Progress and Problems in Radiation Processing of Food

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The need for improvement of food preservation methods to aid in food distribution justifies interest in radiation preservation. Results of work to date on this process are reviewed. A look ahead is attempted. Governmental approval for the process is a first requirement for use. Secondly, products with acceptable or desirable characteristics must be made available at an allowable cost. Radiation-sterilized products must demonstrate a quality improvement over existing products. The use of less than sterilizing procedures will be governed more by economic factors, as quality improvement is unlikely.

DESPITE millennia of human effort on methods of food distribution, important problems still exist today, both economic and technical. Food preservation methods can contribute to the solution of food distribution problems by permitting a food to be saved from time of production to time of consumption and/or be transported from points of production to consumption. However, only when a desirable and useful balance of economic and technical factors exists is a particular preservation process usable. Clearly, particular foods have different requirements and, therefore, it is necessary or desirable to use a variety of preservative processes, each having some limitations in its applicability. Not all that we desire to do can be done. Therefore, there has been a continuing search for new preservation methods and, hence, a well justified interest in irradiation as another approach to food preservation to aid in solving distribution problems.

Today, after almost 20 years of research by countless workers, we can view radiation preservation of foods with a clearer perception of its capabilities and limitations. This paper reviews what has been learned and considers what may lie ahead.

Two comments are in order today with respect to the early views on irradiation: (1) The hope that irradiation would be a panacea was a vain hope, and (2) the opportunity for controlling spoilage without heating or without the use of additives which bring about concomitant changes in the foods was (and still is) a justifiable reason for interest.

Results of Work to Date

Radiation can destroy microorganisms responsible for spoilage. It can also control insect-caused spoilage and some other processes causing spoilage, such as sprouting.

With due allowances for differences in penetration and absorption, electron beams and gamma radiation or x-rays have similar if not identical action.

The amount of radiation required to control a particular spoilage agent varies with the agent over a wide range from about 10,000 to 4,500,000 rads. In control of spoilage by bacteria, two areas of application exist: destruction of all organisms present, and partial destruction, the former leading to essentially unlimited preservation and the latter to limited extension of product life.

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.

Radiation can change taste, appearance, and texture of a given food. The exact effect depends upon the food in question, the amount of radiation, and the conditions of treatment.

While inadequately evaluated at the present, 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.

Certain levels of energy of both electron beams and γ-rays can induce radioactivity in foods; on the other hand, it is possible to select useful levels which avoid this effect. In this way, the question of the significance of radiation-induced radioactivity (which is of an amount comparable with the activity present from naturally occurring isotopes such as potassium-40) can be resolved most simply by controlling the process so as not to produce any.

On the basis of information available to date, wholesomeness—i.e., safety—of irradiated foods appears to be satisfactory.

The radiation-induced changes in nutrients are comparable with those which occur with other food preservation methods commonly in use and hence normally will not be of great importance.

Radiation sources are available, although not all requirements for large scale commercial operation could be fulfilled without further work. The control of sources through adequate dosimetric procedures, while well developed, may require additional work.

The economics of irradiation appear to fall within a reasonable range of requirements. They have not, however, been fully determined and undoubtedly each individual application will require its own appraisal.

Specific Accomplishments

Sterilization of Nonacid Low-Salt Foods. Complete sterilization of nonacid low-salt foods requires close to 4,500,000 rads, according to present estimates. This level will destroy *Clostridium botulinum*, which is the most radiation-resistant organism of spoilage significance. The precise value for destruction of *Cl. botulinum* in nonacid low-salt foods is not known and needs further definition. For foods containing high salt levels or having acidity adequate to make it unnecessary to provide for *Cl. botulinum* destruction, a significantly smaller figure for "sterilization" may be anticipated, but adequate information is lacking on this.

By combining radiation with heat,

a synergistic effect may be obtained. Apparently radiation can sensitize *Cl. botulinum* to heat. Thus with cooked beef, 1,200,000-rad pretreatment reduced fourfold the heat requirements (as measured by F_0 value) for sterilization (*4*). Such combination treatments may offer good approaches to more satisfactory sensory characteristics through reduced requirements for both heat and radiation.

For less than sterilization the requirements for a useful effect vary with the particular food, the conditions of storage, and the desired end result. In general, useful effects are obtained at levels between 10,000 and 500,000 rads. Table I lists a number of values reported for various foods.

