

A public acceptance and test marketing program will be undertaken by IRRADCO through Thompson Farms Company to introduce irradiation sterilized ham into normal consumer channels. This program will include a distributor and consumer education program that will illustrate the techniques and benefits of irradiation sterilization.

IRRADCO, with the assistance of Allen Products Company, will also develop and introduce a new line of irradiation sterilized pet foods. This new product will supplement ALPO's "all-meat" pet food line and will be the only product of its kind on the market. The new food product will be marketed on the same basis used to test other ALPO products.

FRESH FISH EVERY DAY

Among foods which could benefit most from low-dose radiation, fish, a highly perishable product, is one of the most important commercially. In evaluating the potential of radiation pasteurization for the AEC, the Massachusetts Institute of Technology has reported that radiation pasteurization of soft-shelled clams, haddock, flounder, crabs, and shrimp is feasible and would be advantageous to industry and consumer alike. The longer refrigerator storage life resulting from irradiation would greatly broaden the market so that unfrozen fish from the Atlantic and Pacific Oceans could be sold for the first time in the central part of the United States. These factors in turn would tend to stabilize prices.

Clams and Haddock

Another research project, on the effects of radiation on soft-shelled clams and haddock fillets, indicated that bacteria dangerous to health did not flourish after irradiation. Particularly important, the growth of *Clostridium botulinum* was negligible in irradiated samples stored at temperatures of 32 to 37 °F. Because the botulinum toxin is so deadly, additional extensive research is being conducted to make absolutely sure that no combination of circumstances could allow toxin formation before the fish is totally spoiled.

The research showed that pasteurized haddock fillets can be stored under refrigeration from 2 weeks to 1 month longer than the untreated product; with an 800,000-rad dose, the fillets can be held 2 to 3 months.

Shucked soft-shelled clams are effectively preserved for periods of up to 3 months of storage at 45 °F after treatment with 650,000 to 800,000 rads. In addition, the researchers studied the effects of packaging and temperature on the quality of the product throughout its storage life.

Acceptability tests also were conducted. During the first 20 days of storage at 33 °F, air-packed clams irradiated at 450,000 rads were found as acceptable as fresh unirradiated clams. After 30 days the irradiated clams were still acceptable, but slightly less so than freshly shucked

clams. This was also true of irradiated vacuum-packed clams.

Air-packed pasteurized haddock and vacuum-packed pasteurized haddock stored at 33°F suffered very slight decrease in acceptability after 10 days' storage.

In 1966 the effects of commercial handling, shipping, and storing of irradiated fish were investigated. Haddock fillets were commercially packaged, given a dose of 200,000 rads, packed in ice with nonirradiated fish, and shipped from Gloucester, Massachusetts, to Seattle, Washington.

The irradiated fish had a 17-day storage life while the nonirradiated fillets had an 11-day life. These tests are now being expanded. Ten large commercial food chains—with over 8000 retail outlets—are contributing the use of their shipping, storage, and testing facilities to this study.

The Delicate Crab

Crab meat, a highly perishable delicacy, normally has a 7-day life. At the U. S. Bureau of Commercial Fisheries laboratory, Seattle, Washington, samples of crab meat packed in mylar–polyethylene pouches were irradiated with doses ranging from 200,000 to 650,000 rads and were stored at 36°F. The 200,000-rad dose reduced the bacteria count a hundredfold, and the higher doses about a thousandfold. During storage the bacteria counts generally increased but did not reach pre-irradiation levels for 20 days.

Flavor and odor of the samples irradiated at 350,000 rads showed only moderate deviation from fresh crab and had a shelf life of about 40 days. This was judged the most promising level for commercial use.

