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IRRADIATION PRESERVATION OF SHRIMPS AND RESULTS OF A COMMUNITY ACTION

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IRRADIATION PRESERVATION OF SHRIMPS AND RESULTS OF A COMMUNITY ACTION

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With supplement: Synthesis of present status of fish irradiation research
and perspectives for EEC actions

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Contents.

SUPPLEMENT

Synthesis of the present status of fish irradiation research and perspectives for EEC actions

Introduction.

In 1972 a report "Economic and Technological Study of the Irradiation of Shrimps" was published by the Eurisotop Office (34).

The study was intended as a contribution to the technical and economic justification of the irradiation of brown shrimps (Crangon vulgaris Fabr.).

Also in 1972, the Eurisotop Office organized a symposium on "Radiation Preservation of Shrimps" and in the conclusions, the need for further technological and economic research, partly on national, partly on EEC level, was stressed (35).

This further research carried out in the EEC-member countries has led to the present report which updates the first publication and gives the results of the national and EEC sponsored programmes.

The study consists of four chapters.

The first chapter considers the effect of irradiation in relation to the extension of shelf-life. The second chapter deals with the aspect wholesomeness of irradiated shrimps. The third chapter describes the specific irradiation technology of shrimps and in the fourth chapter the economic aspects of the irradiation of shrimps are studied extensively.

Finally, general conclusions are given.

Chapter I - Extension of shelf-life of shrimps by irradiation.

In the previous report (34) the high perishability of shrimps, the advantages and disadvantages of chemical preservation, deep-freezing, lyophilization and heat treatment were described.

Due to a high content of extractable nitrogen compounds, an active proteolytic enzyme system (which is not always fully destroyed in the boiling process) and a relatively large body surface, shrimps constitute a favourable substrate for micro-organisms and therefore become a highly perishable product with a shelf-life of only a few days. For longer storage periods, the use of an antiseptic (usually benzoic acid or its salts) is necessary although it alters the delicate flavour of the brown shrimps and its effectiveness is limited.

Changes also occur, although to a lesser extent, while freezing or freeze-drying, the latter method being furthermore rather expensive.

Another preservation possibility is the use of ionizing irradiation. Many studies in the past decade have shown that seafood is one of the most promising food groups for this preservation method. Hence, experiments were carried out in Belgium, the Netherlands and Germany (F.R.)(*) in order to evaluate the feasibility of radurization for prolonging the shelf-life of brown shrimps. The Eurisotop Office coordinated this research and the progress of work was reported and discussed during six meetings of the "Technical committee for the radurization of crustaceans" held from 1972 to 1975 in Brussels.

(*) France conducted experiments on pink shrimps (<u>Leander serratus</u>) which are not dealt with in this report.

The results of Belgian and Dutch experiments are reported here (*). Both peeled and unpeeled shrimps were studied in both countries but it should be emphasized that unsalted shrimps (ca 1 % salt) were used in the Netherlands and salted shrimps (ca 3 % salt) in Belgium.

§ 1. Belgian experiments.

The influence of peeling, time between catch and irradiation, applied dose, oxygen permeability of the packaging and storage temperature were tested during four series of experiments. All shrimps were caught by a commercial beam trawler off the Belgian coast and cooked for 6 to 10 min. (average : 7 min.) in brine. They were carefully cooled for about 8 min. and kept in polyethylene kits without further refrigeration until the arrival in the harbour, about 6 hours after the catch.

Irradiation was carried out in a Co-60 gamma irradiator at the Mol Nuclear Centre.

For unpeeled shrimps a dose-rate of about 400 krad/h (overdose ratio 1.3) and for peeled shrimps 300 krad/h (overdose ratio 1.1) was applied.

A. Experiments with unpeeled shrimps (70).

Two sets of tests were conducted, the shrimps being radurized with doses of 0.05 - 0.5 Mrad, 40 and 16 hours respectively after catch. The shrimps were packed per 1 kg in paper bags and wrapped in PVC stretch-film. They were kept at 0° C. The quality of the crustaceans was assessed on the basis of organoleptic (5 points-scale), bacteriological and chemical tests.

(*) German results, with the exception of microbiological data (50) were not yet available when this report was written (October 1975).

1. Irradiation experiments after 40 hours' delay.

Organoleptic judgment (fig. 1) showed that irradiation had a marked effect on the shelf-life of the shrimps. With doses of 0.3 and 0.5 Mrad however, an acidic off-flavour ("irradiation flavour") was noticed, which was judged to be unacceptable ; results of these too high doses were not reported on fig. 1.

Sensory scores of the 0.1 and 0.2 Mrad experiments respectively were very similar. In the experiments, an organoleptic score of 3 ("moderate") was set as quality limit. This value was reached after 24 (± 2) days in the irradiated samples and after 9 (± 1) days in the others. It was further noted that in one experiment a slight irradiation odour and -taste appeared after 11 days of storage. This will be discussed further.

Colour of the irradiated shrimps remained unchanged. This was confirmed by chemical analyses carried out at the Laboratory of Food Preservation (University of Louvain) where it has been shown that the carotenoid pigments of the brown shrimp are remarkably stable towards irradiation (63) giving similar results as with other crustacea and contrasting in this respect with the pigments of other fishery products such as salmon (12).

The results of total volatile bases (TVN), total volatile acids (TVA), volatile reducing substances (VRS) and ammonia determinations (fig. 1) carried out until the 24th day, corresponding with a sensory score of 3, confirmed the organoleptic judgments. There was no marked difference between the 0.1 and 0.2 Mrad doses, except to some extent with the VRS test. Individual determinations (not quoted) however varied more with this test than with others.

Non-irradiated samples showed similar steep spoilage curves, contrasting with the curves of the radiopasteurized shrimps.

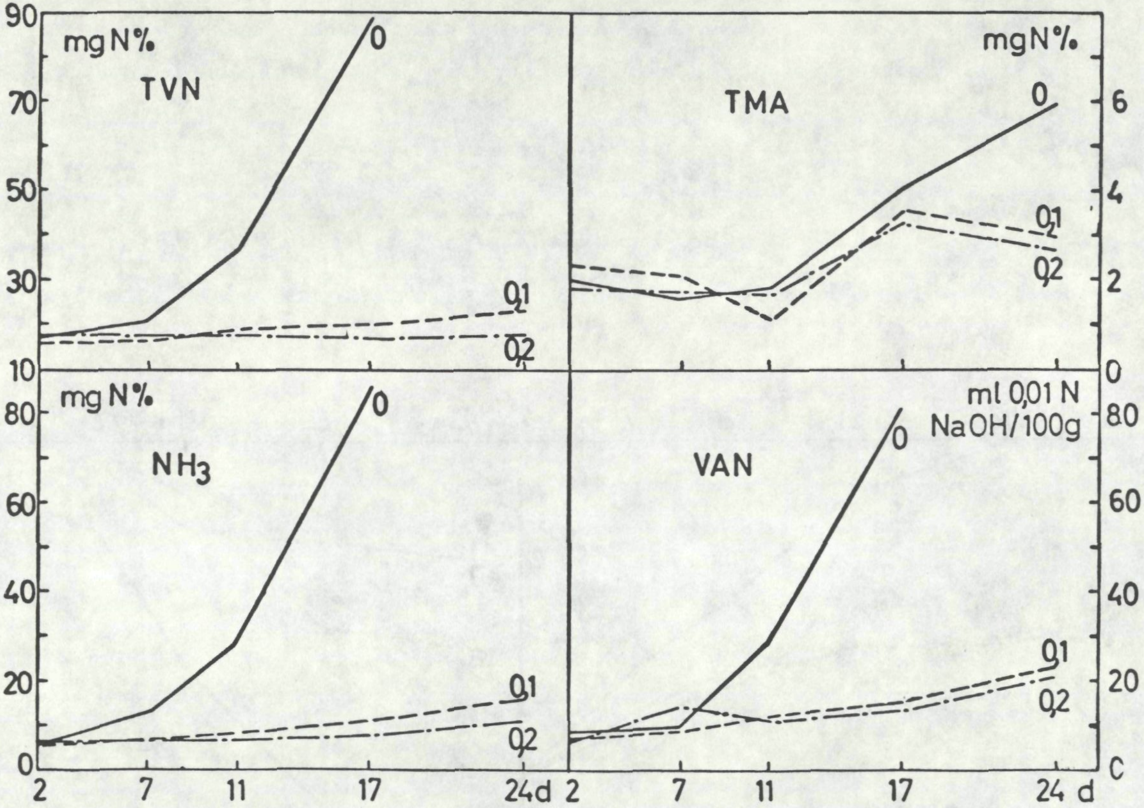


Fig. 1 - Chemical and organoleptic analyses (unpeeled shrimps - 1st experiment).

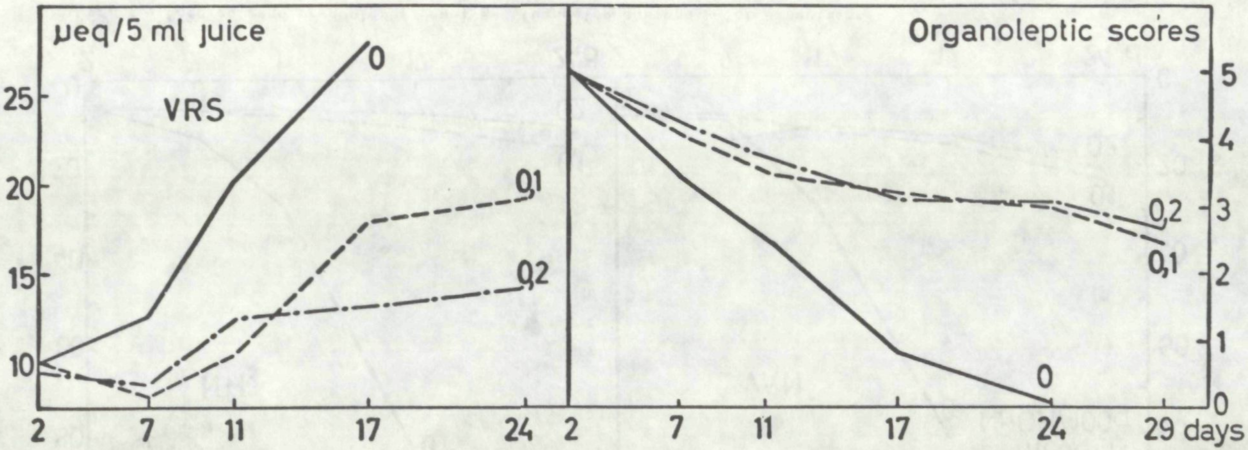


Fig. 1 - (Continued).

Neither the trimethylamine (TMA) values of the untreated samples nor those of the irradiated samples correlated with the organoleptic judgment and remained at an unexpectedly low level, especially in the definitely spoiled shrimps. This confirms previous observations that the TMA determination is a rather poor objective quality test for cooked shrimps (69).

For the reason mentioned above, data of the 0.3 and 0.5 Mrad experiments were not reported in the graphs but they were very similar with the results of the 0.3 Mrad samples.

2. Irradiation experiments after 16 hours' delay.

Organoleptic judgment confirmed the results of the previous series of tests. Even with 0.05 Mrad a marked improvement in shelf-life was noted, although this was slightly less than with the 0.1 and 0.2 Mrad doses. The organoleptic score of 3 was reached after 24(± 2) days for the samples irradiated with doses of 0.1 and 0.2 Mrad and after 19(± 2) days for the 0.05 Mrad shrimps. The non-irradiated lots reached that value after 10 (± 1) days.

As in the previous series, a slight irradiation odour and taste was noted in one experiment. The reason for this might be sought in some fortuitously modified processing method on board. Ludorff et al. (43), Degkwitz et al. (17), Meyer-Waarden (47), Mann (44) and van Spreekens and de Man (67) stressed the importance of the processing method and especially of the cooking procedure on the quality and shelf-life of the shrimps. It is not always easy on deck at sea to obtain an equal degree of boiling. Evidence was gained that cooking time is at least one important factor for avoiding irradiation flavour. The opportunity was given to irradiate two batches of shrimps which had been cooked for only 3 or 4 min. against 6 to 10 min. in the "normal" procedure. Both lots of shrimps showed the characteristic irradiation taste and smell after a few days' storage. Another possibility is the presence of other marine specimens in the catch which are accidentally cooked together with the shrimps, Roskam (59) reported the influence of a small fish, the spotted goby (Gobius minutus), which covers the shrimps with slime and extruded waste matter from its intestines, on the quality of the crustacean.

The influence of irradiation on the spoilage of shrimps is clearly shown by the results of the different laboratory analyses (fig. 2). Of the chemical methods, TVN, ammonia and DMA correlated best with organoleptic judgment, giving e.g. higher values after a 16 days' storage period for the 0.05 Mrad dose. DMA was found in only very small amounts. It should be emphasized that the formation of this base by irradiation cleavage of trimethylamineoxide in different fishery products but especially in gadoid fish was reported by Amano and Tozawa (2). This was obviously not the cas with Crangon vulgaris indicating that the specific enzyme system involved in the reaction was absent. The necessity of this system was demonstrated by the cited Japanese authors.

Oxido-reduction measurements may give useful information on bacterial activity. From fig. 2 it appears that the redox potential quickly decreased in non-irradiated shrimps to reach a minimum level of ca. 10 mV after 15 days ; it remained practically unchanged in the irradiated samples. When comparing these results with bacteriological data (fig. 3) it appears that the redox potential was mainly determined by the activity of the specific spoilage flora (not further studied in this work) and not by the total microbial flora.

Free amino acids decreased markedly in the untreated shrimps, indicating that the activity of bacterial deaminases was stronger than that of the endo- and exopeptidases. This is in good agreement with the increase of ammonia (fig. 2). Deamination was

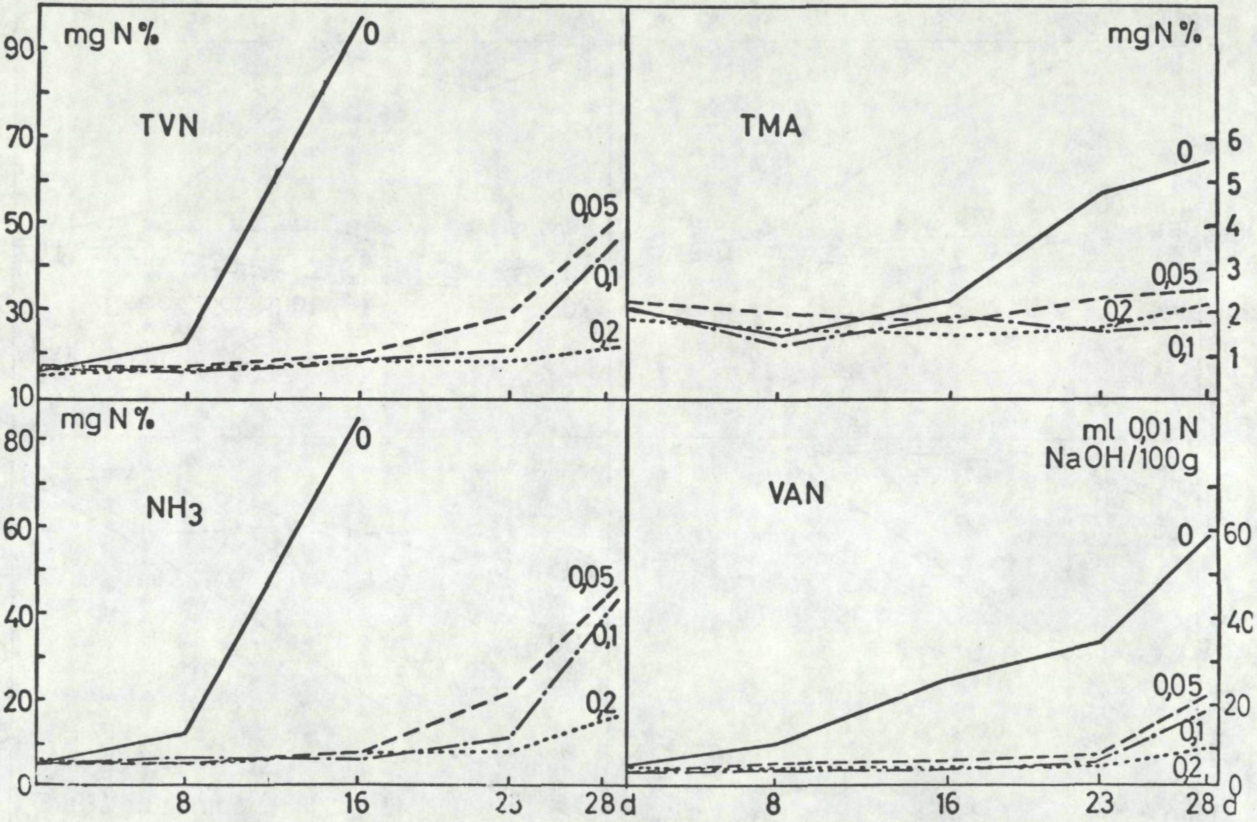


Fig. 2 - Chemical and organoleptic analyses (unpeeled shrimps - 2nd experiment).

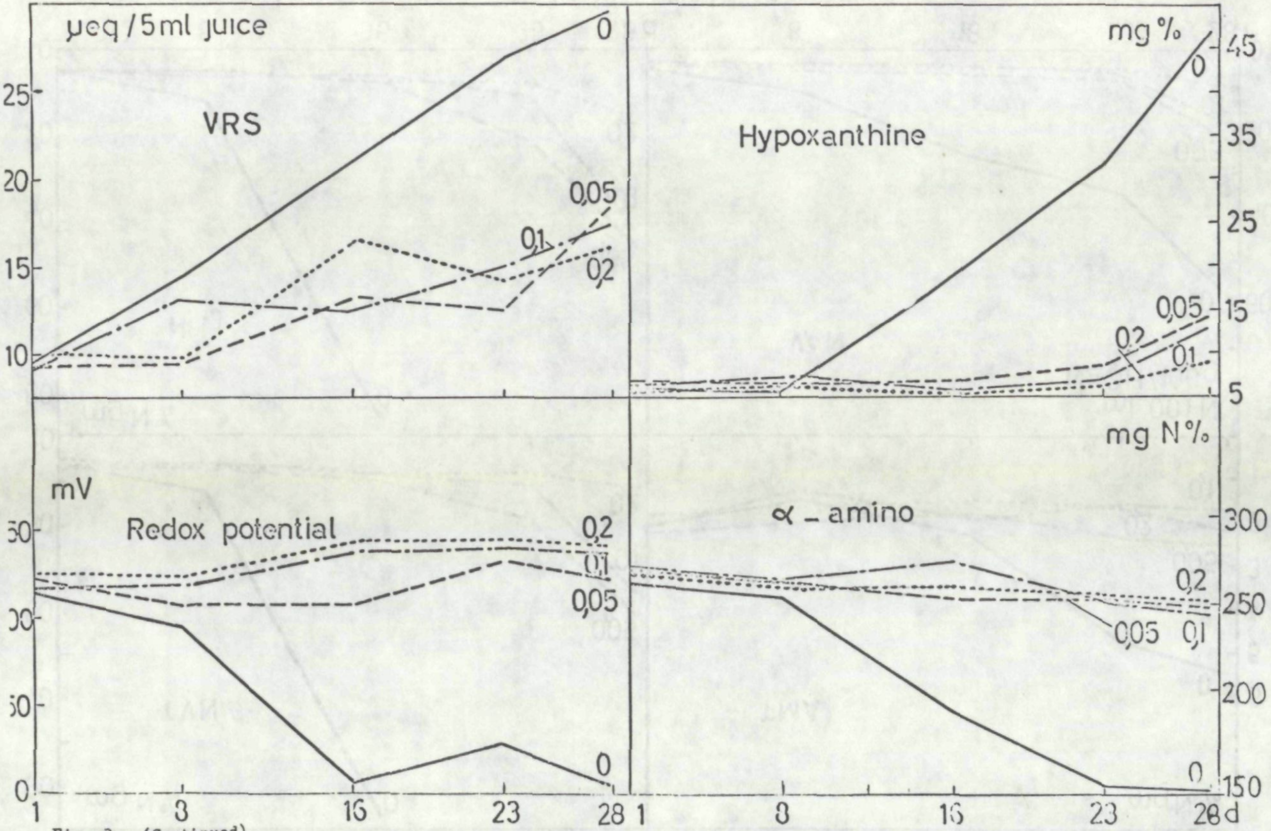


Fig. 2 - (Continued).