Spoilage from Insect Infestation. Spoilage resulting from insect infestation can be controlled by approximately 25,000 rads (*5*). Sprout inhibition of onions can be obtained with 4000 to 8000 rads (*1*) and with potatoes at about 10,000 (*2*).

Sensory Changes. At sterilizing levels of radiation the following foods appear to undergo sufficiently small changes in sensory characteristics as to be generally considered acceptable: chicken, fresh (not cured) pork, oysters, and shrimp.

These are nonacid low-salt foods. Other similar foods show various changes which appear to be objectionable. Among these is a taste change associated with a flavor that seems characteristic of irradiation; it resembles but is not identical with scorching. Beef, for example, develops this off-flavor to a considerable degree. Milk products are especially affected. Eggs, cereals, and vegetables to varying degrees undergo flavor changes, which in some cases are not the typical irradiated flavor. The induction of flavor changes is probably the largest single obstacle to the broad use of irradiation as a preservation method.

Other sensory characteristics of foods may also be altered by radiation. Color is frequently altered, but the character of the alteration usually is specific to the food in question. 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 when irradiated in the absence of oxygen turns pink, as does chicken. Cured meats are generally browned, especially in the presence of oxygen. The orange-yellow color of Cheddar cheese is bleached. Cereals are darkened. Vegetables display a variety of off-colors. Pink salmon is bleached.

Texture may likewise be altered. Loss of firmness is common with certain fruits and vegetables. Beef is "tendered" at several million rads. The thick white of eggs thins.

Functional properties may be harmed. The whipping properties of egg whites can be reduced. The ability of flour to yield normal volumes with baked goods such as cakes is reduced.

Irradiation Flavor Development. Studies have been carried out for the purpose of seeking an understanding of the chemistry of the irradiation flavor development. Much of this work has been directed toward isolating the flavor components.

From beef have been obtained sulfur compounds such as hydrogen sulfide and mercaptans. Work on proteins has suggested that the origin of these sulfur compounds lies with sulfur-containing proteins. Other compounds also have been obtained, including aldehydes, ketones, alcohols, and amines, but their significance seems to be less than that of sulfur compounds. Somewhat strangely, perhaps, the compounds isolated are the same ones found in unirradiated beef, but appear in larger amounts. No single compound has been found to account for the characteristic flavor.

Such work might be expected to give a clue as to the mechanism of the irradiation flavor formation. Results to date need to be extended before we can hope to understand the process and then be able to control it.

Mechanism of Flavor Formation. Even without an understanding of mechanism of flavor formation, attempts have been made to control it. These efforts have postulated that radiation produces free radicals in the food, for which there exists independent evidence. This approach has sought to provide free radical acceptors to compete with the compounds native to the food, which, when acted upon by the free radicals, form the unwanted flavor compounds. Sodium ascorbate is perhaps the best example of such a free radical acceptor. An alternative method freezes the food during irradiation. This method attempts to restrict the "sphere of influence" of the free radicals by irradiating in the solid state. In both approaches the presumed origin of the free radicals is the water natural to the food.

A third approach seeks to eliminate oxygen derived from the atmosphere. Radiation can convert molecular oxygen to active compounds which appear to account for some of the irradiated flavor. There seems little doubt about the desirability of irradiating in the absence of oxygen.

While the value of using these aids seems clear, neither alone nor in combination have they provided sufficient control of the irradiation flavor process.

What Lies Ahead

What lies ahead for food preservation by irradiation? With all the knowledge we possess about the process, why are we not using it? The answer is not simple, but we point out some problems which need solving, and perhaps in this way, we can get some picture of the future.

Table I. Radiation Levels for Useful Effects with Less Than Sterilization Treatments

Food	Rads
Fresh beefsteak	100,000
Pork chop	100,000
Chicken	100,000
Bananas (*3*)	14,000
Oranges, lemons (*3*)	140,000
Grapes (Tokay) (*3*)	465,000
Apples (*3*)	50,000
Cabbage (shredded) (*3*)	47,000
Tomatoes (*3*)	279,000
Spinach (*6*)	1,500,000

The commercial utilization of irradiation of foods cannot become a reality until its use is approved by government regulatory bodies. Under Federal Public Law No. 85-929 (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, not the consumer and not a government agency such as the Federal Food and Drug Administration. In the atmosphere of this law and the attendant philosophy, no sketchy evaluation of food irradiation is acceptable. One can assume as realistic that industry, in the face of other uncertainties of the irradiation process, is not likely to undertake this proof. Fortunately, in the United States military interest in irradiated foods has been considerable and, in accordance with military objectives, a thorough program of evaluation is being conducted under the supervision of the Army Surgeon General in cooperation with the Food and Drug Administration. This program, when complete, should provide the information needed to pass on the safety of irradiated foods. Until it is completed, no commercial use of radiation on foods for preservation is likely to be permitted.

