

# IRRADIATION AS A COLD PASTEURIZATION PROCESS OF FISH AND SEAFOOD

Paisan Loaharanu\*

Food Preservation Section, Joint FAO/IAEA Division of Nuclear Techniques in  
Food and Agriculture, Vienna, Austria

## INTRODUCTION

There is clearly a significant increase in awareness of the risks from food-borne diseases among consumers in western countries in the past decade. The concern about the quality and safety of food appears to be driven by increased affluence, new scientific discoveries, by more sophisticated measurements and analyses, by new information about linkages between diet and health, by new food technologies and by mass communication (Kinsey, 1993). No doubt, growing demand for higher quality and safer food leads, also, to higher demand for effective government regulations of food quality and safety.

The recent outbreaks of *Escherichia coli* 0157:H7 which claimed several children's lives and hospitalized hundreds of adults and children in the USA is a good case in point. The initial outbreak in the west coast of the USA in early 1993 attracted wide media attention as it not only caused fatalities in children but involved consumption of undercooked hamburgers served at a well known restaurant chain. It taught consumers that there are health risks associated with food of animal origin which, if not properly prepared, could lead to hazards or even death. It also provides confirmation that raw foods of animal origin often harbor pathogenic bacteria which are dangerous for consumption if the food is not properly processed or prepared. Because of the serious outbreaks of this bacterial infection policy makers and legislators are calling for

a tighter control of national food protection programs by introducing public statements and legislative bills (Anonymous, 1994; Lee, 1994). In the USA, warning labels of the risks of pathogenic bacteria in or on food have been mandated on some foods of animal origin.

Fish and seafood, although not widely implicated in incidences of food-borne diseases, are not without problems. *Vibrio parahaemolyticus*, a natural microflora of seawater and a common contaminant of fresh fish and shellfish, was responsible for 27 outbreaks in the USA from 1973 to 1991, 22 of which were attributed to contaminated shellfish (Potter, 1994; Personal communication). A survey conducted in shellfish growing areas in 9 states in the USA in mid-1980s showed that mean density of *V. parahaemolyticus* was 100 times greater in oysters than in water (DePaola *et al*, 1990). In the past few years, oysters and clams, often consumed raw, from US States neighboring the Gulf of Mexico were responsible for deaths of dozens of consumers, most of whom were immuno-compromised. The culprit of the fatality was *Vibrio vulnificus* which is part of the natural microflora of seawater in the ocean, especially during summer months. This species of bacteria cannot be cleaned up by routine depuration. The negative impact of media publicity of the incidences attributable to consumption of raw oysters and clams has devastated trade in these delicious and nutritious seafoods in the USA, especially in the Gulf States. Large retail buyers entirely stopped purchasing oysters in 1988; demand and resultant production of oysters dropped 41% nationwide; and per head consumption of domestic eastern oysters dropped 60% (Kilgen, 1993). The estimated added cost of US\$ 0.05-0.08/lb for large volume commercial irradiation was considered a cost-benefi-

---

\* Paper presented in his personal capacity. Any inquiry may be sent to the author at: Bachacker G. 61, A-2380 Perchtoldsdorf, Austria.

Fax: (43-1) 869-7795

cial value-added processing step to the oyster industry in the USA (Roberts, 1992).

Pre-cooked frozen shrimp can be mishandled and resulted in infection to consumers (Beckers *et al*, 1981). This product, often consumed without further heating, represents a high risk if contaminated by pathogens during processing. In the Netherlands, shrimp cocktails served to elderly people in a pension home during Christmas of 1983, claimed 14 lives because of shigellosis. The pre-cooked frozen shrimp used for the preparation of shrimp cocktail, purported to originate from an Asian country, were found to be contaminated with a drug resistant strain of *Shigella flexneri* (Mossel and Stegeman, 1985). The shrimp authorities ordered a ban on importation of all Asian shrimp for 3 months following the incident. It was later discovered that the shrimp were caught in the North Sea, cooked on-board, frozen, exported to an Asian country for hand peeling, refrozen and imported back to the Netherlands. *Shigella* contamination was believed to occur during the hand-peeling process.