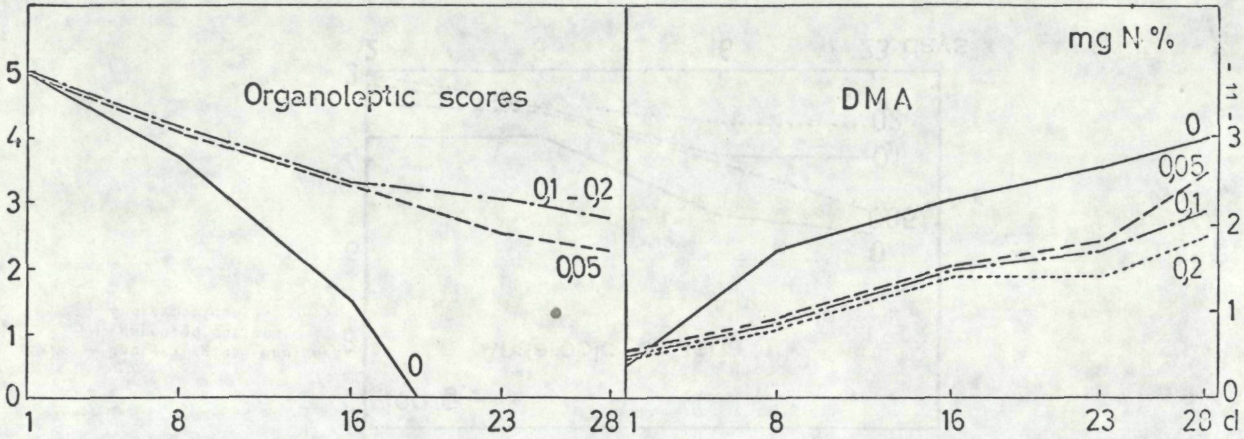


Fig. 2 - (Continued).

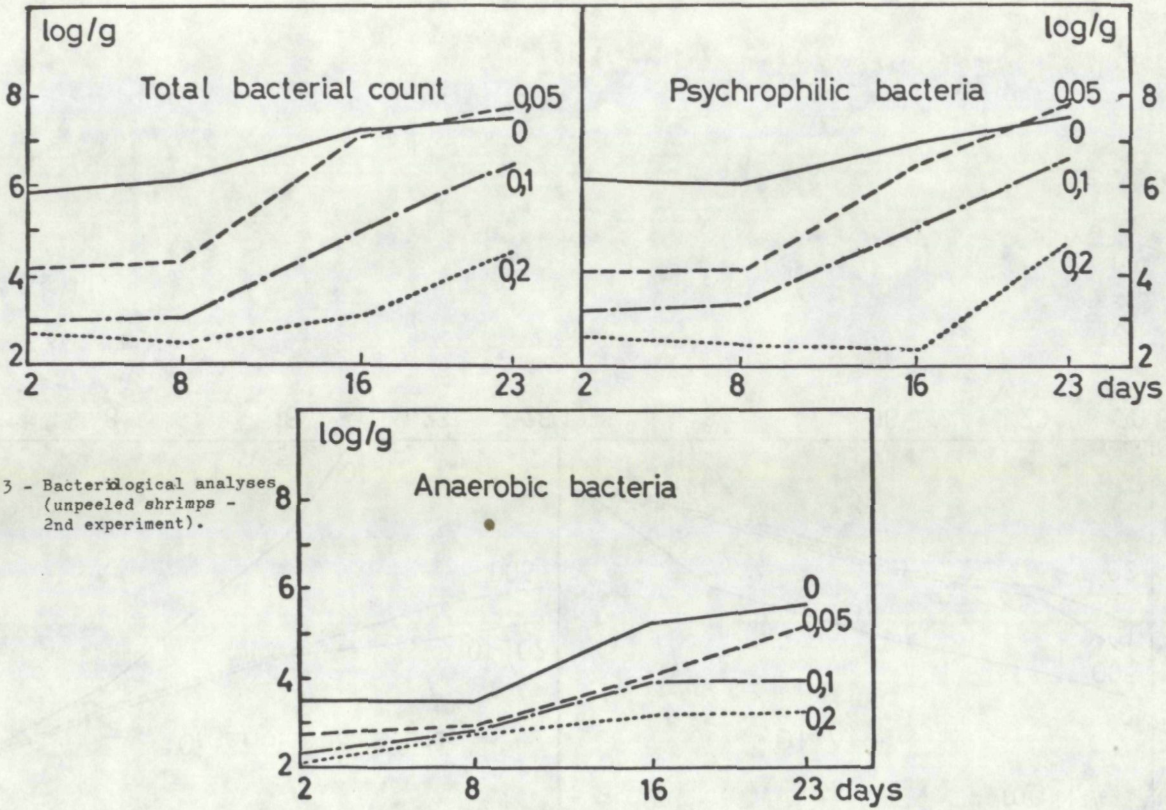


Fig. 3 - Bacteriological analyses (unpeeled shrimps - 2nd experiment).

inhibited by radurization but there was no clear difference between the three applied doses.

As to be expected, radiopasteurization markedly decreased initial bacterial load. The reduction depended on irradiation dosis and ranged from about 10^2 to 10^4. Similar reductions were obtained by other authors on different cooked or parboiled crustacea (25)(40)(41)(48)(56)(64). Psychrophilic bacteria showed practically the same pattern as total bacterial counts, indicating about the whole microbial flora being of a psychrophilic nature. The further increase of bacterial counts during storage correlated neither with organoleptic judgment nor with most chemical analyses. The shrimps treated with 0.05 Mrad doses even achieved higher levels than non-irradiated shrimps at the end of the storage period. This phenomenon was also observed on different fishery products by other workers (41)(42)(45)(49)(62)(64). Slavin et al. (62) suggested that it might be due to the post-irradiation flora being less metabolically active so that greater numbers are needed to produce an aquivalent amount of spoilage. The same authors (41)(42)(45)(49)(62)(64) also emphasized that gamma irradiation radically alters, both qualitatively and quantitatively, the microbial flora of fish and other seafoods. This was once again confirmed by these experiments on Crangon vulgaris.

Anaerobic counts showed a somewhat better agreement with organoleptic and chemical tests but were of few practical value.

When comparing the results of both series of experiments, only a slight difference in keeping quality in favour of the 2nd series was observed between the shrimps irradiated with 0.1 or 0.2 Mrad, as reflected by organoleptic and chemical analyses. The supplementary delay of 24 hrs before gamma irradiation did not seem to influence further shelf-life significantly.

B. Experiments with peeled shrimps (first series)(16).

The shrimps were peeled by laboratory staff. To simulate good commercial practice, normal hygienic precautions were taken but no attempt was made to work in aseptic conditions. The crustaceans were then packed per 100 g in 0.050 mm thick polyethylene pouches and sealed. They were kept at 2 (± 1)° C during transport and storage. They were irradiated the next day about 40 hours after catch. Doses of 0.05, 0.1 and 0.2 Mrad were applied.

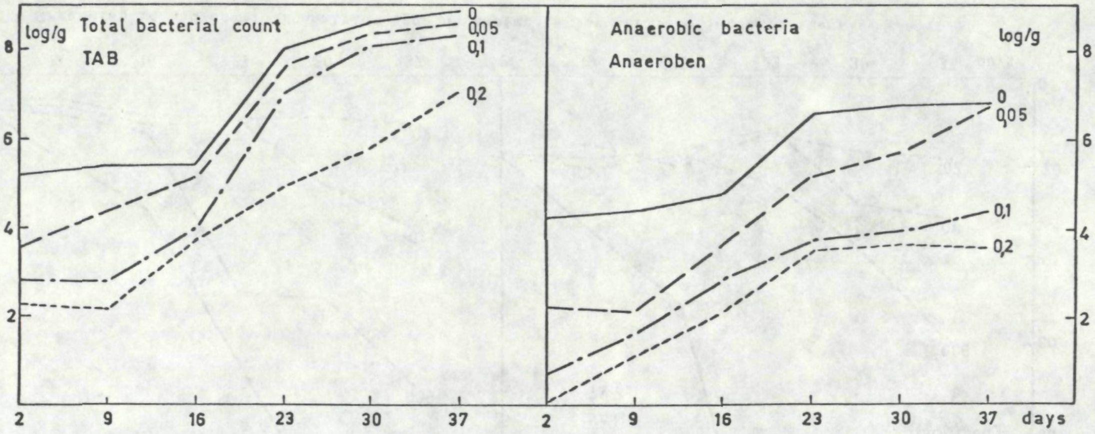
Two experiments were carried out using shrimps with different initial bacterial counts, viz. 163,000 and 56,000 bact/g.

In the first case the storage life (organoleptic limit of 3 points) of non-irradiated peeled shrimps was 16 (± 2) days and in the second case 21 (± 2) days. It is to be noted that in the latter case storage life was longer than that of unpeeled shrimps ; this is in agreement with Dutch results (33)(59).

After radurization with 0.1 Mrad the bacterial count of the first experiment dropped from 163,000 to 1,180 bact/g (fig. 4) and in the second experiment from 56,000 to 121 bact/g shrimp flesh (fig. 6).

These results confirm earlier studies on cooked or blanched shellfish where reductions of 10^2 to 10^3 were found for doses of 0.075 to 0.2 Mrad (25)(56).

In the first case, storage life of irradiated peeled shrimps was 20 (± 2) days for a dose of 0.05 Mrad and 30 (± 2) days or 0.1 and 0.2 Mrad. In the second case shelf-life was 30 (± 2) days for a 0.05 Mrad dose and 35 (± 2) days for 0.1 and 0.2 doses.



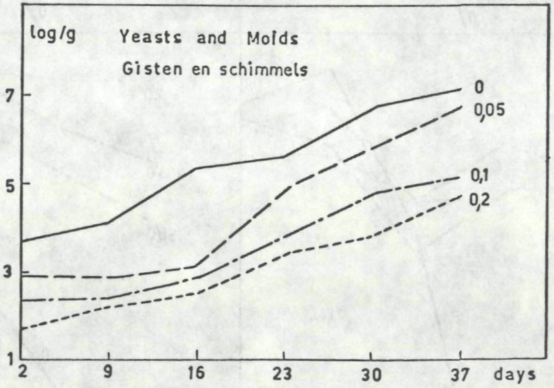


Fig. 4 - Microbiological analyses (peeled shrimps - 1st series - 1st experiment).

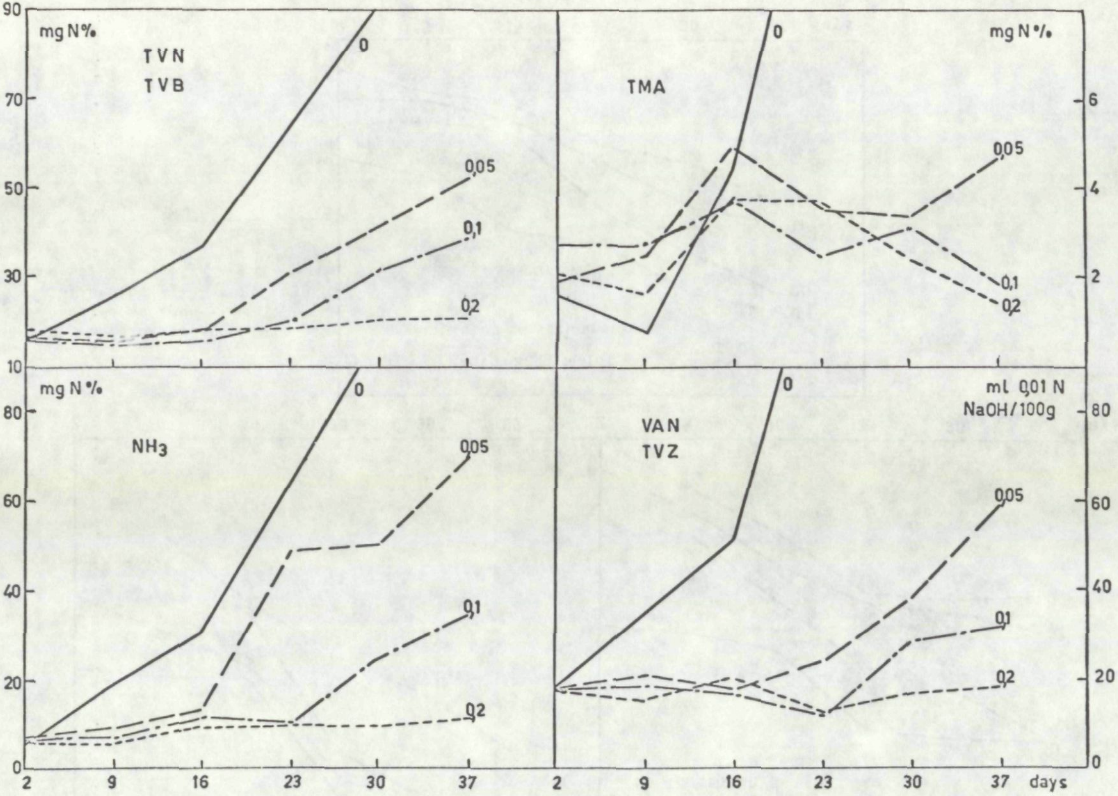


Fig. 5 - Organoleptic and chemical analyses (peeled shrimps - 1st series - 1st experiment).

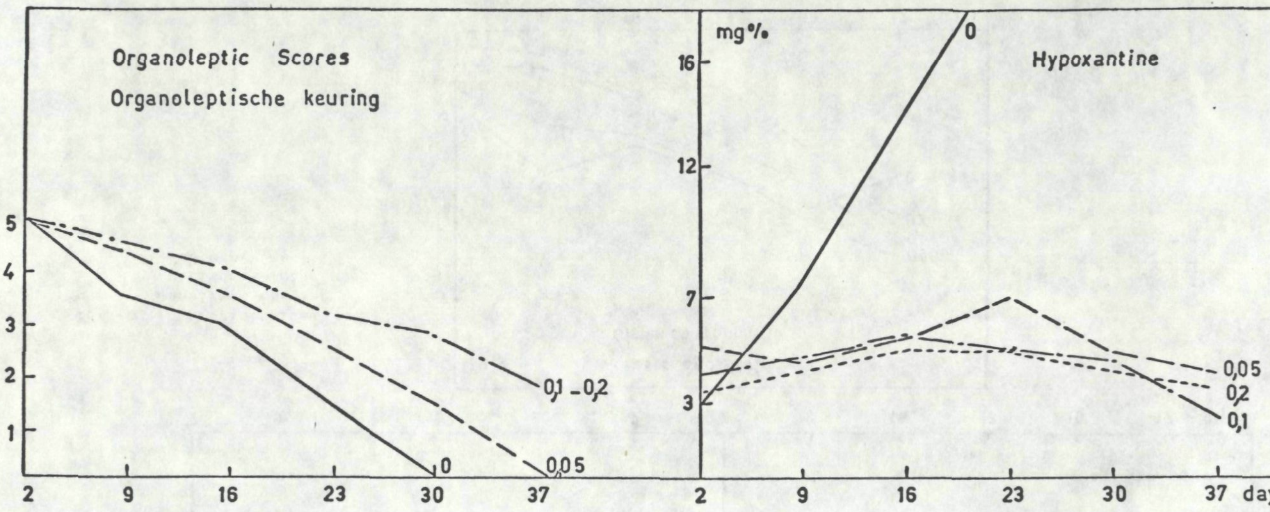
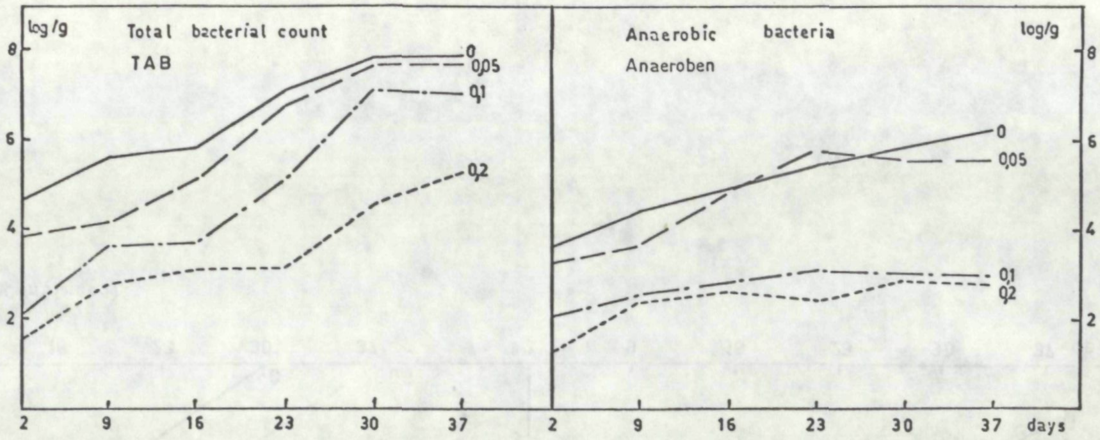


Fig. 5 - (Continued).



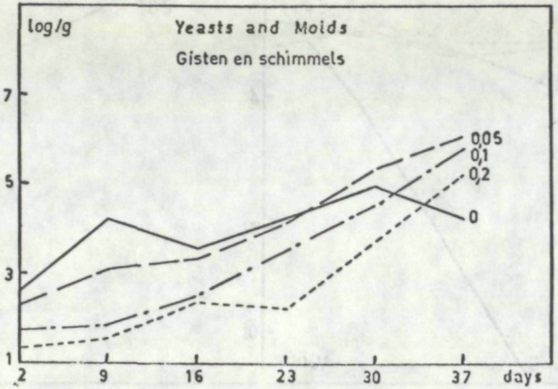


Fig. 6 - Microbiological analyses (peeled shrimps - 1st series - 2nd experiment).

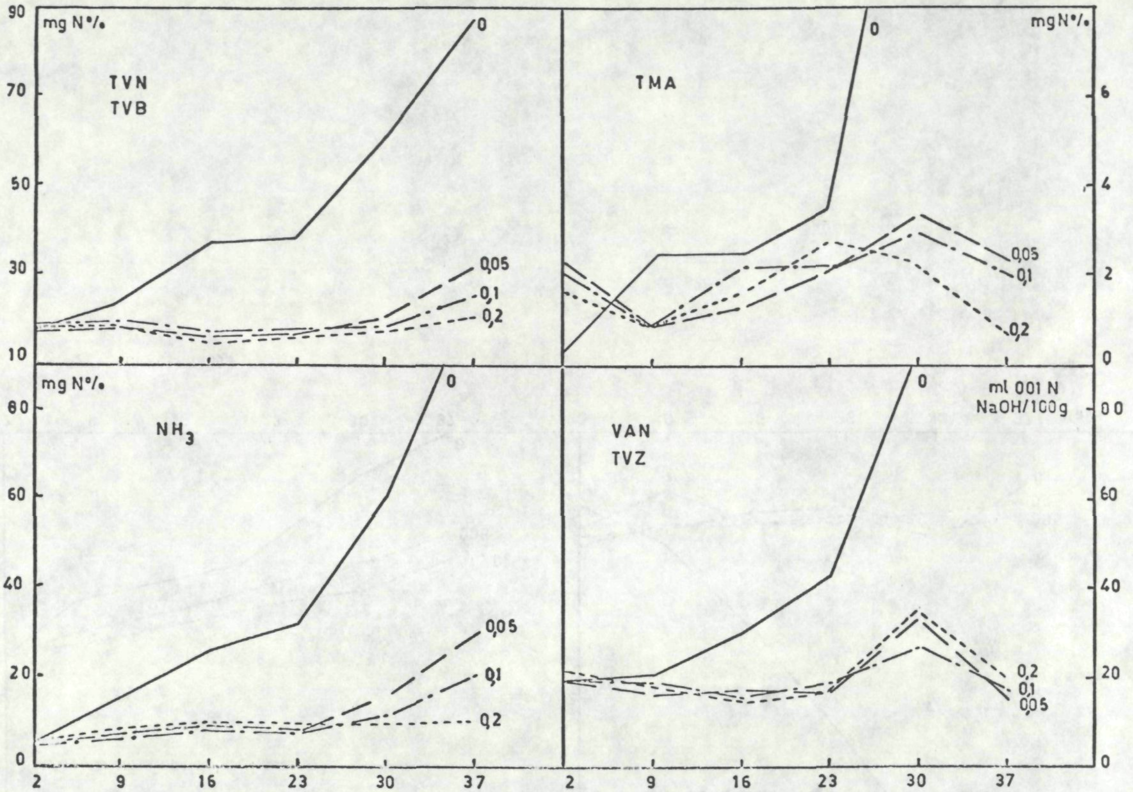


Fig. 7 - Organoleptic and chemical analyses (peeled shrimps - 1st series - 2nd experiment).

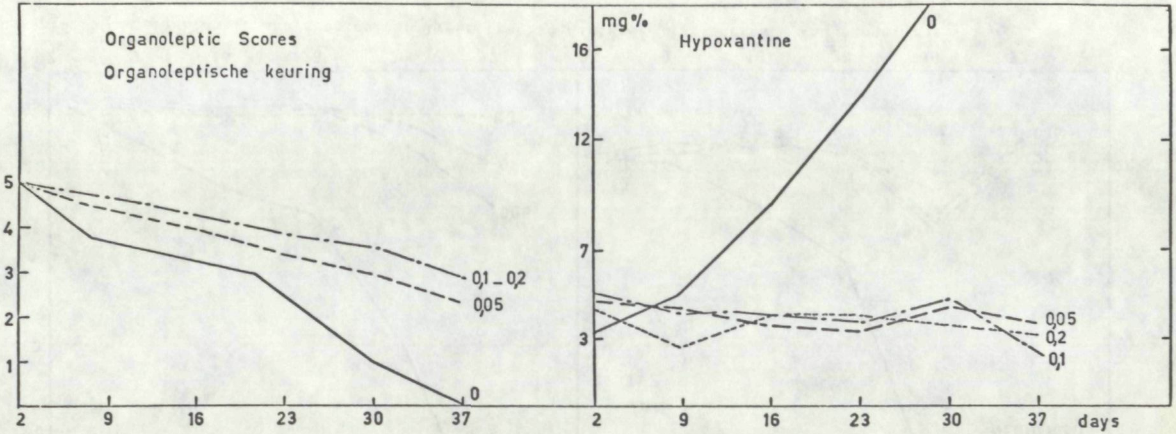


Fig. 7 - (Continued).

