The Atom Preserves Seafoods

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INTRODUCTION

ON JULY 7, 1965 history was made in the seafood industry when the United States Atomic Energy Commission submitted to the United States Food and Drug Administration a petition to permit the commercial use of radiation-pasteurized cod, haddock, pollock, flounder, and sole. Approval of the petition is necessary because the Food and Drug Administration considers radiation from radioisotopes to be a food additive.

We are optimistic that approval will be granted because use of radiation for the sterilization of bacon, deinfestation of grain, and sprout inhibition of potatoes has already been authorized. If granted, approval will, in a sense, mark the beginning of a revolution in the food industry because it will be the first time that food pasteurized by ionizing radiation will be available to the public. Fishery products never before obtainable in the fresh-like state in interior parts of the country will be available on a regular basis.

The following is a very brief review of the history of the radiation preservation of foods and a discussion of highlights of some of the work that has been done on seafood.

Following Roentgen's discovery of X-rays in the last century and Becquerel's discovery of radioactivity, scientists exploited the properties of ionizing radiation to investigate their effects on biological materials (1). It was not long before it was discovered that these radiations could kill bacteria, insects, and higher forms of life.

Early Research

In 1930, a French patent was granted for the use of ionizing radiation for the preservation of foods (16). This appears to be the first known attempt to establish a process for preserving foods based upon the capacity of ionizing radiation to destroy bacteria. However, little was done with this method, and for some years major applications consisted of medical use for diagnostic and therapeutic purposes. Extensive work on the use of radiation to preserve foods

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began at the Massachusetts Institute of Technology in 1942 and 1943 when Proctor, Van de Graaff, and Fram studied the effect of X-rays on the destruction of bacteria in ground meat (3).

After World War II, the U.S. Army became interested in the possibilities of radiation as a means of sterilizing foods, and the large amount of byproducts from materials produced for military purposes enabled them to carry out studies into the use of the energy from radioisotopes for that purpose. This program very quickly became a major investigation. In addition to Army scientists, it included scientists at universities, industrial laboratories, and some government civilian agencies.

The Bureau of Commercial Fisheries began participating in this program in 1956 and conducted some of the earliest studies on the effect of sterilization and substerilization doses of radiation on the shelf life and quality retention of several species of fish and shellfish. Early in our studies, we discovered that fish generally are amenable to this method of preservation. As with any other method of preservation, however, a moderately narrow range of conditions defined the useful limits of the process. For example, in many fishery products high levels of radiation (enough to kill all the bacteria present) produced undesirable flavors and odors. On the other hand, the application of very low quantities of energy was, in some cases, insufficient to obtain a significant extension of shelf life during storage at 33 to 35F.

Present Studies

Our findings indicated to the U.S. Atomic Energy Commission that fishery products were promising subjects for this process. The Commission contracted with the Bureau and with some universities to carry out studies to develop a process for fishery products that would utilize the potential of radioisotopes for preservative purposes and to produce seafoods of high-quality levels and of extended refrigerated storage life.

Initially, studies in the Bureau were made on haddock and clams from the Northwest Atlantic, and petrale sole, dungeness crab meat, and king crab meat from the Northeast Pacific. Later, studies were extended to include other marine species and fresh-water fish such as yellow perch and chubs from the Great Lakes. Simultaneously, studies at various universities were being carried out on shrimp and oysters, and investigations were being made on the organic chemistry, microbiology, and biochemistry of irradiated fishery products. In the following sections details of these studies are given.

STATUS OF THE PROGRAM

Optimum Pasteurization Dose, Shelf Life, and Quality

Destruction of bacteria by radiation can occur at two levels. These are called sterilization and pasteurization. Sterilization destroys all the bacteria in food. Pasteurization involves smaller quantities of radiation and leaves about 1 percent of the bacteria viable. These relatively few survivors are capable of multiplying, and ultimately they cause spoilage. It is necessary, therefore, that foods preserved by pasteurizing levels of radiation be held under refrigeration.

