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Irradiation Preservation of Seafood

Literature Review

P. M. Molton

October 1987

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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IRRADIATION PRESERVATION OF SEAFOOD

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SUMMARY

The application of gamma-irradiation for extending the shelf life of seafood has been of interest for many years. This report reviews a number of studies on seafood irradiation conducted over the past several years. Topics covered include seafood irradiation techniques and dosages, species applicability and differences, the effects of packaging on seafood preservation, and changes in organoleptic acceptability as a result of irradiation. Particular attention is given to radiation effects (likely and unlikely) of concern to the public. These include the potential for generation of toxic chemical products, botulinum toxin production, and other health concerns. No scientifically defensible evidence of any kind was found for any harmful effect of irradiation of seafoods at the doses being considered (less than 300 krad), and all indications are that irradiation is an acceptable and needed additional tool for seafood preservation.

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INTRODUCTION

The U.S. Department of Energy (DOE) is in the process of funding demonstration food irradiation facilities in six states to test the effectiveness of irradiation preservation of local food products. This literature survey was conducted to provide a technical basis for future research specifically related to the Alaska irradiator project. The major application for food irradiation in Alaska is likely to be for parasite control, shelf-life extension, and preservation of fish and other local seafood such as crab.

The literature survey should be an ongoing effort, to maintain a flow of information as new research results are published, and also to report the contents of harder-to-find documents as they become available. Also, as the program develops, comments by interested members of the public may need to be addressed. Such comments in the past have often been based on obscure foreign language reports which are difficult and time-consuming to obtain.

In addition to the literature surveyed here, three other reviews are valuable for an understanding of the seafood irradiation concept. Nickerson, Licciardello, and Ronsivalli (1983) provided a comprehensive survey of seafood irradiation (including 233 references) in a 3-volume CRC (Chemical Rubber Co.) Review entitled "Preservation of Food by Ionizing Radiation", which covers many of the topics in this survey. Another important review is a recent report from the Council for Agricultural Science and Technology (CAST 1986) which covers irradiated food in general and not specifically seafood. In the CAST report, the use of the term "irradiation" is avoided and is replaced with the more cumbersome term "ionizing energy". The CAST report is recommended as an adjunct to this survey as it is technically more comprehensive and gives background research results from other foods to which seafood irradiation can be related. Also, the U.K. government recently published a report entitled "Report on the Safety and Wholesomeness of Irradiated Foods," which provides a carefully researched non-U.S. viewpoint on the subject of food irradiation (Advisory Comm. on Irradiated and Novel Foods 1986). This report consists of a series of summaries and conclusions by the various committees set up by the U.K. government. It deals with the question of irradiated food safety and

wholesomeness from various viewpoints, ranging from technology and radiological, microbiological, and toxicological hazards, to nutrition, labeling, and marketing.

It seems likely that any seafood that will eventually be irradiated for commercial sale in the state of Alaska will first have been thoroughly evaluated, from a technical standpoint, based on the identical product to be sold, and on research performed in the U.S. Although much excellent work has been done outside the U.S., mostly supported by the International Atomic Energy Agency (IAEA) and the Food and Agricultural Organization (FAO) and related agencies, most of it deals with products that are not major Alaskan seafood items. It is unwise to transpose data obtained on one variety of seafood, or even fish, to another species and to assume that the data will be identical for both species. Research to be reported in this review shows clearly that different species of seafood respond differently to irradiation. Apart from the illogical but very real public concern about the reliability of work done in other countries, there are many factors other than the seafood species to be considered, any of which can affect seafood quality. This is best summed up by quoting from a Dutch report (Houwing, Obdam, and Oosterhuis 1978):

> Although many foreign institutes had published their irradiation results in the last 10 to 15 years, we started research on the irradiation of cod and plaice fillets and of shrimps some years ago. The reason was that, despite these publications, we were unable to give a justifiable answer to the question: "Is the irradiation of these fishery products feasible or not?" An answer to a question like this was difficult not only on the basis of foreign studies but also because several parameters such as catching season, fishing grounds, freshness of the raw material and hygiene in processing both at sea and ashore may influence the shelf-life of fish in general and of irradiated products in particular. Even if these influences were known, it is hard to believe that they could be transferred to Dutch circumstances. The crucial point was that we had a strong wish to advise industry about irradiation possibilities in connection with the above-mentioned parameters, for which we could not take the responsibility at that moment.

Seafood irradiation is one of the most intensely researched areas of food irradiation, and potentially one of the most useful and productive. The literature reports obtained and summarized here were identified from a computer data-base survey performed by N. G. Carter of the Hanford Technical Library staff. After restricting the field of search to seafood, irradiation, and

related keywords, the number of citations was reduced to 508, including some duplicates. Over 50 of these citations were requested in hard copy, including some entire conference and symposia proceedings and government-funded reports. The review is based on these reports and proceedings, and some journal articles obtained from other sources. In some cases, the abstracts were deemed sufficiently informative to be used, and in these cases the reference has been tagged "abstract only" in the reference list. Use of abstracts has been restricted as far as possible to foreign language material relating to data of peripheral interest, such as tropical fish irradiation.

Public responses to the prospect of eating irradiated seafood are a critical item in the implementation of any demonstration irradiation plan. There are several market surveys in existence. These have been summarized separately from the technical review in this paper.

The "bottom line" for seafood irradiation is positive. The technical feasibility has been demonstrated, organoleptic tests performed, health and safety aspects investigated, and long-term (multi-generation) feeding studies with animals performed. Market surveys showed a good degree of potential public acceptance. However, none of this material specifically relates to Alaskan seafood. Research will have to be performed to show that conclusions reached for seafood harvested in the continental U.S., Europe, and the Tropics can also be applied to Alaska's seafood industry.

TECHNICAL ASPECTS OF SEAFOOD IRRADIATION

FRESH FISH

"Fresh" is a term that has to be used with care when referring to fish. In the literature, the term seems to be used frequently to refer to any form of uncooked fish, including frozen whole fish and fillets. It is also used to refer to fish on supermarket shelves, which may in fact be nearing the end of its edible life, having been stored on board ship, sold at a wholesale market, transported to a supermarket generally somewhere within 200 miles of the home port, and displayed. Most articles referring to fresh fish specify fillets packed in ice. Irradiation of whole fish on board a trawler immediately after catching has been tried (Bagge and Woelker 1970) but the overall conclusion was that the technique offers little advantage over ice storage. Irradiation of whole fish generally is not favored, because the intestinal contents are anaerobic and are not completely sterilized at radiation doses low enough to avoid off-flavor and potential toxin formation.

The outlook for irradiated fish fillets packed in ice is much more favorable. Since the 1940s, articles and reports have referred to research on the "keeping" properties of various types of irradiated filleted fish. Some examples are summarized below, although to give a complete summary here would be needlessly repetitive.

A review article by Kumta et al. (1973) summarizes results for a number of fish species, based on research conducted by them and at the National Oceanographic and Atmospheric Administration (NOAA) Atlantic Fisheries Products Center (Gloucester, Massachusetts). The effect of irradiation on extending the shelf life of iced fish fillets can be clearly seen from Figure 1, reproduced from the above article.

The Bureau of Commercial Fisheries Technological Laboratory in Seattle was involved in the 1960s and early 1970s with a U.S. Atomic Energy Commission (AEC)-funded project to advance the state of the art in seafood irradiation to the point of commercialization. A summary article was published in 1967, with the conclusion that "Irradiation of northeast Pacific Ocean marine products with doses of 0.1 to 0.2 Mrad gives acceptable products with shelf life

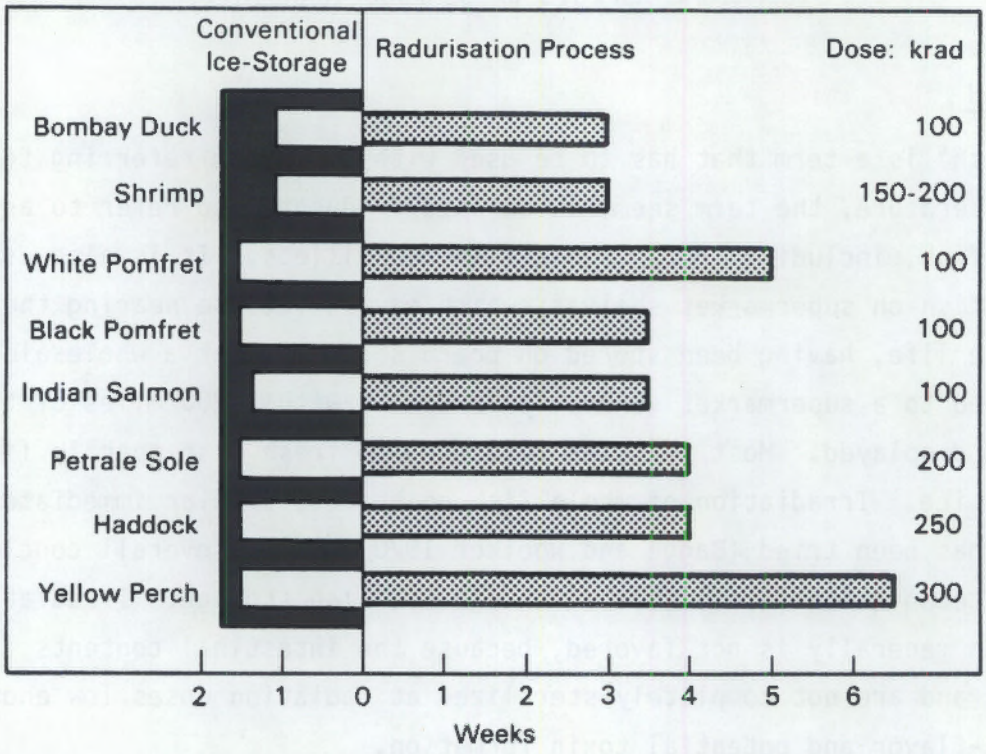

FIGURE 1. Extension of Shelf Life of Seafoods at Ice Temperature (Kumta et al. 1973)

Notes: Acceptability was determined organoleptically by standard methods, using a 9-point hedonic scale with a 6-member trained taste panel. The Figure presents a general summary. Data on yellow perch, haddock, and petrale sole are from the Atlantic Fisheries Products Center, NOAA. (Bombay Duck, Harpodon nehereus, is a small Asiatic lizard fish also known as the bummalo).

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sufficient to allow marketing anywhere in the United States," (Miyauchi et al. 1968). This general conclusion was supported by data on sole, perch, halibut fillets, crab meat, and oysters (Table 1). Similar work and results were reported by Novak, Grodner, and Rao (1967), also summarized in Table 1.

The fish processors in Oregon and Washington from whom the samples were obtained by Miyauchi et al. (1968) supplied the fish in 25-lb polyethylene bags. These bags were normally iced and shipped by truck or rail to the marketing area. The results of the irradiation experiments summarized in Table 1

TABLE 1. Comparison of Shelf Life of Irradiated and Unirradiated Pacific Coast Fishery Products

Product	Dose, krad	Shelf Life, Days at: 33°F 1	33°F 2	42°F 1	42°F 2
Petrale sole fillets	-0-	4-11	4-10	3-7	4-7
	100-150	20-25	NR	3-8	NR
	200	21-42	28-35	12-18	14-17
	300	NR	35-49	NR	14-21
	400	NR	35-42	NR	14-28
	600	NR	42	NR	21
English sole fillets	-0-	4-6	NR	NR	NR
	100	14-21	NR	NR	NR
	200	21-28	NR	NR	NR
Pacific Ocean perch fillets	-0-	6-7	NR	NR	NR
	150-200	25-28	NR	NR	NR
Halibut steaks	-0-	4-18	4-9	<4-8	4-5
	100	14-21	NR	NR	NR
	200	21-56	21-42	14-21	14-28
	300	NR	42-56	NR	NR
	400	NR	42-56	NR	35
	600	NR	42-49	NR	42

NR = Not Reported.
Column 1: Miyauchi et al. (1968); Column 2: Novak Grodner, and Rao (1967).
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show that English sole fillets packed in large polyethylene bags (or heat-sealable polyester bags) and irradiated to 200 krad can be held for 2 weeks at 33°F, repacked into retail packages and held for an additional 5 days (the shelf life of the untreated controls). Hence, an additional 2 weeks storage life was attained by irradiation. Results with Pacific Ocean perch fillets were similar. With halibut, results were best if the fish was vacuum-packed in cans or in heat-sealable polyester bags before irradiation. Organoleptic testing results showed the irradiated fish to be of high quality. Additional work was performed by Miyauchi et al. (1968) to determine the effects of processing

variables such as the package atmosphere and treatment with sodium tripolyphosphate on shelf life and quality, and the effects of irradiation on the subsequent development of microbial flora. These topics are also covered in separate sections, later in this report. Novak, Grodner, and Rao (1967) also studied radiation microbiology of fish and shellfish, and the effects of irradiation on certain B vitamins. There was no loss in quality of the irradiated fish treated at up to 400 krad.