Various chemical tests confirmed these results. TVN and ammonia correlated best with organoleptic assessments (fig. 5 and 7). Results from TMA, TVA and hypoxanthine reproduced clearly the irradiation effect.

The total bacterial count showed that the smaller the surviving microflora, the longer spoilage is postponed (fig. 4 and 6).

With an irradiation dose of 0.1 and 0.2 Mrad a more rapid increase of the total bacterial count was noted towards the end of storage life (fig. 4 and 6). However, this was not true in the case of facultative anaerobic bacteria whose growth was clearly inhibited.

Furthermore, bacteriological tests showed that secondary contamination due to peeling had been significant. Since the bacteriological load of peeled shrimps is inferior to the load of unpeeled shrimps, it is the number of micro-organisms in the shell which, in turn, contaminates the shrimp flesh.

When testing yeasts and moulds during the second experiment (with a better bacteriological quality) it appeared that the counts in non-irradiated shrimps were lower after 3 weeks than in irradiated ones. This seems to show that with irradiated packed shrimps yeast are more irradiation-resistant than bacteria, and by a strong reduction of the latter are better able to develop. The same phenomenon was observed for crabs (19).

C. Experiments with peeled shrimps (second series)(71).

In these experiments, the influence of the oxygen permeability of the pouches was tested. Two flexible polythylene films commonly used in the food industry were utilized, viz. 0.050 and 0.100 mm thick films.

The oxygen permeability was 1500 and 500 ml/m^2/24 hrs/atm. for the 0.050 and 0.100 mm films respectively. The pouches were practically sterile.

The shrimps were kept at 2 (± 1° C) during transport and storage. They were irradiated at 100 krad about 40 hours after catch.

Besides organoleptic and chemical determinations, more attention was paid to microbiological determination during this second series of experiment.

The average results of the chemical and organoleptical determinations are given in fig. 8.

As in the previous experiments, sensory assessment showed radurization to have a marked effect on the shelf-life of the shrimps. There was however no difference between the two package types. A score of 3 (lowest acceptable quality grade) was reached after 23 (± 2) days. No discolouration, off flavours or odours were noticed.

With the non-irradiated samples on the other hand, shelf-life was much shorter and depended on the oxygen permeability of the pouch. The score of 3 was obtained after 9 (± 2) and 16 (± 2) days for the 0.050 and 0.100 mm films respectively. These results are in agreement with Murray and Shewan (51), Huss (36) and Hansen (27) who showed shelf-life of different fish species to be dependent upon the percentage of oxygen in the package and the oxygen permeability of the film. Lowering the oxygen content results in a longer storage life.

The results of the total volatile bases (TVN), ammonia, dimethylamine (DMA) and to a lesser extent hypoxanthine and total volatile acids (TVA) determinations confirmed the organoleptic judgment. The difference between the two unirradiated batches was

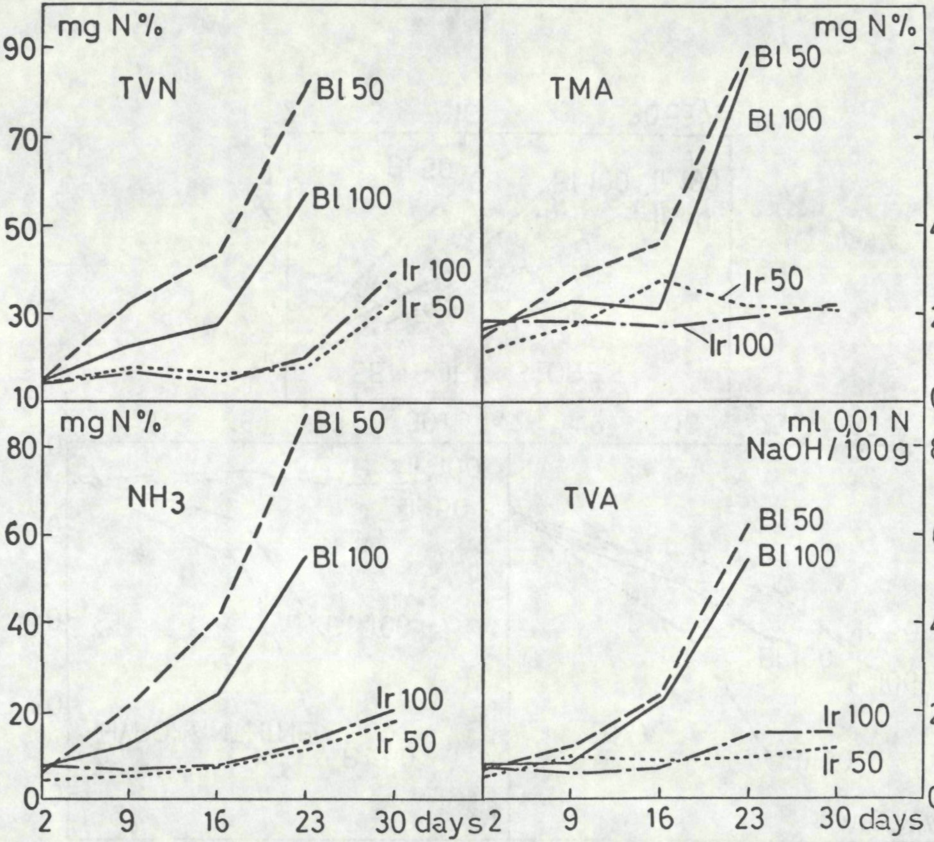


Fig. 8 - Organoleptic and chemical analyses (2nd series).

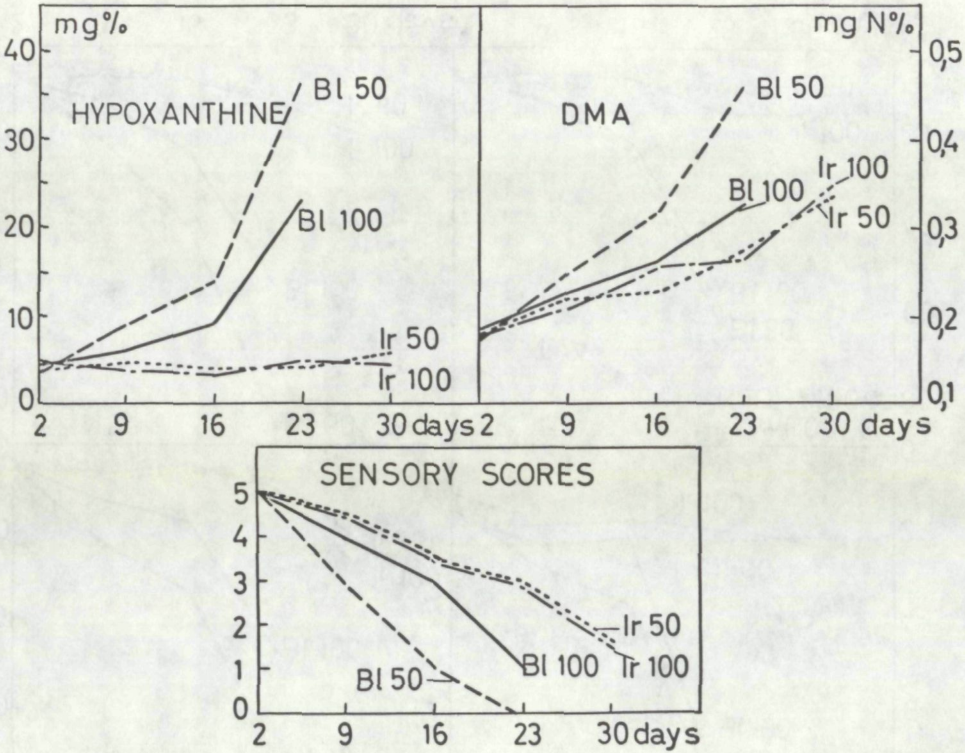


Fig. 8 - (Continued).

obvious. It could also be concluded that TVN consisted for the greater part of ammonia, a fact also observed in Dutch experiments (33)(53). Trimethylamine values remained at a low level, even in the spoiled sample and individual determinations (not quoted) showed important differences. Furthermore, there was no significant TMA-formation in irradiated shrimps. This was also found in the previous experiments ; Kamat and Kumta reported similar results with tropical shrimps (38).

It should also be noticed that in contrast with the experiments on unpeeled shrimps there was practically no volatile acids and hypoxanthine formation in the irradiated shrimps even in the spoiled state. The reason for this is not clear but should be related to the change of microbial flora after irradiation. The flora producing the necessary enzymes for the formation of these compounds must have been eliminated by irradiation.

TVA, which consist mainly of acetic acid formed during the reduction of trimethylamineoxide to TMA, corresponded fairly well with the latter base in the irradiated samples. A TVA of 10 ml corresponds with 6 mg acetic acid per 100 g of shrimps and theoretically with 2,8 mg TMA-nitrogen. This confirms that no TMA was formed in the radurized samples and furthermore that no significant amounts of other acids were formed as a result of deamination of amino-acids. This was not the case for the non-irradiated shrimps, where the amount of volatile acids was about twice as high as the expected amount of acetic acid, taking the TMA-content into account.

The total bacterial count on non-irradiated shrimps before storage averaged approximately 5×10^4 per gram. Anaerobic bacteria and yeasts and moulds reached 1×10^4 and 1×10^3 per gram respectively. During storage total counts increased regularly in both types of packages. No significant increases of total counts of anaerobic bacteria and yeasts and moulds were observed during storage (fig. 9).

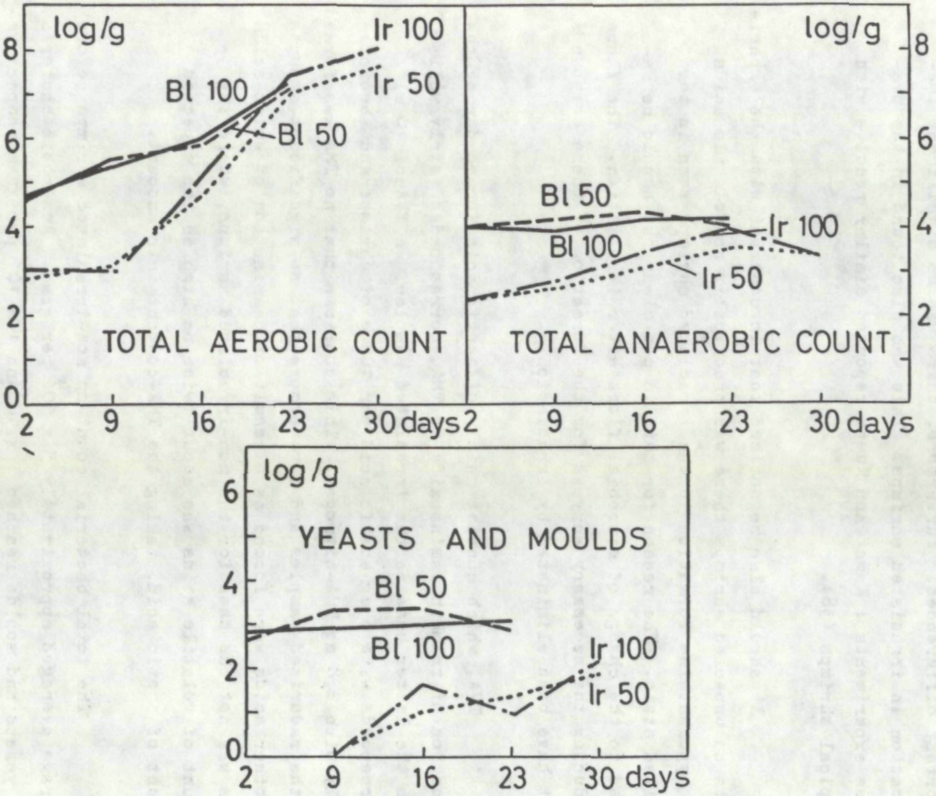


Fig. 9 - Microbiological analyses (2nd series).

Organisms isolated (table 1) in order of decreasing number consisted of Acinetobacter, Gram positive cocci, Pseudomonas, Flavobacterium, Coryneforms and Enterobacteriaceae.

The higher percentage of Pseudomonas in the 0.050 mm pouches should be noticed. As these organisms are known as active spoilage agents (26) this could explain, at least partially, the difference in shelf life between the two types of packages, the greater oxygen permeability enhancing the growth of pseudomonads.

The percentage of Acinetobacter (Achromobacter) was also higher in the 0.050 mm pack but these bacteria are biochemically less active although more radiation resistant (26).

Irradiation at 0.1 Mrad reduced the overall bacterial number by 1.7 log cycle (fig. 9). No yeasts or moulds were counted immediately after irradiation. During storage, yeasts and moulds reappeared and increased regularly but their total number was rather low. At the end of the storage period total bacterial counts were higher in the irradiated shrimps than in the unirradiated shrimps, a fact which was also observed in the previous tests.

Pseudomonas and Flavobacterium which were initially present, were not recovered after irradiation (table 2). The elimination of pseudomonads was also noted in Dutch experiments on shrimps (53), while Masurowsky et al. (45) reported Pseudomonas to be highly susceptible to irradiation and to be greatly reduced in number when haddock fillets were irradiated. Enterobacteriaceae were no longer isolated after the 7th day of storage. Münzner (50) also found a significant reduction of these organisms after irradiation and stressed the public health aspect.

The decreasing number of gram positive cocci in irradiated shrimps should also be emphasized.

Table 1 - Change of microbial flora of non-irradiated peeled shrimps packed in 0.050 and 0.100 mm thick pouches and stored at 2° C.

Micro-organisms	Flora distribution (%)					
	2 days		9 days		16 days	
	0.050	0.100	0.050	0.100	0.050	0.100
Pseudomonas type III and IV	14.6	14.6	12	8.9	17.9	7.2
Acinetobacter	31.2	29.2	57.5	44.5	60.7	50
Enterobacteriaceae	2	2	2.5	2.2	0	0
Flavobacterium	10.4	8.3	5	2.2	0	0
Lactobacillus	0	0	0	0	0	0
Bacillus	0	0	0	0	0	0
Coryneforms	8.3	8.3	10	6.7	7.1	11.9
Gram + cocci	25	29.2	13	22	14.3	21.4
Unclassified	8.5	8.4	0	13.5	0	9.5
No. identified	48	48	40	45	56	42

Table 2 - Change of microbial flora of irradiated peeled shrimps packed in 0.050 and 0.100 mm thick pouches and stored at 2° C.

Micro-organisms	Flora distribution (%)									
	2 days		9 days		16 days		23 days		30 days	
	0.050	0.100	0.050	0.100	0.050	0.100	0.050	0.100	0.050	0.100
Pseudomonas	0	0	0	0	0	0	0	0	0	0
Acinetobacter	67.5	52.5	82.8	81.6	85.5	86	95.5	90.7	100	84
Enterobacteriaceae	2.5	2.5	0	0	0	0	0	0	0	0
Flavobacterium	0	0	0	0	0	0	0	0	0	0
Lactobacillus	0	0	0	0	0	0	0	0	0	0
Bacillus	0	0	0	0	0	0	0	0	0	0
Coryneforms	0	0	0	0	0	0	0	0	0	0
Gram + cocci	22.5	35	17.2	18.4	14.5	14	4.5	9.3	0	6
Unclassified	7.5	10	0	0	0	0	0	0	0	10
No. identified	40	40	35	58	55	50	45	43	48	50

No significant differences in population could be found between the irradiated 0.050 mm and 0.100 mm packages. The Acinetobacter-group was the predominant and constituted nearly the whole flora of irradiated shrimps at the end of storage. The predominance of Acinetobacter after irradiation was noted by Kamat and Kumta (38) in tropical shrimps, by Corbett et al. (13) in dover sole, by Pelroy et al. (55) in petrale sole and by Kazanas (39) in yellow perch. They seem to be responsible for the slow but nevertheless steadily progressing spoilage. For the same reason, no putrid odours normally associated with spoiled fish and shellfish appeared but sweetish odours characteristic of Achromobacter (26).

D. Experiments with peeled shrimps (third series)(72).

The work described in C was continued in a third series of tests by including an air-tight pouch (polyamide-polyethylene laminate XPL) and at the same time studying the influence of storage temperature (0 and 2° C). The pouch of 0.100 mm thickness was also used for the sake of comparison.

The sensory (fig. 10) and chemical tests (fig. 11) showed the shelf-life of the non-irradiated shrimps to be influenced by the oxygen permeability of the packaging material. The difference was 2(± 1) days in favour of the air-tight pouch at 2° C and 4(± 1) days at 0° C. With irradiated samples however no significant differences between the two types of films were noted. These findings confirmed previous results (71).

Lowering the storage temperature by only two degrees had a marked influence on the shelf-life of the shrimps, especially the radurized ones. A score of 3 (minimum acceptable quality) was reached 3-4 days later with non-irradiated samples kept at 0° C and 7 to 14 days later when irradiated.

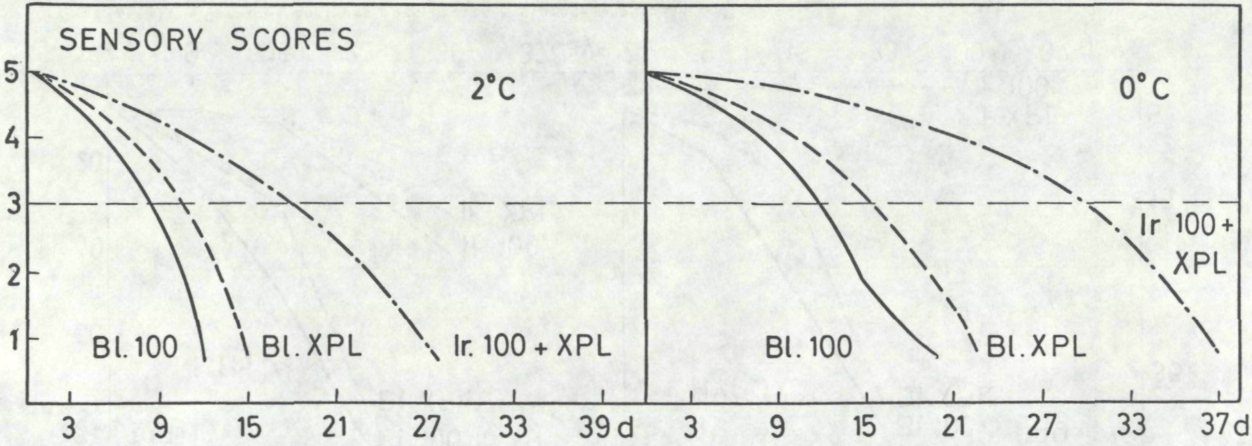


Fig. 10 - Sensory scores (3rd series).

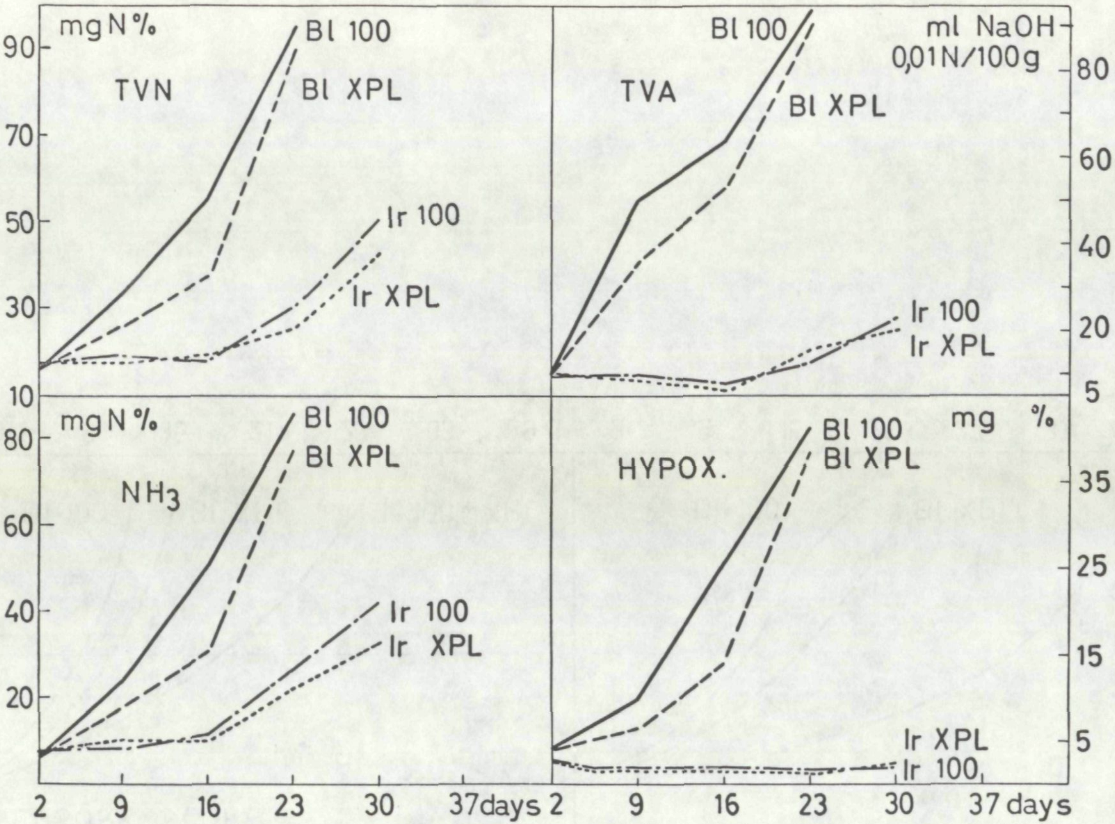


Fig. 11a - Chemical analyses (3rd series - storage temperature 2° C).