Optimum pasteurization dose determinations in nearly all cases were carried out in hermetically sealed cans. Shrimp were packed in flexible-film pouches and oysters were packed in 1-pint cans with friction-fit lids. In most experiments, products were packed in air and under vacuum. Petrale sole fillets and halibut steaks were packed under vacuum only because of the rapidity with which the fats in the irradiated flesh of these species developed oxidative rancidity during storage (2).

After irradiation, which ranged from 50,000 rads to 600,000 rads, depending on the species, the products were stored at 33F. and at 42F. In some experiments, storage was in melting ice. Periodic sensory tests told us the conditions that gave us a significant storage-life extension consistent with the retention of product quality. The optimum doses found for products stored at 33F., and in melting ice in the case of raw shrimp, are shown in Table 1. Storage life shown is an average and indicates only approximately when the product reached borderline acceptability. Samples stored at 33F. had about twice the extension of storage life as did those stored at 42F. As a result, tests at the higher temperature were soon discontinued.

The optimum dose levels increased the shelf life at 33F. of Northwest Atlantic products by about two to three times. Pacific Ocean products could be held four to five times as long as their unirradiated counterparts. Yellow perch showed a doubling of storage life, as did raw shrimp. Raw, shucked oysters could be held for about one and one-half times their normal shelf life.

TABLE 1

SHELF LIFE OF SELECTED SEAFOODS: NONIRRADIATED VS. IRRADIATED

Product	Packaging	Unirradiated		Irradiated		
		Storage conditions (°F)	Shelf-life (days)	Optimum dose (rads)	Storage temp(°F)	Shelf life (days)
Raw shrimp	mylar bags	melting ice	14	150,000	melting ice	25
Raw shucked oysters	pint cans	33	15	200,000	33	21
Pollock fillets	air pack cans	melting ice	10-14	150,000	33	30
Ocean perch fillets	air pack cans	melting ice	12-14	250,000	33	30
Haddock fillets	air pack cans	melting ice	10-14	250,000	32	30
Petrale sole fillets	vacuum can or mylar-polyethylene pouch	33	4-10	200,000-300,000	33	21-42
Pacific halibut	vacuum can	33	4-9	200,000	33	30
Yellow perch fillets	air pack plastic pouch	33	8-13	300,000	33	20
Cod fillets	air pack can	melting ice	12-14	150,000	33	30
Soft-shell clam meats	air pack in enamel cans	melting ice	5-8	450,000	33	30
King crab meats	air or vacuum in can	33	5-14	200,000	33	35
Dungeness crab	air or vacuum in can	33	6-11	200,000	33	35
English sole	cans	33	4-6	200,000	33	25

Pre-irradiation Quality and Post-irradiation Shelf Life

The shelf-life extensions shown were obtained with products usually caught 24 to 36 hours prior to irradiation. Since fish of this very high quality level will not be available in sufficient quantity to satisfy large markets, it was necessary to carry out studies to relate the quality and shelf-life extension of post-irradiated fish to the quality of the same fish before irradiation. Several experiments with haddock and cod have been carried out in which the gutted fish have been stored in ice in the laboratory for periods up to 10 days. Irradiation of samples of these fish at different storage intervals has shown that storage periods of up to about 7 days on ice still permits at least a two-fold extension of storage life at 33F. after irradiation. However, if the fish are stored on ice for more than 7 or 8 days before irradiation there is little significant extension in shelf life over that of fish that have not been irradiated. Detailed studies have not been made on other products, but it is a maxim that high initial quality ensures the maintenance of quality for a longer period.

Other Possible Benefits for Shellfish

The U.S. Public Health Service Cooperative Program for the Certification of Interstate Shellfish Shippers defines microbiological standards for shellfish.

Shellfish from many areas cannot be harvested because of pollution. It is also not infrequent that shellfish taken from approved growing areas have MPN's (most probable numbers) and/or coliform counts that preclude their commercial use.

Exploratory studies show that 60,000 rads for unshucked soft-shell clams (5) and 200,000 rads for oyster meats (8) reduce their microbiological values to acceptable values.