#### IRRADIATION AS A COLD PASTEURIZATION PROCESS

While thermal pasteurization of liquid foods such as milk and fruit juices is a well established and satisfactory means of terminal decontamination/disinfection of such commodities, this process is not suitable for solid foods such as meat, poultry, seafood and dry ingredients such as spices. Irradiation is instead a more efficient method, both from technological and economic points of view, to "pasteurize" these solid foods to avoid changes in the physico-chemical and sensory quality of the product. Irradiation acts through changes induced in the DNA structure of the microbial cells, which results in prevention of replication or function. The energy level used for food irradiation to achieve any technological purpose is normally extremely small. At the maximum energy level or dose of irradiation recommended by the Codex Alimentarius Commission (which sets worldwide standards for food trade) for treating food, *ie* 10 kGy, this energy level is equivalent to the heat energy needed to increase the temperature of water by only 2.4°C (calculated on the basis that 10 kGy of ionizing energy is equivalent to a heat energy of 10 J/kg and the heat capacity of water is

4.2 J/kg; 10 J/kg 4.2 J/kg = 2.4°C). The dose of irradiation to ensure hygienic quality of fresh or frozen seafood is in the range of 1-5 kGy depending on the product and its state. Thus, the increase in heat energy in such products is in the range of 0.24 - 1.2°C. Irradiated food, therefore, remains at essentially the original natural state after the treatment.

Being a cold process with penetrating power, irradiation is unique in its ability to "pasteurize" fresh and frozen food products including seafood without changing product quality. Irradiation therefore provides a new "critical control point" for eliminating pathogenic bacteria in these food.

#### EFFECTIVENESS OF IRRADIATION AS A COLD PASTEURIZATION PROCESS OF FISH AND SEAFOOD

Irradiation is an effective method to ensure hygienic quality of food of animal origin including fish and seafood. Its use, however, should not be a substitute for good manufacturing practices (GMP) required for such products.

##### A. Irradiation of raw fish and seafood

Raw fish and seafood can be contaminated with certain non-spore forming bacteria such as enteropathogenic *E. coli*, *Salmonella*, *Shigella*, *Vibrio parahaemolyticus*, *V. vulnificus*, *V. cholerae*, fecal streptococci, *Staphylococcus aureus* and viruses if caught from polluted waters or through post-harvest handling. Viruses are generally resistant to radiation at the dose levels required for pasteurization or shelf-life extension. Other means of disinfection of viruses such as depuration would have to be considered in addition to irradiation. Non-spore forming pathogenic bacteria are, however, relatively radiation sensitive. *Vibrio* spp, in particular, is sensitive to radiation with D-value in various seafood ranged from 0.03 to 0.16 kGy depending on salt concentration and serotype (Loaharanu, 1973; Grodner and Andrews, 1991; Kilgen, 1993). Quinn *et al* (1967) estimated radiation resistance of various pathogens or non-pathogenic members of genera containing pathogenic species in different seafood as follows:

Bacteria	D-value (kGy)
<i>E. coli</i>	0.15 - 0.35
<i>Proteus vulgaris</i>	0.10 - 0.20
<i>Shigella</i>	0.25 - 0.40
<i>Salmonella</i> (7 serotypes)	0.50 - 1.0
<i>Streptococcus faecalis</i>	0.75 - 1.0
<i>Staphylococcus aureus</i>	0.80 - 1.90

The storage temperature of seafood following irradiation is of critical importance not only from the shelf-life point of view but also because of the risk from botulinum toxin. *Clostridium botulinum*, strain A-G, are spore-forming bacteria which are resistant to low dose irradiation. Types E and F are of particular concern as they occur in marine environments and could grow and produce toxin at refrigeration temperature. Similar to food sub-sterilized by other means, eg. thermal pasteurization, modified atmosphere packaging, prevention of botulinum toxin in irradiated fresh seafood can be achieved by a storage temperature of 3°C or below.

Of more recent interest is the possible use of irradiation to disinfect *Vibrio* spp in live oysters and clams which are often consumed raw. This species of bacteria cannot be depurated from these live mollusks and could pose health problems to consumers, especially those immuno-compromised. *Vibrio* spp are natural inhabitant of seawater especially in warm areas and can contaminate live fish and shellfish. Live mollusk bacteria are, however, relatively resistant to low dose irradiation. A dose of 1 kGy appears to be sufficient to inactivate *Vibrio* spp in the live mollusks. This dose level has little affect on mortality of the shellfish during the first 10 days of storage (Mallet *et al*, 1987; Kilgen, 1995). Irradiation therefore appears to be the only known method for pasteurizing live mollusks of *Vibrio* spp without significantly affecting their mortality.

