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Food Irradiation:

A Look at Regulatory Status, Consumer Acceptance, And Economies of Scale*

by

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Food irradiation is receiving renewed attention by many individuals--scientists, policy makers, agricultural producers, public health officials, and consumers. Interest in food irradiation's benefits and limitations has been piqued by recent concerns over the safety of chemical fumigants and preservatives and interest in reducing the incidence of food borne diseases. Individuals concerned with food shortage problems in developing countries are anxious to see if irradiation can be used to eliminate high spoilage losses in those countries. Food processors and retailers are always looking for less costly preservation methods and exploring new techniques to achieve desirable qualities in fresh and processed foods.

Although research on food irradiation has been conducted for over 40 years, commercial use of the process is still in its infancy. Very few of the world's commercial irradiators are devoted solely to food. Commercial use of food irradiation depends on many factors such as technical feasibility, the existence of demand for the benefits irradiation provides, processor and consumer acceptance, the cost of the technology and its competitiveness with alternative techniques, and approval by regulatory authorities.

Today, in the United States, commercial irradiation is legal for a few foods. Spices for ingredient use are the only foods irradiated, and the volumes are small. However, pork producers and Hawaiian papaya growers are two groups voicing interest in different applications of irradiation. This paper discusses the current regulatory status of food irradiation in the United States and highlights some recent research on consumer reaction to the process. Previous research on treatment costs and economies of scale for gamma irradiation facilities is presented.

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Current Uses and Regulatory Status

Irradiation is a process where products are exposed to ionizing radiation to achieve a variety of effects. Ionizing radiation is radiant energy capable of breaking molecules into smaller ionized, or electrically charged, particles. The source of the radiation used to treat foods can be gamma rays from radioactive isotopes or machine-produced radiation in the form of high energy electrons or X-rays. The energy levels of all three sources, used in accord with restrictions imposed by the U.S. Food and Drug Administration (FDA), will not make the food radioactive.

In foods, irradiation can be used to sterilize or kill insects and microorganisms and to inhibit maturation in fresh fruits and vegetables. The effects of irradiation depend on the dose absorbed by the product, usually measured in kilorads (krads).[1] Irradiation is considered a "cold treatment" that achieves its effects without raising the temperature of the product significantly and leaves the food closer to its unprocessed state. However, not all foods tolerate exposure to radiation, and in some cases undesirable changes in texture, appearance, flavor, or odor occur (Morrison and Roberts, 1985; Urbain, 1978).

Irradiation is used to treat a variety of non-food items ranging from sterilizing disposable medical supplies to curing scratch-resistant coatings on magnetic tape. Its use on foods has been much more limited. Although 22 countries presently allow irradiation to be used on a variety of foods, less than ten countries use the process commercially and the quantities treated are small (Table 1). The dominant use is to decontaminate high-valued, dried foods and spices. Other commercial uses include decay control in fresh strawberries, disinfestation of grain, and salmonellae reduction in shrimp and frog legs.

Table 1.

Selected Commercial Uses
of Irradiation on Foods

Country	Application
The Netherlands	Microbial control in spices, egg powders, marine products, dried vegetables
South Africa	Decontaminate dehydrated foods, spices, tea. Extend shelf life of fresh produce.
Japan	Inhibit sprouting in potatoes
Soviet Union	Disinfest grain
Norway France Belgium United States	Insect and microbial control in spices

One essential criterion governing the use of irradiation is regulatory approval to use the technology. A 1958 amendment to the Federal Food, Drug, and Cosmetic Act specifically includes "any source of radiation" used in processing or packaging food in the definition of a food additive (21 U.S.C. 321).[2] Thus, processors must comply with FDA regulations prescribing safe use of radiation to treat foods or submit a food additive petition with data supporting an amendment to these regulations (21 U.S.C. 348). For meat and poultry products, approval must be granted by USDA's Food Safety and Inspection Service (FSIS). FSIS has begun rule making procedures to add irradiation to their list of approved food additives (9 CFR 318.7).

Table 2.