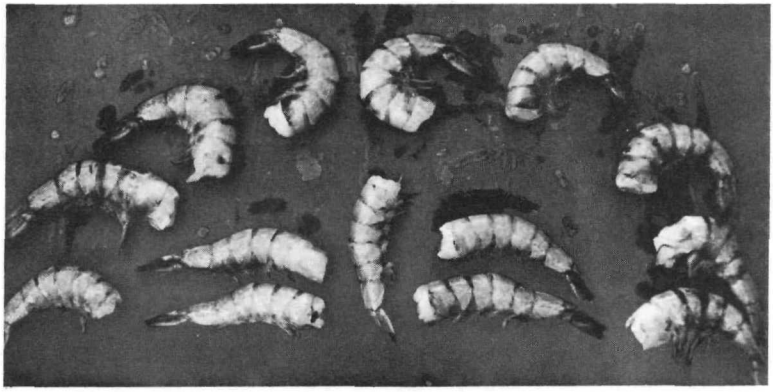
Shrimp

Freshly caught shrimp have an ice-storage life of 14 to 16 days, which can be extended to 20 days if antibiotics or chemicals are used as washes or dips. The Department of Food Science and Technology at Louisiana State University found that radiation-pasteurized shrimp had an increased ice-storage life of at least 2 weeks over untreated shrimp. In one instance a sample irradiated at 100,000 rads and

maintained in crushed ice was acceptable in taste, odor, and appearance after 7 weeks; an unirradiated sample stored under the same conditions was spoiled after 3 weeks.

Cooked shrimp, radiation sterilized, can be stored at room temperature for many months and still be acceptable. Shrimp preserved in this fashion is now being served to guests at the Army's Natick laboratory.

Similar studies have been made on cod, pollock, ocean perch, salmon, and petrale sole fillets. In the treatment of all these, it has been found that a high-quality catch, cleanliness in early handling, and proximity to the source of radiation are essential for a desirable end product.



The shrimp in both pictures are the same age. The seafood below was preserved with radiation and that above was not.

PRESERVING THE TASTE OF THE ORCHARD

Fruit in its raw state is more widely desired and enjoyed than any other food, yet it has been estimated that one-fifth of the fruits and vegetables grown in the United States is never consumed because of postharvest deterioration. Losses in California strawberries, for instance, average 25%; the cash loss is $5 million each year.

Postharvest deterioration stems from a variety of causes, including disease organisms, overripeness, chilling injury, sprouting, and undesirable dehydration. Chemical fungicides and cool storage are used to control these hazards. Radiation pasteurization promises to keep these commodities edible and acceptable longer.

On the Davis campus of the University of California, citrus fruits, strawberries, tomatoes, peaches, and grapes have been subjected to low levels of radiation. For each, information was compiled on the importance of: (1) temperature during irradiation; (2) atmospheric composition; (3) subsequent resistance to mechanical injury; (4) strains of decay organisms; (5) maturity; (6) subsequent ripening or other physiological processes; (7) host-parasite relations; (8) nutritional adequacy; and (9) flavor and texture.

Citrus Fruit

Citrus fruit — lemons and oranges — were the first fruits for which a petition for clearance was submitted to the Food and Drug Administration. These fruits are picked into field boxes or large bulk bins, brought into the packing houses and dumped into tanks of water for washing and waxing. Oranges are normally not stored for any length of time but move directly from the washer on conveyor belts to be sized and packed. Many lemons are stored at temperatures from 58 to 60°F after they have been washed and waxed.

The wash–wax application is important in citrus fruit handling because it protects the "button" at the stem end of the fruit, loss of which leaves the fruit susceptible to decay.

Oranges were subjected to 100,000 rads at 32° F and stored at the same temperature together with a control group of unirradiated oranges. At the end of 3 months only 2% of the irradiated oranges had decayed, compared to 66% of the unirradiated group. There was no apparent difference in flavor between irradiated and unirradiated oranges, and no differences could be detected in the vitamin-C content.

On the other hand, there have been difficulties with the irradiation of lemons. The fruit becomes spongy, and the vitamin-C content declines by 50% in fruits subjected to 200,000 rads or more. Radiation can destroy the buttons, which tends to leave a clear road to invasion by microorganisms and subsequent rotting. Scientists are hopeful that changing the processing conditions will lessen these reactions, and research is continuing.

Cherries and Peaches

Sweet cherries, a $30-million crop grown and harvested within a short period each summer, usually suffer 25% spoilage. Researchers have found that irradiation at 200,000 to 300,000 rads can drastically reduce losses and hold back decay for 2 to 3 weeks, permitting wider distribution. Radiation pasteurization of peaches inhibits brown rot and rhizopus (black bread mold), two diseases that commonly attack this fruit.