Another possible application of irradiation is the use to control parasitic infection, especially by trematodes, from consuming raw fresh water fish. Fresh fish of cyprinoid family is highly infected by metacercariae of *Opisthorchis viverrini* and other trematodes. A dose of 1 kGy is sufficient to render these parasites in fish flesh non-infective without causing significant change

in sensory quality of the raw fish. Control of parasitic infection from raw fish consumption by irradiation treatment may not be practical from logistic point of view, however.

## B. Irradiation of frozen fish and seafood

The primary reason for irradiating frozen fish and seafood is to ensure its hygienic quality from pathogenic microorganisms such as *Vibrio* spp which naturally contaminate the product, and Enterobacteriaceae which may contaminate product during handling and processing. With regard to the former species of bacteria, good manufacturing practices including HACCP employed pre-during and post-freezing can only reduce but not eliminate the contamination. GMP and HACCP are important tools to avoid contamination of the latter group of bacteria, however. Human handling of products such as peeled and de-veined shrimp prior to freezing can increase the risk of contamination by *Salmonella* and related group of bacteria as well as *Staphylococcus* spp.

Frog-legs are often processed and traded by the seafood industry. Live frogs are naturally contaminated by *Salmonella* and related bacteria. GMP employed during butchering and processing including chlorination do not eliminate this group of pathogenic bacteria from frog-legs. Frozen frog-legs are, therefore, often contaminated with *Salmonella* and cannot gain access to markets in countries which have strict hygienic standards.

Irradiation is unique in inactivating non-spore forming pathogenic bacteria in frozen food without changing physico-chemical and sensory characteristics of the product. The dose levels of radiation required to "pasteurize" frozen food including seafood are slightly higher than that for comparable fresh products because of low water activity of the former. A minimum dose of 3 kGy is normally required for pasteurizing frozen seafood and frog-legs to ensure hygienic quality from *Salmonella* and related bacteria. Thus, irradiation appears to provide a realistic step under HACCP to prevent pathogenic microorganisms from reaching the consumer.

## Irradiation of ready-to-eat fish and seafood

In addition to contamination by *Salmonella* and related microorganisms because of human handling as

mentioned above, a number of ready-to-eat foods including seafood have been found to be contaminated by *Listeria monocytogenes*. The US Food and Drug Administration and the USDA introduced zero tolerance for *L. monocytogenes* in ready-to-eat foods in 1989 (Tompkin *et al*, 1992). Ready-to-eat foods such as cheeses, sausages, pate', cooked meat and cole slaw have been implicated in human listeriosis (Tompkin *et al*, 1992; McLaughlin, 1991). *L. monocytogenes* is ubiquitous in nature and can resist heat, nitrite, salt, and acidity better than many other pathogenic microorganisms. It can multiply slowly at temperature as low as 1°C. Some strains of *L. monocytogenes* have developed resistance to antibiotics such as tetracycline, erythromycin, co-trimoxazole, and clindamycin (Barbuti *et al*, 1992).

Although data are limited, surveys suggested that cooked fish and other seafood may also be contaminated with *L. monocytogenes*. About 4-8% of cooked crabmeat and 3-4% of shrimp samples may yield the organism on analysis. One study on frozen, butterfly shrimp using a genetic probe suggested that 200 organisms per g may be present (WHO, 1988).

*L. monocytogenes* has a relatively high sensitivity to irradiation. Its D-values have been reported to range from 0.27 to 1.0 kGy depending on strains, growing media, and irradiation conditions (Patterson, 1989; Huhtanen *et al*, 1989). In most cases, however, the D-values are similar to those reported for *Salmonella* spp irradiated under similar conditions. Thus, *L. monocytogenes* in ready-to-eat seafood may be controlled by the same dose required for *Salmonella* and related pathogenic bacteria.

#### ECONOMICS OF IRRADIATION OF FISH AND SEAFOOD

Economics of food irradiation facilities is best characterized as capital intensive but low operating cost. It requires an economy of scale to justify investment in an irradiation facility *ie* large quantities of food must be treated to achieve reasonable average unit costs. Factors which are important to determine the cost of operation of irradiation facility and consequent treatment cost include type of radiation, efficiency of radiation source, minimum throughput capacity, dose absorbed, number of hours the facility is operated

over a given time period, types of product and their packaging configuration, etc (Urbain, 1993).