Acceptability Tests

Almost all sensory tests of irradiated products have been held in laboratories and by small expert panels. These tests have been used to determine optimum dose levels and to estimate product acceptability. Because of the small size of the panels, acceptability tests are of limited value in determining acceptability by large populations.

As a start in the determination of acceptability, tests of irradiated haddock held 15 days and 29 days at 33F. were held at Fort Lee, Virginia, using several hundred soldiers as panelists. Acceptability was good, and the product qualified for standard troop meals (9). A similar test with irradiated shrimp showed that this product too was of sufficient acceptability for acceptance by the Department of Defense for standard troop meals (7).

Nutrition Studies

Read (10) has shown that sterilizing doses of radiation have little or no effect on macronutrients. Fat-soluble vitamins are destroyed easily and some water-soluble vitamins appear to be labile, although radiation causes no greater damage than does cooking. We felt that limited nutritional studies would be desirable and studied the effect of the optimum dose and 10 times the optimum dose on the B-vitamins and amino acids of haddock fillets and soft-shell clam meats after storage for 30 days at 33F. Results of these analyses were compared with those made on comparable commercial products—for example, heat-processed canned clam meats, clam meats stored on ice for 5 days, haddock fillets frozen at –5F. for 12 months, and haddock fillets stored on ice for 10 days. In very few cases did differences of any significance exist between the irradiated and the unirradiated products.

Flavor and Odor Studies

Pasteurizing levels of radiation destroy about 99 percent of the bacteria in the flesh of seafood. Although the survivors are able to regrow and ultimately cause spoilage at 33F., this requires a period of time at least twice that required for the unirradiated product held at the same temperature. Further, many biochemical processes are able to continue in the refrigerated flesh and produce changes that would never have occurred in the absence of irradiation, because spoilage would have precluded their detection. To determine their relation to the changes that ultimately occur in the flavor and odor of irradiated products, we have undertaken a project to study the volatile compounds removed from them and to compare them with those removed from unirradiated fresh and ice-stored fish. Several differences in the composition of the volatile compounds present in irradiated and unirradiated fish have been noted, but it is still too early to determine the significance of these differences. Continued studies will help us to understand the chemistry of flavor and odor changes and to take steps to prevent them.

Chemical Tests for Quality

Many objective chemical tests exist for the determination of the quality of fishery products. Few of these have a high degree of reliability. However, because irradiated fish spoil in a manner different from that of unirradiated fish, several commonly used chemical tests were tried on irradiated and unirradiated petrale sole fillets, king crab meats, and dungeness crab meats to determine their degree of usefulness for irradiated products (14). These tests include trimethylamine, total volatile bases, and volatile acids. The results of these tests were correlated with sensory evaluations and microbiological determinations. Trimethylamine and total volatile base production were found to be retarded by irradiation, and neither test could be considered a good one for the determination of the quality of irradiated fishery products. The formation of volatile acids was a better index of quality, but it appeared to leave considerable room for a test that will better measure the quality of irradiated fishery products.

Efforts were also made to use total volatile acids, total volatile bases, and volatile reducing substances as indices of quality of irradiated yellow perch fillets. Total volatile bases and volatile reducing substances were without value in that they did not indicate significant change in content until the occurrence of spoilage. Total volatile acids correlated reasonably well with the results of sensory tests (12).

Packaging Materials

Most investigations have been carried out with the product sealed in tin cans. This is not a suitable container for the sale of fresh fish, so several flexible films have been examined to determine if they have properties adequate for the protection of the product before, during, and after irradiation. In films of relatively high oxygen transmission rates, irradiated fish fillets and clam meats spoiled in a shorter time than did the same products packed in hermetically sealed cans. However, when films of low oxygen transmission rates were used as packaging materials the storage life of the products was comparable with that obtained with the use of the can. Investigation showed that the reduction in storage life was due to the passage of oxygen from the atmosphere to the interior of the container. Oxygen is necessary for growth of most of the bacteria that survive the radiation process. In the presence of adequate supplies of oxygen, the rate of reproduction of bacteria thus is more rapid than it is in an environment deficient in oxygen.