At first, in soft fruits such as peaches and nectarines there was textural damage caused by the levels of radiation needed for effective rot and mold control. Now a hot-water dip plus a radiation dose one half of that previously used provides effective control without textural damage. This will permit an extended shelf life for these relatively expensive foods.

A calcium chloride dip prior to irradiation is being tried for cherries, but tests have not been completed.

The shelf life of these irradiated fruits is 14 days at room temperature and 30 to 45 days at 40°F.

Tomatoes

Since fresh tomatoes are a large-volume commodity, the economic potential of irradiation is of prime commercial interest.

A shelf-life extension of 8 to 15 days for tomatoes irradiated at the "pink" to "full-ripe" stages has been demonstrated at the University of California. Early work with tomatoes, somewhat unsuccessful, was designed to delay ripening of green tomatoes.

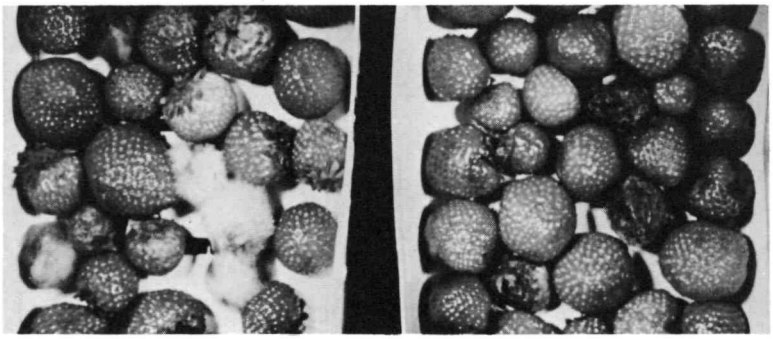
Present research at the University of California uses tomatoes harvested in the pink to full-ripe stages because the fruit is of a higher quality than when picked green. This new approach has yielded an 8 to 15 day shelf-life extension.

Papayas and Mangoes

At the University of Hawaii a 3 to 4 day shelf-life extension is obtained for papayas and mangoes with a combination of 75,000 rads and a hot-water dip. This process also destroys the fruit flies and mango seed weevils. Irradiation is the only process that destroys the weevils without damaging the fruit, making it possible to ship mangoes to U. S. Mainland for the first time.

Strawberries

The storage life of fresh strawberries, normally 7 to 10 days, can be effectively extended to about 2 weeks when the fruit has been pasteurized. At 200,000 rads the vitamin-C



Nonirradiated (left) and irradiated (215,000 rads) strawberries.

content of strawberries is slightly lower than that of the unirradiated fruit, but the difference is of little nutritional significance.

The significant accomplishment of radiation as applied to strawberries is the tremendous reduction of spoilage during normal transportation. Large-scale shipments of irradiated and nonirradiated strawberries have shown a reduction in spoilage from 25% for the nonirradiated ones to only 5% for irradiated berries. This is an increase of 20% more fruit for marketable use. This savings would be able to absorb the cost of radiation.

Taste evaluations were made by a panel of 12 trained judges on acceptability of strawberries irradiated at 100,000, 200,000, and 300,000 rads. The panel was not able to distinguish between the unirradiated and the irradiated berries on flavor, except at the higher doses.

POTENTIAL MARKET FOR IRRADIATED FISH

Along with the technology of radiation pasteurization, its feasibility for commercial adoption has been studied carefully. The AEC has cooperative programs with the Department of Agriculture and the Department of the Interior to develop cost and marketing information. Isotopes and accelerators as sources of radiation are being compared with each other and with conventional preservation processes. The probable impact of radiation pasteurization on prices, supplies, and marketing is being studied.

Changing Distribution

The marketing of irradiated fish fillets, for instance, would bring about a radical departure from existing fresh fish distribution practices. At present most of the fresh fish landed in Boston, for example, is sold in the fresh state within a 200-mile radius of that city. Although some fresh fish is sold in all cities, most inland consumers buy frozen fish because it offers more variety, better quality, and often lower price. A high percentage of fresh fish spoils during shipment.

Even in coastal cities, where the demand now is fairly stable, fresh fish prices vary sharply with the supply: If fish are not available, prices are high; if supplies are plentiful, prices plummet because of the highly perishable nature of fish.