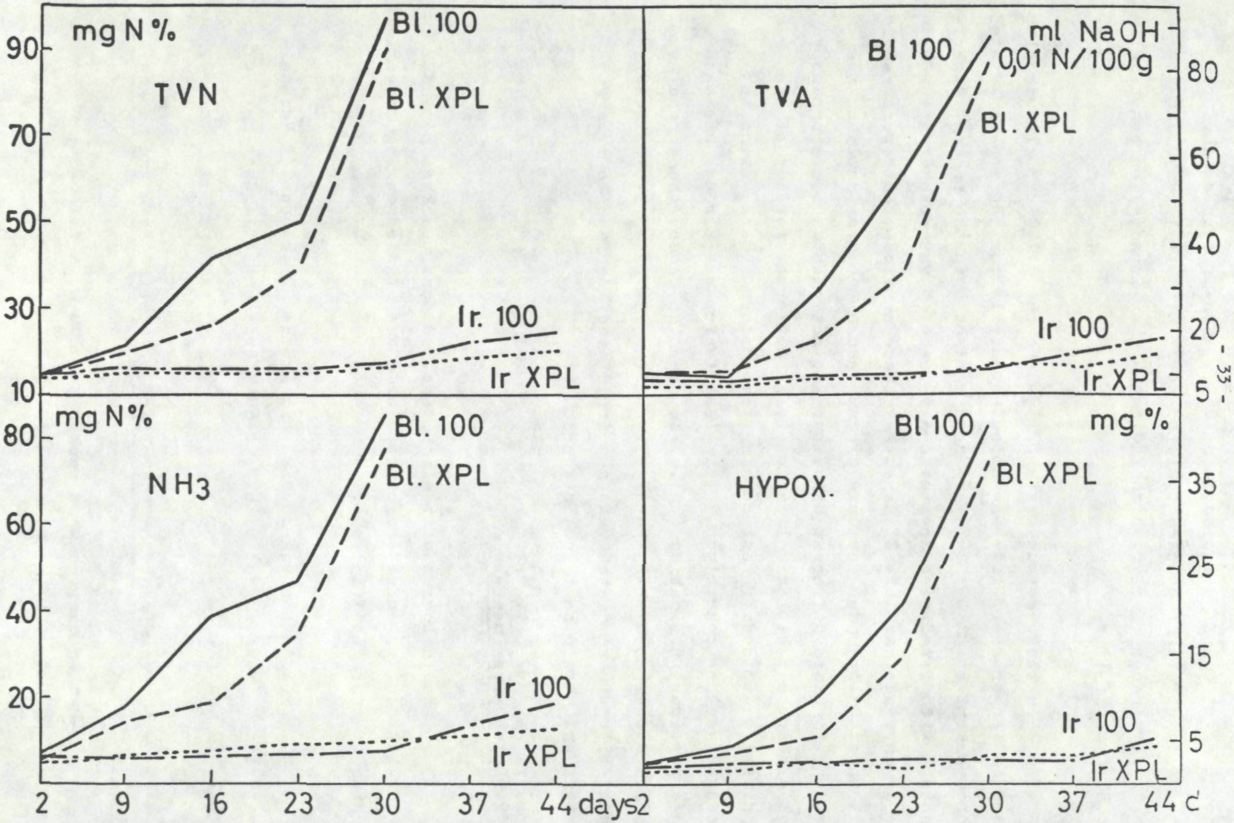


Fig. 11b - Chemical analyses (3rd series - storage temperature 0° C.

Radurized samples had a shelf-life of 18(± 2) days when stored at 2° C and 30(± 3) days at 0° C. Non-irradiated shrimps packed in air-tight pouches could be kept for 10(± 1) days and 15 (± 1) days respectively, which indicates that irradiation practically doubled shelf-life.

In the previous tests (71) where the 0.100 mm film was also used, a longer shelf-life was noted especially for the non-irradiated shrimps kept at 2° C : 16 (± 2) days against 8 in the present experiments. With irradiated specimens a score of 3 was reached after 23 (± 2) days against 18(± 2) days. As these previous tests were carried out practically under the same circumstances one year earlier, the reasons for this different behaviour are not clear. It is probably due either to a biological factor (e.g. different feeding of the shrimps) or to a different cooking temperature at sea, owing to changed weather conditions. This last factor was already stressed in a previous publication (70). Whatever the cause, these results indicate once more that the quality of the raw material influences shelf-life of irradiated (and non-irradiated) shrimps to a large extent and should be taken into account.

§ 2. Dutch experiments.

The influence of peeling, applied dose, packaging, and synergistic effect of added benzoic acid was studied during several series of tests (31)(33)(59).

Irradiation was carried out at the "Proefbedrijf Voedselbestraling" (Wageningen) with a Co-60 source and at a dose-rate of about 120 krad/h.

A. Experiments on the effect of applied dose and packaging.

Peeled shrimps were packed per 200 g as follows :

(a) in polystyrene trays (12 x 16 x 2 cm) and wrapped in polyethylene bags of 50 μm thickness,
(b) in polyethylene bags (Hostaphap, thickness 105 μm).

As with all commercial shrimps, a small amount of benzoic acid was added (0,4 %). They were irradiated at 0, 50 and 100 krad and stored at 4° C.

All samples were tested organoleptically on a 9 points scale (4 being the borderline of acceptability)by a trained taste panel.

Average shelf-life is reported in table 3.

Table 3 - Shelf-life of shrimps packed in polystyrene trays and in vacuum.

Packaging	Irradiation dose (krad)	Shelf-life (days)
Polystyrene tray	0	5.8
Polystyrene tray	50	17.0
Polystyrene tray	100	17.8
Vacuum	0	5.4
Vacuum	50	5.0
Vacuum	100	2.6

Storage life of shrimps was markedly shorter when vacuum packed. The main reason was a very bad texture of the shrimps packed that way. They became very rapidly dry and tough. Vacuum packaging appeared to be not suitable for irradiated shrimps.

Irradiation increased shelf-life of the aerobically packed shrimp about three times, the difference between the 50 and 100 krad doses being very small.

B. Experiments on the effect of peeling and addition of benzoic acid.

As mentioned in the previous report (34), the only way to keep fresh shrimps in actual commercial practice for some time is by adding a preservative such as benzoic acid.

Dutch research workers are of the opinion that even with radurization benzoic acid could probably not be dispensed with fully (32). Indeed, it is almost impossible to irradiate the whole amount of shrimps at moments of peak landings on the same day. Especially on week-ends, adding no preservative could cause difficulties, so that from a technological point of view adding benzoic acid is almost inevitable.

For that reason, the study of the effect of benzoic acid was included in several series of experiments with shrimps from different fishing grounds.

When benzoic acid was used, a mixture of cooking salt and benzoic acid was added (ratio 1:1). In these cases the blanks received the same amount of salt.

Peeled shrimps were packed on polystyrene trays and wrapped in polyethene bags (see A). The unpeeled shrimps were packed in polyethene bags only.

The irradiation dose was 100 krad ± 10 %. The shrimps were stored at 4° C.

The samples were tested organoleptically as described in A.

The following chemical tests were carried out : total volatile bases (TVN), trimethylamine (TMA), ammonia and hypoxanthine (Hx).

1. Results of sensoric analyses.

All data available have been averaged (table 4). The influence of the amount of benzoic acid (HBe) was tested separately (table 5). The shelf-life was expressed in days at ± 4° C.

Table 4 - Influence of peeling and addition of benzoic acid on shelf-life.

Treatment	Peeled	Unpeeled
0 krad	3.1	2.6
0 krad + 0.4 % HBe	9.6	7.2
100 krad	7.4	8.0
100 krad + 0.4 % HBe	17.1	12.3

Non irradiated shrimps were mostly rejected because of the bad odour, whereas with irradiated shrimps the taste determined the score as well most of the time.

Table 5 - Influence of increasing amounts of benzoic acid on shelf-life

Benzoic acid concentration	Shelf-life in days of peeled shrimps	
	0 krad	100 krad
0 % + 0.4 % NaCl	2.9	7.9
0.2 % + 0.4 % NaCl	6.3	10.4
0.4 % + 0.4 % NaCl	8.6	11.0
0.6 % + 0.4 % NaCl	10.0	16.0
0.8 % + 0.4 % NaCl	11.3	15.2
1.0 % + 0.4 % NaCl	14.6	11.3

In most cases the colour was determining the final score. In fewer cases the lowest score was given for odour.

In general, peeled shrimps had a longer shelf-life than unpeeled ones, in spite of an interruption of the cooling chain and a reinfection during the peeling process.

Adding 0.4 % benzoic acid to shrimps approximately tripled shelf-life.

The effect of irradiation at 100 krad was of the same order as adding 0.4 % benzoic acid.

Irradiation of shrimps containing 0.4 % benzoic acid quintupled shelf-life, compared with untreated shrimps.

Benzoic acid (0.4 %) had a synergistic action with irradiation (100 krad) on peeled shrimps.

Using 0.4 % benzoic acid resulted in a considerable extension of the shelf-life of irradiated shrimps. Adding much more is not adviseable mainly because of the bad colour.

2. Results of chemical analyses.

The results have been compiled in table 6 (combination of increase rate and level)

During storage of untreated peeled and unpeeled shrimps TVN, NH_3, TMA and Hx were formed. The increase rate was greater with unpeeled shrimps.

Table 6 - Influence of peeling and addition of benzoic acid on chemical analyses.

Treatment	Peeled				Unpeelded			
	TVN	NH_3	TMA	Hx	TVN	NH_3	TMA	Hx
0 krad	+++	+++	+++	++++	++++	++++	++++	++++
0 krad + 0.4 % HBe	++	++	0	0	+++	+++	+	++
100 krad	++	++	+	++	+++	+++	+	+
100 krad + 0.4 % HBe	+	+	0	0	+	+	0	+

Irradiation of untreated shrimps (without benzoic acid) had a negative influence on the formation of these products, especially on the formation of TMA.

Adding 0.4 % benzoic acid had a negative influence on the formation of these products. Unpeeled shrimps did not form TMA and Hx at all within the shelf-life if benzoic acid was added. They were formed during the storage of peeled shrimps however.

Irradiation of peeled shrimps containing 0.4 % benzoic acid had a negative influence on the formation of these products along the same pattern as with shrimps treated with benzoic acid only. The level however was lower.

Irradiated unpeeled shrimps containing benzoic acid did not form TMA as well.

Benzoic acid had more effect on peeled than on unpeeled non irradiated shrimps. Assuming that the enzymatic activity is nil, because the shrimps had been cooked, the only reason for the formation of Hx could be the activity of bacteria which are able to produce Hx. Another indication for the exactness of this statement is the fact that Hx is hardly formed in case benzoic acid has been added.

3. Results of microbiological analyses.

The most striking results on the day of passing the borderline of acceptability have been listed in table 7.

Table 7 - Influence of peeling and addition of benzoic acid on microbiological analyses.

Treatment	Peeled			Unpeeled		
	Moraxella	Shrimp spoiler	Lactic acid bacteria	Moraxella	Shrimp spoiler	Lactic acid bacteria
0 krad	0	+++	0	0	+++	0
0 krad + 0.4 % HBe	+	++	++	+	++	+
100 krad	++++	0	0	++++	+	+
100 krad + 0.4 % HBe	+++	0	++	+++	0	+

Untreated peeled or unpeeled shrimps did not contain Moraxella or lactic acid bacteria and Coryneforms at the end of the shelf-life but almost only typical shrimpspoilers.

When benzoic was added to non irradiated shrimps, either peeled or unpeeled, less shrimpspoilers were found and more Moraxella, lactic acid bacteria and Coryneforms.

Irradiated shrimps contained almost only Moraxella and sometimes lactic acid bacteria and Coryneforms when benzoic acid was used. In case benzoic acid was absent only Moraxella could be found. In these cases shrimpspoilers were absent.

Chapter II - Wholesomeness of irradiated shrimps.

The wholesomeness of irradiated shrimps is a primary condition before considering the feasibility of commercial applications. In this respect a distinction should be made between the microbiological safety and the general toxicological aspects resulting from animal feeding tests.

Furthermore, as irradiated shrimps may necessitate special control measures (i.e. in connection with low storage temperatures), attention should also be paid to the analytical problem of the detection of irradiation.

§ 1. Microbiological safety.

Due to the specific effects of irradiation on the microbial flora the *Clostridium botulinum* hazard and the presence of other potential pathogens are considered seperately.

A. *Clostridium botulinum*.

Although the presence of *Clostridium botulinum* in brown shrimps has not been reported so far, this problem should not be overlooked, botulism being of concern in relation with many seafoods, especially when caught in coastal waters. Moreover, it should be kept in mind that most brown shrimps are not heated any more before consumption.

In a recent review, Hannesson (26) discusses the possible hazard that is associated with *Cl. botulinum* in radurized fishery products.

Cl. botulinum is a spore-forming bacterium that is the causative agent of the severe type of food poisoning known as botulism. Although this is not a common disease, it is of particular concern because of its high mortality. Botulism is not an infection with Cl. Botulinum, but an intoxication by a potent neurotoxin liberated by certain strains of the organism during its vegetative growth. It must be emphasised that the spores of Cl. botulinum, *which occur widely in nature (evidence for its widespread existence* has been found in soils and sediments in fresh and coastal waters), do not produce toxin. It is only when these spores germinate that a hazard exists ; the toxin formed when germination does occur is extremely potent.

A number of genotypes of Cl. botulinum have been recognized, of which type A, type B, type E and type F cause botulism in humans (types C and D are usually associated with botulism in animals). These different types have differing properties with respect to the conditions under which they grow and produce toxin, and their toxins vary somewhat in their properties, particularly in their relative stability if heated, although thorough cooking is sufficient to inactivate the toxin.

Because the habits of Cl. botulinum are such that germination of the spores occurs only under rather specific conditions, and because the toxin is rather easily destroyed by heating, botulism is fortunately a rather rare phenomenon ; the circumstances under which foods are distributed and consumed tend to preclude hazard. Contamination of fresh food is unimportant because the organism is present in the spore form. In preserved foods, the organism will only grow in the absence of oxygen, and it will not germinate or grow under highly acidic conditions (pH 4.0 or below). If the salt content is 8 percent or higher (i.e., in many cured products) the spores will not germinate. Furthermore, most types of Cl. botulinum are unable to grow and produce toxin at refrigeration temperatures.

It is in connection with this latter fact that Cl. botulinum, type E is of concern in relation to radurization of fishery products because it has been reported that type E can grow and produce toxin at a temperature as low as 3.3° C (20). Temperature control during distribution and retailing of fishery products and in the domestic refrigerator, is not usually good enough to preclude all possibilities that seafood could conceivably reach this temperature before it is consumed. Type E is particularly associated with fish and other marine products and several outbreaks of botulism have been associated with the consumption of smoked or inadequately cooked fish in North America, Japan and Scandinavia.

In fish and other seafoods, type E is most often encountered although A, B and F may be also present (60). Type E has a widespread geographic distribution in fish (and sea environment generally) in Western Europe, Russia, North America and Japan (4)(14)(37)(58)(60)(73). Vast environmental differences have been found. In the Baltic, fish and sea muds are universally contaminated (37). In the North Sea (in areas around Britain) Cl. botulinum type B (non-proteolytic) was found in 15 out of 429 samples of bottom deposits from 143 locations (11) ; types E and F have been found in one or two instances, although high incidence of Cl. botulinum type E was found in herring from Norwegian fishing grounds landed in the United Kingdom. The number of spores was estimated to be about one spore per 16 g. of fish or less (10). Goldblith and Nickerson (23) report a value of 17 spores per 100 g of fish in commercially produced haddock fillets in the United States. In a survey carried out by the Torry Research Station on 600 samples of packaged fish (mainly sold frozen) Cl. botulinum was detected in five samples (10).

It has been clearly established that pasteurizing doses of irradiation will not eliminate spores of Cl. botulinum type E if present. The question arises then if radurization makes the botulinum hazard greater or less. To answer these questions a considerable amount of work has been carried out especially in the United Kingdom and in the United States. These investigations were aimed at studying a variety of factors such as species of fish, time and temperature of storage with various levels of Cl. botulinum contamination or without, and the irradiation dose itself.

Work in the United Kingdom has dealt with factors affecting toxin production in herring, kippers, haddock, smoked haddock, scallops, cod and plaice and recently of pre-packed fishery products. These studies have established a relationship between toxin production, inoculum level and storage temperature. There was considerable variation in the rate of toxin production in different species and even variation with different fish of the same species. Thus, Cann et al. (9) indicated that, for cod and plaice, toxin production is quicker in the irradiated product, but, in herring, toxin production appeared at the same time in the irradiated and non-irradiated products. However, once toxin production started it proceeded at a higher rate and to a higher level in the irradiated herring for a given number of spores ; in cod, no differences were found.

Whatsoever,toxin production is markedly influenced by the initial number of spores present, particularly, when the level is below 10^3/g, and these differences are accentuated at storage temperatures below 10° C (8)(28)(29)(61). Also the time for toxin production with an inoculum of 1 spore per g is noticeably greater than with 10 spores per g (28). It should be pointed out that toxin was regularly found to be produced in irradiated haddock (0.3 Mrad) level as low as 1 spore per g (28).

The main conclusion to be drawn regarding the hazard of type E, B and F botulism are that provided the storage temperature of seafoods radurized up to 0.3 Mrad can be maintained at or below 3-4° C until it is consumed, there appears to be little danger of formation of toxin before the fish reaches an advanced state of spoilage.

B. Other pathogenic micro-organisms.

In studying irradiation inactivation of food infection micro-organisms in seafoods (crab meat, shrimp meat, oyster meat and salmon) as compared to broth, Anderson (3) and Quinn et al. (57) found the existence of a "tail" at the end of the survival curves in seafoods, indicating increased resistance to irradiation of bacteria tested in seafoods. The potential pathogenic bacteria tested were various Salmonella species, Shigella species, *Escherichia coli*, *Streptococcus faecalis* and *Streptococcus pyogenes*, *Staphylococcus aureus*, *Proteus vulgaris*, etc. Shigella species, *E. coli* and *P. vulgaris* were eliminated by doses of 0.1 to 0.25 Mrad depending on the seafood substrate. All the Salmonellae could be recovered after exposure to 0.3 Mrad and most showed the "tailing off" effect. *Str. faecalis* was recovered up to 0.5 Mrad and *Str. pyogenes* and *Staph. aureus* up to 0.3 to 0.5 Mrad. Apart from *Staph. aureus* and *Str. pyogenes*, *S. typhosa*, *S. paratyphi B*, *S. wichita* and *S. cholerasuis* were most resistant of the organisms tested. The "tailing off" effect was not noticed when these organisms were irradiated in broth.

The radiation resistance of *Vibrio parahaemolyticus* has been found to be very low (46). This organism appears, therefore, not to be a problem in radurized fishery products.

In the Netherlands and in Germany (F.R.), the occurrence and irradiation resistance of several pathogens on *Crangon vulgaris* were studied.

Table 8 summarizes the results obtained by van Schothorst (68). The shrimps were irradiated with 150 and 300 krad respectively and kept at 4° C during 3-4 days.

Table 8 - Influence of irradiation on pathogens in shrimps (68).

	Before storage			After 3-4 days' storage (4° C)		
	0 krad	150 krad	300 krad	0 krad	150 krad	300 krad
Enterobacteriaceae in 0.1 g (37° C)	7/7(a)	0/7	0/7	7/7	0/7	0/7
Faecal streptococci in 0.1 g	6/7	0/7	0/7	-	-	-
Salmonellae in 20 g	0/7	0/7	0/7	-	-	-
St. aureus in 0.1 g	14/21	0/21	0/21	5/14	0/14	0/14
B. cereus in 0.1 g	0/7	0/7	0/7	-	-	-
Cl. perfingens in 0.1 g	0/21	2/21	2/21	1/14	2/14	1/14
V. parahaemolyticus in 0.1 g	0/7	0/7	0/7	-	-	-

(a) 7/7 = 7 occurrences on 7 determinations.

Enterobacteriaceae, faecal streptococci and St. aureus were eliminated by irradiation. St. aureus is known to be rather irradiation resistant, but its elimination could be explained by the very low number of organisms originally present.

Münzner (50) treated brown shrimps from the German North Sea with X-rays at a dose of 100 krad either before or after peeling. Control samples remained untreated or were preserved with benzoic acid (table 9).