FDA Approvals and Proposals for Irradiating Foods
As of September 1985

Food	Dose (krads)	Application	Year Approved
Wheat and wheat flour	20 to 50	Control insect infestation	1963
White potatoes	5 to 15	Inhibit sprouting	1964
Spices and dried vegetable seasonings	Up to 1,000	Control microbial contamination	1983
		Control insect infestation	1984
Dried enzyme preparations	Up to 1,000	Control insect and microbial contamination	1985
Fresh pork	30 to 100	Control trichinella spiralis	1985
Fresh fruit and vegetables	Up to 100	Inhibit growth and maturation	Proposed
Food	Up to 100	Insect disinfestation	Proposed
Spices and dried vegetable seasonings	Up to 3,000	Microbial disinfestation	Proposed

Table 2 lists the foods for which FDA has granted approval to irradiate. In the early 1960s, FDA approved the use of radiation at doses between 20 and 50 krads (.2 to .5 kGy) to control insect infestation in wheat and wheat flour and doses of 5 to 15 krads (.05 to .15 kGy) to inhibit sprouting of potatoes. Neither of these applications has ever been used because of the availability of less expensive easier to use chemical alternatives. In 1963, FDA approved a petition submitted by the Department of the Army for irradiation of canned bacon at doses of 4,500 to 5,600 krads (45 to 56 kGy) (28 FR 1465). However, in 1968, FDA revoked the approval after additional data from animal feeding studies raised doubts about the safety of irradiated bacon (33 FR 15416). At that time; the Army withdrew a 1966 petition for irradiated ham because it was based on the same data as the bacon petition (33 FR 11098).

In 1979, FDA established the Bureau of Foods' Irradiated Food Committee (BFIFC) to examine FDA's policy toward irradiated foods and to establish appropriate safety tests. The BFIFC made separate recommendations for different used of irradiation on foods (Brunetti et al., 1980, pp. 16-19):

- Foods irradiated at doses up to 100 krads (1 kGy) are wholesome and safe for human consumption.

- Foods comprising no more than 0.01 percent of the daily diet and irradiated at 5,000 krads (50 kGy) or less could be safely irradiated without toxicological testing.

- Other foods irradiated above 100 krads (1 kGy) must be tested in a series of short-term mutagenic tests to detect any toxic substances. In addition, these foods must be evaluated in 90-day feeding studies in one rodent and one non-rodent species.

These recommendations and other findings of the BFIFC have served as the basis for FDA's regulatory action and proposals in the last few years. In 1983, FDA approved irradiation at doses up to 1,000 krads (10 kGy) to control microbial contamination in dried spices and dehydrated vegetable seasonings (onion and garlic powders) (48 FR 30613). A year later, this approval was expanded to insect infestation (49 FR 24988).

Two uses were approved in the summer of 1985. Dried enzyme preparations can be irradiated at doses up to 1,000 krads for insect and microbial control. In July, FDA approved the treatment of pork carcasses and fresh cuts of pork at doses between 30 and 100 krads (0.3 to 1 kGy) to control trichinella spiralis (the organism that causes trichinosis) (50 FR 24190 and 50 FR 29658). A processor interested in irradiating federally-inspected pork carcasses or cuts would need to submit a description of the equipment, operating procedures (including how the dose will be controlled and verified), and labeling intentions for approval by FSIS. In addition, if the processor's facility is not already a USDA-inspected meat establishment, such as a contract irradiator, the facility would need to be approved by FSIS as a federally-inspected establishment (Gast, 1985).

Up until now, permission to use irradiation on foods has been granted or denied in response to individual petitions submitted to FDA. However, FDA can also issue generic permission through Agency action. In 1984, FDA proposed new rules that would allow processors to use doses up to 100 krads (1 kGy) to delay ripening of fresh fruits and vegetables and to kill insects that infest foods (49 FR 5714-22). This proposed rule would also raise the level permissible for spices from 1,000 to 3,000 krads (10 to 30 kGy). As of September 1985, a final rule has not been issued. Petitions for uses above 100 krads would have to include the results of appropriate safety tests.

While FDA is only contemplating a 100-krad (1 kGy maximum, other countries allow the 1,000-krad (10 kGy) maximum adopted by the Codex Alimentarius Commission in July 1983. The Codex Alimentarius Commission is an international group set up by the Food and Agriculture Organization of the United Nations and the World Health Organization to develop global food standards.

Consumer Acceptance [3]

Consumer acceptance of irradiated foods and willingness to purchase them are critical to the commercial success of food irradiation. Public acceptance depends on the benefits of radiation treatment being passed on to consumers. If not, then there is no reason to try irradiated foods. If spoilage reduction is the only benefit, then consumers should receive some of the extended shelf life in their own homes or see a reduction in price (reflecting cheaper handling methods or transportation modes made possible by the longer shelf life).