In the 1960s the Bureau of Commercial Fisheries Technological Laboratory in Gloucester, Massachusetts, was funded by the AEC Division of Isotopes Development and the Division of Biology and Medicine to develop the technology for seafood irradiation. Their irradiator, known as the Marine Products Development Irradiator (MPDI), was licensed to operate with 275,000 Ci of cobalt-60 on March 17, 1965 (Kaylor 1965). On April 19, 1965, the MPDI formally became operational, and by October 10 it had been used to irradiate over 10,000 pounds of seafood products in 56 different jobs, about 20% of which were for industry. During the period of research with the MPDI, close contacts were maintained between the Technological Laboratory and the local seafood industry; their experience may be well worth tapping for the development of Alaskan seafood irradiated products. At least a part of this group is still in existence since a 1985 publication on soft-shell clam irradiation involved two authors from the Gloucester laboratory (Mallett, Kaylor, and Licciardello 1985).

The MPDI has not been refueled, and currently is operated only for small jobs. Its activity has decreased to ~1000 Ci and it is essentially in storage. A decision is due by the end of March 1987 as to whether to 1) refuel, 2) decommission, or 3) sell the MPDI to industry. Each option would cost about $300K. This information was obtained by telephone from Dr. Wilhelm of the National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) of Gloucester, Massachusetts.

The effects of irradiation on cod and plaice fillets were investigated by Houwing, Obdam, and Oosterhuis (1978), under Dutch government sponsorship. This work was directed more towards exploring the effects of handling and pre-irradiation storage on the fish product than on the effects of the actual irradiation treatment. For example, this study provided results on the shelf

life of fish fillets that had been subjected to bad commercial practices rather than laboratory cleanliness. Irradiation was performed to a total dose of 100 krad in 50 min from a 150,000-Ci cobalt source. Main conclusions were derived from an organoleptic evaluation. The pertinent results are summarized in Table 2.

As expected, the time after catch and pre-irradiation storage conditions are important variables in determining post-irradiation shelf-life and acceptability, as shown by the data in Table 2.

Power et al. (1964) reported irradiation work with haddock fillets treated with up to 250 krad of cobalt-60 gamma irradiation at a dose rate of 1.05 Mrad/h. However, the source was much weaker (15,216 Ci) than in the research summarized above. The interesting factor about this report is the care given to details of pre-irradiation treatment. The fish were caught and transported in ice to the processing plant within 41 h. Within 48 h of being caught, they had been filleted, skinned, packed, and irradiated. One batch of

TABLE 2. Effects of Vacuum, Freshness, and Irradiation of Cod and Plaice Fillets on Shelf Life (Houwing, Obdam, and Oosterhuis 1978)

Treatment	Radiation dose (krad)	Shelf Life (days at 39.2°F) Cod Fillets		Plaice Fillets	
Packaging		Air	Vacuum	Air	Vacuum
Aerobic/Vacuum	-0-	3.0	3.2	4.1	NR
	50	NR	NR	9.3	9.0
	100	6.5	12.0	11.9	21.9
	200	Dis	Dis	NR	NR
Freshness and Packaging					
Aerobic/vacuum (0 days in ice)	-0-	6.4	NR		
	50	9.6	16.0		
	100	11.6	23.0		
Aerobic/vacuum (7 days in ice)	-0-	3.2	NR		
	50	3.6	4.3		
	100	5.5	15.5		

NR = Not Reported; Dis = Discarded, off-odor and off-flavor due to treatment.
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fillets was dipped (pre-irradiation) into 10 ppm chlortetracycline ("acronized") for 30 sec. (This "acronization" treatment was to reduce the initial microbial load on the outside surface of the fish.)

The fillets were packed in 1-lb batches into polyethylene (inner layer) bags laminated to cellophane (outer layer), and heat-sealed. They were then divided into six batches: 1) packed into waxed cardboard fillet boxes, placed in shallow aluminum freezing trays, and frozen in a pre-chilled plate freezer with a refrigerant temperature of -40°C before storage in a freezer at -26°C; 2) stored in ice at 0°C; 3) treated by acronizing and also iced; 4), 5), or 6) irradiated with 75, 125, or 250 krad, respectively, and stored on ice. All treatments were carried out within 48 h of catching. Irradiation cell temperature rise was a maximum of 4°C (of which 0.25°C can be attributed to 100 krad radiation energy absorption). Because of the care given to treatment, and the thoroughness of the microbial, chemical, and organoleptic evaluations (by a trained panel of 8 tasters), Power et al. (1964b) data is presented in detail from their report in Tables 3 and 4 and Figures 2 and 3.

TABLE 3. Bacterial Counts per Gram of Haddock Fillets After Storage at 0°C Based on Single Determinations (Power et al. 1964b)

Days in Ice	Frozen	Control	Antibiotic Treated	Irradiation at (krad) 75	150	250
1	21	11.4	3	5.2	0.021	0.024
6	3.1	201	57	6.6	8.1	0.12
10	2.7	10,500	6,900	2,550	116	21.3
16	15	40,200	24,000	12,300	8,400	144
23	6.6	-	39,000	-	6,000	3,000
30	6.6	-	-	123,000	48,000	14,700

NOTE: Bacterial counts in thousands per gram. The higher bacterial count after a 150 krad dose compared with a 75 krad dose after 6 days storage is an experimental anomaly, not statistically significant.

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TABLE 4. Progression of Changes in Taste and Texture Characteristics After Cooking of Control Group and Irradiated Haddock Fillets Stored in Ice (Power et al. 1964a)

Days After Filleting	Untreated		Acronized		75,000 rad		125,000 rad		250,000 rad	
	Taste	Texture	Taste	Texture	Taste	Texture	Taste	Texture	Taste	Texture
1	more or less tasteless	tender, sl. dry	more or less tasteless	sl. tough	more or less tasteless	sl. mealy	sl. stale sl. burnt	mealy	sl. stale sl. burnt	mealy
6	sl. stale	sl. mealy	more or less tasteless	sl. tough	more or less tasteless	dry, some mealiness	sl. burnt	mealy, stringy	sl. burnt	mealy, stringy
10	stale, sl. sour	mealy sl. tough	more or less tasteless	sl. tough	more or less tasteless	sl. dry	sweet-burnt	mealy, stringy	sweet-burnt	mealy, stringy
16	sour, NH_3 very stale	mealy	more or less tasteless	sl. tough	more or less tasteless	sl. dry	sweet-burnt sl. stale	mealy, stringy	sweet-burnt sl. stale	mealy, stringy
23			stale, some sourness	dry, some mealiness	some off-flavors	sl. dry	sweet-burnt sl. stale stronger irr. odors	mealy, stringy	sweet-burnt sl. stale stronger irr. odors	mealy, stringy
30			putrid NH_3	soft, mealy	bitter, stale NH_3	soft, mealy	sweet-burnt sl. stale strongerirr. odors	tough	sweet-burnt sl. stale stronger irr. odors	tough

Notes: The frozen control fillets maintained the initial tender, slightly dry texture and bland to neutral flavor to 30 days at -26°C. The untreated controls packed in ice were becoming unacceptable in taste after 10 days.

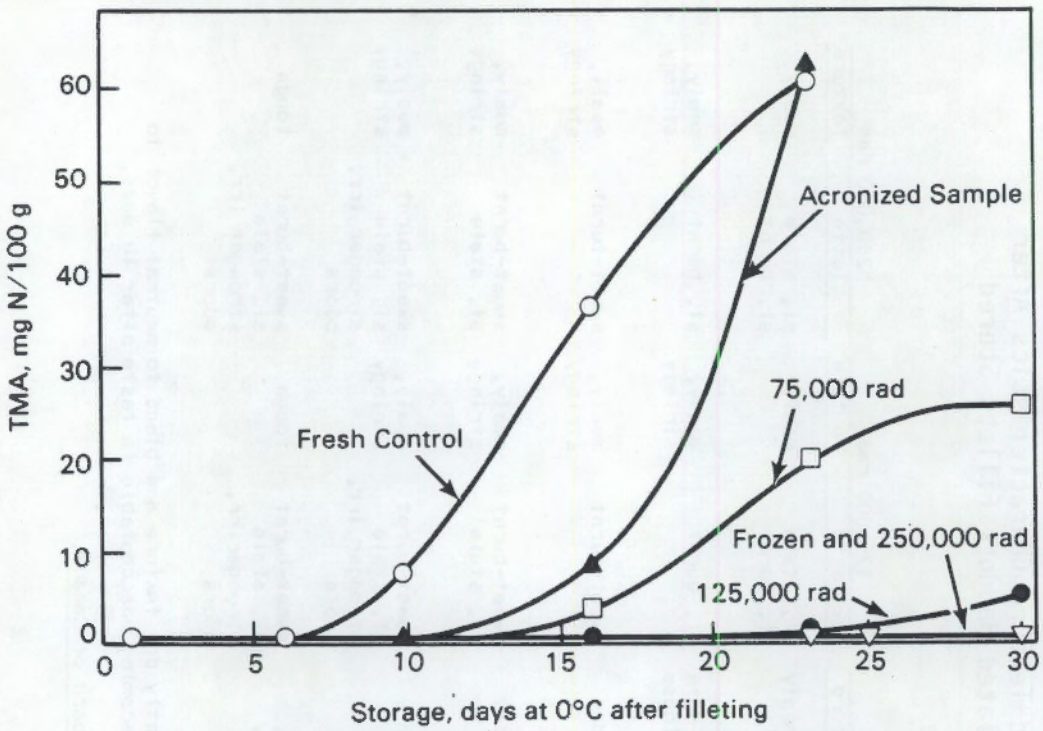

FIGURE 2. Variations in Trimethylamine (TMA) Values for Haddock Fillets (Power et al. 1964b)

Notes: Production of trimethylamine (TMA) from seafood by aerobic bacteria is a common method of early detection of spoilage; the TMA has a characteristic "off" odor which is easily recognized. TMA is also easily detected and quantitated by gas chromatography.

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OTHER FRESH SEAFOOD

The fresh seafood discussed in this section includes clams, shrimp, crab, and oysters which can be obtained in any condition from live, in the shell, to precooked and canned. Fresh (live) seafood is the most sought-after, but the storage life is very limited. Consequently, most of the limited research performed on these types of seafood has been on the separated raw or precooked meat rather than on the live catch. One exception is a study from the Gloucester Laboratory of the U.S. Dept. of Commerce (Mallett, Kaylor, and Licciardello 1985) in which the effect of irradiation on the viability and bacterial contamination load of live and shucked soft-shell clams was reported.

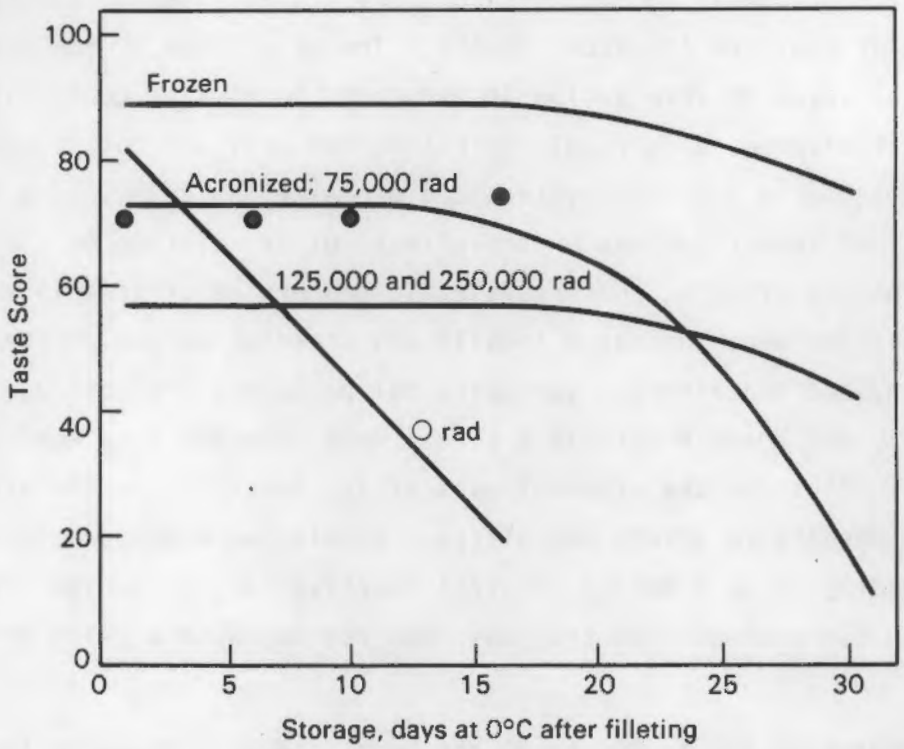

FIGURE 3. Taste Panel Scores for Treated Haddock Fillets Stored in Ice (Power et al. 1964b)

Notes: The taste score was determined by a trained panel of eight testers; borderline acceptability was at a score of 40. Curves represent the taste scores for haddock fillets frozen at -26°C, irradiated at 0, 75, or 250 krad and stored on ice, or treated with Acronizing antibiotic and irradiated at 75 krad and stored on ice.

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There was no significant effect of doses below 100 krad on live clam shelf life, while a 100 krad gamma-ray dose to bacterially contaminated shucked clam meat caused a 2 to 3 log reduction in the loading of *E. coli*, *Salmonella typhimurium*, and *Staphylococcus aureus*. There was no detectable change in taste after irradiation up to 330 krad (although the clams were evaluated fried, which masks any changes caused by irradiation).