Best results were obtained when shrimps were irradiated after peeling. Total bacterial counts and numbers of Staphylococci, Enterococci and Enterobacteriaceae were reduced by at least two orders of magnitude. Double irradiation (before and after peeling) did not influence those figures markedly.

Table 9 - Total counts, Staphylococci, Enterococci and Enterobacteriaceae per g (50).

A. Unpeeled and peeled untreated shrimps (ca 10 hrs after catch)

	Total counts (20° C)	Total counts (37° C)	Staphyl.	Enteroc.	Enterobact.
Unpeeled	$4.2x10^4$	$1.0x10^4$	$3.6x10^3$	$3.5x10^2$	$3.7x10^3$
Peeled	$4.9x10^4$	$2.4x10^4$	$4.0x10^3$	$3.3x10^2$	$5.6x10^2$

B. Shrimps peeled after chemical treatment or irradiation (ca 34 hrs after catch).

	Total counts (20° C)	Total counts (37° C)	Staphyl.	Enteroc.	Enterobact.
Untreated	$1.8x10^5$	$1.1x10^5$	$5.8x10^4$	$4.5x10^4$	$1.7x10^3$
With benzoic acid	$1.1x10^5$	$5.8x10^4$	$3.2x10^4$	$8.9x10^3$	$3.5x10^3$
Irradiated	$7.2x10^4$	$8.6x10^4$	$2.7x10^4$	$2.7x10^4$	$1.1x10^4$

C. Shrimps irradiated after peeling with and without irradiation of raw material (ca 35-40 hrs after catch)

	Total counts (20° C)	Total counts (37° C)	Staphyl.	Enteroc.	Enterobact.
Irradiated only after peeling	$1.7x10^3$	$1.5x10^3$	$8.0x10^2$	< 100	< 100
Irradiated both before and after peeling	$5.7x10^3$	$3.5x10^3$	$9.8x10^2$	< 100	< 100

The general conclusion from both Dutch and German experiments is that radurization improves the hygienic quality of shrimps.

§ 2. Toxicological aspects.

Toxicological tests were carried out in the Netherlands on Crangon vulgaris (65). Seven groups each of ten male and ten female rats received for 90 days either a standard diet or diets containing non-irradiated, 150 krad or 300 krad irradiated shrimps at a level of 2.8 or 28 % on a dry weight basis.

A. Food intake and growth.

The weight of food consumed increased as the dietary level of shrimps increased. This could be explained partly by the fact that the water content of the diet was much higher when fresh shrimps, with a water content of 80 %, were incorporated. However, the food intake of the males and females receiving 28 % shrimps in the diet was some 2-3 times higher than that of the control group. A direct comparison of the food intakes was impossible, as evaporation of water from the diets was not estimated. In some cases, the food intake of the animals ingesting 300-krad irradiated shrimps was higher than that of the animals ingesting non-irradiated shrimps. The growth of the animals was also greater when shrimps were incorporated in the diet except in the case of the males of the group receiving 28 % non-irradiated shrimps.

B. Haematological and biochemical studies.

The significant differences in haematological parameters were few and scattered throughout the test groups. They were clearly not related to the administration of non-irradiated or irradiated shrimps. The determination of the activity of serum glutamic-pyruvic transaminase did not reveal any significant differences between the groups.

C. Organ weights.

The addition of 28 % shrimps to the diet caused an increase in the weights of the liver, kidneys and ovaries expressed as a percentage of body weight. The thymus weight was increased in males but decreased in females. In the males a decrease in the heart weight was found. The addition of 28 % 300-krad irradiated shrimps to the diet decreased the relative spleen weight in males and females, but spleen weight was also decreased in the animals receiving 2.8 % non-irradiated shrimps. In addition the weight of the testes was decreased in animals fed 28 % 300-krad irradiated shrimps. The effect on the relative weight of the brain was probably a reflection of the increase in body weight, since brain weight is relatively stable while the body weight changes. The other significant differences were most probably unrelated to the administration of irradiated shrimps.

D. Histopathology.

The results of the histopathological studies of the different organs did not show any changes that could be ascribed to the administration of non-irradiated or irradiated shrimps, except in the liver. The principle finding in the other organs was perivascular cuffing in the lungs, but the incidence of this, as of the less common pathological changes, was no higher in the test groups than in the controls. In the liver, however, vacuolation was observed at the periphery of the liver lobules in animals receiving 28 % non-irradiated or 300-krad irradiated shrimps.

The degree of vacuolation was independent of the irradiation. At the lower dietary level of shrimps, the vacuolation was greater in the males than in the females.

The general conclusion of this study was that the changes found were no more serious or extensive in irradiated than in non-irradiated shrimps even when the shrimps were fed at a dietary level of 28 % on a dry weight basis. There were no indications that the wholesomeness of shrimps was decreased by irradiation.

§ 3. Detection of irradiation.

Adriaanse (1) has developed a method for the detection of low dose γ-irradiation in cooked brown shrimps by disc protein patterns.

The shrimps are homogenised with 5 % sodium chloride solution adjusted to pH 7.4. The homogenate is centrifuged, dialyzed against water and freeze-dried. Disc electrophoresis is then applied at 3 mA on the freeze-dried sample dissolved in a buffer solution of pH 8.3. Electrophoresis is completed in 45 min. After staining, the mobilities of the bands are referred to that of bromophenol blue taken as 1.

No substantial changes in the disc patterns owing to variations in the cooking procedure of the shrimps were found. Irradiation had a series of distinct effects on the bands of the salt-extracted proteins of cooked shrimps in the disc patterns (fig. 12) ; in general the patterns gradually alter with increasing dose. Going from left to right of fig. 12 (from 0-300 krad) it can be seen that the strong 0.43-band dissociates and that the 0.45-band vanishes ; the 50 krad sample shows an "intermediate" triplet, the 0.43-band not having yet been affected strongly but the 0.39-band already appearing ; the 100 krad and the 300 krad samples show a clear triplet. Also, the triplet with mobilities 0.51, 0.55 and 0.60 vanishes slowly ; the 50 krad sample shows only one clear band (0.51), which still is present in the 100 krad sample, but no longer in the 300 krad sample.

In addition, a new, radio-induced band (0.73) appears as the dose increases. The triplet : 0.82, 0.84, 0.89 remains equally intense in the range 0-100 krad ; in the 300 krad sample the 0.82-band has vanished. Since spoilage by Pseudomonas of these shrimps on prolonged storage was to be expected and was later proved, the effects of enzymes with proteolytic activity, excreted by these microorganisms, on the protein bands of the disc patterns had to be in-

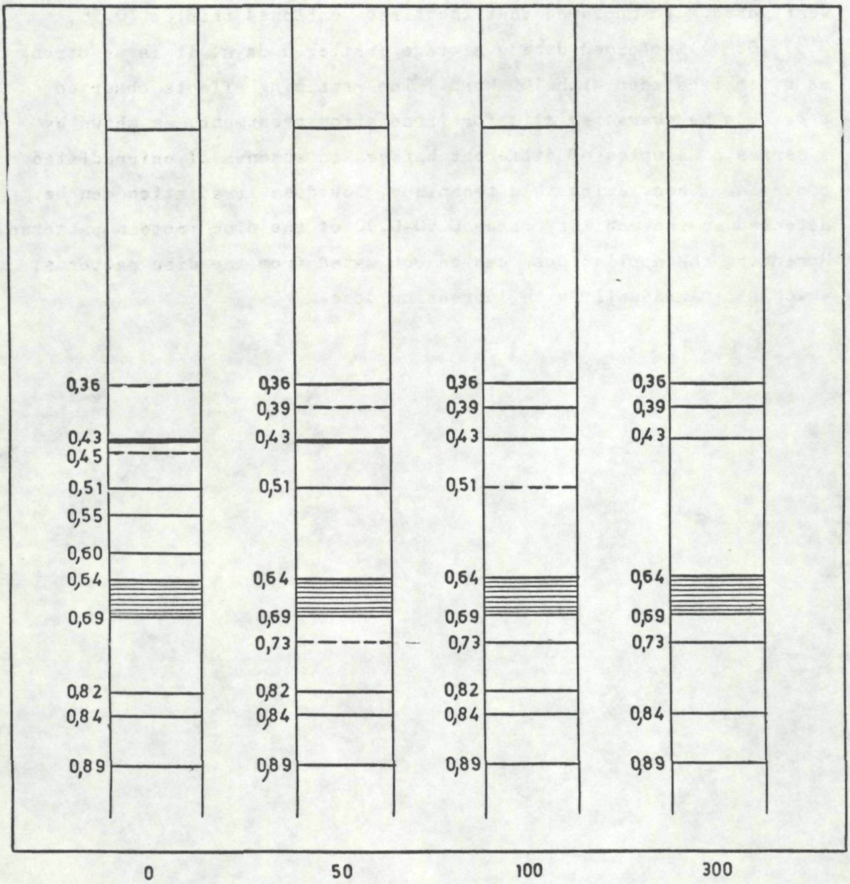


Fig. 12 - Disc patterns of salt-extracted proteins of cooked shrimps irradiated with various doses of γ-rays (Dotted lines indicate bands of weak intensity)(1).

vestigated. It appeared that the first-mentioned triplet (0.36, 0.39, 0.43) is formed during storage ; after 5 days, it is as strong as after treatment with 100 krad. The remaining effects observed proved to be characteristic for irradiation treatment, as shown by a series of samples of different batches in absence of unirradiated controls. Thus, using this technique, low dose irradiation can be detected in the mobility range 0.50-0.90 of the disc protein patterns. Moreover, the applied dose can be estimated from the disc patterns, which alter gradually with increasing dose.

Chapter III - Irradiation technology of shrimps.

When it is accepted as a general principle that the type of irradiation source and irradiation installation chosen must be in relation to the application intended, it is also important that, in making a choice of the source and installation, the technological development of the different available processes are taken into account. In this respect a relatively greater development in the sector of electron accelerators has in recent years been noted when compared with the sector of gamma irradiators. As a reason the difference in number of industrial applications may be cited. The X-ray irradiation apparatus is less generally developed, but was specifically studied with respect to the irradiation of fishery products (30).

The basic principles affecting the choice of an option for one or another irradiation form are firstly the physical characteristics of the irradiation installation and secondly, the product to be irradiated and the industrial characteristics of the process.

More specifically the following factors are to be distinguished :

1. The physical characteristics of the irradiation.

These characteristics are :

- the nature of the irradiation, viz. gamma rays, X-rays, electrons ;
- the energy which is relatively low for isotopes sources but which have a high penetration capacity and which is dependent on the apparatus used for X-rays and electrons; in any case the penetration capacity is lower for electrons ;
- the dose rate, i.e. the rate of the dose applied and the heating up during irradiation are different for gamma rays and electrons.

2. The industrial characteristics of the irradiation installation.

These characteristics are related to :

- the availability on a sufficiently developed industrial level, whereby as factors play a rôle : efficiency ; possible optimalization ; flexibility in use (treatment of various products) ; cost of maintenance and control and replacement of spare parts (electrons and X-rays) or replenishment (radioisotopes);
- the investment costs and exploitation costs ;
- the facilities for integration in the production process.

3. The characteristics of the product.

As to the product the following factors have to be taken into account :

- the density (adjustment of the layer thickness) ;
- the homogeneity, packing included ;
- the dimensions depending upon industrial treatment (loose or packed) ; large or small containers ;
- the packing material (metal, cardboard, plastics etc.) ;
- the sensitivity to mechanical damage (adaptation to the conveyor belt system) ;
- the sensitivity to heating up.

4. The industrial characteristics of the process.

These characteristics are :

- the availability of the product throughout the year ;
- the uniformity of the task distribution ;
- the volume of the yearly production in relation to the dose required.

As regards these various elements it is possible to retain three systems for the irradiation of shrimps according to the conditions put forward in this present study.

The fundamental technical limitations of each type of irradiation source may briefly be summarized as follows.

1. Gamma irradiation sources.

The Co-60 installations have undoubtedly reached the highest degree of development in the sector of food irradiation. According to the present prospects Cs-137 may offer slight, but definite advantages (5)(18) ; the practical application is however still dependent on the further industrial development of the sources (21). Cs-137 certainly offers an advantage when mobile installations are concerned.

Gamma irradiation sources do not constitute any problem for the irradiation of the product in containers of normal use as those which will be proposed for the cost price calculation. This applies for containers with unpeeled shrimps as well as for containers with pre-packed peeled shrimps. A combination with fish fillets is also possible.

2. X-ray apparatus.

According to recent developments the irradiation possibility at production capacities up to 3-3.5 tons per hour could exist.

Unpeeled as well as peeled shrimps and fish fillets could be treated simultaneously in a same installation.

The X-ray facilities seem to be a promising technique for irradiation on board (30).

3. Electron accelerators.

Two types are to be distinguished.

In the first place, there are accelerators of the direct type (energy of 3-5 MeV.). Only packed and peeled shrimps (possibly fish fillets) in layers with a maximum thickness of 1 cm for a one-sided irradiation and of 3 cm thickness for a two-sided irradiation can be considered as practical with these apparatus.

The other types are accelerators of the indirect type or linear accelerators (energy up to 10 MeV.). Only packed and peeled shrimps (and fish fillets) can be considered for practical purposes. The layer thickness may however reach 3 cm for a one-sided irradiation or 8 cm for a two-sided irradiation when a 10 MeV irradiator is used (7).

Apart from these technical remarks the earlier evaluations (6) and the industrial conditions defined in chapter IV should be taken into account. Thus, the irradiation with a linear electron accelerator on the basis of cost price comparison should only be preferred to Co-60 irradiation at a working regime of eight hours a day during the busiest period. From the present study it will appear that this can also apply for zone II with a two-shifts system during the peak month.

If on the other hand the selling conditions and the treatment in the different zones which will be described further are taken into account, it appears that the electron accelerators would rather be appropriate for zones III and IV where 90 % of the treated raw material consists of peeled shrimps. Zone I would be appropriate for gamma irradiation as only 20 % of peeled shrimps are treated.

These elements added to the ones mentioned above are important factors which have to be taken into account when elaborating a pilot research project.

In the present state of development of the irradiation technique it has not yet been determined which of the three methods mentioned should on the whole be preferred. Above mentioned indications are useful in defining the technical concept of a pilot installation.

The specification of the conservation methods themselves, viz. the exact dose, the allowable dose variance, the exact type of packing, the temperature requirements, etc. must supplement the previous elements.

Furthermore, the localization is another important element not only from the economic but also from the technical point of view.

Finally, the organization aspects which must supplement the study of a pilot research project.

Chapter IV - Economic aspects of the irradiation of shrimps.

The economic aspects of the application of the technique of irradiation are only considered from the point of view of costs. The calculation of the costs is ultimately related to the problem of the quantity to be irradiated. As background information an analysis of the shrimp fishery and shrimp market seems however to be necessary.

§ 1. Shrimp fishery and shrimp market in the EEC.

The background information about the shrimp fishery and market in the EEC gives an idea of the production capacity (fleet), the production (landings) and the domestic and international trade. The fleet and landings are considered as indices of the quantity to be irradiated, whereas the data concerning the domestic and international trade give an idea of the quantities of irradiated unpeeled and peeled shrimps which may be sold. The figures about the foreign trade show at the same time the necessity to set up a harmonized procedure regarding the acceptability and the clearance.

As regards the statistical data the period 1970-74 has been taken into account. The figures for the year 1969, the last year of the previous study, are mentioned as an illustration.

As since the publication of the previous study Denmark and the United Kingdom became members of the EEC some data are given for these countries. It will become clear however, that with respect to the estimation of irradiation costs, the study can be limited to zones considered in the previous study.

The economic data are given for the EEC as a whole and for the member-countries individually.

A. European Economic Community.

The shrimp fishery is a typical coastal fishing activity and thus extends over a wide area which means that the landings are highly decentralized.

The fishery is carried out by rather small vessels (130-175 hp).

It must be stressed however, that in recent years, the modernization of the fleet increased. Older vessels were replaced by modern vessels and frequently larger ones, high powered engines have been installed in the vessels and fishing gear and processing equipment of more rational design have been introduced.

World landings of shrimps are mainly concentrated in EEC countries, viz. about 90 %.

In the years 1970-74 landings of shrimps reached on average 18.4 million kg, worth 15.1 million Eur or an average price of 0.82 Eur per kg (table 10).

During the period 1970-74 landings dropped in the years 1971 and 1972 (viz. 16.1 million kg and 16.3 million kg). After 1972 landings again increased and in 1974 a figure of 20.4 million kg was reached.

As table 10 shows, Germany (F.R.) is the main producer (43.5 %), followed by The Netherlands (28.8 %), France (12.5 %), the United Kingdom (8.2 %), Belgium (6.5 %) and Denmark (0.5 %).

Apart from 1971 (12.8 million Eur) the total value of the landings increased between 1970 and 1974 from 12.9 million Eur

Table 10 - Landings, value and average landing price of shrimps in the EEC, 1969-74 (a).

Countries	1969	1970	1971	1972	1973	1974	1970-74
Landings (million kg)							
Belgium	1.4	1.4	0.9	0.9	1.6	1.3	1.2
Denmark	0.2	.	.	.	0.1	0.2	0.1
Germany (F.R.)	8.7	9.7	6.7	7.7	6.7	9.4	8.0
France	2.3	2.3	2.7	2.5	2.4	1.7	2.3
Netherlands	6.8	7.1	4.2	3.9	5.1	6.1	5.3
United Kingdom	1.3	1.4	1.6	1.3	1.5	1.7	1.5
Total	20.7	21.9	16.1	16.3	17.4	20.4	18.4
Value (1000 Eur)							
Belgium	1,032	1,048	960	995	1,612	1,620	1,247
Denmark	71	27	43	34	101	92	59
Germany (F.R.)	4,440	4,210	4,207	5,542	6,036	6,377	5,274
France	2,771	2,485	3,169	3,673	3,745	2,771	3,169
Netherlands	3,525	4,586	3,649	4,464	4,899	5,730	4,666
United Kingdom	469	537	728	568	592	926	670
Total	12,308	12,893	12,756	15,276	16,985	17,516	15,085
Average price (Eur)							
Belgium	0.74	0.75	1.07	1.11	1.01	1.25	1.04
Denmark	0.40	0.38	0.75	0.65	0.71	0.52	0.59
Germany (F.R.)	0.51	0.43	0.63	0.72	0.90	0.68	0.66
France	1.20	1.08	1.17	1.47	1.56	1.63	1.38
Netherland	0.52	0.65	0.87	1.14	0.96	0.94	0.88
United Kingdom	0.36	0.38	0.46	0.44	0.39	0.54	0.45
Total	0.59	0.59	0.79	0.94	0.98	0.86	0.82

(a) Sources :
- Belgium : N.I.S. and Ministerie van Landbouw, Dienst voor de Zeevisserij.
- Denmark : Fiskeriministeriet.
- Germany (F.R.) : Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Forsten and Fischereiamt des Landes Schleswig-Holstein.
- France : Ministère des Transports, Direction des Pêches maritimes and Comité Central des Pêches Maritimes.
- The Netherlands : Ministerie van Landbouw en Visserij, Directie van de Visserijen ; Produktschap voor Vis en Visprodukten and C.B.S.
- United Kingdom : Ministry of Agriculture, Fisheries and Food.

to 17.5 million Eur or an increase of 35.7 %.

With the exception of 1970 the highest total values were recorded in Germany (F.R.)(on average about 35 %), followed by The Netherlands, France, Belgium, the United Kingdom and Denmark.

Average landing prices show substantial variations, viz. from 0.59 Eur/kg (in 1970) to 0.98 Eur/kg (in 1973). During the period under consideration, France always obtained the highest landing prices. Belgium came second. The United Kingdom had the lowest prices.

Shrimps are marketed in various forms. In the first place, they may be sold unpeeled. Secondly, they may be peeled and are then preserved, semi-preserved, deep-frozen or sold fresh in that form.

International trade in shrimps between the EEC countries is particularly closely integrated.

Exporting countries are Germany (F.R.) and The Netherlands. Belgium and France are importing countries.

B. Member countries.

1. Belgium.

During the period 1970-74 about 70 vessels were engaged in the shrimp fishery. For about 65 vessels the shrimp fishery was the sole or main activity (table 11).

Table 11 - The Belgian shrimp fleet, 1969-74 (a).

	1969	1970	1971	1972	1973	1974
Total number of vessels engaged in the shrimp fishery	86	81	74	68	63	73
Number of vessels engaged solely or mainly in the shrimp fishery	74	77	69	62	57	67
Average engine power (hp)	122	131	139	147	144	157

(a) Situation as per 31 December.

The number of vessels engaged in the shrimp fishery decreased by 18 units between 1970 and 1973. From 1973 to 1974 the number again increased by 10 units.

The same evolution was noticed for the vessels solely or mainly engaged in the shrimp fishery. Between 1970 and 1973 their number decreased by 20 units but from 1973 to 1974 their number increased by 10 units.

In general, for the period considered, it can be noted that the average engine power continued to increase (from 131 hp in 1970 to 157 hp in 1974).

Between 1970 and 1974, on average, 1.2 million kg of shrimps were landed ; the value of the landings was 61.2 million BF (or 51.0 BF/kg)(table 12).