Before consumers will decide whether the benefits offered by irradiation are appealing, they must believe that irradiated foods are safe to eat. Consumer acceptance in other countries has been mixed. Irradiated potatoes in Japan met with opposition by consumer groups. In South Africa, where irradiated food is not labeled at retail and the initial test marketing was accompanied by an extensive educational campaign, irradiated strawberries, herbal teas, and dried foods are successfully sold.

Because the only irradiated foods in the U.S. marketplace are microingredients, consumer acceptance of this new process must be estimated through consumer interviews. Consumer surveys can measure awareness and reaction to food irradiation; but the results do not guarantee that respondents voicing little or no concern with the process will actually purchase or consume irradiated foods, and vice versa.

A survey of 1,000 consumers was conducted for the Department of Energy and the National Pork Producers Council in February 1984 (Weise Research Assoc., Inc., 1984). After being asked a series of questions about their concern with chemical preservatives and sprays, food borne diseases, and spoilage, consumers were asked whether they had a major, minor, or no concern about a new method to kill harmful organisms in food. Between 33 and 43 percent of the respondents said they had a major concern for this new process, depending on which term was used--gamma waves, irradiation, or ionization (Ibid., p. 28). The term "irradiation" elicited the greatest number of major concern responses. This finding emphasizes how important terminology is in consumer acceptance. A little less than 25 percent of the consumers said they had heard of the process prior to the interview (Ibid., p. 26).

Respondents were asked to volunteer possible advantages this new process could offer. The most common answer was "don't know" (43 percent), but other respondents mentioned less chance of sickness from food (11 percent), elimination or reduction of chemicals (10 percent), and longer shelf life (6 percent) (Ibid., p. 34). Thus, there is opportunity to introduce people to irradiation's potential benefits.

Respondents were also asked what concerns they might have with this process. The volunteered concerns varied depending on which descriptive term was used in the earlier question on initial concern. Concern over radiation left in the food showed the most variability. Twenty-four percent of the people who were read "irradiation" listed this concern versus only 8 percent of the people read "ionization" listed this concern versus only 8 percent of the people read "ionization" (Ibid., p. 36). Other concerns included irradiation's possible harm to people, side effects, insufficient testing, its effect on the food, and lack of information about the process (Ibid., p. 36).

Interestingly, a greater portion of the sample (55 percent) expressed a major concern about chemical sprays used on fruits and vegetables than the number of people (38 percent) expressing the same level of concern about irradiation. It is important to remember that this survey was conducted the same month that the controversy over ethylene dibromide (EDB) was picked up by the press. A characteristic of consumer surveys is their sensitivity to concerns at the time of the interview.

Survey participants were asked which factor out of a list of eight is the most persuasive attribute in favor of food irradiation. The most often selected reasons were no residual radiation in the food (selected by 23 percent of the respondents), no chemical residues (17 percent), irradiated foods being fed to patients with immune problems (cancer patients on special diets) (16 percent), and FDA approval (12 percent).

Information on U.S. consumers' awareness of food irradiation was gathered more recently as part of a 1985 Food Marketing Institute national survey on consumers' attitudes and shopping practices (Food Marketing Institute, 1985, p. 34). Twenty-nine percent of the 1,005 respondents had heard of irradiation (compared to 25 percent in the 1984 survey). When asked which method they would prefer--irradiation or chemical preservatives--39 percent of those who had heard of irradiation said they would prefer its use to chemicals. Among the respondents who had not heard of irradiation, a greater portion were uncertain which technique they prefer, but more (28 percent) prefer chemical preservatives than prefer irradiation (22 percent). These findings suggest irradiation may become more acceptable as people learn more about the technology.

To better understand U.S. consumers' attitudes toward food irradiation, the Department of Commerce is partially funding a market research study to be concluded by the end of 1985. The study will analyze consumers' responses to irradiation technology and evaluate alternative education approaches.

As the two surveys suggest, how irradiation is described and presented influences people's perceptions. Thus, retail labeling is an important component in consumer acceptance. Current FDA regulations require irradiated foods to be labeled "treated with ionizing radiation" or "treated with gamma radiation" (21 CFR 179.22). However, FDA's 1984 proposed rule does not maintain this labeling provision at retail (49 FR 5714-22). Comments from consumers and consumer groups responding to the proposal were almost unanimous in demanding that irradiated foods, if allowed on supermarket shelves, be labeled. At this time, the controversy over retail labeling has not been resolved.

Food companies are approaching food irradiation very cautiously. Even if no retail labeling were required, food processors are concerned about potential anti-irradiation campaigns targeted toward their product. U.S. food companies do not want to risk the good will of their brand names if irradiation was to be rejected by consumers. At the same time, it could be desirable to be the first to capitalize on irradiation's potential benefits.