The effect of radiation pasteurization on the demand-supply picture would be dramatic. Irradiators might be placed on a "mother ship" to provide a light dose of 50,000 to 100,000 rads to whole fish soon after the catch and reduce bacterial populations; another pasteurizing dose could be applied later, after processing and packaging had been completed at shore plants. Fishermen could operate at greater distances from home ports and stay out for longer periods.

The longer keeping time of 21 to 30 days would be sufficient so that gluts and shortages would nearly cancel out. Movement of supplies could be planned to handle peak demands, such as those on Fridays or special holidays.

Fish fillets are prepared, wrapped, and sealed prior to radiation exposure at the Department of Food Technology, Massachusetts Institute of Technology.

The fillets are placed in the ^{60}Co research irradiator at MIT to prolong their shelf life by radiopasteurization.

Surpluses could still be frozen, and untreated fresh fillets could be distributed locally.

Radiation pasteurization, by providing better quality food at a favorable price, could open a new market for fresh fish in the high-population areas of the Midwest.

The increase in demand would stabilize the production and price of fishery products by increasing the scope of the operation. It also would permit establishment of quality controls and create brand allegiance heretofore impossible, and help the fishing industry obtain a more stable footing.

Cost Factors

The cost of irradiated fish over nonirradiated fish would be raised only by the cost of the radiation process. This, however, is not expected to be greater than the present cost of freezing. A survey of processors indicates that a cost of ¼ to 1¢ per pound for irradiation would be acceptable; more than half said they would be able to assume a 1- to 3¢-per-pound cost increase. It is believed such higher expenditures would be balanced by increased markets and reduced losses.

In addition, the establishment of large community food irradiators at the major fishing ports in New England, Florida, California, and the Pacific Northwest would permit cheaper large-scale operation on a continuing basis. Modernization, concentration, and stabilization of the processing function would reduce cost and increase marketing advantages.

Fish at Retail

Consumer food-buying habits have undergone a dramatic change in the United States during the past 20 years. Most U. S. homemakers now go once or twice a week to supermarkets or self-service stores. This pattern has sharply reduced the sale of fresh fish. Supermarket operators frequently are not interested in handling fresh items unless they are prepackaged and preprocessed. Fresh fish cannot be handled easily as a self-service item and has limited refrigerator storage life. When a housewife buys fresh fish, she ordinarily cooks it the same day. If she is plan-

ning meals for several days ahead, she is naturally biased against the purchase of an item which demands priority on her menu.

A radiation-pasteurized marine product with all the desirable characteristics of a fresh item—no need to thaw, ease of preparation, good flavor, storage stability, and portion control—could be purchased along with the rest of the week's food, however, and prepared when convenient.

FRUIT-STAND ECONOMICS OF THE FUTURE

The average annual value of tomatoes, oranges, grapes, peaches, strawberries, grapefruit, lemons, and limes raised in the United States is $1,162,000,000. Nearly $100 million worth, or about 10% of this value, is lost each year between farm and market. This loss comes from molds and rots, poor moisture conditions, unfavorable temperatures, or bruising during shipment. These hazards to fresh produce exist at all stages of the distribution process, but they are increasingly costly as the commodity moves further toward the consumer.

Marketing Practices

Marketing practices for various fruits differ widely. For instance, the amount of fresh grapes going to market is kept under control in order to maintain the price level; the surplus is diverted to process uses such as jelly-making. On the other hand, growers try to market strawberries fresh whenever possible because this is more profitable.

Despite individual differences, marketing channels for all produce are essentially similar. Prior to shipment, most fruit goes through a packing house in the growing area and is shipped under refrigeration to a terminal market or wholesale warehouse. Wholesale markets hold auctions to set the competitive retail price and to supply institutions, restaurants, and small retailers. Many large food corporations, however, now purchase directly from packing houses.

Product Protection

Throughout the farm-to-market chain, steps are taken to preserve the product and improve shelf life. Orchard sprays are used to kill insects, chemical fungicides to control decay, baths to remove soil bacteria, prepackaging to protect from bruising.

Under present practices the life-span of produce ranges from 8 to 12 days for strawberries to 90 to 180 days for European grapes. Only strawberries and ripe tomatoes have normal cold-storage lives of 10 days or less.