Table 12 - Landings, value and average landing price of shrimps in Belgium, 1969-74.

Years	Landings (million kg)(a)	Value (million BF)	Average price (BF/kg)
1969	1.4	51.6	37.7
1970	1.4	52.4	38.4
1971	0.9	48.0	53.2
1972	0.9	48.4	55.9
1973	1.6	78.4	48.6
1974	1.3	78.8	63.3
1970-74	1.2	61.2	51.0

(a) Landed weight.

Landings were irregular. The peak year was 1973 with 1.6 million kg. The lowest landings were recorded in 1971 and 1972 with 0.9 million kg.

The total value of the landings continuously increased between 1970 and 1974, viz. from 52.4 million BF in 1970 to 78.8 million BF in 1974.

With the exception of the year 1973, the average auction prices increased to reach the level of 63.3 BF per kg in 1974.

The production is mainly sold fresh (and unpeeled) on the domestic market. Deep-freezing industries and canning industries take up only a small percentage of the peeled shrimps.

Landings of shrimps in Belgium are insufficient to cover the demand. Considerable quantities of both unpeeled and peeled shrimps are thus imported.

During the period 1970-74, an average of 0.7 million kg of unpeeled shrimps and 1.6 million kg of peeled shrimps or a total of 6.0 million kg of shrimps were imported. The value of imports was on average 338.0 million BF, 41.0 million BF being accounted for by unpeeled and 297.0 million BF by peeled shrimps (table 13).

Table 13 - Imports of shrimps in Belgium, 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 BF	t.	1,000 BF	t.	1,000 BF
1969	704	22,987	1,387	211,321	5,327	234,308
1970	1,095	39,086	1,598	251,934	6,421	291,020
1971	567	37,835	1,276	248,037	4,820	285,872
1972	760	54,842	1,377	274,071	5,350	328,913
1973	378	23,539	1,685	332,810	5,994	356,349
1974	777	49,474	1,924	378,291	7,190	427,765
1970-74	715	40,955	1,572	297,029	5,955	337,984

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.

A peak year for the imports of unpeeled shrimps was recorded in 1970 (1.1 million kg) and for peeled shrimps in 1974 (1.9 million kg).

The traditional country of origin of the imports is The Netherlands (92.8 %)(*).

Belgian exports of shrimps are rather small (table 14).

(*) Based on total quantity 1970-74.

Table 14 - Exports of shrimps from Belgium, 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 BF	t.	1,000 BF	t.	1,000 BF
1969	13	893	50	6,187	180	7,080
1970	63	3,254	21	3,374	133	6,628
1971	29	3,675	33	5,193	139	8,868
1972	234	26,473	85	10,735	517	37,208
1973	209	20,207	66	8,432	429	28,639
1974	148	17,882	111	14,959	518	32,941
1970-74	137	14,298	63	8,539	347	22,837

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.

In the years 1970-1974, exports were on average 137 tons (14.3 million BF) of unpeeled shrimps and 63 tons (8.5 million BF) of peeled shrimps, being a total of 347 tons (22.8 million BF).

The highest export figures for unpeeled shrimps were noted in 1972 (234 tons) and for peeled shrimps in 1974 (111 tons).

The most important clients are The Netherlands (45.8 %) and France (36.0 %)(*).

2. Denmark.

The number of vessels engaged in the shrimp fishery is very small (table 15).

(*) Based on total quantity 1970-74).

Table 15 - The Danish shrimp fleet, 1969-74.

	1969	1970	1971	1972	1973	1974
Total number of vessels engaged in the shrimp fishery	8	7	3	5	6	8
Average engine power (hp)	99	103	110	124	116	118

The number of shrimpers varied between 3 and 8 in the period 1970-74. The engine power of the vessels was about 120 hp.

The catches of shrimps were also small. In the period 1970-74 an average of 100 tons of shrimps was landed, worth 0.4 million DKr or an average price of 4.5 DKr per kg (table 16).

Table 16 - Landings, value and average landing price of shrimps in Denmark, 1969-74.

Years	Landings (t)(a)	Value (1,000 DKr)	Average price (DKr/kg)
1969	175	530	3.03
1970	71	203	2.87
1971	57	326	5.97
1972	54	259	4.80
1973	143	769	5.40
1974	176	698	3.98
1970-74	100	451	4.51

(a) Landed weight.

Table 16 shows that in recent years the landings tend to increase.

The Danish international trade of shrimps is not very significant. Shrimps are exported to Germany (F.R.) and the United Kingdom, whereas the imports (from Sweden) are negligible.

3. Germany (F.R.).

About 365 vessels were engaged in the shrimp fishery in the period 1970-74 and for about 350 vessels the shrimp fishery was the sole or main activity (table 17).

Table 17 - The German shrimp fleet, 1969-74 (a).

	1969	1970	1971	1972	1973	1974
Total number of vessels engaged in the shrimp fishery	410	403	394	362	348	328
Number of vessels engaged solely or mainly in the shrimp fishery	397	389	375	350	334	310
Average engine power (hp)	119	130	135	145	155	160

(a) Situation as per 31 December.

The total number of vessels engaged in the shrimp fishery decreased by 75 units from 1970 to 1974, whereas the number of vessels solely of mainly engaged in this fishery decreased by 79 units.

The average engine power of these vessels also increased (from 130 hp to 160 hp).

During the period 1970-74, on average, about 8 million kg of shrimps were landed. The total value of the landings was DM 17.7 million (or 221 pf per kg)(table 18).

Table 18 - Landings, value and average landing price of shrimps in Germany (F.R.), 1969-74.

Years	Landings (million kg)(a)	Value (million DM)	Average price (pf/kg)
1969	8.7	17.4	200
1970	9.7	15.4	159
1971	6.7	15.4	230
1972	7.7	19.4	252
1973	6.7	19.9	297
1974	9.4	20.5	218
1970-74	8.0	17.7	221

(a) Landed weight.

The best catches occurred in 1970 (9.7 million kg) and 1974 (9.4 million kg). On the other hand 1971 and 1973 (6.7 million kg) were poor years.

After a decline in the years 1970-71, the total value of the landings increased to reach a figure of DM 20.5 million in 1974.

The average landing prices fluctuated between 159 pf per kg (1970) and 297 pf per kg (1973).

Shrimps are sold unpeeled (about 10 %) and peeled. Peeled shrimps are marketed unpacked and packed (in boxes), deep frozen or preserved.

No precise figures are available about the foreign trade. An approximate idea can be obtained from the imports and exports of the other EEC member-countries, i.e. The Netherlands and Belgium.

In the period 1970-74, Germany (F.R.) seems to have exported an average of 4.4 million kg of shrimps, the value amounting to DM 13.7 million and imported 0.6 million kg worth DM 2.4 million.

Shrimps are exported mainly to The Netherlands, whereas the country of origin of the imports is also The Netherlands.

4. France.

The number of vessels engaged in the shrimp fishery varied between 350 and 400 units. About 50 % of these vessels were permanently engaged in the shrimp fishery.

In the period 1970-74 on average 2.3 million kg of shrimps valued at 17.8 million FF (or 7.74 FF per kg) were landed (table 19).

Table 19 - Landings, value and average landing price of shrimps in France 1969-74.

Years	Landings (million kg)(a)	Value (million FF)	Average price (FF/kg)
1969	2.3	14.2	6.16
1970	2.3	13.8	5.95
1971	2.7	17.6	6.52
1972	2.5	20.4	8.03
1973	2.4	20.8	8.69
1974	1.7	16.6	9.76
1970-74	2.3	17.8	7.74

(a) Landed weight.

The highest landings were recorded in 1971 (2.7 million kg) and the lowest in 1974 (1.7 million kg).

The total value of the landings on the contrary increased up to 1973 (20.8 million FF), but decreased in 1974 (16.6 million FF).

As to the average landing prices a continuous increase was noted.

Most shrimps in France are marketed fresh (unpeeled and peeled). Processing of peeled shrimps to semi-preserves is minimal.

Between 1970-74 on average 2.7 million kg of unpeeled shrimps valued at 20.5 million FF were imported as well as 100 tons of peeled shrimps worth 2.1 million FF, or a total of 3.1 million kg or 22.6 million FF (table 20).

Table 20 - Imports of shrimps in France 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 FF	t.	1,000 FF	t.	1,000 FF
1969	2,978	13,748	89	1,516	3,275	15,264
1970	3,599	18,849	125	2,129	4,016	20,978
1971	2,043	16,021	75	1,736	2,293	17,756
1972	2,496	20,990	125	2,366	2,913	23,356
1973	2,480	19,922	98	2,269	2,807	22,191
1974	3,126	26,926	79	1,961	3,389	28,887
1970-74	2,749	20,542	100	2,092	3,082	22,634

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.

The imports of unpeeled shrimps were highest in 1970 (3.6 million kg) and the imports of peeled shrimps in 1970 and 1972 (125 tons).

The most important country of origin is The Netherlands (about 95 %)(*).

Exports of unpeeled shrimps amounted in 1970-74 on average to 21 tons, for a value of 380,000 FF ; exports of peeled shrimps were on average 23 tons for a value of 367,000 FF (table 21).

Table 21 - Exports of shrimps from France, 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 FF	t.	1,000 FF	t.	1,000 FF
1969	2	34	4	27	14	61
1970	9	150	1	14	12	164
1971	25	334	6	94	45	428
1972	22	417	.	12	22	429
1973	25	480	102	1,589	365	2,069
1974	23	518	6	128	43	646
1970-74	21	380	23	367	97	747

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.

With the exception of 1970 (9 tons) the exports of unpeeled shrimps remained practically on the same level, whereas the exports of peeled shrimps had a peak in 1973 (102 tons).

Export figures per country are not available.

(*) Based on total quantity 1970-74.

5. The Netherlands.

The number of vessels engaged in the shrimp fishery in the years 1970-74 was about 200 units. For about 150 vessels the shrimp fishery was the sole or main activity (table 22).

Table 22 - The Dutch shrimp fleet, 1969-74 (a).

	1969	1970	1971	1972	1973	1974
Total number of vessels engaged in the shrimp fishery	289	238	210	192	191	197
Number of vessels engaged solely or mainly in the shrimp fishery	194	164	145	131	143	156
Average engine power (hp)	145	157	159	155	159	169

(a) Situation as per 31 December.

Between 1970 and 1974 the number of vessels engaged in the shrimp fishery decreased by 41 units. The number of vessels engaged solely or mainly in the shrimp fishery decreased up till 1972 (131 units) but in the following years the number increased by 25 units. Mostly the smaller inshore boats which have obtained disappointing results in the beam trawl fishery have changed to the shrimp fishery.

In general, the average engine power of the shrimpers increased in the period 1970-74 (from 157 hp in 1970 to 169 hp in 1974).

Between 1970 and 1974, on average, 5.3 million kg of shrimps for a total value of 16.3 million guilders (or 308 cents per kg) were landed (table 23).

Table 23 - Landings, value and average landing price of shrimps in The Netherlands, 1969-74.

Years	Landings (million kg)(a)	Value (million fl)	Average price (cents/kg)
1969	6.8	12.8	189
1970	7.1	16.6	233
1971	4.2	13.3	312
1972	3.9	15.7	404
1973	5.1	17.0	333
1974	6.1	19.1	302
1970-74	5.3	16.3	308

(a) Landed weight.

In the period considered, landings decreased till 1972, the lowest figure of 3.9 million kg was then recorded. After 1972 landings increased again and in 1974 a figure of 6.1 million kg was attained.

The total value of the landings was low in 1970-71, but increased since 1972 and in 1974 a figure of 19.1 million guilders was reached.

The average auction prices attained a peak in 1972 (405 cents per kg) and in 1974 a price of 302 cents per kg was recorded.

Shrimps are sold peeled and unpeeled. On the market there are also deep frozen peeled shrimps as well as semi-preserves and preserves.

In the period 1970-74 the exports of unpeeled shrimps were on average 3.6 million kg or 16.2 million guilders and exports of peeled shrimps were 1.7 million kg or 22.7 million guilders, making a total of 9.2 million kg for a value of 38.9 million guilders (table 24).

Table 24 - Exports of shrimps from The Netherlands, 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 fl	t.	1,000 fl	t.	1,000 fl
1969	3,646	11,408	1,385	15,339	8,262	26,747
1970	4,687	15,491	1,472	17,421	9,593	32,912
1971	2,674	12,785	1,238	17,694	6,800	30,479
1972	3,161	16,984	1,401	20,266	7,831	37,250
1973	3,132	15,670	1,926	26,764	9,551	42,434
1974	4,227	20,222	2,438	31,130	12,353	51,352
1970-74	3,576	16,230	1,695	22,655	9,226	38,885

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.
The fact must also be taken into account that the figures also include small quantities of Pandalus spp.

Exports had high figures in 1970 for unpeeled shrimps (4.7 million kg) and in 1974 for peeled shrimps (2.4 million kg).

The shrimps are exported mainly to Belgium (59.2 %) and France (32.9 %)(*).

The average imports of unpeeled shrimps during 1970-74 amounted to 1.7 million kg and of peeled shrimps to 0.7 million kg, making a total of 4.2 million kg. The values of the imports amounted to an average of 12.8 million guilders, 4.9 guilders being attributable to unpeeled and 7.9 million guilders to peeled shrimps (table 25).

Table 25 - Imports of shrimps in The Netherlands, 1969-74.

Years	Unpeeled shrimps		Peeled shrimps		Total (a)	
	t.	1,000 fl	t.	1,000 fl	t.	1,000 fl
1969	768	1,744	666	5,889	2,988	7,633
1970	1,613	3,371	741	6,468	4,083	9,839
1971	1,429	4,344	443	5,585	2,905	9,929
1972	1,888	6,166	711	7,507	4,258	13,673
1973	1,421	5,083	1,057	10,699	4,944	15,782
1974	2,222	5,547	767	9,343	4,778	14,890
1970-74	1,715	4,902	744	7,920	4,194	12,823

(a) For determination of the total, 100 kg of unpeeled shrimps have been substituted for every 30 kg of peeled shrimps.

The highest imports of unpeeled shrimps were recorded in 1974 (2.2 million kg) and of peeled shrimps in 1973 (1.1 million kg).

The main country of origin of the imports is Germany (F.R.)(about 95 %)(*).

6. United Kingdom.

No data on the fleet engaged in the shrimp fishery are available.

In the period 1970-74 landings in the United Kingdom averaged 1.5 million kg, the value amounting to £ 313, 404 or 20.9 p per kg (table 26).

(*) Based on total quantity 1970-74.

Table 26 - Landings, value and average landing price of shrimps in the United Kingdom 1969-74.

Years	Landings (million kg)(a)	Value (1,000 £)	Average price (p/kg)
1969	1.3	195.3	15.5
1970	1.4	223.9	16.1
1971	1.6	303.5	18.6
1972	1.3	242.9	18.5
1973	1.5	302.4	20.1
1974	1.7	494.4	28.5
1970-74	1.5	313.4	20.9

(a) Landed weight.

Landings were highest in 1974, viz. 1.7 million kg whereas in 1972 the lowest figure was noted, viz. 1.3 million kg.

The value for the year 1970 reached its lowest point with about £ 223,000, but in 1974 the total value of the landings was more than doubled (about £ 494,000).

Average landing prices have increased constantly namely from 16.1 p per kg in 1970 to 28.5 p per kg in 1974.

As for the fishing fleet no exact data about the British international trade of shrimps are available.

§ 2. The problem of quantity and irradiation costs.

From an economic point of view the quantity to be irradiated is a very important factor in the application of the irradiation technique. In order to keep operating costs within reasonable limits a sufficient quantity must be irradiated. The fixed costs are relatively high, so that costs per unit fall (rise) as the quantity to be irradiated rises (falls) for a given capacity of the installation.

With regard to the quantity of shrimps to be irradiated a number of factors have to be taken into account. In general three factors play an important rôle, viz. the decentralization of the landings, the fluctuations of the landings and the handling and selling conditions.

A. Decentralization of the landings.

The landings of shrimps in the EEC member-countries **are** very decentralized.

- In Belgium, shrimps are landed at Ostend, Zeebrugge and Nieuwpoort.

In the last five years, on average 74.0 % of the total landings were sold at Zeebrugge, 19.0 % at Ostend and 7.0 % at Nieuwpoort (table 27). Considered year by year these relationships remained practically unchanged.

Table 27 - Landings (in t.) by ports, 1969-74 (a).

Ports	1969	1970	1971	1972	1973	1974	1970-74
Ostend	340	210	178	113	392	267	232
Zeebrugge	910	1,079	645	691	1,107	920	888
Nieuwpoort	120	74	80	62	117	77	82
Total	1,370	1,363	903	867	1,615	1,264	1,202

(a) Landed weight.

- In Denmark the small quantities landed are sold in Havneby.

- In Germany (F.R.) landings are divided geographically between two areas, Schleswig-Holstein and Lower Saxony. Table 28 shows that, of the two areas, Schleswig-Holstein predominates. Between 1970 and 1974, an average of 56.9 % of the landings was sold in Schleswig-Holstein. Lower Saxony accounted for 43.1 % of the landings.

Except in the year 1971 (38.2 % for Lower Saxony and 61.8 % for Schleswig-Holstein) the relationship between the two areas remained practically unchanged.

Table 28 - Landings (in t.) by areas, 1969-74 (a).

Years	Lower Saxony	Schleswig-Holstein	Total
1969	3,604	5,105	8,709
1970	4,031	5,621	9,652
1971	2,558	4,135	6,693
1972	3,418	4,285	7,703
1973	3,076	3,669	6,745
1974	4,301	5,183	9,484
1970-74	3,477	4,579	8,056

(a) Landed weight.

In the Schleswig-Holstein area, the main ports are : Frederichskoog (29.6 %), Husum (25.4 %), Büsum (21.9 %) and Tönning (16.0 %)(table 29).

For Lower Saxony, the principal ports are : Greetsiel (18.7 %), Dorum (13.4 %), Fedderwardersiel (11.0 %), Norddeich (10.0 %), Cuxhaven (8.1 %) and Spieka (7.5 %)(table 29).

Table 29 - Landings (in t.) by ports, 1969-74 (a).

Ports	1969	1970	1971	1972	1973	1974	1970-74
Cuxhaven	366	374	228	275	221	311	282
Spieka	255	311	183	261	224	325	261
Dorum	455	473	330	476	432	612	465
Wremen	134	129	97	145	154	229	151
Bremerhaven	15	10	1	-	-	-	2
Fedderwardersiel	312	295	277	372	372	604	384
Varel	129	119	65	107	93	136	104
Dangast	63	70	70	81	57	82	72
Wilhelmshaven	15	20	11	12	-	-	9
Hooksiel	104	120	71	133	107	163	119
Horumersiel	13	14	-	24	6	7	10
Harlesiel	156	191	112	152	144	152	150
Neuharlingersiel	150	180	65	134	101	183	133
Accumersiel-Dornumersiel	202	234	130	154	174	165	171
Bensersiel	24	27	8	17	9	20	16
Borkum	100	98	76	58	36	47	63
Norddeich	367	463	248	323	299	404	347
Greetsiel	642	836	493	585	553	778	649
Ditzum	102	67	93	109	94	83	89
Total Lower Saxony	3,604	4,031	2,558	3,418	3,076	4,301	3,477
List	574	515	308	262	4	4	219
Hörnum	143	150	125	124	35	33	93
Wijk	3	1	3	6	4	6	4
Husum	1,114	1,424	1,033	1,075	939	1,350	1,164
Tönning	684	759	532	506	703	1,169	734
Büsum	1,164	1,237	874	1,064	814	1,024	1,003
Meldorf-Barlt	4	10	7	6	-	-	4
Friedrichskoog	1,419	1,525	1,253	1,242	1,170	1,597	1,357
Total Schleswig-Holstein	5,105	5,621	4,135	4,285	3,669	5,183	4,578
General total	8,709	9,652	6,693	7,703	6,745	9,484	8,056

(a) Landed weight.

- In France, landings are divided amongst different areas. Table 30 gives the figures for the principal areas.

Table 30 - Landings (in t) by areas, 1969-74 (a).

Areas	1969	1970	1971	1972	1973	1974	1970-74
Oléron	333	239	242	415	394	211	300
Marennes	155	127	116	131	129	142	129
Caen	363	495	806	456	441	276	495
Boulogne	260	311	302	200	248	239	260
St. Nazaire	146	142	138	238	258	168	189
Le Havre	187	66	106	161	41	44	84
St. Malo	136	131	135	106	117	92	116
Dieppe	192	209	211	82	138	124	153
Others	549	605	424	750	627	451	571
Total	2,321	2,325	2,480	2,539	2,393	1,747	2,297

(a) Landed weight.

The most important areas are Caen, Oléron, Boulogne, St. Nazaire and Dieppe. In the period 1970-74 on average 21.5 % of the landings was attributable to the Caen area, 13.1 % to the Oléron area, 11.3 % to the Boulogne area, 8.2 % to the St. Nazaire area and 6.7 % to the Dieppe area.

Considered year by year, it appears that the significance of the Caen area relatively decreased. As from 1972 the Oléron area also declined whereas from that year the Boulogne area gained in importance and took again the position it held in 1970. The importance of the St. Nazaire area also increased in comparison with 1970. The Dieppe area had in 1974 no longer the significance of the year 1970.