Treatment Costs and Economies of Scale

Building a commercial scale irradiator requires a large investment in special shielded structures, conveyor machinery, and source material. Analysts have asserted that this high investment means large quantities of food must be treated in a large scale plant to achieve reasonable unit costs.

This hypothesis was tested by examining the plant economies of scale for five cobalt-60 irradiators, each treating a different food product.[4] The term economies of scale refers to the relationship between total long-run average cost per unit of output and the size of the plant. Economies of scale exist if long-run unit costs fall as size increases. Substantial economies of scale could put operators of small irradiators at a distinct cost disadvantage. It could also discourage an industry of small, widely-scattered agricultural firms from using the technology.

Irradiation costs were estimated for the five applications listed in Table 3. The radiation dose levels are all below the 1,000 krad (10 kGy) level proposed by the Codex Alimentarius Commission.

Table 3.

Food Product	Purpose	Dose krad	Dose kGy
Free standing:			
Fish fillets	Extend shelf life	175	1.75
Papayas	Satisfy quarantine requirements	26	0.26
Strawberries	Extend shelf life	200	2.0
Integrated:			
Young chicken	Kill food poisoning microorganisms	250	2.5
Pork	Inactivate *trichinella spiralis*	30	0.3

Irradiators treating papayas, fish, and strawberries were assumed to be free standing facilities. Costs for the pork and chicken irradiators are based on their being physically integrated into slaughtering plants. Costs were estimated at four sizes for each of the five irradiators. The largest irradiators for each application have capacities designed to meet the needs of larger production areas in appropriate geographic locations in the United States, such as a major fishing port or the California county with the greatest concentration of strawberry production. These maximum throughputs were then successively halved to approximate annual volumes of existing agricultural plants. Yearly throughputs for the pork and chicken irradiators reflect processing capacities of large and medium sized U.S. slaughtering plants.

Irradiator design and operation are very specific to the particular commodity, its reaction and tolerance to radiation, occupational safety requirements, and other variables. However, development of cost relationships by plant size requires specific assumptions about costs and operating procedures. The major assumptions and input prices underlying this analysis are discussed in Morrison, 1985. A capital recovery factor was used to estimate the levelized annual cost of the capital assets. The costs presented here are meant to provide an idea of the magnitude of in-house irradiation treatment costs and how these generalized costs might vary with plant size. Actual costs will depend on the design of the irradiator, construction costs, land prices and necessary site preparations, wage levels, financing arrangements, and other variables which vary by locality.

Table 4 lists the initial investment levels and irradiation treatment costs per pound based on the specific set of assumptions and input prices. Treatment costs are for irradiators processing the hourly volumes for which they were designed and operating three shifts a day, five days per week (except for strawberries, see footnote 4 on Table 4). Unit costs for the applications and volumes analyzed range from 8.5 to 0.2 cents per pound.

Irradiators treating all five commodities exhibit economies of scale, as demonstrated by their decreasing unit costs as size is doubled. This means that, considering only the treatment cost, larger irradiators would be able to treat products at a lower unit cost than small irradiators. However, in all cases the scale economies become less pronounced as size increases. Potential scale economies become less important at annual volumes greater than 50 to 100 million pounds. For example, unit costs for the two largest strawberry irradiators operating at full capacity differed by only two-tenths of a cent per pound.

Economies of scale result from production inputs expanding less than proportionally with plant capacity. For a cobalt-60 irradiator, the most important sources of production economies are labor, buildings and shielding, and machinery. Certain employees--plant manager, quality control person, maintenance and clerical personnel, and shift supervisors--are needed regardless of the size of the irradiator. Spreading their fixed salaries over the large output of a high-volume irradiator, lowers average fixed labor costs. When salaried employees are a major cost item, such as in the fish irradiators which span a smaller size range, large economies occur. Biological shielding and machinery costs follow the general construction relationship where productive capacity increases faster than cost (McGee, 1974, p. 58). This relationship also contributes to the existence of larger scale economies for small irradiators.

Cobalt-60 is an important cost item, especially for large capacity irradiators. However, cobalt-60 is not a source of production economies because cobalt needs are directly related to hourly throughput. Only minor economies could be realized by cobalt-60 suppliers offering volume discounts. As plant capacity increases, cobalt becomes a large portion of total costs and less scale economies are possible.

Raising the dose of radiation applied to the food product also causes cobalt-60 to become a greater portion of total costs. Therefore, large capacity irradiators applying higher doses would demonstrate less scale economies. The declining rate of reduction in unit costs for the chicken and strawberry irradiators as throughput increases illustrates this.