ECONOMICS OF FOOD PRESERVATION

Background

Radiation processing is most applicable when the products have:

1. A large well-established market so that economic success of extended shelf life does not necessarily depend on changing consumer food-buying habits,
2. High spoilage losses at present,
3. High prices so that spoilage losses are an incentive to incur the relatively modest additional costs of radiation processing;

and when industry has:

1. Adequate production in a single location to justify an irradiation facility (in some cases this can be satisfied by the possibility of processing several products),
2. Stable production and demand throughout the year to permit efficient use of a facility,
3. Economic justification and need for extended marketing time that cannot be met by a lower cost or more effective alternatives to radiation processing,
4. Companies and organizations that are receptive to and interested in new processes.

Cost—Benefit Study

In a cost–benefit study* of the AEC's low-dose irradiation program, the following foods were studied:

1. East Coast finfish† (cod, haddock, sole, and flounder)
2. West Coast Dungeness crab
3. Alaska king crab
4. Bananas
5. Papayas
6. Mangoes

*In December 1966. See Report NYO-3666-1 in Suggested References.

†Fish with fins as compared with shellfish, such as clams and oysters.

These goods were chosen because technology for their preservation was well-advanced, and because East Coast and West Coast marine products were represented as well as a large well-established tropical fruit (bananas), and two exotic specialty fruits (papayas and mangoes).

NEW ENGLAND FINFISH A shelf-life extension of 2 to 3 weeks is obtained through finfish irradiation.

On the basis of consumer surveys, trade opinions, and trend projections it is estimated that an inland market of 6 to 11 million pounds per year for irradiated finfish could be developed by 1980. This compares with the present inland market for fresh finfish—3.5 million pounds in 1965 out of the total market of 35 million pounds.

Currently, retail losses due to spoiled fish are relatively small for two reasons: (1) "short buying" so that the demand exceeds the supply and no fish are left by closing time on Friday or Saturday, and (2) the practice of freezing remaining supplies before the fish spoils. Enough stores report spoilage losses, however—approximately 4% by weight—so that even this can be considered an appreciable problem. The retail price of fresh New England fish is often at least 69 to 79 cents per pound in Eastern markets, so it is apparent that saving any part of this loss by shelf-life extension would be significant.

There is also a revenue loss due to short buying. While the exact value of this is unknown, the nominal loss, based on conservative estimates of the unmet demand and retailers' assumptions, is 10% of present marketings.

A study undertaken with the help of Boston fish processors has determined that a 21-million-pound radiation plant could be built on the Boston fish pier and that a price increase of less than 2 cents per pound would cover capital amortization, operating costs, and a good return on the investment.

Several large commercial food processing firms have studied food irradiation prospects and are now awaiting FDA approval of the project. These firms' financial strength and marketing knowledge indicate that the chance for economic success is great.

For these reasons New England finfish might well be the first radiation-preserved item to reach the public in sizable quantities.

HAWAIIAN PAPAYAS Irradiated papaya has a shelf-life extension with radiation of 3 to 4 days, which would reduce retail losses now estimated at $11\frac{1}{2}\%$ of the fruit's value. Half of this loss is from reduced-price sales to clear shelves of ripe fruit and half from spoiled fruit.

Papayas are now fumigated chemically to kill fruit flies before shipment. Radiation would provide disinfestation and save the present fumigation cost of $\frac{1}{4}$ to $\frac{1}{2}$ cent per pound. Also it would reduce the time of handling between picking and shipment.

Benefits from radiation processing would be magnified if shelf life could be extended 7 or 8 days. This would allow for surface shipment of fruit, rather than air shipment, thus saving another 5 to 8 cents per pound. This is 10 to 15% of the typical retail price.

Distributors already have developed a good West Coast market and are now expanding to the Middle West and East; shelf-life extension would enhance prospects for success in these areas.

Papayas are grown primarily on the Island of Hawaii and have a year-round growing season, so a central radiation facility could be kept busy all year.

Grove of papaya trees.

HAWAIIAN MANGOES Mangoes, which have an irradiated shelf-life extension of 3 to 4 days, cannot be shipped to the U. S. Mainland because of the seed weevil. Irradiation processing is presently the only known way of destroying seed weevils without harming the fruit.

However, the outlook for radiation processing of this fruit is dim for several reasons. The harvest season is only about 3 months long. The acreage in commercial production is small and commercial benefits would be delayed, because it takes 5 years for trees to bear fruit and 15 years to mature. The irradiation of mangoes for seed weevil control is still attractive because it could be coupled with the facility for irradiation of papayas.