A OOE-funded project on shellfish depuration by gamma irradiation (Beghian and Melnick 1986) was begun on October 1, 1985. The first progress report (dated July 25, 1986) is now available from these researchers, who are located

at the University of Lowell Radiation Laboratory (Lowell, Massachusetts) and Baylor College of Medicine (Houston, Texas). The objectives of the project are to determine the value of irradiation in reducing the risk of contacting shellfish-borne viral diseases as a result of eating raw or inadequately cooked shellfish, particularly American oysters and hard-shelled clams. The study reports results of investigations on the effects of irradiation on shellfish mortality, virucidal effects, and organoleptic properties of irradiated shellfish. The shellfish were purchased locally and irradiation was performed in 2-liter polyethylene containers. Various viral pathogens (Poliovirus I, Simian Rotavirus SA-11, and Human Hepatitis A virus) were injected into some samples (into the mantle fluid or the visceral mass of the shellfish as the viral suspension medium appears to affect mortality). Results were not promising for the use of irradiation as a method of viral inactivation, as a high irradiation dose of between 136 krad and 662 krad was required to cause a 1-log reduction in viral load.

Gamma irradiation (75 to 800 krad) has been used by a group at the Fisheries Research Board of Canada (Power et al. 1964a) to extend the shelf life of scallop meat. Spoilage was measured by the rate of glycolysis in iced irradiated scallop meat, compared with a frozen control by trimethylamine content, bacterial plate counts, and organoleptic testing of the iced and baked, shucked scallops. Even the lowest dose of 75 krad increased the storage life to 28 days from 13 to 17 days (iced, uncooked), or up to 43 days for the cooked product. However, even the lowest radiation dose resulted in detectable changes in flavor, characterized by the development of a sour-to-bitter flavor associated with a spongy, mushy texture.

Irradiation of fresh shrimp has been studied by several groups of researchers. In one report (Novak and Rao 1972), the effect of shipboard and dockside irradiation of fresh-caught shrimp was evaluated. The researchers caught some of the shrimp to be tested by trawling off the Georgia and Florida coasts. The shrimp were separated from other species, washed in seawater, and beheaded. One half were packed in heat-sealable polyethylene pouches and/or wax-coated boxes and irradiated at sea to a dose of 100 to 300 krad; the other half were unirradiated controls. All of the shrimp were stored at 30 to 32°F

for the duration of the cruise; the time elapsed between catch and docking ranged from 50 to 79 h. Part of the control was then irradiated on land. Novak and Rao also purchased shrimp from the commercial fishermen who caught the shrimp at sea, stored them on ice, and who guaranteed (verbally) that the catch was no more than 5 h out of the water. The shrimp were maintained at or below the freezing point until they could be tested. They were tested chemically (for indole, ammonia, and trimethylamine formation); microbially (general plate-counting method, species not identified); and organoleptically (by 292 untrained servicemen).

The results demonstrated the value of ship-board irradiation of shrimp. Indole concentrations of the shipboard irradiated shrimp at 20 days were only slightly higher than indole concentrations in controls after 11 days. By measuring indole concentrations, incipient spoilage was detected after 23 days for irradiated shrimp, compared to 11 to 16 days for controls. Trimethylamine nitrogen testing indicated spoiling after 11 days for controls and after 18 days in irradiated samples. Ammonia nitrogen testing showed 9 to 11 days before controls spoiled, versus 16 days before irradiated samples spoiled. Microbial plate counts for controls were as high or higher after 11 days storage as 200 and 300 krad-treated samples after 23 days. The results from shrimp purchased and irradiated at dockside generally paralleled the results from shipboard-irradiated shrimp, except for lower storage lives due to poorer maintenance by the commercial fishers. The organoleptic testing (summarized later) of shrimp in shrimp cocktail gave a higher score for the irradiated (200 krad) product than for the ice-stored untreated product, after a storage time of between 7 to 21 days.

One particular problem with shrimp is the development of "black spot", or melanin formation, caused by the action of an enzyme that becomes active after the death of the organism. In the Novak and Rao study (1972), none of the irradiated samples showed any sign of black-spotting, while controls developed the problem after 7 days. The optimum dose was found to be 200 krad; a lower dose (100 krad) did not give optimum shelf-life extension, while a larger dose (300 krad) gave no significant advantage in terms of shelf-life extension. The beneficial effect of irradiation in preventing blemish (which consumers use to

detect "old" shrimp) was confirmed by Snauwaert, Tobback, and Maes (1973), who showed that irradiation of brown shrimp increased carotenoid stability. Unirradiated shrimp pigments were readily extracted by acetone, while irradiated shrimp carotenoids were very stable and did not extract as well. Hence the irradiated shrimp would keep their fresh color longer than the untreated controls.

Research into the effects of irradiation on crab and oysters was carried out by the Bureau of Commercial Fisheries group in Seattle, and reported by Miyauchi et al. (1966, 1968), as well as by Novak, Grodner, and Rao (1967). Their results are summarized in Table 5. The crabmeat was packaged in heat-sealable polyethylene bags or in jars with screw-cap lids; oysters were packed in cans.

TABLE 5. Comparison of Shelf Life of Unirradiated and Irradiated Crab and Oysters

Product	Dose,	Shelf-life, days at			
33°F 42°F	krad	1	2	1	2
Dungeness crab meat	-0-	6-14	7	2-9	2-5
	100	14-35	21-35	14-21	14-21
	200	21-56	28-42	21	14-21
	300	NR	49-56	NR	21-28
	400	NR	56	NR	45
King crab meat	-0-	5-14	5-14	3-7	3-7
	100	21	21	7-14	7-14
	200	28-42	28-42	14	14
	300	NR	42	NR	14-21
	400	NR	49	NR	28
	600	NR	49	NR	35
Pacific oysters	-0-	20	NR	9	NR
	100	30	NR	11	NR
	200	30-34	NR	20-25	NR

Column 1: Miyauchi et al. 1968; column 2: Novak, Grodner, and Rao 1967.
NR = not reported.
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The optimum radiation dose as reported by Miyauchi et al. (1966) for fresh Dungeness crab meat packed in cans or polyethylene bags was between 100 and 200 krad, which produced meat with a storage life of up to five times that of the unirradiated control. Vacuum packing and nonvacuum packing in cans were equally effective in attaining this storage life extension, but storage life at 42°F was only half that at 33°F.

Effect of Cooking Prior to Irradiation

Some work has been done on extension of shelf life of boiled or cooked seafoods. Heat treatment of fresh seafood will reduce the bacterial load going into irradiation, and can be expected to provide an additional increment in storage life beyond that of irradiation alone. However, the product can then by no means be called "fresh." For example, Loaharanu et al. (1973) examined the effect of gamma radiation on boiled chub mackerel, a popular Thai fish not normally available in the interior of Thailand due to rapid spoilage of the (nonrefrigerated) product. The normal processing method results in a boiled fish with a storage life of 2 days at ambient temperature in Thailand. After packing in cellophane-saran-laminated bags and irradiating in ice at up to 300 krad, the room temperature storage life of the mackerel was increased by 3 days with no adverse effects on taste; the irradiated fish could withstand transport up to 800 km inland by train.

Work on other seafoods includes work done by Power et al. (1967) on the effect of radiation on cooked lobster meat. A dose of 75 krad extended the shelf life of the cooked meat stored in ice to 28 to 35 days for both tail and claw meat, compared to 14 to 21 days for unirradiated controls. However, higher irradiation levels caused a detectable loss in quality due to toughening and loss of flavor.

Kumta et al. (1973) investigated the effect of various heat and irradiation combination processes for shrimp preservation. Their results are summarized in Figure 4.

Blanching prior to irradiation of iced headless shrimps also prevented melanosis (black-spot formation) by inactivating the phenolase enzymes, an effect achieved much more easily by heat than by radiation.

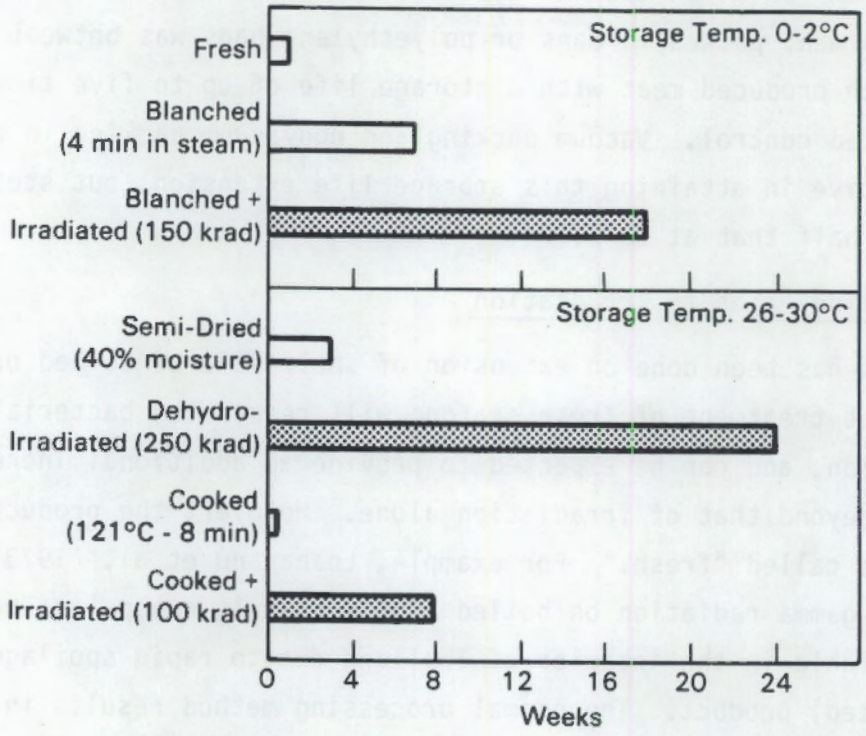

FIGURE 4. Extension of Shelf Life of Irradiated and Processed Shrimp (Kumta et al. 1973). Reprinted with permission from the International Atomic Energy Agency, Vienna.

COMBINED CHEMICAL/IRRADIATION SHELF-LIFE EXTENSION

Several treatments involving chemicals in combination with radiation appear to extend the shelf life of seafood beyond the range of the individual treatments. Generally this is because the chemical treatment results in a lower microbial load on the seafood going into the irradiation process, or because the chemical treatment prevents the development of off-flavors by trapping radiation-generated free radicals which cause fat rancidity, or by acting as an anti-oxidant. (Off odors are usually the result of microbial rather than chemical processes.) Among chemical treatments the most common are dipping in antibiotics or other chemicals such as sodium tripolyphosphate or benzoic acid. However, seafood treated with chemicals or heat cannot be described as "fresh" and therefore would be directed towards a different market than irradiated fresh products. With the ready availability of food freezers in the U.S., the value of extending the shelf life of seafood beyond 2 to

3 weeks is debatable. In tropical countries where refrigeration is not commonly available and some markets are remote from the coast, the additional extension of shelf life attained by combination treatments is unquestionably of value.

Because chemically treated seafood is likely to be of less interest to Alaskan fish processors than the irradiation of fresh, raw, iced seafood, the chemical pretreatment topic is illustrated by only one example--the combination of benzoic acid and irradiation to preserve shrimp, reported by Houwing, Obdam, and Oosterhuis (1978). These authors reported work on the preservation of shrimp in Holland. The shrimp were caught and sorted, then boiled in salt water for 6 to 10 min, cooled in seawater which reinfected them with marine bacteria, and preserved with up to 1% benzoic acid. Because of the unpleasant taste of benzoic acid, this preservation method is not favored by consumers. In a series of irradiation experiments, cooked shrimp treated with either 0.4% of extra salt or 0.4% of benzoic acid were irradiated at 100 krad total dose. Table 6 shows the results for peeled and unpeeled shrimp treated with 0.4% benzoic acid (unirradiated controls treated with 1% benzoic acid, the maximum legally allowed, had a shelf life at 39.2°F of 14.3 to 14.6 days).

TABLE 6. Average Shelf Life of Peeled and Unpeeled Shrimp as a Function of Benzoic Acid Concentration and Irradiation (Houwing, Obdam, and Oosterhuis 1978)

Treatment		Shelf Life, days	
Irradiation	Benzoic Acid	Peeled	Unpeeled
0	0	3.4 days	2.7 days
0	0.4%	9.1	7.2
100 krad	0	7.0	8.5
100	0.4	17.6	12.9

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The taste test panel "detected" the untreated controls as irradiated 4% of the time. For peeled and unpeeled shrimp, respectively, the irradiated and benzoic acid treated shrimp were detected 20% and 25%; irradiated only, 19% and 13%; and benzoic acid-treated only, 13% of the time. The results were judged to be quite acceptable.

PRESERVATION OF DRIED SEAFOOD

Three reports illustrating the value of irradiation of dried and/or salted fish in tropical countries are discussed below. They come from research groups in the Philippines, Thailand, and Indonesia, and all relate to dried mackerel.

In the Philippine study (Pablo, Fernandez, and Coronel 1973), fresh, commercially obtained striped mackerel were cleaned, eviscerated, and washed in tap water. They were soaked in a 10% brine solution for 30 min to leach out the blood, then in a 25% brine for 3 h. Following this, the fish were drained and dried in a cabinet air dryer at 150 to 160°F for 5 to 6 h. The dried fish were irradiated at 100 krad in air in sealed polyethylene bags and stored at 86°F or 43°F. The stored product was evaluated for visible signs of spoilage or mold growth, taste after frying, microbial plate counts, and chemical changes (trimethylamine, total volatile base, and moisture). For the fish stored at 86°F, a shelf-life extension of about 3 weeks was obtained by irradiation. At the lower 43°F-storage temperature, the dried and irradiated fish took 136 days to reach 50% spoilage compared to 35 days for the unirradiated controls (spoilage was generally defined as the appearance of blue-gray mold).