Processors can suffer stiff production cost penalties if too large a plant is run at substantially less than capacity, rather than operating a smaller plant at its ideal throughput. A large irradiator treating small volumes of products has less output over which to spread its high fixed costs. The short-run cost curves for strawberry irradiators in Figure 1 illustrate the point clearly. These short-run cost curves were estimates by computing costs at 25, 50, 75, and 100 percent of design capacity. If 50 million pounds of strawberries were treated in a facility designed for that annual volume, the unit cost would be close to 2 cents per pound. A plant built to handle double that volume would incur a unit cost of 3 cents per pound. If the largest strawberry irradiator only processed 50 million pounds per year, it would be running at 25 percent of capacity and unit costs would be above 5 cents per pound.

Seasonality of production which results in unused capacity and higher unit costs may be the typical situation if irradiation is used for treatment of fruits and vegetables. Production of these commodities is very seasonal. Even those commodities that are grown year round like papaya have definite seasonal harvest patterns. To accommodate the seasonal high volumes, irradiators would have excess capacity during off periods.

The unit costs presented in Table 4 are for the radiation treatment alone. For free standing facilities that combine throughputs from several producers, the cost of shipping the commodity to the irradiator is an added cost not considered here. As free standing irradiators increase in size and production density remains constant, they will have to draw on larger geographic areas for their throughput. The transportation costs of getting commodities to a larger irradiator may outweigh any gains in production economies. This may bring the total cost of using a small irradiator more closely in line with that of a large irradiator.

As regulatory approval for expanded uses of food irradiation is granted, processors will have to consider whether irradiation offers any marketing opportunities for their products. Prospective users must also consider whether irradiation is competitive with alternative treatments in terms of cost and compatibility with current production and marketing procedures. And finally, food companies must feel confident about consumer acceptance of irradiated foods.

Endnotes

[1] A krad is a unit of absorbed energy equaling 1,000 rads. One rad equals 100 ergs of energy absorbed per gram of absorber. The International System of Units replaces the rad with the Gray (Gy). One kGy equals 100 krads.

[2] U.S.C.--United States Cost; FR--Federal Register; and CFR--Code of Federal Regulations.

[3] This section is based on a chapter in Morrison and Roberts, 1985.

[4] Cobalt-60, a radioactive isotope, is a common radiation source in commercial irradiators. An alternative source is machine-produced radiation in the form of high-energy electrons or X-rays.

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Table 4.

Investment and Unit Costs for Selected Cobalt-60 Irradiators[1]

Commodity and Annual Throughput in Millions of Pounds	Dose ---------- krad (kGy)	Initial Investment[2] ----------- $1,000,000	Irradiation Unit Costs --------------- cents per pound
Fish fillets[3]	175		
6	(1.75)	1.0	8.5
12		1.1	4.5
24		1.4	2.6
48		1.9	1.6
Papayas[3]	26		
12	(0.26)	1.0	4.2
24		1.2	2.3
48		1.5	1.4
96		2.4	1.0
Strawberries[3] [4]	200		
25	(2.0)	2.0	2.7
50		3.4	2.1
100		5.8	1.7
200		10.5	1.5
Young Chicken[5]	250		
52	(2.5)	2.0	1.6
104		3.3	1.2
208		6.0	1.0
416		11.2	0.9
Pork[5]	30		
66.5	(0.3)	.9	0.7
133		1.1	0.4
266		1.6	0.3
532		2.5	0.2

[1]Costs in this table are based on a specific set of assumptions and input prices listed in Morrison, 1985, Appendix A.

[2]Investment items include: cobalt-60, biological shielding and other building space, irradiator machinery and auxiliary systems, product handling equipment, refrigerated warehouse space, design and engineering, land, and working capital.

[3]Free standing facility.

[4]The strawberry irradiators operate 7 days a week for 4 months per year, instead of 5 days year round as do the other irradiators. Employees other than the plant manager, are hired for 4 months of the year. Radiation safety officer, shift supervisors, and plant operators receive 30% bonus to compensate for part time employment. Plant manager is hired for the full year to maintain the irradiator during the non-use season.

[5]Integrated facility. Split pork carcasses are assumed to move through the irradiator suspended for a monorail track. Therefore, machinery and product handling costs are different than for the other foods.

Figure 1.

Irradiation costs for free standing facility; 4 month operation per year,
24 hours per day, 7 days per week; 200 krad (2kGy) dose