- The most important ports in The Netherlands are Den Oever, Lauwersoog-Zoutkamp, Termunten, Harlingen, Breskens, Colijnsplaat en Goedereede (table 31).

Between 1970 and 1974 these ports accounted for approximately 98.7 % of the quantity landed. The figures for the individual ports were as follows : Den Oever 29.8 %, Lauwersoog-Zoutkamp 19.1 %, Termunten 15.9 %, Harlingen 10.6 %, Breskens 9.6 %, Colijnsplaat 7.5 % and Goedereede-Stellendam 6.2 % (table 31).

Table 31 - Landings of shrimps (in t) by ports, 1969-74 (a).

Ports	1969	1970	1971	1972	1973	1974	1970-74
Breskens	587	456	421	361	733	570	508
Colijnsplaat	534	543	233	200	559	448	397
Brouwershaven	35	36	-	-	-	-	7
Goedereede-Ouddorp-Stellendam	211	204	154	211	385	682	327
Scheveningen	118	111	25	7	32	22	39
IJmuiden	105	110	33	5	10	1	32
Den Oever	1,994	2,527	1,442	881	1,249	1,785	1,577
Harlingen	1,262	646	367	432	633	720	560
Dokkum-Nieuw Zijlen	221	228	142	200	112	-	136
Lauwersoog	-	-	-	-	393	1,187	316
Zoutkamp	785	1,055	679	729	305	-	554
Termunten	897	1,219	747	867	691	681	841
Total	6,749	7,135	4,243	3,893	5,102	6,096	5,294

(a) Landed weight.

In the period considered, it can be noted that the importance of Harlingen as port has diminished, whereas Brouwershaven disappeared and as a consequence the relative importance of Goedereede-Stellendam increased. Dokkum, Nieuw Zijlen and Zoutkamp also have disappeared and shrimps are now landed at Lauwersoog.

The importance of Scheveningen and IJmuiden also diminished.

In The United Kingdom about 30.0 % of the shrimps were landed in Kings Lynn during the period 1970-74, 15.7 % in Boston, 14.9 % in Peterhead and 6.8 % in Southport (table 32).

Table 32 - Landings (in t) by ports, 1969-74 (a).

Ports	1969	1970	1971	1972	1973	1974	1970-74
Kings Lynn	284	362	346	392	601	573	455
Boston	260	279	209	193	245	259	237
Southport	129	108	163	96	91	61	104
Flookborough	77	78	65	52	86	71	70
Ayr	8	11	13	10	7	9	10
Peterhead	-	94	359	168	163	346	226
Others	498	457	477	399	312	415	412
Total	1,256	1,389	1,632	1,310	1,505	1,734	1,514

(a) Landed weight.

From table 32 it can be ascertained that between 1970 and 1974 Boston and Southport lost somewhat of their significance whereas Kings Lynn and Peterhead increased their importance.

A concentration of the landings can be realized by a setting up of zones. In the report "Economic and Technological Study of the Irradiation of Shrimps" four zones have been proposed : zone I to irradiate the landings of Nieuwpoort, Ostend, Zeebrugge, Breskens, Colijnsplaat and Goedereede, zone II to take the landings of Den Oever, Harlingen, Lauwersoog and Termunten, zone III to process shrimps landed in Lower Saxony and zone IV to take the landings in Schleswig-Holstein.

The criteria for the choice of these four zones are geographical (ease of access, distance to an irradiation centre) and economic/commercial (acceptable volume of landings and quantity to be irradiated).

B. Fluctuations of the landings.

The landings of shrimps show important fluctuations. Great fluctuations can be noted year by year, month by month, week by week, day by day and voyage by voyage.

These characteristics are clearly illustrated by the landing figures.

In table 33 the year figures by zones are given.

Table 33 - Landings (in t) by zones, 1969-74.

Zones	1969	1970	1971	1972	1973	1974
I	2,736	2,602	1,711	1,638	3,293	2,964
II	5,159	5,675	3,377	3,109	3,383	4,373
III	3,604	4,031	2,558	3,418	3,076	4,301
IV	5,105	5,635	4,135	4,285	3,669	5,183

Table 34 shows the seasonal indices of the landings by zone.

Tables 35 and 36 give the weekly landings (February - March 1973 - 74 and September-November 1973 - 74) for zones I and II.

Table 34 - Seasonal indices of the landings by zone.

Months	Zones			
	I	II	III	IV
January	72	108	9	16
February	53	65	7	12
March	53	69	24	33
April	47	61	88	114
May	54	82	97	113
June	80	84	118	114
July	100	77	137	117
August	135	83	149	124
September	177	94	193	162
October	203	171	215	215
November	120	142	123	134
December	105	164	40	46

Table 35 - Landings (in kg) by zone and per week, 1973-74.

Week	1973		Week	1974	
	Zone I	Zone II		Zone I	Zone II
26/2-3/3	37,144	45,667	25/2-2/3	51,428	95,984
5/3-10/3	27,828	44,071	4/3-9/3	51,843	76,124
12/3-17/3	26,513	44,895	11/3-16/3	49,367	108,441
19/3-24/3	32,449	40,522	18/3-23/3	44,026	81,930
26/3-31/3	27,928	45,135	25/3-30/3	56,643	113,652

Table 36 - Landings (in kg) by zone and per week, 1973-74.

Week	1973		Week	1974	
	Zone I	Zone II		Zone I	Zone II
3/9-8/9	91,107	54,892	2/9-7/9	54,674	25,682
10/9-15/9	20,868	77,944	9/9-14/9	98,972	77,921
17/9-22/9	118,296	79,744	16/9-21/9	84,098	84,445
24/9-29/9	129,216	94,193	23/9-28/9	56,673	62,980
1/10-6/10	143,180	121,759	30/9-5/10	83,143	106,397
8/10-13/10	128,105	126,204	7/10-12/10	81,913	139,754
15/10-20/10	106,035	135,398	14/10-19/10	88,349	151,072
22/10-27/10	143,013	159,606	21/10-26/10	67,108	125,437
29/10-3/11	140,935	163,934	28/10-2/11	58,262	105,950
5/11-10/11	80,154	77,978	4/11-9/11	95,503	169,600
12/11-17/11	60,344	55,231	11/11-16/11	50,024	60,777
19/11-24/11	139,282	125,064	18/11-23/11	75,635	150,677
26/11-1/12	53,780	85,538	25/11-30/11	25,048	34,075

For zone III week landing figures could only be obtained for the following ports : Ditzum, Greetsiel, Norddeich, Borkum, Bensersiel, Accumersiel-Dornumersiel, Neuharlingersiel, Harlesiel, Horumersiel and Hooksiel. For zone IV weekly landing figures were only available for Husum and Tönning. For the sake of completeness these figures are given in tables 37-38 and 39-40 respectively.

Table 37 - Landings (in kg) per week, 1973-74 - Zone III.

Week	1973	Week	1974
26/2-3/3	1,713	25/2-2/3	4,271
5/3-10/3	7,954	4/3-9/3	4,240
12/3-17/3	17,163	11/3-16/3	7,646
19/3-24/3	21,802	18/3-23/3	17,188
26/3-31/3	24,899	25/3-30/3	30,957

Table 38 - Landings (in kg) per week, 1973-74 - Zone III.

Week	1973	Week	1974
3/9-8/9	47,729	2/9-7/9	28,640
10/9-15/9	58,576	9/9-14/9	55,571
17/9-22/9	54,611	16/9-21/9	66,013
24/9-29/9	68,553	23/9-28/9	49,059
1/10-6/10	80,617	30/9-5/10	72,767
8/10-13/10	63,734	7/10-12/10	65,380
15/10-20/10	65.728	14/10-19/10	83,048
22/10-27/10	93,516	21/10-26/10	55,864
29/10-3/11	57,694	28/10-2/11	35,390
5/11-10/11	35,616	4/11-9/11	68,605
12/11-17/11	18,178	11/11-16/11	27,573
19/11-24/11	16,728	18/11-23/11	42,002
26/11-1/12	4,164	25/11-30/11	7,295

Table 39 - Landings (in kg) per week 1973-74 - Zone IV.

Week	1973	Week	1974
26/2-3/3	9,500	25/2-2/3	20,440
5/3-10/3	14,786	4/3-9/3	2,506
12/3-17/3	22,402	11/3-16/3	16,888
19/3-24/3	23,943	18/3-23/3	48,183
26/3-31/3	39,679	25/3-30/3	57,062

Table 40 - Landings (in kg) per week, 1973-74 - Zone IV.

Week	1973	Week	1974
3/9-8/9	53,502	2/9-7/9	23,663
10/9-15/9	53,339	9/9-14/9	80,936
17/9-22/9	49,461	16/9-21/9	73,503
24/9-29/9	52,574	23/9-28/9	62,994
1/10-6/10	87,804	30/9-5/10	102,518
8/10-13/10	77,210	7/10-12/10	91,703
15/10-20/10	79,478	14/10-19/10	107,402
22/10-27/10	80,556	21/10-26/10	67,050
29/10-3/11	81,429	28/10-2/11	69,472
5/11-10/11	32,466	4/11-9/11	71,989
12/11-17/11	15,687	11/11-16/11	17,617
19/11-24/11	27,616	18/11-23/11	61,839
26/11-1/12	50,041	25/11-30/11	12,647

Table 41 gives, as an example, landings day by day during the months September-November 1974 for the ports of Ostend, Zeebrugge and Nieuwpoort.

Tables 42,43 and 44 show, as an example, landings voyage by voyage of ten vessels for the months September-November 1974.

Table 41 - Landings (in kg) by day for the ports Ostend, Zeebrugge and Nieuwpoort, September-November 1974.

September		October		November	
Date	Landings	Date	Landings	Date	Landings
1	30	1	7,052	1	1,422
2	6,768	2	4,750	2	2,899
3	1,982	3	5,758	3	175
4	3,257	4	2,683	4	7,696
6	4,005	5	268	5	2,642
7	335	7	2,183	6	7,597
9	9,038	8	8,601	7	4,521
10	7,991	9	3,465	8	6,057
11	7,251	10	3,303	9	774
12	6,757	11	8,638	10	125
13	5,679	12	1,274	12	873
14	716	13	40	13	2,092
16	7,299	14	3,353	14	1,993
17	6,533	15	8,464	15	2,092
18	6,356	16	5,125	16	2,359
19	6,948	17	6,625	17	135
20	6,063	18	5,732	18	6,991
21	1,819	19	80	19	1,368
23	1,294	20	71	20	3,924
24	98	22	1,554	21	6,232
25	2,458	23	2,929	22	4,268
26	325	24	2,438	23	740
27	8,379	25	6,766	24	25
28	1,469	26	782	26	745
30	9,270	27	50	27	3,559
		30	276	28	1,029
		31	3,943	30	618

Table 42 - Landings (in kg) of ten vessels, per voyage, September 1974 (a).

Voyage (day)	1	2	3	4	5	6	7	8	9	10
1	-	-	-	-	-	-	-	-	-	-
2	209	312	414	-	-	-	253	200	142	255
3	161	231	-	86	90	-	131	199	-	-
4	214	-	149	-	62	-	230	-	-	338
5	-	-	-	-	-	-	-	-	-	-
6	188	-	197	-	86	-	351	-	-	263
7	-	-	-	74	48	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-
9	297	368	260	154	129	204	193	202	275	177
10	193	401	199	206	165	236	192	201	162	220
11	149	246	43	176	177	172	237	148	165	231
12	159	218	-	151	132	191	168	187	227	143
13	200	279	-	96	120	214	282	191	190	215
14	-	-	-	-	130	136	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-
16	422	292	419	167	124	159	186	198	189	342
17	204	314	317	160	105	175	147	234	178	293
18	147	123	250	124	123	164	179	246	275	281
19	224	312	215	117	110	190	152	231	215	262
20	170	310	176	105	113	194	142	316	-	314
21	-	-	-	185	180	87	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-
23	-	262	376	-	131	-	370	-	-	-
24	-	-	-	-	-	-	-	-	-	-
25	-	271	-	-	234	-	194	-	-	196
26	-	-	-	-	-	-	-	-	325	-
27	355	316	179	263	253	576	203	-	418	274
28	-	-	-	-	176	180	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-
30	368	344	142	264	178	314	277	296	276	327

(a) Source : Dienst voor de Zeevisserij.

Table 43 - Landings (in kg) of ten vessels, per voyage, October 1974 (a).

Voyage (day)	1	2	3	4	5	6	7	8	9	10
1	126	285	200	236	135	227	203	145	384	182
2	149	342	115	121	123	364	150	204	205	163
3	158	321	191	191	28	355	144	158	203	140
4	149	-	154	38	107	50	185	158	150	107
5	-	-	-	84	96	88	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-
7	479	-	82	-	-	-	-	-	417	-
8	358	-	-	335	378	330	289	542	306	507
9	197	-	-	-	121	-	243	-	-	-
10	-	-	-	149	-	349	-	395	387	396
11	362	-	172	343	-	987	296	178	243	274
12	-	-	-	171	281	216	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-
14	137	-	202	-	-	-	247	-	178	170
15	270	-	104	493	484	488	202	-	189	92
16	131	-	151	179	325	-	138	-	-	143
17	153	-	117	198	229	-	149	373	387	182
18	99	-	90	128	173	-	198	-	256	199
19	-	-	-	-	-	-	-	-	-	-
20	-	-	71	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-
22	-	317	-	-	-	-	-	-	-	-
23	164	-	95	218	194	-	183	153	-	153
24	281	313	-	-	-	-	-	202	-	-
25	294	-	190	342	389	-	249	334	377	-
26	-	-	-	202	168	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	62	-
31	46	371	203	96	93	88	261	32	-	158

(a) Source : Dienst voor de Zeevisserij.

Table 44 - Landings (in kg) of ten vessels, per voyage, November 1974 (a).

Voyage (day)	1	2	3	4	5	6	7	8	9	10
1	-	-	-	76	147	-	-	-	-	-
2	116	-	-	98	125	215	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-
4	182	335	186	-	145	222	246	303	318	228
5	-	236	125	130	193	261	-	-	-	36
6	142	306	229	185	372	469	240	407	341	257
7	129	236	-	69	97	130	156	153	-	-
8	180	163	249	98	125	122	131	206	396	305
9	63	-	-	91	132	107	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-
12	-	-	71	-	-	-	-	-	-	-
13	154	280	-	71	120	113	-	-	-	-
14	148	-	-	63	104	109	300	-	73	200
15	112	227	156	63	198	203	-	-	135	115
16	136	-	-	135	129	93	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-
18	152	211	237	-	161	115	333	361	403	217
19	32	-	-	98	-	-	-	-	-	-
20	116	281	-	-	161	-	-	354	263	-
21	-	204	203	-	196	401	243	197	-	139
22	123	-	208	-	124	178	179	138	233	204
23	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-
26	-	-	119	-	-	-	150	-	216	-
27	138	22	-	66	119	144	200	-	199	64
28	-	-	157	97	-	-	-	197	115	-
29	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-

(a) Source : Dienst voor de Zeevisserij.

C. Handling and selling conditions.

Finally, the handling and selling preferences have to be considered. With regard to the quantity to be irradiated there is a difference e.g. if only unpeeled or only peeled shrimps are irradiated and sold, or if a certain proportion peeled - unpeeled shrimps must be taken into account.

§ 3. The irradiation costs.

To calculate the costs of irradiation it is first of all necessary to consider a number of assumptions. Subsequently, the basic data for the estimates can be given and ultimately the costs per kg can then be defined. For the calculations a Co-60 irradiation unit has been chosen, but, a comparative cost analysis with other irradiation sources has also been carried out.

A. Assumptions for the cost estimates.

To estimate the costs the following factors must first of all be taken into account :

- the average or the maximum yearly quantity landed (and to be irradiated) ;
- the quantity of shrimps marketed peeled (and irradiated) and
- the seasonal distribution of the landings.

It is further necessary to determine the possible working-schedule before calculating the production capacity per hour of the unit. The capacity per hour can be calculated for the total landings or for a part of them.

Finally an option must be taken as regards the type of irradiation source and as regards the type of facility. With respect to the unit a concrete cost estimation for a Co-60 irradiation unit of a certain type was made. This type of installation was adapted to the products to be irradiated and more attention was paid to the staffing according to the special working-programme chosen.

The technical elements, viz. the choice of source element, the manner of reloading the source and the efficiency of the installation are assumed to be optimalized.

For the four zones and the quantity to be irradiated the facility was further dimensioned for a specified maximum hour capacity (p_{max}). The investments proposed were then adapted to the maximum dimension of the unit so as to obtain comparable cost prices per kg.

The relative cost price of irradiation with other than Co-60 irradiation sources for which an option could also be taken was evaluated with literature data as a basis.

B. Basic assumptions for the calculations.

1. Yearly landings and quantities to be processed.

For the calculations the quantity landed per zone during the last six years was taken into account. These quantities were for the four zones divided into unpeeled and peeled shrimps and are presented in table 45.

The figures show that on average for zone I 20 %, for zone II 60 % and for zones III and IV 90 % of the landings are shrimps to be peeled. As peeling causes a 70 % weight loss the quantities to be irradiated can easily be deduced (table 46).

Table 45 - Classification of the quantities landed, in tons per year (unpeeled and peeled shrimps).

Zone I

Disposition	1969	1970	1971	1972	1973	1974	Average($\bar{x}$)
Unpeeled	2,148	2,016	1,291	1,277	2.611	2.489	1,972
Peeled	588	586	420	361	682	475	519
Total	2,736	2,602	1,711	1,638	3,293	2,964	2,491

Zone II

Disposition	1969	1970	1971	1972	1973	1974	Average($\bar{x}$)
Unpeeled	2,051	2,484	1,295	1,478	926	1,462	1,616
Peeled	3,108	3,191	2,082	1,631	2,457	2,911	2,563
Total	5,159	5,675	3,377	3,109	3,383	4,373	4,179

Zone III

Disposition	1969	1970	1971	1972	1973	1974	Average($\bar{x}$)
Unpeeled	360	403	256	342	308	430	350
Peeled	3,244	3,628	2,302	3,076	2,768	3,871	3,148
Total	3,604	4,031	2,558	3,418	3,076	4.301	3.498

Zone IV

Disposition	1969	1970	1971	1972	1973	1974	Average($\bar{x}$)
Unpeeled	511	564	414	429	367	518	467
Peeled	4,594	5,071	3,721	3,856	3,302	4,665	4,202
Total	5,105	5,635	4,135	4,285	3,669	5,183	4,669

Table 46 - Quantities to be irradiated in tons per year.
Zone I

Disposition	1969	1970	1971	1972	1973	1974	Average($Q\bar{x}$)
Unpeeled	2,148	2,016	1,291	1,277	1,611	2,489	1,972
Peeled	177	177	126	108	204	142	156
Total	2,325	2,193	1,417	1,385	2,815	2,631	2,128

Statistical maximum value of the total : Q_{max} = 2,128 x 1.75 = 3,724 tons/year.

Zone II

Disposition	1969	1970	1971	1972	1973	1974	Average($Q\bar{x}$)
Unpeeled	2,051	2,484	1,295	1,478	926	1,462	1,616
Peeled	932	957	625	490	737	874	769
Total	2,983	3,441	1,920	1,968	1,663	2,336	2,385

Statistical maximum value of the total : Q_{max} = 2,385 x 1.75 = 4,175 tons/year.

Zone III

Disposition	1969	1970	1971	1972	1973	1974	Average($Q\bar{x}$)
Unpeeled	360	403	256	342	308	430	350
Peeled	973	1,088	691	923	830	1,161	944
Total	1,333	1,491	947	1,265	1,138	1,591	1,294

Statistical maximum value of the total : Q_{max} = 1,294 x 1.50 = 1,941 tons/year.

Zone IV

Disposition	1969	1970	1971	1972	1973	1974	Average($Q\bar{x}$)
Unpeeled	511	564	414	429	367	518	467
Peeled	1,378	1,521	1,116	1,157	991	1,399	1,290
Total	1,889	2,085	1,530	1,586	1,358	1,917	1,727

Statistical maximum value of the total : Q_{max} = 1,727 x 1.50 = 2,590 tons/year.

As average quantity to be irradiated ($Q_{\bar{x}}$) the average of the last six years was taken. As maximum quantity to be expected (Q_{max}) a quantity was taken into account obtained by multiplying the average quantity with a factor which according to the calculated standard deviation of the quantity to be treated for the period under review can be considered with a confidence interval of 95 % to be the maximum per zone. In the context of these maximum quantities the annual production capacity (P_{max}) of the unit is dimensioned.

For the calculation of the annual capacity of the unit it can be assumed that either the total landings (Q_{max}) or only a part of it are to be irradiated.