Thiaminase Sensitivity to Radiation

Thiaminase is an enzyme present in the flesh of certain species. It uses thiamine as a substrate and, in so doing, destroys thiamine in the fish that is used as an animal feed. Cooking at a sufficiently high temperature will destroy the enzyme. However, high temperatures alter the texture of the fish enough to reduce their acceptability to the animals to which they are fed and may also lower the nutritive value of the fish. Experiments were carried out, therefore, with thiaminase-containing alewives, carp, and shad to determine if irradiation could destroy the enzyme without altering the acceptability of the product. At 33F., 4 million rads reduced the activity of the enzyme by about 50 percent in some samples. When irradiation at the same level was carried out at room temperature, greater reductions were obtained (4). No conclusions can yet be drawn regarding the effectiveness of gamma radiation in destroying thiaminase in raw fish destined for animal feed, and there are no data presently available concerning the effect of relatively high levels of radiation on the acceptability of irradiated fish by the animals to which they are fed.

Marine Products Development Irradiator and Commercialization

Laboratory investigations on the irradiation of fishery products are continuing, but the results obtained to date show clearly that the preservation of fishery products by ionizing radiation has great commercial promise. In anticipation of approval by Food and Drug Administration, the Atomic Energy Commission has constructed on the site of the Bureau of Commercial Fisheries Technological Laboratory at Gloucester, Massachusetts, a Marine Products Development Irradiator (MPDI) that makes possible a scaling-up from laboratory studies to semi-industrial studies. Details of the MPDI have been described elsewhere (6), (13).

The installation is capable of irradiating 2,000 pounds of fish per hour at 250,000 rads. The capacity of the installation will enable us to carry out studies on (1) the effect of commercial handling methods on the quality of irradiated fishery products, (2) large-scale consumer evaluation of these products, and (3) the economics of the irradiation process.

We are presently investigating methods of handling fresh fish in interstate commerce, since these methods may have a direct bearing on the quality of irradiated fishery products on arrival at their destination. This study includes determination of the principal users of fresh seafoods, commonly used methods of packaging, and monitoring of product temperatures at which fresh fish are held during distribution throughout the entire commercial channel, including store display cases where fresh fish are ordinarily held for retail sale. This information, when complete, will give us the total temperature history of fresh fish from seaport to the retail consumer's grocery cart. Although we are determining current practices in the handling of fresh fish, we are alert to the possible presence of deficiencies that exist and are prepared to make recommendations wherever necessary to improve the quality of fresh fishery products.

We are convinced that the industry will have products of high desirability to sell, but we do not yet know precisely where the markets are nor the degree to which the consumer prefers new species of fresh-like fish to those already available in a form preserved by conventional means. We plan to determine, as accurately as possible, whether the market for irradiated fishery products is primarily retail or institutional. Prior to that, we plan to determine the retail consumer's reaction to the idea of eating irradiated fish and of serving it to her family. We will establish the existence of regional preferences for different species of fish by conducting large-scale consumer tests with the cooperation of institutional dining halls, chain stores, and civic and religious organizations where occasional mass feeding is carried out.

Irradiation at Sea

Bacteria exposed to ionizing radiation die at a logarithmic rate, and plots of the logarithm of the number of survivors against radiation dose can be defined mathematically in much the same way as thermal resistance curves. It follows then that the fewer the numbers of bacteria exposed to the same dose, the fewer will be the number of survivors. Hopefully, regrowth of survivors would take longer, and dose levels now used to increase shelf life 2 or 3 times could either be reduced considerably, thereby improving the efficiency with which the source is used and improving the quality of landed products (15).

The Atomic Energy Commission has had completed for them the construction of two irradiators suitable for installation aboard vessels and to be used for irradiation at sea. These irradiators are now being subjected to tests in the Northwest Atlantic and in the Gulf of Mexico before being released for use. We hope that by irradiation at sea we will be able to (1) land fish of extremely high quality for immediate use in local fresh markets after landing or for pre-irradiation and shipment to more distant markets, or (2) permit vessels to stay at sea longer and thereby improve the economics of their operation by permitting them to come in with more nearly full loads.

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