A number of cost estimates on irradiation of fish and seafood have been made using a number of assumptions. These estimates together with actual cost charged by a commercial irradiation facility in France are listed below:

Product	Absorbed dose (kGy)	Treatment cost/kg (US\$)
Frozen shrimp	2	0.08 - 0.10 <sup>1</sup>
Frozen froglegs	4	0.10 - 0.12 <sup>1</sup>
Fish fillet	1.75	0.06 - 0.15 <sup>2</sup>
Live oysters	1	0.10 - 0.15 <sup>3</sup>

Source: <sup>1</sup>Henon Y, Gammaster-Province, France. (Personal communication), <sup>2</sup>Morrison (1985); <sup>3</sup>Roberts (1992)

#### COMMERCIAL APPLICATION OF FOOD IRRADIATION

The number of countries which use irradiation for processing food for commercial purpose has increased steadily from 19 in 1987 to 28 at present. The majority of the increase in recent years is in developing countries which either need irradiated food for their domestic market or see an opportunity to develop market overseas. Spices and vegetable seasonings are the most common products which have been irradiated in some 20 countries. After the European Union issued a Directive which prohibits the use of ethylene oxide in food and food ingredients in January 1991, the use of irradiation to ensure hygienic quality of spices and vegetable seasonings has increased significantly, to about 40,000 tonnes in 1994.

The most significant event which created an awareness of food irradiation among the governments, food industry, and the media was the opening of the first commercial food irradiator in the USA, at Mulberry. Irradiated strawberries outsold non-irradiated ones by a margin of 10 to 1 to 20 to 1 depending on the time of sale. Apparently, the consumers were attracted by the premium quality of

"natural field ripe" irradiated berries as compared to half-to-three-quarter ripe non-irradiated ones normally available. This retail store also reported significant saving by reducing spoilage losses from about 10% for non-irradiated strawberries to about 2% for irradiated ones. This reduction not only provided them with additional profit but enabled them to compete with larger retailers by offering better quality products at the same price charged by other store for lower quality products (Corrigan, 1993). The successful sale of irradiated produce has led to the sale of irradiated chicken at the retail level in the USA starting late 1993 which was also successful.

Increasing number of countries has approved the use of irradiation for extending shelf-life/ensuring hygienic quality of fish and seafood as well as frog-legs (Anonymous, 1995). Currently, no country

is using this technology for shelf-life extension or ensuring hygienic quality of raw fish and seafood. There is little potential in using irradiation as long as regulatory authorities do not recognize health risks from consumption of these products which are naturally contaminated by *Vibrio* spp which can cause illness and even death.

Irradiation is used commercially, however, to ensure hygienic quality of frozen seafood and frog-legs in Belgium, France and the Netherlands. Because of strict microbiological standards in France, frozen frog-legs and cooked, peeled and deveined shrimp are routinely irradiated for this purpose. The quantities of frozen seafood and frog-legs irradiated commercially in these three countries are relatively small, *ie* a few thousand metric tonnes per annum.

Table 1

Optimum radiation dose levels and shelf-life at 0.6°C (33°F) for fish and shellfish aerobically packed in hermetically sealed cans.

Seafood	Optimum dose (kGy)	Shelf-life (weeks)
Oysters (shucked)	2.0	3-4
Shrimp	1.5	4
Smoked chubs	1.0	6
Yellow perch fillets	3.0	4
Petrale sole fillets	2.0	2-3
Pacific halibut steaks	2.0	2
King crab meat (cooked)	2.0	4-6
Dungeness crab meat (cooked)	2.0	3-6
English sole fillets	2.0-3.0	4-5
Soft-shell clam meats	4.5	4
Haddock fillets	1.5-2.5	3-4
Pollock fillets	1.5	4
Cod fillets	1.5	4-5
Ocean perch fillets	1.5-2.5	4
Mackerel fillets	2.5	4-5
Lobster meat (cooked)	1.5	

Source: Quinn *et al* (1967)

### CONCLUSIONS

Irradiation is increasingly recognized as a cold pasteurization process of food of animal origin including fish and seafood. Its role to enhance microbiological safety of fish and seafood is expanding in view of the increase incidence of infection caused by patho-

genic bacteria and parasites. With the Agreement on the Application of the Sanitary and Phytosanitary Measures, adopted during the GATT Uruguay Round and now in force, irradiation could facilitate wider trade in fish and seafood and to ensure safety from various foodborne diseases commonly associated with these products.