Setting aside the need for governmental approval as a consideration, the utilization of the process commercially depends upon two factors: the fulfilling of a useful purpose at an allowable cost, and the availability of products having acceptable or desirable characteristics. As of today certain irradiated foods appear to have met these requirements. One might include pork, chicken, oysters, and shrimp in this category even when completely sterile. Among the less than sterile foods may fall certain meats such as liver and pork sausage, frozen eggs, fruits such as strawberries, peaches, grapes, and citrus fruits, and vegetables such as cabbage, tomatoes, and potatoes.

In order to speculate as to whether such products would be produced commercially, one might attempt to determine what value could be ascribed to their availability. Complete sterilization of meats, fruits, and vegetables could yield products superior to those now available as fully preserved foods, specifically canned or dried products. Such quality improvements could justify added costs and make economics a secondary consideration. For example, the ability to sterilize a truly roasted piece of meat (dry-heat-cooked outside the storage container and then radiation-sterilized after packaging) would represent a substantial quality improvement over conventional thermal processing. Consumer acceptance of such an item might warrant its commercial preparation. Similarly, fruits and vegetables having fresh characteristics would be improvements over the usual canned products. While cost considerations would be significant, improvement of quality in shelf-stable products would be a factor of prime importance.

When products are treated only to extend their normal life, quality improvement, detectable by 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 their commercial preparation. On this basis one might conclude that the most likely applications will fall in the field of fruits and vegetables where distribution problems exist and losses today are large, and not in meats or poultry where losses are nominal. Which fruits and vegetables, will depend upon individual situations. At present, strawberries and potatoes afford some interesting possibilities.

To sum up the look ahead, we can list two points: Before any commercial use, we must have government clearance for the process, and for less than sterilized products, there must be favorable economics. For sterilized products there must be a clear-cut product quality improvement plus reasonable economics.

How do we proceed? The military program should determine whether government approval can be had. Assuming irradiated foods are cleared, then for less than sterilized foods we shall need suitable radiation sources, and beyond this little else from a technical point of view. For sterilized products, in addition to sources we shall need adequate controls to guarantee delivery of a minimum sterilizing dose for reasons of safety. But most of all for sterilized products we need quality improvement. Perhaps this is available now in pork, chicken, oysters, and shrimp. For other foods we need new knowledge in order to control the undesired sensory changes, particularly flavor. In view of the effort of the past years which has supplied little understanding of the mechanism of these changes, it is clear that what is needed is more basic research. This is a highly important area for the future.

There is one final aspect. Consumer or public attitude toward irradiated foods will be a large if not dominant factor in their success. Even with the assurance of safety based on government approval for irradiated foods, the public will act on its own confidence and understanding. Public consciousness of the hazards of potentially carcinogenic substances in foods, 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 foods will require education to clarify. The seller of irradiated foods will need to secure public confidence through an organized information program.

Prior events actually outside the area of irradiated foods will have great significance in the reaction of the public. We do not know what these will be and any counteraction of them will have to wait until we are ready to sell irradiated foods. It would appear, however, that we shall not be ready to offer irradiated foods for sale for some time to come.

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RADIATION PRESERVATION OF FOOD

Current Aspects of the Wholesomeness of Irradiated Food

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RADIATION PRESERVATION OF FOOD represents a rather radical innovation. It was first proposed nearly 15 years ago as a possible supplement to existing food-processing techniques. Its potential application has been under active investigation for over ten years. Throughout this period, the lay press, as well as the technical journals, has shown an exceptional interest in the research results as they were made available. As a result, food irradiation has been alternately heralded as a panacea for the world food problem and as a technological (or economic) impossibility. At present a fair interpretation would appear to be that radiation preservation of food will provide an important supplement to present food-processing practices but will by no means completely supplant any process now in use.

This conclusion is based upon two facets of the over-all problem of suitability: technological feasibility and the health-hazard potential (wholesomeness) of the treated food. Of these, technological development has presented the more formidable problems, particularly from the viewpoint of "commercially sterile" products. However, recent releases to the lay press have stressed the unsuitability of irradiated foods for human use from the whole-

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