In the Thai report (Loaharanu 1975), work was performed between 1971 and 1974 and was directed at reducing or preventing insect infestation of dried mackerel. The drying process was primitive: fresh mackerel was de-scaled, the gills and internal organs were removed, and the fish was washed in clean water. It was then soaked in brine for 12 h, dried in screened cages in sunlight for 3 days to 22 to 23% moisture, and stored at 83°F before artificial infestation with various growth stages of insects which had previously been irradiated.

Another group of the dried fish was irradiated (up to 300 krad) without artificial infestation. Fish were cooked at periods ranging from 15 to 180 days after irradiation. In an untreated control group, infestation of 60 to 70% of the dried fish by six different species of flies had occurred. A dose of 200 krad was sufficient to prevent the larvae of the (most resistant) cheese skipper fly from developing into pupae. The dried product, irradiated to 300 krad, stored for up to 6 months, and cooked, was acceptable to the taste panel. There was some problem with packaging, due to physical puncture of the bags by fins, leading to re-infestation by insects entering through the puncture holes. Bags made of polyethylene and polypropylene 6- to 8-mm thick were required to avoid this problem. Fisher strain rats were fed on irradiated dried mackerel in a histopathological study (Bhanarapravati et al. 1975). However, the findings of this study were marred by the discovery of foci of pneumonitis in the lungs of every animal, including controls, which may have been responsible for the nonsignificant changes from normal observed in all rat organs examined.

Finally, the Indonesian study by Maha (1981) on irradiated dried fish was directed more towards packaging, transportation, and consumer acceptance than technical feasibility. The results showed that a dose of 50 krad prevented insect infestation in dried fish, which could then be marketed for 3 to 4 months under ambient conditions. Fermented, salted fish could be best treated with a combination of 200 krad of irradiation after dipping in 2% potassium sorbate as a preservative.

PACKAGING

Studies on the effect of packaging on the preservation of irradiated fish have been mentioned above. This section deals specifically with problems encountered by the use of different packaging materials and methods, the use of aerobic (air-permeable) packages or anaerobic packages, and related considerations. There are two main areas of concern in regard to seafood irradiation and packaging: rancidity in air-filled packages and toxin production in anaerobic packages.

One concern is premature rancidity that can occur in particularly fatty seafoods stored in aerobic packaging. Irradiation generates free radicals in the food (as does conventional cooking), some of which are long-lived. If the food is packed in packaging that admits or contains air, the oxygen of the air reacts with free radicals from unsaturated fat in the food to form peroxides, which are the characteristic products of fat rancidity. By exposure of seafood to air during and after irradiation, premature rancidity can occur; this is more of a problem with higher irradiation doses and with fatty fish. This fact was noted by Miyauchi et al. (1968) who commented that: "Some fish and shellfish--notably haddock, shrimp, and Dungeness and King crab--lend themselves to irradiation with air in the package, but sole and flounder fillets irradiated this way become rancid after 10 to 14 days of refrigerated storage. These oxidative changes occur primarily in the fatty layer along the lateral line and on the edges of the fillets exposed to the air in the package."

There may also be some unfounded public concern about the hypothetical formation of carcinogens during irradiation, from free radical reactions in the seafood, although there is no evidence in any publication or abstract examined of any carcinogen formation during seafood irradiation. (This failure to identify novel or carcinogenic compounds produced by radiation processes is not surprising in view of the low doses used in treatments.)

Anaerobic packaging is also of concern because it provides an air-tight environment which can encourage the growth of some toxin-producing bacteria. One potential toxin that is produced in anaerobic conditions is that from Clostridium botulinum whose spores are radiation resistant and can produce viable bacteria that generate toxin after long storage. Harmless bacteria which normally cause changes in the fish (odor, visible colonies, etc.) and provide warning of impending spoilage are killed by the radiation. Clostridium, which gives no detectable warnings in taste, smell, or color, is not killed by irradiation at the low doses used. Hence, it is possible (although highly unlikely) to have apparently fresh fish which contain the toxin. Formation of Clostridium toxin in fish after irradiation has been the subject of a large number of reports, summarized in a separate section. This problem could perhaps be avoided by selection of a packaging material with

limited permeability to oxygen. After irradiation in vacuum or in an inert gas, the package would gradually (over several hours or days) allow oxygen diffusion into the interior, replacing the inert gas or vacuum with an aerobic environment. A very low level of oxygen (1 ppm or more) will prevent germination of Clostridium spores.

If these two concerns--rancidity in air-filled packages and toxin formation in vacuum or inert gas-filled packages--can be dealt with, then the actual nature of the package seems to be a minor problem. Most reports describe the use of polyethylene for irradiation work; other materials which do not discolor or form leachable breakdown products during irradiation could also be used. In a review by Kumta et al. (1973), results of fish irradiation in various forms of packaging were described. Polyethylene films (0.076 to 0.165 mm) and their laminates with paper or cellophane and aluminum foil and paper were found to be impermeable to bacteria. Laminated film with aluminum foil was impermeable to water vapor at 98°F and 80% relative humidity, whereas other materials showed considerable variability in water vapor transmission. Polyethylene-cellophane laminates showed water vapor transmission rates lower than polyethylene and other laminated films.

Miyauchi et al. (1966) reported the comparative effects of vacuum and non-vacuum packaging of Dungeness crab meat, and also a comparison between packaging in polyethylene pouches and in cans under vacuum. Their results (excluding bacterial count data) are reproduced in Tables 7 and 8.

TASTE, OOOR, AND TEXTURE OF IRRADIATED SEAFOOO

Because of the diverse nature of seafood and the fact that it is used in forms ranging from completely raw to dried, cooked, and smothered in spices, organoleptic changes during irradiation vary from negligible to completely unacceptable. End use of the product is therefore a factor in deciding whether an irradiation-induced change in flavor, odor, or texture is acceptable. The following examples of organoleptic changes induced in different seafoods illustrate this point.

TABLE 7. Comparison of Storage Characteristics of Dungeness Crab Meat Packed in Cans Under Vacuum or No Vacuum and Irradiated (Miyauchi et al. 1966)

Series No.	Storage Temperature, °F	Storage Time, weeks	Sensory Score No Vacuum	Sensory Score Vacuum
3	33°	0	7.6	7.7
		1	6.9	6.6
		2	6.8	6.8
		3	6.5	6.7
		4	6.3	6.5
		5	6.4	6.6
		6	5.4	5.4
4	33°	0	8.2	8.3
		2	7.7	7.8
		3	6.0	7.8
		4	7.5	8.0
		5	6.6	7.2
		6	6.8	7.2
		7	2.7	2.0
	42°	0	8.2	8.3
		1	7.7	8.0
		2	7.3	7.3
		3	5.0	4.0

Notes: Sensory score was based on a 10-point scale as determined by a panel of trained testers evaluating appearance, odor, flavor, and texture. Samples were considered unmarketable at a score of <5. Irradiated samples received 200 krad.

Miyauchi et al. (1968) determined the acceptability of deep-fat-fried petrale sole and halibut, baked halibut, King and Dungeness crab meat cocktails, and Dungeness crab meat salad, after storage at 2 to 4 weeks after irradiation to 0.2 or 0.25 Mrad. Table 9 reproduces the results of the taste testing by 158 U.S. Army personnel at Fort Lee, Virginia.

These authors also prepared a general figure based on their results, which shows the overall variation of acceptability and quality of irradiated fish over five weeks of storage at 33°F. This figure agrees well with results reported by other workers, and is reproduced below (Figure 5).

TABLE 8. Comparison of Storage Characteristics of Dungeness Crab Meat Vacuum-Packed in Plastic Pouches or Cans and Irradiated (Miyauchi et al. 1966)

Lot, No.	Radiation Dose, Mrad	Storage Time, weeks	Sensory Score Pouch	Sensory Score Can
1	0.2	0	8.3	8.3
		2	7.0	7.8
		3	6.3	7.8
		4	7.5	8.0
		5	6.4	7.2
		6	5.8	7.2
		7	5.3	2.0
		8	2.0	--
2	0.1	0	8.7	8.5
		2	8.4	7.5
		2.5	6.8	4.0
		3	4.5	2.0
	0.2	0	8.2	8.3
		2	7.6	7.0
		3	6.3	5.8
		4	6.3	5.3
		5	4.0	2.0

Notes: Sensory score was determined as for Table 7. Plastic pouches were of polyester-polyethylene material.

Power et al. (1964b) determined the effects of various cooking methods on taste of irradiated fish (haddock fillets). They found that steaming for 10 min compared favorably with baking as a desirable method for detection and comparison of taste differences, but, as expected, frying was the least sensitive method, tending to mask adverse flavor, odor, and texture changes. Frozen unirradiated fish developed stale, slightly sour odors and flavors after 10 days, with very stale, ammonia-like odors and flavors dominating after 16 days. This change was associated with an increase in the trimethylamine level to 8 mg N/g and then to 37 mg N/g. Irradiated fish developed the same odor and flavor pattern after 23 to 30 days. Fish irradiated at 125 and 250 krad initially had slightly lower scores due to a slight "burnt" taste.

TABLE 9. Mean Preference Scores of Irradiated and Unirradiated Seafoods (Miyauchi et al. 1968)

Product	Number of Judges in Panel	Storage Time, Weeks	Dose, Mrad	Mean Preference Score[a]	
				Nonirradiated, Stored at -20°F	Irradiated, Stored at 33°F
Deep-fat-fried petrale sole fillets	50	2	0.2	7.68	7.52
	53	4	0.2	7.49	7.32
Deep-fat-fried halibut	43	2	0.25	7.60	7.72
	46	4	0.25	7.59	7.33
Baked halibut	30	2	0.25	7.17	7.13
	32	4	0.25	7.16	7.34
King crab meat cocktail	43	2	0.2	7.23	7.14
	47	4	0.2	6.93	7.47
Dungeness crab meat cocktail	55	2	0.2	7.14	7.23
Dungeness crab meat salad	63	2	0.2	7.33	7.44
Dungeness crab meat rice casserole	63	2	0.2	7.76	7.46

(a) Based on a 9-point hedonic scale where 1 to 4 indicate degrees of "dislike," 5 indicates neither like nor dislike, and 6 to 9 indicate degrees of "like."

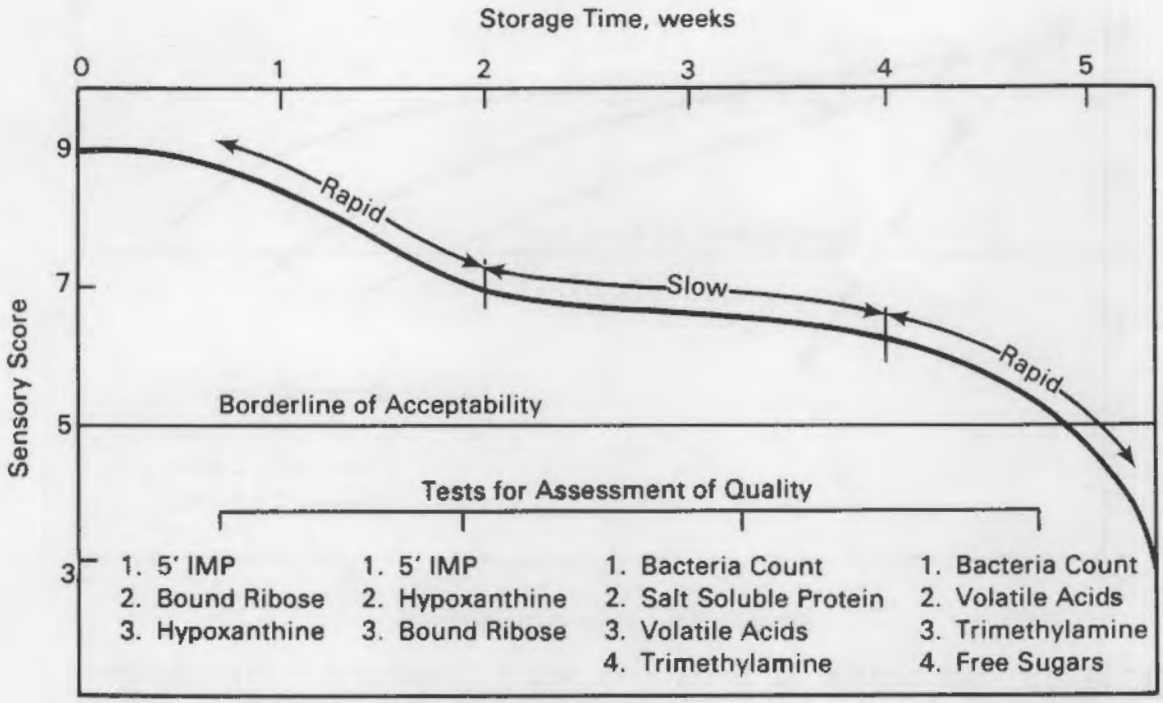

FIGURE 5. Pattern of Sensory Changes Occurring With Age of Irradiated Fish (Miyauchi et al. 1968)

Notes: Fish were irradiated at 200 krad and stored at 33°F. Tests listed in each column are the most useful for detecting spoilage at the corresponding storage period listed above the column. 5'-IMP is a test for 5'-Inosine monophosphate.