WEST COAST DUNGENESS CRAB While there is a market for fresh crab, which has a shelf life of 4 days, and while radiation is suitable for preservation, its prospects are limited because:

1. For unknown reasons the catch has been diminishing in recent years.
2. Many small fisheries at different coastal points bring in the catch, so a central facility would not be useful.
3. The season lasts only 6 months making a radiation facility for crab alone uneconomic.

ALASKA KING CRAB There is virtually no commercial market for fresh king crab. It is now preserved through canning and freezing for as long as a year with barely detectable loss in flavor.

BANANAS Commercial irradiation prospects for bananas are small because:

1. Radiation would reduce losses due to ripening, but these losses are small anyway. New varieties, which have a high disease resistance, are now replacing old varieties.
2. Shrinkage reduction as a benefit is not considered sufficient reason to incur the cost of irradiation, for two reasons. These losses are less than 8% of potential sales, and there is alternative packaging, which reduces this loss more cheaply than radiation processing.

TOTAL IMPACT

Research into the utilization of radiation for food preservation has had several beneficial side effects.

Of great importance has been the discovery that radiation is an effective tool in the control of *Salmonella* food-borne illnesses, high on the list of public health problems both here and abroad. The infecting organisms may originate in animal feeds and can be passed along in undercooked or uncooked eggs. Exposure of animal feeds to about 500,000 rads of gamma radiation destroys *Salmonella* germs. In countries like Great Britain, where most of the egg supply is imported, whole frozen eggs can be irradiated in storage to accomplish this result.

Insect infestation renders many tropical fruits unfit for import into temperate climates. Radiation to control deeply imbedded insect larvae offers the possibility of new markets to these quarantined items.

Radiation may also permit elimination of some chemical sprays now in use, such as biphenyl, a preservative used on oranges, which has some undesirable characteristics.

Nutritional Knowledge

Another by-product of food irradiation research is new general knowledge of nutrition. In evaluating studies of long-term animal feeding experiments, scientists have profoundly increased our knowledge of the interaction of vitamins, the destruction of vitamins and the other trace elements in food, the destruction of proteins, and the multitude of other changes which take place in food through cooking, canning, and freezing.

Sterilized Food in the Civilian Economy

It is difficult to assess the final effect of the Army's sterilization program on civilian food processing. The cost of sterilization ranges from 1 to 6¢ per pound, compared with 2 to 3.5¢ for freezing foods. It is likely that advances in technology will bring these costs down.

In the past, there has often been a spillover of benefits into the civilian economy, and this is likely again. Just as Nicolas Appert developed canning for Napoleon's troops, present methods of producing dehydrated foods originated in Army programs in World War II, and deboned "4-way beef", first developed as an Army ration, is now common fare in TV dinners.

Consumer Attitudes

In the 1966 cost-benefit study, interviews with consumers yielded these conclusions:

1. Twenty-four percent said they had heard about radiation pasteurization, but only 6% understood the concept.
2. Without further information 53% said they would buy such foods, 36% said they didn't know how they would react, and 11% said they would not buy.
3. After the process was explained, 82% appeared to accept it. Of these some would buy immediately while others would wait, but felt they would eventually buy.

Scientists and administrators, harvesters and retail merchants agree that a public education program must be conducted to make consumers aware of the nutrition and safety of irradiated foods.

Industry Attitudes

A survey of industry personnel revealed that, like consumers, the more they knew about radiation processing, the more enthusiastic they were about its use. Most agreed that they depended upon the government for assurance of safety in all food processing. They also felt that most consumers would buy FDA-approved radiation-processed foods.

Of those interviewed, 8% approved of the process without reservations, 46% would buy, sell, and use FDA-approved irradiated foods, 37% did not consider safety a problem but had no opinion on radiation-processed foods, and 9% were opposed to the method.

Some food never will be preserved by radiation, of course. The established techniques of freezing, canning, and drying will be used where they are best and where demand for them exists. In the 1970s, however, it is probable that a typical U. S. family, understanding that radiation-processed foods are fresh, wholesome, tasty, and vitamin complete, will include them in its weekly diet.

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