## REFERENCES

- Anonymous. National Performance Review calls for single food agency. *News-O-Gram. Am Assoc Food Hyg Vet* 1994; 18.
- Anonymous. Clearance of irradiated food by countries. *Food Irrad Newsl* 1995; 22 (suppl) : 2.
- Barbuti S, Maggi A, Casoli C. Antibiotic resistance in strains of *Listeria* spp. from meat products. *Lett Appl Microbiol* 1992; 15: 56-8.
- Beckers HJ, Van Schothorst M, Van Spreekens KJA, Oosterhuis JJ. Microbiological quality of frozen precooked and peeled shrimp from Southeast Asia and from the North Sea. *Zbl Bakt Hyg, I Abt Orig B* 1981; 172: 401-10.
- Corrigan JP. Experience in selling irradiated food at the retail level. In: "Cost-Benefit Aspects of Food Irradiation Processing", STI/PUB/905. Vienna: International Atomic Energy Agency, 1993.
- DePaola A, Hopkins LH, Peeler JT, Wentz B, McPhearson RM. Incidence of *V. parahaemolyticus* in US coastal waters and oysters. *Appl Environ Microbiol* 1990; 56.
- Grodner RM, Andrews LN. Irradiation. In: Word DR, Hackney CR, eds. *Microbiology of Marine Food Products*. New York: Van Nostrand Reinhold, 1991; 429-40.
- Huhtanen CN, Jenkins RK, Thayer DW. Gamma radiation sensitivity of *Listeria monocytogenes*. *J Food Protect* 1989; 52: 610-3.
- Kilgen M. Economic benefit of irradiation of molluscan shellfish in Louisiana. In: *Cost-Benefit Aspects of food Irradiation Processing*, IAEA, Vienna, 1993.
- Kilgen MB, Hernard MT. Evaluation of commercial irradiation and other processing methods for *Vibrio vulnificus* control in Louisiana oysters. Paper presented at the Seafood Science and Technology Society of the America, Humacao, Puerto Rico, 5-9 November 1995.
- Kinsey J. GATT and the economics of food safety. *Food Policy*. April 1993.
- Lee P. From the Assistant Secretary for Health, US Public Health Service. *J Am Med Assoc* 1994; 272.
- Loaharanu P. Gamma irradiation of fishery products in Thailand with special reference to their microbiological and entomological aspects. In "Aspects of the Introduction of Food Irradiation in Developing countries", STI/PUB/362. Vienna: International Atomic Energy Agency, 1973.
- Mallet JC, Beghian LE, Metcalf T. Potential of irradiation technology for improved shellfish sanitation. In: Otwell WS, Rodrick GE, Martin RE, eds. "Molluscan Shell-fish Depuration". Boca Raton: CRC Press, 1987: 247-58.
- Marcotte M. Irradiated strawberries enter the US market. *Food Technol* 1992; 46: 5, 80-6.
- McLaughlin J. The epidemiology of listeriosis in Britain. Presented at Intl Conf on *Listeria* and Food Safety, Laval, France, June 13-14, 1991.
- Morrison R. Economics of scale in single-purpose food irradiators. In "Food Irradiation Processing", STI/PUB/695. Vienna: International Atomic Energy Agency, 1985.
- Mossel DAA, Stegeman H. Irradiation: an effective mode of processing food for safety. In "Food Irradiation Processing", STI/PUB/695. Vienna: International Atomic Energy Agency, 1985.
- Patterson M. Sensitivity of *L. monocytogenes* to irradiation on poultry meat and in phosphate-buffered saline. *Lett Appl Microbiol* 1989; 8: 181-4.
- Pszczola, D. Irradiated produce reaches Midwest market. *Food Technol* 1992; 46: 5. 89-92.
- Quinn DJ, Anderson AW, Dyer JF. The inactivation of infection and intoxication microorganism by irradiation in seafoods. In: "Microbiological Problems in Food Preservation by Irradiation", STI/PUB/168. Vienna: International Atomic Energy Agency, 1967.
- Roberts K. Louisiana State University Co-operative Extension Service, presentation to the International Conference on Seafood Irradiation, New Orleans, Louisiana, June 1992.
- Slavin JW, Nickerson JTR, Ronsivalli LJ, Goldblith SA, Licciardello JJ. The quality and wholesomeness of radiation pasteurized marine products with particular reference to fish fillets. *Food Irradiat* 1966; 3: 365-81.
- Tompkin RB, Christiansen LN, Shaparis AB, Baker RL, Schroeder JM. Control on *Listeria monocytogenes* in processed meats. *Food Aust* 1992; 44: 370-6.
- Urban WM. Economic aspects of food irradiation. In "Cost-Benefit Aspects of Food Irradiation Processing", STI/PUB/905. Vienna: International Atomic Energy Agency, 1993.
- WHO. Food-borne listeriosis - Report of WHO Working Group *Bull WHO* 1988; 66 : 421-8.