The 250 krad dose also caused a slight mealiness in texture compared with unirradiated controls, and gradually developed a slight toughness and stringiness on iced storage. Lower doses (75 krad) and treatment with an antibiotic (Acronizing) resulted in a very slight dryness and mealiness initially, leading to a softening at the onset of spoilage.

In a study on the acceptability of irradiated tropical fish (boiled and salted chub mackerel) in Thailand by Loaharanu et al. (1973), eviscerated fish boiled in saturated brine for 5 to 10 min were irradiated in cellophane-Saran-laminated bags to 300 krad. The odor and taste scores of the product are reproduced in Figures 6 and 7. Unirradiated fish scored lower after 3 days of storage at room temperature (up to 86°F) and were rejected as unacceptable

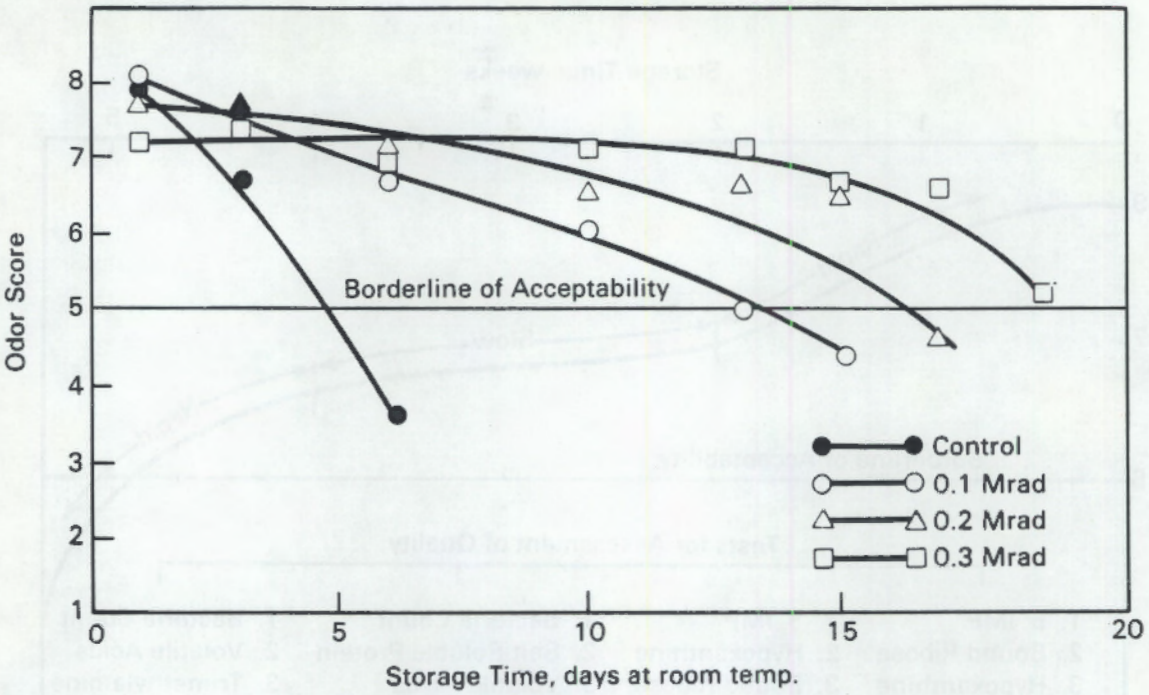

FIGURE 6. Odor Scores of Irradiated and Unirradiated Boiled Mackerel (Loaharanu et al. 1973) Reprinted with permission from the International Atomic Energy Agency, Vienna.

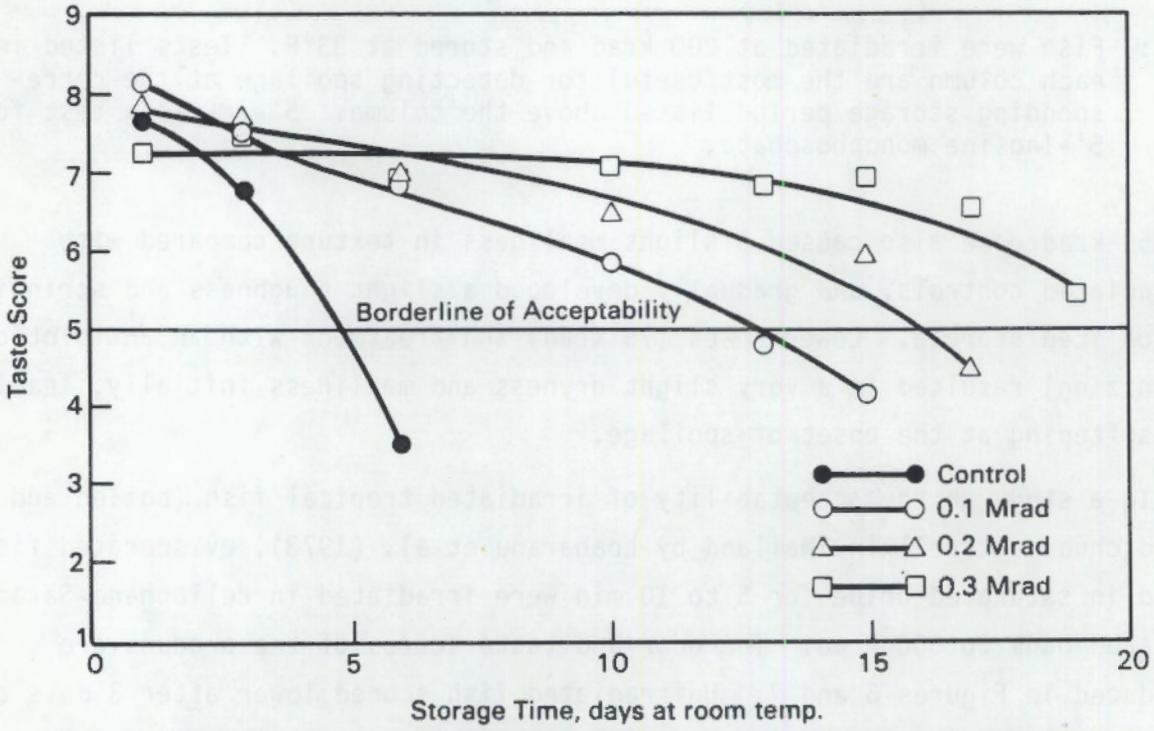

FIGURE 7. Taste Scores of Irradiated and Unirradiated Boiled Mackerel (Loaharanu et al. 1973) Reprinted with permission from the International Atomic Energy Agency, Vienna.

after 6 days. No objectionable odor or taste was detected in fish irradiated at up to 300 krad, although some taste changes would have been masked by the high salt content of the fish.

Power et al. (1967) performed an organoleptic assessment on boiled lobster meat which had been irradiated raw at 75 to 250 krad. Control samples were unacceptable after 21 days iced storage, while the samples irradiated at 250 krad were acceptable to 42 days. Changes in odor and flavor closely paralleled formation of trimethylamine by bacterial spoilage. Frozen control meats developed a slight toughness and dryness towards the end of the testing period. Irradiation at 75 and 250 krad caused an initial slight toughness, dryness, and chewiness. Sporadic slight yellowing of the tail meat occurred in some of the samples given higher doses.

The same research group (Power et al. 1964a) determined the effect of irradiation up to 800 krad on iced scallop meat. These irradiations were performed at a rate of 1.08 Mrad/h in air and resulted in a warming of the samples from 0 to 2°C initially to 9.5°C after the highest dose. An organoleptic assessment was performed on the product after irradiation, storage on ice, and baking at 450°F for 12 min. The results are shown in Figure 8. Iced controls developed a sour to bitter flavor and spongy/mushy texture after 13 to 17 days. Irradiation at 75 krad resulted in a score of unacceptable after 43 days, while higher doses caused "burned" flavor development after 18 days. The texture of the meat was judged to be spongy or mushy after a dose of 150 krad or higher. The optimum dose was judged to be 75 krad for scallops.

Organoleptic ratings for cooked, packaged, and irradiated shrimp and uncooked Bombay duck were reported by Kumta et al. (1973). The shrimp were peeled, deveined, washed, cooked (at 121°C for 8 min), packaged, and irradiated at 100 krad before storing at ambient temperature (in India). Results of organoleptic assessments are reproduced in Figures 9 and 10. The major flavor change in the shrimp was ascribed to a loss of free amino acids (principally glycine) which give shrimp their characteristic sweet taste. In Bombay duck (a tropical fish), the principal change due to irradiation was a change in texture caused by extensive liquid drainage from the fish (15 to 20% by weight in 3 days). This problem was reduced by pretreating the fish with 10% salt or

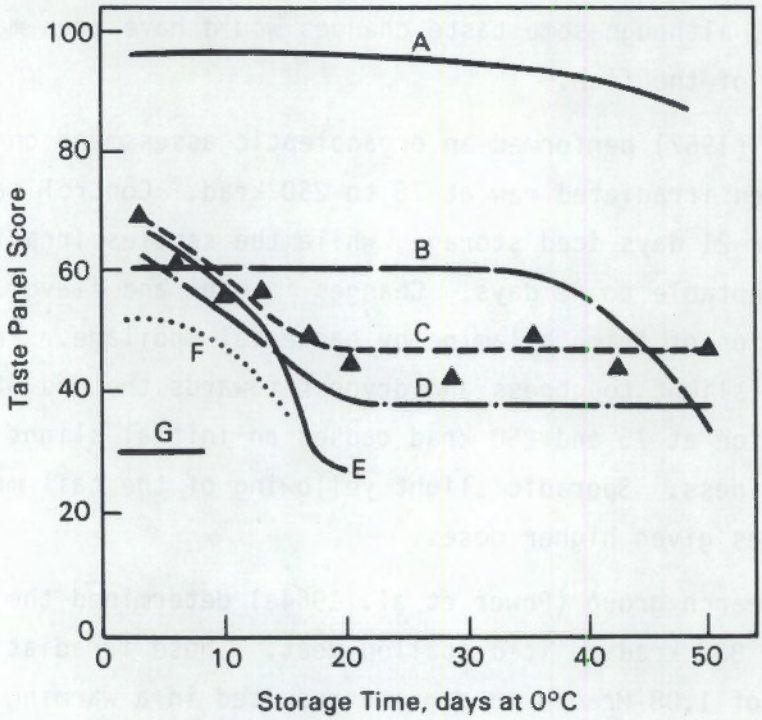

FIGURE 8. Taste Scores of Irradiated and Control Scallops After Baking (Power et al. 1964a)

Notes: Scallops were stored in ice after irradiation, except for unirradiated controls which were stored frozen at -26°C. After baking, a trained panel of 8 tasters graded for texture, taste, and overall acceptability. Scoring was by standard methods, with 100 as perfect and 40 as the limit of acceptability. In the Figure above, A = frozen control; B = 75 krad dose; C = 150 krad; D = 300 krad; E = iced control, 0 krad; F = 400 krad; G = 800 krad dose.

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sodium tripolyphosphate and partial dewatering, by pressing between two metal plates. Some browning was observed, due to enzyme action, which could be avoided by blanching the fish.

Novak and Rao (1972) did organoleptic evaluations of shrimp which were irradiated on ship or at dockside to 200 krad and then stored on ice in polyethylene pouches. A panel of 12 experienced judges evaluated the irradiated

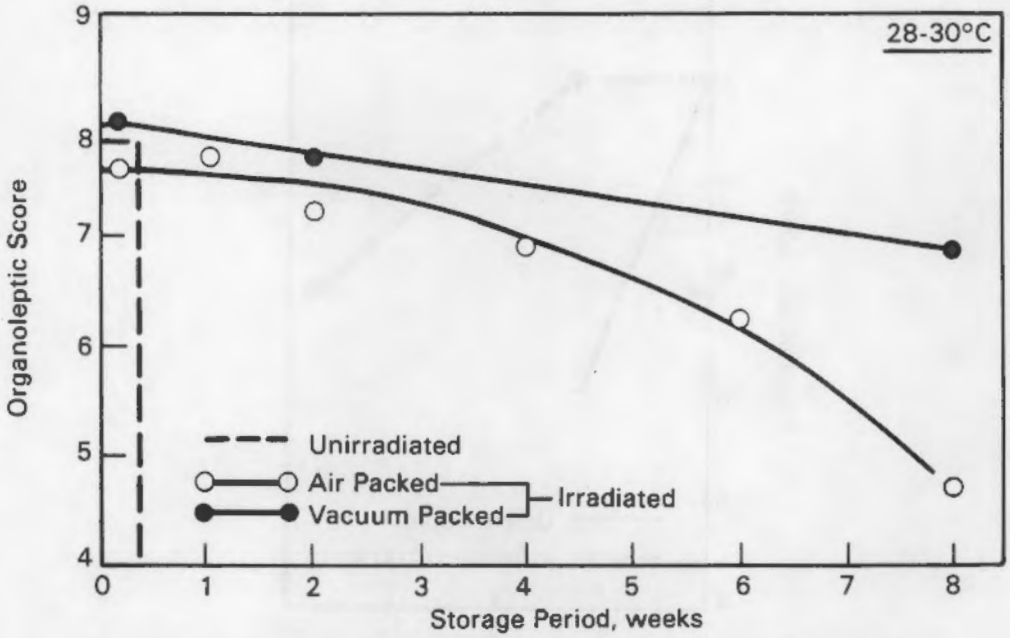

FIGURE 9. Organoleptic Ratings of Heat and Radiation Processed Shrimp (Kumta et al. 1973)

Notes: Shrimp were processed and cooked as described in the text, irradiated in air or vacuum in sealed packages to 100 krad, and stored at 28 to 30°C. For tasting, they were immersed in boiling water for 5 minutes and assessed by a 6-member trained taste panel using a 9-point hedonic scale.

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shrimp cooked in boiling, unsalted water for 9 min. Shrimp in shrimp cocktail was evaluated by 292 U.S. Army personnel. Novak and Rao's results are shown in Tables 10 and 11, below.

The effect of irradiation on the quality of Dungeness crab meat, after irradiation at 100 or 200 krad was evaluated (Miyauchi et al. 1966). No appreciable differences in quality were found between vacuum- and nonvacuum-packed crab meat, although spoilage due to "yeasty" odors and flavors occurred after 3 weeks.

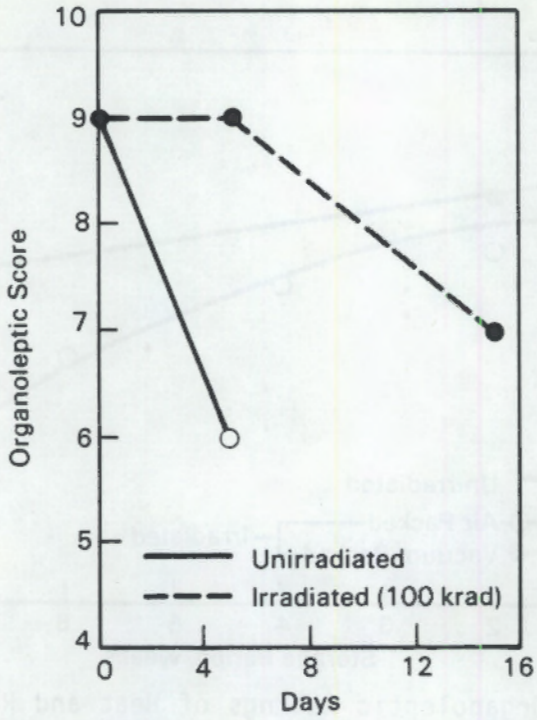

FIGURE 10. Organoleptic Score for Irradiated Bombay Duck Laminates (Kumta et al. 1973)

Notes: Bombay duck laminates were irradiated at 100 krad and stored at 0 to 2°C. Uncooked samples were evaluated by the same procedure as for Figure 9 above.

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HEALTH ASPECTS - TOXIN PRODUCTION

Spoilage of irradiated seafood generally occurs because of the growth of residual microorganisms; irradiation at the doses being considered for commercial use does not sterilize the seafood but merely reduces the initial bacterial load. Most spoilage organisms are benign--that is, harmless--but they indicate by their presence (odor, sliminess, visible colonies, etc.) that other pathogenic or toxin-producing species may have had the chance to grow, and that the seafood is not fresh.

TABLE 10. Comparison of Organoleptic Scores on Irradiated and Unirradiated Shrimp (200 krad) (Novak and Rao 1972)

Sample Treatment	Score After Listed Storage Period			
	Initial	7 Days	14 Days	21 Days[a]
Unirradiated	9.8	7.9[b]	6.2[b]	3.9[b]
Irradiated	9.8	9.1	8.1	6.9

(a) No statistical analysis was required after 21 days because by then the irradiated products were preferred unanimously.
(b) Blackspot noted by all judges.

Notes: Ratings are averages for 12 individuals. Values are averages for participants on taste panel for the attributes of appearance, odor, flavor, and texture. Code of scores:
9 - No change from fresh product of highest quality.
7 - First noticeable slight change in attributes.
5 - Moderate degree of changed attribute: increased in intensity and occurrence from score of 7.
3 - Definite or strong degree of changed attribute.
1 - Extreme degree of changed attribute.

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TABLE 11. Average Hedonic Ratings for Irradiated and Unirradiated Shrimp Cocktail (200 krad) (Novak and Rao 1972)

Company	Irradiated (200 krad)		Unirradiated	
	No. Men Rating	Average Rating	No. Men Rating	Average Rating
Hq Co Spec Troops	118	5.29	188	5.18
OCS - Co. B	65	7.09	111	7.54
OCS - Co. D	109	7.16	104	6.73
Total participants	292		403	
Overall average		6.39		6.23

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One major concern regarding the use of irradiation to extend the shelf life of seafood is that there may be a differential killing of benign organisms relative to harmful ones. The most well-documented case of this is the killing of Pseudomonas and related bacteria which produce the off-odor of trimethylamine by irradiation, while radiation-resistant spores of Clostridium botulinum type E, the causative organism of the notorious botulism toxin, survive. The food industry is, however, well-prepared to deal with this problem, as the identification of botulism toxin-producing organisms surviving after canning and other food preparation processes is a primary function of quality control laboratories. Periodic failures in this control lead to heavily publicized incidents of botulism and frequently to the demise of the company responsible for the failure. Hence, with adequate research into irradiation and packaging methods, botulism resulting from inadequate control over irradiation should not be an adverse factor in the acceptance of irradiated seafood products. The following summary of published data provides some background to this conclusion.

Grecz et al. (1973) examined the effect of gamma radiation on various types of Clostridium botulinum grown in liquid culture. Over the past 50 years, over 200 individual strains of this organism have been reported, with wide variation in their ability to generate toxin. That this variability extends to radiation resistance is shown in Figure 11, where some strains demonstrate the ability to recover and proliferate after a dose of 2 Mrad, while others are killed. This figure also demonstrates the basic fact that must be borne in mind in seafood irradiation commercialization: At the radiation doses being considered for commercial use (below 300 krad) there is very little killing effect on Clostridium botulinum. Hence, good food preparation practices in use in the food industry must be extended to irradiated food. Table 12, derived from Grecz et al. (1973), gives D_{10} values (the radiation dose required to cause a 10-fold reduction in cell number) for 15 different strains of Clostridium botulinum in two different media.

Staphylococcus aureus is another bacterium responsible for a milder type of food poisoning than botulism. Lewis et al. (1973) reported the killing

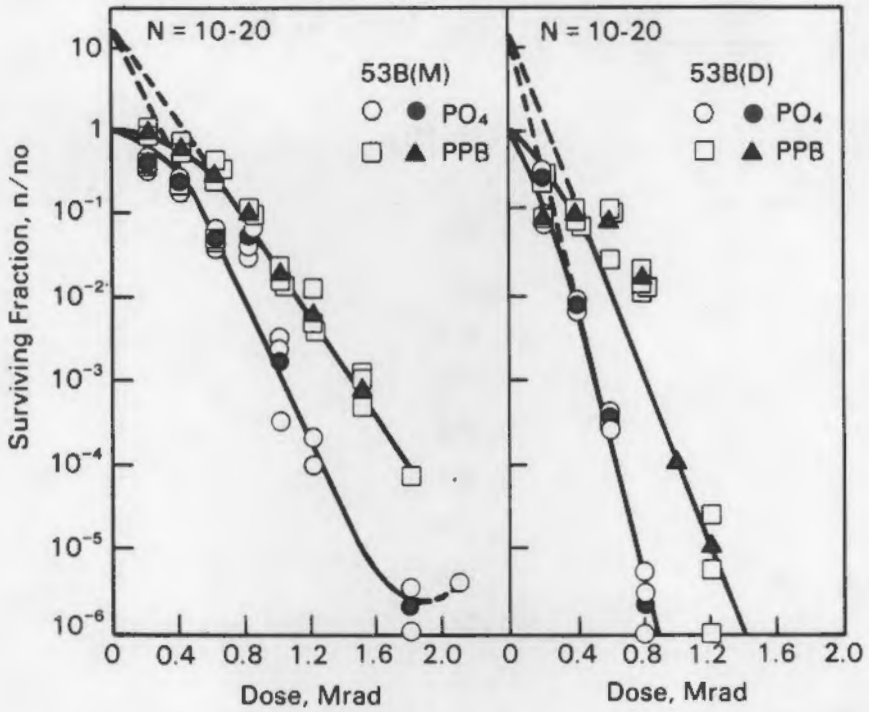

FIGURE 11. Differences in Radiation Resistance of Two Cl. botulinum Strains (Grecz et al. 1973). Reprinted with permission from the International Atomic Energy Agency, Vienna.

effect of a 40-krad dose of gamma radiation on cultures of this organism. Figure 12 shows their results, which can be compared with the Clostridium data. Lest it be thought that radiation treatment has the same effect on different types of bacteria, these same authors presented data (Figure 13) on several different types. Salmonella, the third major food poisoning causative organism of interest, is killed relatively easily by irradiation, as shown in Figure 14, from data published by Kampelmacher (1981).

Further work on Clostridium infection of irradiated Gulf shrimp and oysters was performed by Grodner (1965) under contract to the U.S. AEC. Examination of over 700 pounds of commercially purchased shrimp and oysters indicated the absence of Clostridium and Type E toxin, as well as Salmonella. Deliberate inoculation of a mixed-spore stock culture consisting of Clostridium botulinum Type E Boluga, Alaska, Minneapolis, and 8 E strains did not lead to toxin formation in 14 days of storage on ice in fresh shrimp irradiated at

TABLE 12. Summary of Gamma-Radiation Resistance of Spores of *Clostridium botulinum* Types A, B, and E (Grecz et al. 1973)

Strain	D_{10} in PO_4 (Mrad)	Method Used for Calculation[a]
36A	0.336	1
62A	0.224	1
9B	0.227	1
40B	0.371	1
41B	0.318	1
53B	0.329	1
51B	0.129	1
Type E, VH	0.128	1
	0.084	3
	0.14	2
Type E, Alaska	0.137	1
	0.130	3
	0.17	2
	0.10	2
Type E, Beluga	0.136	1
	0.08	3

(a) Methods used for calculation of D_{10}-value:
(1) D_{10} values were calculated from partial spoilage method, or most probable number data.
(2) D_{10} values were calculated from radiation survival curves (exponential plus shoulder portion of the curve)
(3) D_{10} values were calculated from the E portion.

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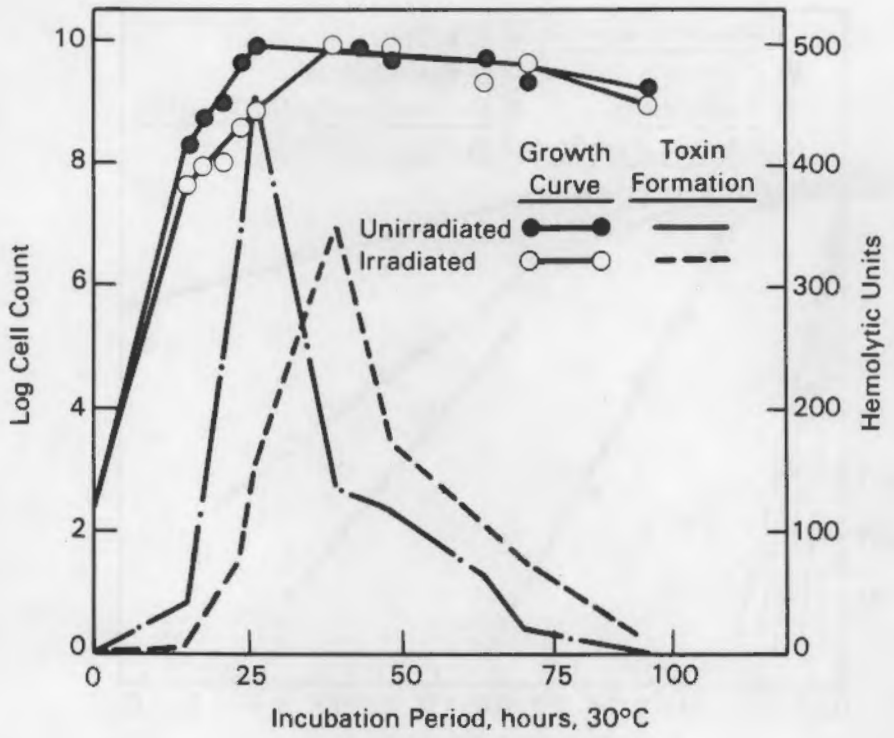

FIGURE 12. Effect of Gamma-Radiation on Growth and Toxin Formation by Staphylococcus aureus in TYSE Medium (Lewis et al. 1973)

Notes: Radiation dose of 40 krad; toxin formation is represented as a function of hemolytic activity using rabbit blood cells.

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150 to 500 krad. However, after storage at 40°F for 7 and 14 days, toxin was produced, as indicated by the death of laboratory mice ingesting the shrimp irradiated at up to 300 krad. Mice ingesting shrimp irradiated at 500 krad did not die, showing some radiation effect. Prevention of germination of Clostridium spores by a radiation dose of 500 krad following an inoculation of 10^3 and 10^4 spores/g is at variance with the results reported by Grecz et al. (1973) with irradiated liquid cultures, indicating some difference in organism viability between laboratory culture broths and whole shrimp. Also, care should be taken in interpreting the results of artificial inoculation of spores, since the amounts inoculated generally far exceed the levels likely to occur naturally.

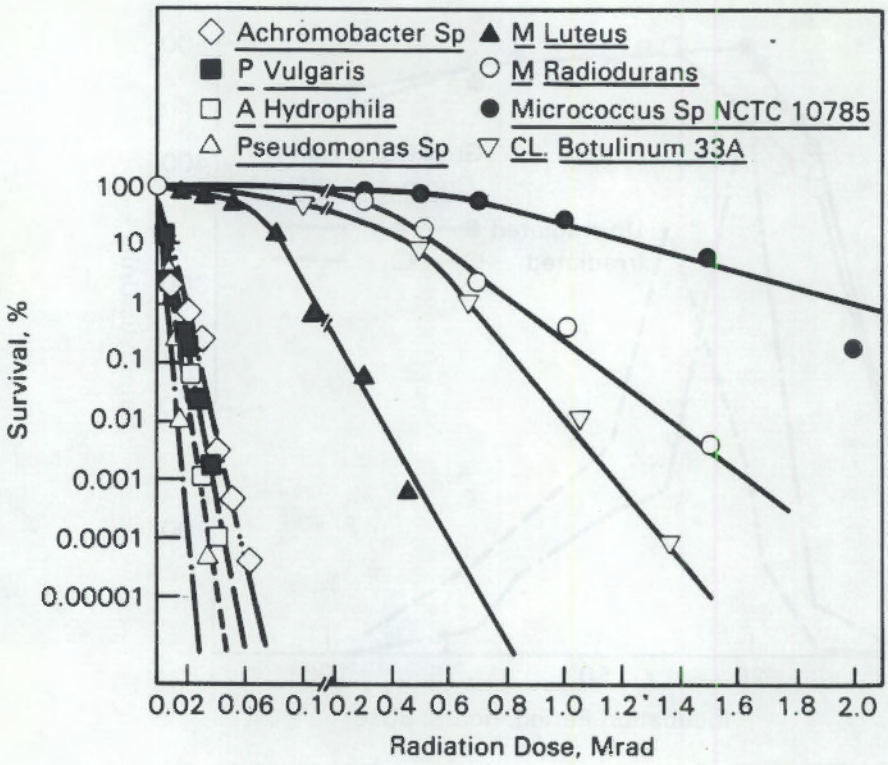

FIGURE 13. Radiation Sensitivities of Gram-Negative and Positive Bacteria (Lewis et al. 1973)

Notes: Percent survival was obtained after exposing buffered cell suspensions to gamma radiation at a dose rate of 11.1 krad/min.

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Toxin production by Clostridium botulinum Type B in radiated raw pindang fish was studied by Suhadi (1981) under IAEA sponsorship of the Indonesian National Atomic Energy Agency. After inoculation with spores of Cl. botulinum, radiation doses of 200 and 300 krad were applied to the fish, which were then stored at various temperatures. In general, after storage at 51°F, toxin production was detected before the fish were obviously spoiled, while during storage at lower temperatures toxin was detected after spoilage. Storage of irradiated fish at or below 42°F was recommended to avoid botulism toxin production before obvious spoilage had occurred.

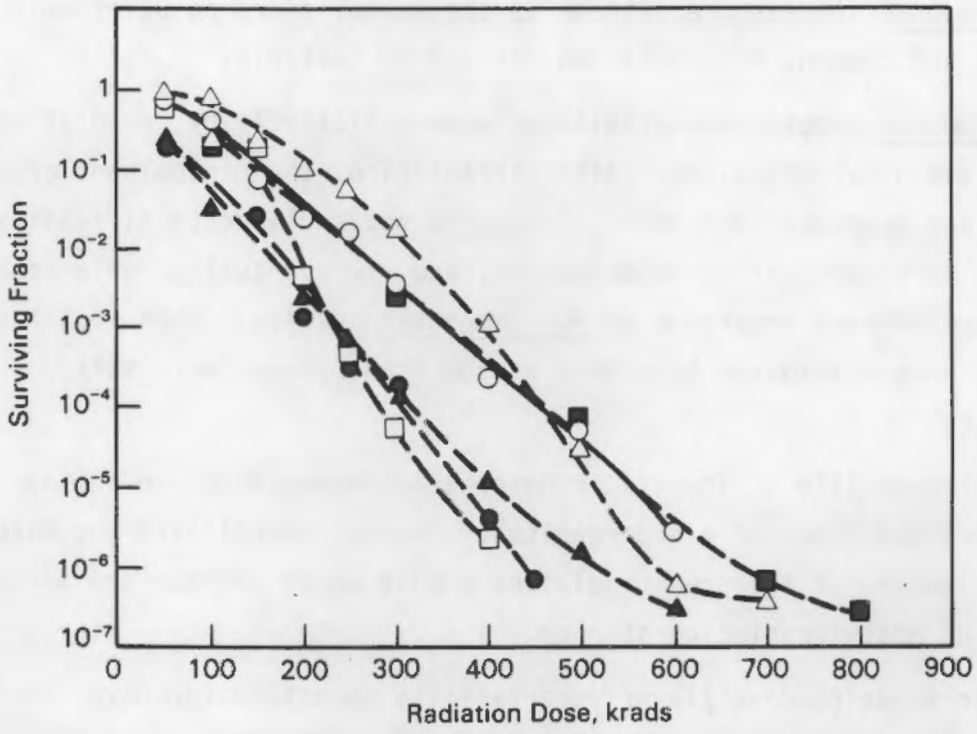

FIGURE 14. Dose-Survival Curves for Various Salmonella Serotypes (Kampelmacher 1981)

Note: Determined in horse meat at -15°C.

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A detailed study of the effects of irradiation in general on the microbial flora of Dover sole was reported by Sinnhuber and Lee (1964), working at the Oregon State University Dept. of Food Science and Technology (Corvallis, Oregon) under U.S. AEC sponsorship. They used radiation doses of up to 500 krad, with fish storage at 34 or 43°F. Their detailed findings are summarized below:

1. Microbial growth in irradiated Dover sole followed a biphasic growth curve, with little or slow growth initially followed by a very rapid increase. The inactive growth period is a function of the radiation dose and was increased by preservation treatment with 0.1% sodium benzoate.

2. Pseudomonas species predominate as the normal flora on Dover sole; these are common, generally non-pathogenic bacteria.

3. Pseudomonas species are eliminated more efficiently by irradiation than are other organisms. After irradiation, the predominant organisms are gram-positive cocci. These do not proliferate as readily as other survivors during cold storage, and are eventually replaced as the predominant organisms by Achromobacter species. When most bacteria were eliminated by a dose of 500 krad, yeasts were still viable.

4. The storage life of irradiated Dover sole depended on the initial numbers and types of microorganisms. Hence, control over the microbial loading of the pre-irradiation sample would improve the success rate of post-irradiation storage.

5. The irradiation dose flavor acceptability threshold for Dover sole as determined by organoleptic testing by an expert panel was 500 krad.

A similar study on Bombay duck irradiated with 100 krad was reported by Bhadra, Chandhuri, and Bose (1973). The variations in microbial flora at 32 to 36°F over a storage period of up to 42 days were complex. Nine different groups (genera) of bacteria were tracked during this period, and their populations increased and decreased after irradiation in a non-predictable manner. A summary of the results is reproduced in Table 13. It is interesting to note that, despite the climatic differences between Corvallis, Oregon, and Bombay, India, the finally predominant organisms just before spoilage occurred were species of Micrococcus and Achromobacter in both studies. Note that, in Table 13, results are qualitatively expressed as a percentage of the total population (colony counts), rather than in terms of actual colony numbers.

TABLE 13. Qualitative Changes in the Bacterial Flora in Irradiated and Unirradiated Bombay Duck Laminates During Storage (Bhadra, Chaudhuri, and Bose 1973)

Batch No.	Genus and/or Type of Bacteria	Proportion of Bacteria Expressed in Percentage — Days of Storage: 7		14		21		28		35		42	
		Cont.	Irr.	Cont.	Irr.	Cont.	Irr.	Cont.	Irr.	Cont.	Irr.	Cont.	Irr.
I	Pseudomonas												
	Non-fluorescent	12	2	15	6	14	12	-	10	-	2	-	2
	Fluorescent	4	0	16	0	14	0	-	0	-	0	-	0
	Aeromonas	16	10	10	6	20	0	-	0	-	2	-	0
	Proteus	14	10	18	10	30	10	-	6	-	2	-	0
	Achromobacter	12	23	18	30	8	34	-	36	-	38	-	44
	Vibrio	10	0	4	0	4	0	-	0	-	0	-	0
	Micrococcus	28	50	16	42	10	42	-	48	-	54	-	50
	Flavobacterium	2	0	0	0	0	0	-	0	-	2	-	2
	Coryneforms	2	0	2	2	0	0	-	0	-	0	-	0
II	Pseudomonas												
	Non-fluorescent	2	0	8	0	10	0	12	0	-	0	-	-
	Fluorescent	0	0	2	0	0	0	0	0	-	0	-	-
	Aeromonas	18	10	10	10	15	8	24	0	-	0	-	-
	Proteus	26	26	32	18	31	14	28	8	-	8	-	-
	Achromobacter	16	20	20	25	20	32	20	38	-	46	-	-
	Vibrio	6	0	4	0	4	0	2	0	-	0	-	-
	Micrococcus	24	40	22	45	20	44	12	48	-	44	-	-
	Flavobacterium	6	4	2	2	0	0	0	0	-	0	-	-
	Corneforms	2	0	0	0	0	0	2	0	-	2	-	-
III	Pseudomonas												
	Non-fluorescent	10	2	12	4	12	2	-	2	-	0	-	0
	Fluorescent	4	0	8	0	4	0	-	0	-	0	-	0
	Aeromonas	14	10	18	10	16	4	-	4	-	2	-	2
	Proteus	26	12	20	10	28	4	-	4	-	6	-	6
	Achromobacter	16	36	20	36	20	40	-	40	-	40	-	38
	Vibrio	4	0	2	0	2	0	-	10	-	0	-	0
	Flavobacterium	4	0	0	0	4	0	-	2	-	0	-	0
	Micrococcus	20	40	16	40	14	46	-	46	-	50	-	52
	Coryneforms	2	0	4	0	0	2	-	2	-	2	-	2

Colonies were isolated from TGY (containing 0.5% each of peptone and sodium chloride agar plates.

HEALTH ASPECTS - MUTAGENICITY, CARCINOGENICITY, AND TERATOGENICITY

Apart from fears that irradiated seafood may contain toxins resulting from the growth of radiation-resistant bacteria, there is the more general concern that the irradiation process itself may lead to the formation of chemicals or unique radiolytic products (URPs), which are carcinogenic (causing cancer), mutagenic (causing mutations), or teratogenic (causing fetal malformations). No evidence has been found in the literature on seafood irradiation to suggest that, at the doses contemplated for use (<300 krad), any such problems may arise. In fact, there is no evidence for the formation of URPs at any dose. However, lipid peroxidation and "cooked" or "burnt" flavors have been noted after seafood irradiation at high doses, as described earlier in the text. Research performed to identify the source of these off-flavors and odors pinpoints the fats as the primary reactant, and then only with oxygen in the air, which is exactly the same process as that occuring during cooking.

One report (Gower and Wills 1986) studied possible associations between seafood irradiation and carcinogenic chemical production. Only the abstract is available at present. It deals with a highly artificial system in which mackerel and cod liver oils were exposed to 1 to 4 Mrad of gamma radiation in air; "large quantities" of lipid peroxides were formed, which were shown to oxidize added benz[a]pyrene to highly carcinogenic benzpyrene quinones (Gower and Wills 1986). Similar oxidation also took place during air storage of the fish oils after addition of the benzpyrene. Antioxidants such as BHA and Vitamin E inhibited the reaction.

The relevance of this report to food irradiation is not clear, despite the warning in the report abstract. Benz[a]pyrene is not a normal constituent of food, although it is formed in traces during heavy cooking (burning) of food. Lipid peroxidation has been known for years and is a cause of rancid flavors. Hence, heavy cooking of fish in air could lead to both lipid peroxidation and benzpyrene formation and presumably to some degree of carcinogen formation, although the extent to which this would occur in whole fish or fillets (as opposed to oils) is unclear. There is thus a potential danger in eating burned, rancid fish, which however would be highly unpalatable anyway. Irradiation at any level reported (up to 1 Mrad) has never been shown to lead

to detectable quantities of benz[a]pyrene formation, and in fact there is no plausible theoretical reason why it should. Fish lipid peroxidation can be prevented by suitable packaging. Lipid peroxidation would lead to off-flavors and consumer rejection anyway. All the data we have reviewed seems to support irradiation as a safe way to extend shelf life.

On a more scientific level, lipid oxidation during seafood irradiation in air is a fact. The products are not URPs, but appear identical to normal peroxides formed during prolonged air storage, cooking, or rancidity. The double bonds in unsaturated fish oils are prone to reaction with oxygen, which is itself a free (di)radical.

A detailed review of chemical changes observed to occur in irradiated seafoods has been published (King et al. 1972). Although 14 years have passed since its publication, this is still one of the best summaries available. The following is a precis of this review.

> The effects of radiation, heating, and storage on the formation of volatile organic compounds (VOCs) from clam meat have been reported. There is an increase in total volatiles up to the time of spoilage, followed after this time by a gradual dissipation and reduction in VOC concentration. The general trend is accelerated or decelerated by various treatments. Vacuum packaging minimized these effects on volatiles (mainly carbonyl compounds). The effects of radiation, cooking, and storage on the headspace gas components from clam meat have also been determined (by gas chromatography/mass spectrometry (GC/MS)). Compounds identified were:

Hydrogen sulfide	Methyl mercaptan	Dimethyl sulfide
Diethyl sulfide	Ethyl n-butyl sulfide	Acetaldehyde
Acetone	Isovaleraldehyde	Valeraldehyde
Heptanone	Butene	1-Pentene
Toluene		

The effect of 350 krad of gamma radiation on these air-packed clam meats was to increase the concentrations of dimethyl sulfide, acetaldehyde, 1-pentene, and methyl mercaptan and decrease the concentrations of the other components. There was no change observed after a dose of 450 krad in vacuum-packed clam meats. Cooking and storage caused similar changes.

A study of the effect of irradiation on fresh haddock or cod fillets was performed, with the general results shown in Table 14.

TABLE 14. Compounds Identified in Fresh Irradiated and Unirradiated Haddock Fillets (King et al. 1972)

Non-Irradiated	Irradiated at 130 krad	Irradiated at 260 krad[a]	Irradiated at 650 krad	Irradiated at 1300 krad	Irradiated at 6500 krad
Acetaldehyde	Acetone	Benzene	Benzene	Acetone	Acetone
Acetone	Benzene	Dimethyl disulfide	Dimethyl disulfide	Benzene n-Butane	Benzene n-Butane
Butene	Butene	Dimethyl sulfide	Dimethyl sulfide	Butene Dimethyl disulfide Dimethyl sulfide	2-Butane thiol Butene Carbon disulfide
Diethyl ether	Dimethyl disulfide	Methyl mercaptan	Dimethyl trisulfide	n-Heptane 1-Heptyne Hydrogen sulfide	Carbonyl sulfide Dimethyl disulfide Dimethyl sulfide
Dimethyl disulfide	Dimethyl sulfide		Methyl mercaptan	2-Methyl-1-butene Methyl ethyl ketone Methyl mercaptan	2,3-Dithiohexane Ethyl alcohol n-Heptane
Dimethyl sulfide	Hydrogen sulfide		Methyl thio-acetate	2-Methyl propene n-Octane 1-Octyne	1-Heptene 1-Heptyne 1-Hexene
Toluene	Methyl mercaptan		Toluene	n-Pentane 1-Pentene 2-Thiobutane	Hydrogen sulfide Isopentane 2-Methyl-1-butanal
	Toluene			Toluene	Methyl ethyl ketone Methyl heptane 2-Methyl pentane 2-Methyl propanol n-Octane 1-Octyne n-Pentane 1-Pentene 2-Thiobutane Toluene

(a) The smaller number of identifications in this sample is believed to be a result of the center fraction being more dilute when used for mass spectral analysis. Gas chromatograms of the head gas from the total volatile condensate did not show this anomaly.

The types and relative amounts of volatile compounds formed during chilled storage of fish suggest that the most significant effect of irradiation is to alter the importance of microbial activity during storage.

Free amino acids in seafood are believed responsible for much of the flavor, and may have a significant role in inhibiting or accelerating lipid oxidation during seafood storage (Brooke et al. 1964). Model system studies show that radiation can fragment amino acid molecules, although results with actual seafood suggest that reality is more complex than the model system studies would indicate. In one study, a dose of 4.5 Mrad led to an increase of 40% in the amount of extractable free amino acids from raw clam meat. Slight increases in the free amino acid content of cod and haddock were noted after a dose of as little as 200 krad. As amino acids are a normal part of the diet, these slight increases are of little concern from the standpoint of possible harmful products from food irradiation. They may affect taste, however, since the sweetish taste of shrimp has been attributed to their free amino acid content (of about 3%).

Fatty acid composition changes after irradiation have been documented. Characteristically "fatty" species of fish contain a larger proportion of triglyceride lipid, mainly deposited in adipose tissue, while "lean" species such as cod or haddock contain more phospholipid as an integral part of their muscle tissue. Radiation-induced changes in lipids were not well documented at the time of King et al.'s (1972) review; although some changes in fatty acids and lipids were noted, they were not chemically characterized. In one other report (Tobback and Snauwaert 1978), radiolytic destruction of the fat-soluble vitamin A alcohol and its acetate derivative was reported after radiation doses of up to 240 krad in an organic solvent. The alcohol was much more labile than the acetate under these conditions.

One report of research funded by the IAEA (Moyuddin 1975), performed at the Nuclear Institute for Agriculture and Biology, Pyallpur, Pakistan, and entitled "Cytotoxic and Mutagenic Effects of Conventionally Processed Foods in Comparison with Irradiated Foods" may generate some public concern.

A series of curries were prepared, and their mutagenic effects determined. The tests used were the production of streptomycin-resistant mutants in cultures of Pseudomonas fluorescens and of chromosomal abnormalities in developing root tips of onions. All of the curries tested showed mutagenic properties under the experimental conditions; a 10 krad dose to onions and potatoes led to a 97 to 100% chromosome abnormality rate, as did a 200 krad dose to fish subsequently incorporated into a fish curry. The fish curry was mutagenic at a 64 to 89 % incidence even with a 1:100 dilution of the curry. These results are not supported by any work on any sort of controls and are widely variant from many studies done by others.

Moyuddin concluded that the curries were mutagenic because of the spices. The spices themselves in unirradiated or irradiated form were responsible for the effects, and where any effect due to irradiation could not be separated from the toxic effect of the spices. States Moyuddin: "We feel there is absolutely no need of getting alarmed at the consumption of irradiated foods because they cause abnormalities in onion root tips. These spices have been used for centuries and it is impossible to correlate any disease with the consumption of these spices not to mention of any carcinogenesis" (sic). Further, "It is abundantly clear from the data on cytogenicity that almost all the spices used for human consumption are cytotoxic or nucleotoxic in nature" (Moyuddin 1975).

The only fish dish used in this research was a curry prepared from fish irradiated at 200 krad. This report also quotes previous reports by Stone, Wuss, and Haas (1947, 1948) that irradiation of Staphylococcus aureus growth substrates leads to cell mutations, and by Swaminathan et al. (1963) that irradiated food enhanced the spontaneous mutation frequency in Drosophila melanogaster. However, the data produced by Moyuddin clearly indicate that irradiated fish curry is mutagenic. Unfortunately no control experiment was performed with any unirradiated fish. The experiments are therefore flawed because the effect of irradiation cannot be distinguished from the effects of other components, particularly spices.

Many detailed studies using animals fed irradiated diets have been performed. Without exception, the reports examined to date indicate that there is

no mutagenic or toxic component in these diets, which have often been irradiated at high sterilizing doses of several Mrad. The following examples illustrate this point.

The dehydro-irradiation process for shrimp being developed in India was tested for nutritional effects of the product in four successive generations of young rats, at a level of 25% of the diet. Both sexes of rats were used, and the effects on growth, reproduction, lactation, longevity, organ histology, and other biochemical parameters were determined (Aravindakshan, Vakil, and Sreenivasan 1973). The results indicated that there were no adverse health effects to the rats from a diet of 25% irradiated shrimp for four generations.

The Japanese are generally reluctant to consider using irradiated food (although irradiation to achieve sprout inhibition of potatoes has been applied commercially in Japan for some years now). One of the most thorough investigations on the safety of irradiated food was performed by Yoshikawa et al. (1982) and Iwahara and Kobayashi (1983), who reported data on an examination of the mutagenicity of unirradiated and irradiated fish-meat cake, wieners, and oranges. The fish-meat cake was irradiated at 600 krad and extracted with 70% methanol/water. Mutagenicity was determined on the streptomycin dependence of Salmonella typhimurium TA100 SM_D. There was no difference between the irradiated and unirradiated fish-meat cake extracts. The 2-year long-term genetic toxicity effect of irradiated fish paste was determined by testing three generations of rats, mice, and monkeys with various mutagenicity tests. There was no toxic effect.

Over 20 other feeding studies have been reported in which the potential harmful effects of feeding irradiated fish were investigated. None showed any harmful effects. Some of these studies were multi-generational, while others went into great depth of detail on a single generation. The overall conclusion of these studies, involving a total of thousands of animals and many man-years of effort, is that feeding of irradiated fish is safe and does not lead to carcinogenic, mutagenic, or teratogenic effects.

Listing all these studies here would be needlessly repetitive. A typical example is a Russian study (Zajtsev and Maganova 1981; Zajtsev and Ostpova 1982) in which gamma-irradiated (200 krad) and hot smoked fish were fed as part

of the diet to Wistar rats. In one part of the study, 52 female rats produced 611 embryos, and 35 rats supplied 2426 cells which were examined for chromosomal aberrations. The embryo abnormality incidence and the chromosomal aberration incidence rate were normal compared with controls at the end of the experiment. In a chronic (long-term) experiment of six generations of rats fed irradiated fish, no chromosomal aberrations above the normal incidence were observed.

In other studies of this type where fish was compared with other foods, there was no genetic toxicity of fish, even when other accepted foods (e.g., dried dates; Renner et al. 1982) showed significant toxicity. Altmann (1982) found an enhanced rate of DNA synthesis in Chinese hamsters fed fish irradiated at 100 to 700 krad. Renner et al. (1982) explained this effect on DNA synthesis as either the induction of an immunoactive compound as a result of feeding irradiated fish, or as the persistence of an immunoactive compound due to the removal by irradiation of spoilage organisms that would normally degrade it. However, Renner (1982) also performed micronucleus, sister-chromatid exchange, and spermatagonia tests, considered the most sensitive in vivo mutagenicity tests available, on Chinese hamsters, rats, and mice, and found no evidence for any mutagenic effect of feeding irradiated fish. Some evidence for an increased mitosis rate in pigs fed irradiated fish (400 or 700 krad) has been shown to be fallacious by Reusse, Messow, and Geister (1979). These authors demonstrated a spontaneous, random variation in mitosis rate in pigs; chance was considered as the causative agent, as the same high mitosis rate was also found in some control groups.

Feeding studies to determine the effects of irradiated fish on various mammalian species are notoriously difficult to carry out, time-consuming and expensive, and difficult to interpret. Numerous variable factors have to be taken into account. The fact that so many studies have been performed, with results indicating that irradiated fish is a safe food, is encouraging. Occasional reports indicating harmful effects of irradiated food are to be expected, but examination of these reports reveals that the study was flawed in some way rather than that the irradiation process is harmful. The balance of the evidence overwhelmingly indicates the safety of irradiated seafood at radiation dosages much higher than those proposed (<300 krad).

PUBLIC REACTION TO IRRADIATED SEAFOOD

Several market studies have been performed to determine public acceptance of irradiated seafood. These studies focus more on the way in which the food is presented to the public than on technical factors of irradiation. These studies are in general agreement that if the fact of irradiation is dissociated from "contagion" with the nuclear industry, acceptance increases markedly. The Canadian Gallup Poll Ltd. survey (1984) found a negative attitude towards irradiation among traders, who felt that as they already were geared towards a quick turnaround time (2-day delivery, 24-h storage) for fresh seafood, additional shelf life would be unnecessary. Reduction of waste was also not seen as an advantage. Their major focus was on the frozen seafood market.

Considerable emphasis was placed on information and labeling supplied with the irradiated fish in this study. A symbol denoting irradiation together with a statement was preferred, although any use of the word "irradiation" or "radiation" had very negative connotations. Emphasis on irradiated fish as containing "no preservatives" and "no added chemicals" was seen as positive, and considerable consumer confusion about the exact meaning of "fresh" was noted. A lack of factual knowledge about the process was apparent among members of the public; this would have to be addressed to dispel fears about irradiated seafood.

The National Marine Fisheries Service funded a study of the marketability of irradiated seafood (Doyle and Casey 1986). This study was specifically directed at evaluating the extent and nature of consumer fears of irradiation. Further objectives were to present a strategy for minimizing fear reactions on the part of consumers and to assess the potential impact of consumer acceptance of irradiated seafoods on the seafood industry. The study determined that 5 to 10% of consumers would reject irradiated seafood based on their existing values, and that education would not affect this rejection; 25 to 30% would accept irradiated seafood on a similar basis, but could be swayed by negative findings or exposure to the "negative" group; and the remainder were

undecided, confused, concerned, and uncertain. The last group represents the best potential for confirming positive attitudes through providing factual information on seafood irradiation.

Currently, most consumers express a lack of interest and/or lack of knowledge regarding food irradiation, a situation which is likely to change when they have to make a choice on the supermarket shelves. The major factors leading to a high acceptance level (over 70%) related to demand for fresh seafood and its availability. Market success for irradiated seafood was found to be related more to consumer acceptance of the product than to acceptance of the process. The National Marine Fisheries Service study recommended a thorough educational program for consumers prior to the introduction of irradiated seafood, including a summary of the strategies opponents use to misinform; adoption of a standardized retail symbol denoting irradiated food (but no mandatory labeling); and continual monitoring of consumer attitudes during the acceptance phase to determine changes in attitude. This study is in general agreement with the Canadian Gallup Poll study mentioned above, except that no emphasis on fears associated with the use of the term "irradiated" was noted in the fisheries study.

These findings are positive, and are supported by an earlier presentation by a consumer advocate (Young 1982) to a joint FAO/IAEA consulting meeting on marketing. Young commented that the first reaction of a lay person to the concept of irradiated food was one of "horror, revulsion, and disbelief that we could seriously anticipate such a thing" (sic), due to ignorance and association with the nuclear industry. She went on to say that "before anyone rushes into marketing irradiated foods, a lot of careful preparation must be done. A consumer education program is essential."

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