Three hypotheses were considered :

(a) Total landings are irradiated :

$P_{max} = Q_{max} = 1.75\ Q_{\bar{x}}$ (zone I and II)

$P_{max} = Q_{max} = 1.50\ Q_{\bar{x}}$ (zone III and IV)

(b) Only 80 % of the landings are irradiated :

$P_{max} = 0.8\ Q_{max} = 1.4\ Q_{\bar{x}}$ (zone I and II)

$P_{max} = 0.8\ Q_{max} = 1.2\ Q_{\bar{x}}$ (zone III and IV)

(c) Only 60 % of the landings are irradiated :

$P_{max} = 0.6\ Q_{max} = 1.05\ Q_{\bar{x}}$ (zone I and II)

$P_{max} = 0.6\ Q_{max} = 0.90\ Q_{\bar{x}}$ (zone III and IV)

In order to take account of the yearly fluctuations of the landings and to evaluate their effect on the cost at lower landings and lower quantities to be irradiated (Q) for a calculated maximum production capacity of the unit (P_{max}) the cost price was also calculated for various percentages of the expected maximum annual capacity. These percentages are given in table 47. This table also shows the relation with respect to the maximum (Q_{max}) and the average landings ($Q_{\bar{x}}$).

Table 47 - Percentage of quantities landed to be irradiated in relation to the maximum capacity (P_{max}) and maximum landings (Q) taken into account for the cost estimations.

Percent. with respect to P_{max} (Q/P_{max})	Percent. with respect to Q_{max} (Q/Q_{max})	Percent. with respect to $Q_{\bar{x}}$ ($Q/Q_{\bar{x}}$)	
Zone I - IV	Zone I - IV	Zone I and II	Zone III and IV
Total landings irradiated			
100	100	175	150
86	86	151	130
80	80	139	120
60	60	105	90
50	50	87	75
40	40	70	60
20	20	35	30
80 % of the landings irradiated			
100	80	140	120
75	60	105	90
63	50	87	75
50	40	70	60
25	20	35	30
60 % of the landings irradiated			
100	60	105	90
83	50	87	75
67	40	70	60
33	20	35	30

2. Seasonal fluctuations and working programme.

Considering the monthly fluctuations of the landings caused by seasonal influences as presented in table 34 the landings (in percentages) based on the statistical data of the last six years were calculated for the peak month of October (table 48) and for the four other high season months (table 49).

Table 48 - Percentage of the total landings during the peak month (October).

Year	Zone I	Zone II	Zone III	Zone IV
1969	19.4	13.0	18.7	16.1
1970	12.4	12.3	14.0	14.3
1971	22.5	18.5	22.8	22.3
1972	19.7	12.5	18.1	14.8
1973	16.7	16.6	20.3	22.9
1974	10.7	11.5	13.9	17.0
$\bar{x}$	16.9	14.1	18.0	17.9

Maximum for the four zones : 20 %.

Table 49 - Percentage of the total landings during the four high season months.

Year	Zone I	Zone II	Zone III	Zone IV
1969	41.3	41.8	51.2	38.9
1970	38.1	33.5	43.1	41.3
1971	53.8	50.6	64.6	60.1
1972	50.0	50.8	51.9	45.2
1973	48.7	43.0	45.5	41.3
1974	36.7	34.5	44.5	40.9
$\bar{x}$	44.8	42.4	50.1	44.8

Maximum for the four zones : 50 %.

Based on these figures the following percentages of the yearly quantities to be irradiated were assumed to be maximum fluctuations per month for the four zones :

during 1 month (October) = 20 %
during 4 months : 50 %
during 7 months : 30 %

For the calculation of the maximum hour capacity of the unit (p_{max}) it was postulated that the unit must be able to treat the landings during the peak month, viz. 20 % of Q_{max}.

This quantity can be treated in a varying number of hours according to the accepted working-schedule.

Three possible working-programmes were considered to estimate the costs, viz. :

(a) Working-programme 3-2-1 :
Three shifts during the peak month, two shifts during the high season and one shift during the low season.

(b) Working-programme 2-1-1 :
Two shifts during the peak month and one shift during the high and the low season.

(c) Working-programme 1-1-1 :
One shift during the whole year.

As general working-programme it was accepted that the unit would work during :
300 days per year ;
25 days per month ;
5 days per week ;
7.5 hours per day and per shift.

According to the working-programme the following effective working hours are obtained :

3.2.1. : Peak month : 562.5 h
High season : 1,500 h
Low season : 1,312.5 h
Total : 3,375 h per year

2.1.1. : Peak month : 375 h
High season : 750 h
Low season : 1,312.5 h
Total : 2,437.5 h per year

1.1.1. : Peak month : 187.5 h
High season : 750 h
Low season : 1,312.5 h
Total : 2,250 h per year

According to the accepted fluctuations of the landings and the maximum landings of 20 % during the peak months the respectively required hour capacities for the three working-programmes were calculated as percentages of the annual maximum capacity (P_{max}) :

Working-programme	Hour capacity (tons per hour)
3.2.1.	P_{max} x 0.0355 %
2.1.1.	P_{max} x 0.0533 %
1.1.1.	P_{max} x 0.1066 %

The following elements were taken into account for the calculation of the labour costs :

- only the number of workers strictly required for the quantity to be treated is taken into account ;
- the workers needed for the supplementary shifts during the peak month and the high season are only paid during the respective number of twelfths of the year ; the pay however is increased by 30 % ;
- at lower landings or at smaller quantities to be irradiated the working-programme is adjusted to the remaining quantity to be treated.

In tables 50 to 61 the number of required workers and the yearly costs are given per working-programme and per zone and according to the quantity irradiated (depending on the assumption taken as regards the part of the landings to be irradiated)(fig. 13). The manpower costs are calculated as follows :

General management : 20 % of 600,000 FB/year
Technical management : 1 x 400,000 BF/year
Workers : x x 300,000 BF/year
(Supplementary shifts at 390,000 BF/year)

C. Cost price for Co-60 irradiation.

1. Type of installation and source strength.

The proposed type of irradiator is in principle identical to the fish irradiation unit described by Gard in 1968 (22)(fig. 14). It concerns an irradiator equipped with an operation system allowing a continuous loading and unloading. The packed products stacked in containers move around a horizontal irradiation source. Container units of approximately 30 kg are preferably to be used. The dimensions are : 30 x 40 x 23.5 cm. In this manner about three hundred bags of 100 g peeled shrimps (15 x 15 x 1 cm) can be stacked per container. The irradiation chamber is cooled so as to reduce the heating up of the products during irradiation.

The irradiation source chosen is Co-60 with relatively high specific activity (50-60 Ci/g on loading). The type of source element and the dimensions of the source have been chosen in such a way that an optimum utilization of the gamma irradiation is possible and that only a minimum yearly or two yearly replenishment is required (13 % per year).

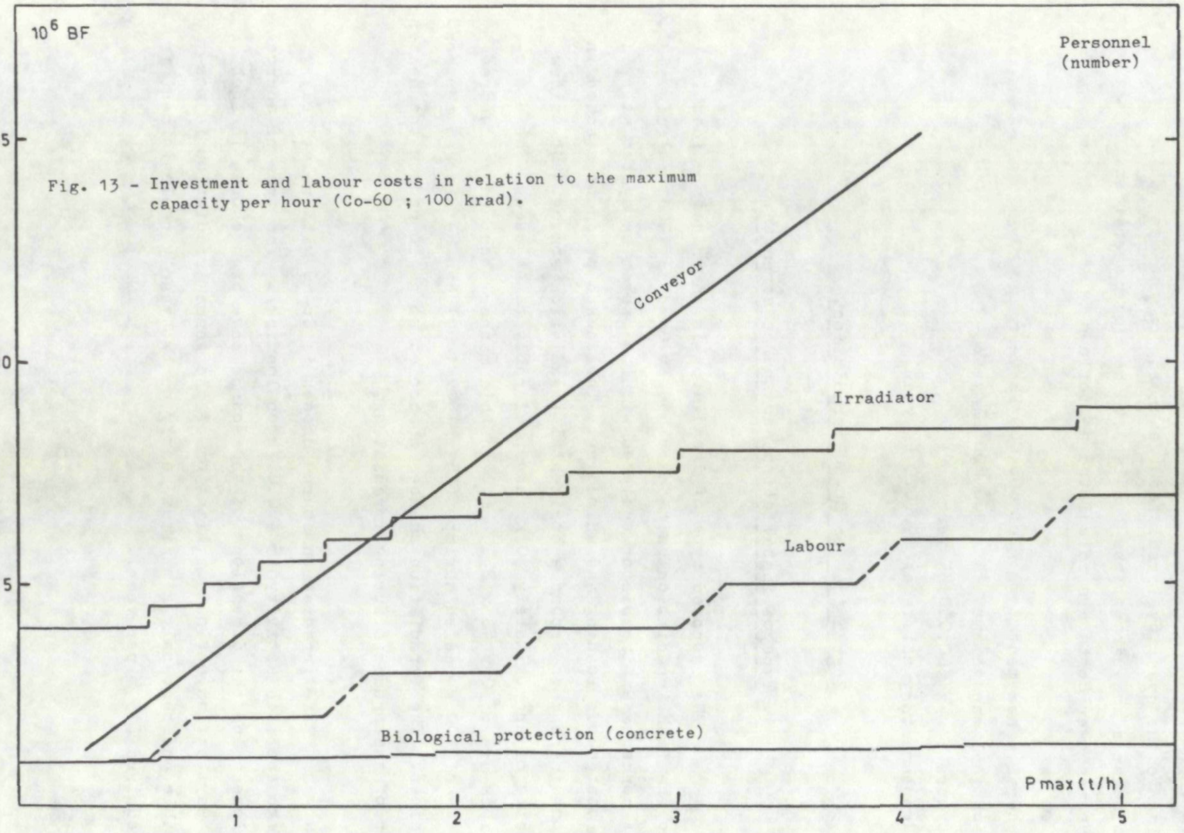


Fig. 13 - Investment and labour costs in relation to the maximum capacity per hour (Co-60 ; 100 krad).

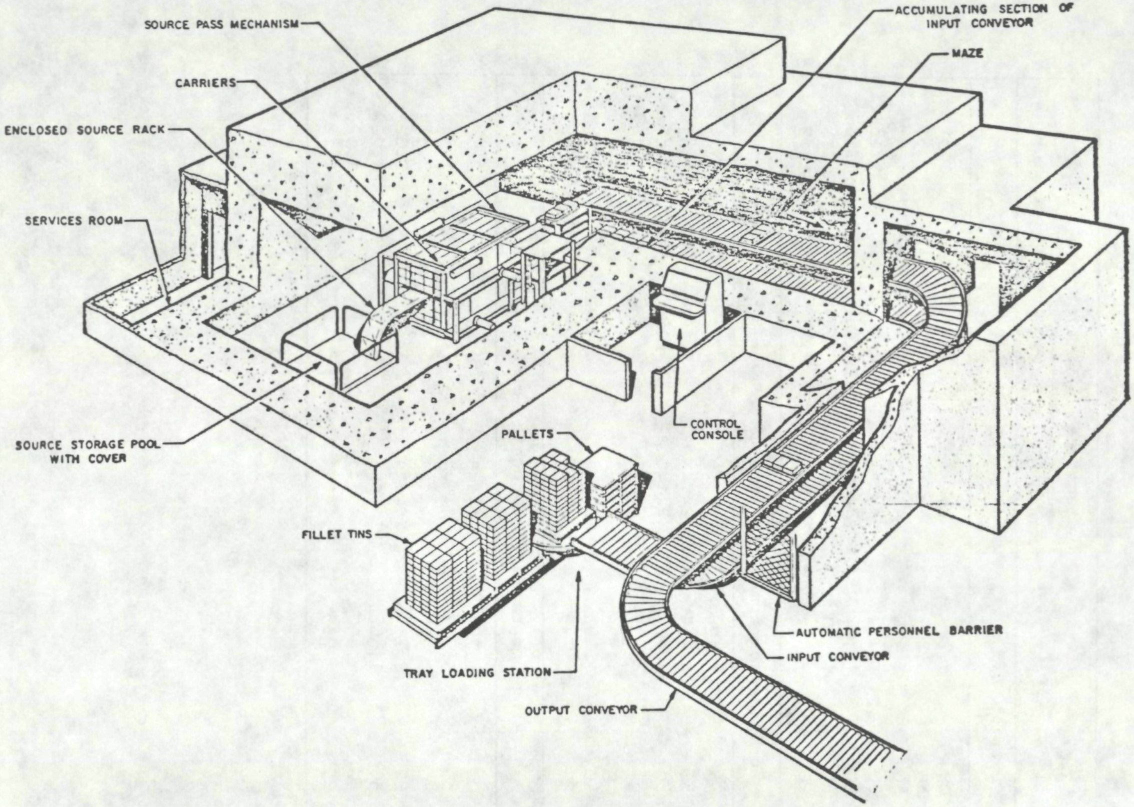


Fig. 14 - Commercial Fish Irradiator (22).

Table 50 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone I : Total landings irradiated.

Q/P_{max} (%)	Q (tons/year	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	3,724	3-2-1	4/12+8/12+2	1.51
86	3,203	3-2-1	4/12+8/12+2	1.51
80	2,979	3-2-1	4/12+8/12+2	1.51
60	2,234	2-1-1	2/12+2	1.185
50	1,862	2-1-1	2/12+2	1.185
40	1,490	2-1-1	2/12+2	1.185
20	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	3,724	2-1-1	4/12+4	1.85
86	3,217	2-1-1	4/12+4	1.85
80	2,979	2-1-1	4/12+4	1.85
60	2,234	2-1-1	2/12+2	1.185
50	1,862	2-1-1	2/12+2	1.185
40	1,490	2-1-1	2/12+2	1.185
20	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	3,724	1-1-1	7	2.62
86	3,217	1-1-1	6	2.32
80	2,979	1-1-1	6	2.32
60	2,234	1-1-1	5	2.02
50	1,862	1-1-1	4	1.72
40	1,490	1-1-1	2	1.12
20	745	1-1-1	2	1.12

Table 51 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone I : 80 % of the landings irradiated.

Q/P_{max} (%)	Q (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	2,979	3-2-1	4/12+8/12+2	1.51
75	2,234	3-2-1	4/12+8/12+2	1.51
63	1,862	2-1-1	2/12+2	1.185
50	1,490	2-1-1	2/12+2	1.185
25	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	2,979	2-1-1	4/12+4	1.85
75	2,234	2-1-1	2/12+2	1.185
63	1,862	2-1-1	2/12+2	1.185
50	1,490	1-1-1	2	1.12
25	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	2,979	1-1-1	6	2.32
75	2,234	1-1-1	5	2.02
63	1,862	1-1-1	4	1.72
50	1,490	1-1-1	2	1.12
25	745	1-1-1	2	1.12

Table 52 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone I : 60 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	2,234	3-2-1	4/12+8/12+2	1.51
83	1,862	3-2-1	4/12+8/12+2	1.51
67	1,490	2-1-1	2/12+2	1.185
33	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	2,234	2-1-1	2/12+2	1.185
83	1,862	2-1-1	2/12+2	1.185
67	1,490	2-1-1	2/12+2	1.185
33	745	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	2,234	1-1-1	5	2.02
83	1,862	1-1-1	4	1.72
67	1,490	1-1-1	2	1.12
33	745	1-1-1	2	1.12

Table 53 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone II : Total landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	4,174	3-2-1	6/12+1+3	2.005
86	3,590	3-2-1	4/12+8/12+2	1.51
80	3,339	3-2-1	4/12+8/12+2	1.51
60	2,504	2-1-1	2/12+2	1.185
50	2,087	2-1-1	2/12+2	1.185
40	1,670	2-1-1	2/12+2	1.185
20	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	4,174	2-1-1	4/12+4	1.85
86	3,607	2-1-1	4/12+4	1.85
80	3,339	2-1-1	4/12+4	1.85
60	2,504	2-1-1	2/12+2	1.185
50	2,087	2-1-1	2/12+2	1.185
40	1,670	2-1-1	2/12+1	1.185
20	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	4,174	1-1-1	7	2.62
86	3,607	1-1-1	6	2.32
80	3,339	1-1-1	6	2.32
60	2,504	1-1-1	5	2.02
50	2,087	1-1-1	4	1.72
40	1,670	1-1-1	4	1.72
20	835	1-1-1	2	1.12

Table 54 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone II : 80 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	3,339	3-2-1	4/12+8/12+2	1.51
75	2,504	3-2-1	4/12+8/12+2	1.51
63	2,087	2-1-1	2/12+2	1.185
50	1,670	2-1-1	2/12+2	1.185
25	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	3,339	2-1-1	4/12+4	1.85
75	2,504	2-1-1	2/12+2	1.185
63	2,087	2-1-1	2/12+2	1.185
50	1,670	2-1-1	2/12+2	1.185
25	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	3,339	1-1-1	6	2.32
75	2,504	1-1-1	5	2,02
63	2,087	1-1-1	4	1.72
50	1,670	1-1-1	2	1.12
25	835	1-1-1	2	1.12

Table 55 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone II : 60 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	2,504	3-2-1	4/12+8/12+2	1.51
83	2,087	3-2-1	4/12+8/12+2	1.51
67	1,670	2-1-1	2/12+2	1.185
33	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	2,504	2-1-1	2/12+2	1.185
83	2,087	2-1-1	2/12+2	1.185
67	1,670	2-1-1	2/12+2	1.185
33	835	1-1-1	2	1.12
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	2,504	1-1-1	5	2.02
83	2,087	1-1-1	4	1.72
67	1,670	1-1-1	4	1.72
33	835	1-1-1	2	1.12

Table 56 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone III : Total landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	1,941	3-2-1	4/12+8/12+2	1.51
86	1,669	3-2-1	2/12+4/12+1	1.015
80	1,553	3-2-1	2/12+4/12+1	1.015
60	1,165	3-2-1	2/12+4/12+1	1.015
50	970	2-1-1	1/12+1	0.852
40	776	2-1-1	1/12+1	0.852
20	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	1,941	2-1-1	2/12+2	1.185
86	1,669	2-1-1	2/12+2	1.185
80	1,553	2-1-1	2/12+2	1.185
60	1,165	2-1-1	2/12+2	1.185
50	970	1-1-1	2	1.12
40	776	1-1-1	2	1.12
20	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	1,941	1-1-1	4	1.72
86	1,669	1-1-1	4	1.72
80	1,553	1-1-1	4	1.72
60	1,165	1-1-1	2	1.12
50	970	1-1-1	2	1.12
40	776	1-1-1	2	1.12
20	388	1-1-1	1	0.82

Table 57 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone III : 80 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	1,553	3-2-1	2/12+4/12+1	1.015
75	1,165	3-2-1	2/12+ 4/12+1	1.015
63	970	2-1-1	1/12+1	0.852
50	776	2-1-1	1/12+1	0.852
25	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	1,553	2-1-1	2/12+2	1.185
75	1,165	2-1-1	2/12+2	1.185
63	970	2-1-1	1/12+1	0.852
50	776	2-1-1	1/12+1	0.852
25	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	1,553	1-1-1	4	1.72
75	1,165	1-1-1	2	1.12
63	970	1-1-1	2	1.12
50	776	1-1-1	2	1.12
25	388	1-1-1	1	0.82

Table 58 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone III : 60 % **of the** landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	1,165	3-2-1	2/12+4/12+1	1.015
83	970	3-2-1	2/12+4/12+1	1.015
67	776	2-1-1	1/12+1	0.852
33	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	1,165	2-1-1	2/12+2	1.185
83	970	2-1-1	1/12+1	0.852
67	776	2-1-1	1/12+1	0.852
33	388	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	1,165	1-1-1	2	1.12
83	970	1-1-1	2	1.12
67	776	1-1-1	2	1.12
33	388	1-1-1	1	0.82

Table 59 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone IV : Total landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	2,590	3-2-1	4/12+8/12+2	1.51
86	2,227	3-2-1	4/12+8/12+2	1.51
80	2,072	3-2-1	4/12+8/12+2	1.51
60	1,554	2-1-1	2/12+2	1.185
50	1,295	2-1-1	2/12+2	1.185
40	1,036	2-1-1	1/12+1	0.852
20	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	2,590	2-1-1	2/12+2	1.185
86	2,227	2-1-1	2/12+2	1.185
80	2,072	2-1-1	2/12+2	1.185
60	1,554	2-1-1	2/12+2	1.185
50	1,295	1-1-1	2	1.12
40	1,036	1-1-1	2	1.12
20	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	2,590	1-1-1	5	2.02
86	2,227	1-1-1	5	2.02
80	2,072	1-1-1	4	1.72
60	1,554	1-1-1	4	1.72
50	1,295	1-1-1	2	1.12
40	1,036	1-1-1	2	1.12
20	518	1-1-1	1	0.82

Table 60 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone IV : 80 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	2,072	3-2-1	4/12+8/12+2	1.51
75	1,554	3-2-1	2/12+4/12+1	1.015
63	1,295	3-2-1	2/12+4/12+1	1.015
50	1,036	2-1-1	1/12+1	0.852
25	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	2,072	2-1-1	2/12+2	1.185
75	1,554	2-1-1	2/12+2	1.185
63	1,295	2-1-1	2/12+2	1.185
50	1,036	1-1-1	2	1.12
25	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	2,072	1-1-1	4	1.72
75	1,554	1-1-1	4	1.72
63	1,295	1-1-1	2	1.12
50	1,036	1-1-1	2	1.12
25	518	1-1-1	1	0.82

Table 61 - Staffing and costs according to working-programme and quantities to be irradiated.

Zone IV : 60 % of the landings irradiated.

Q/P_{max} (%)	% (tons/year)	Working-programme	Number of workers	BF/year (10^6)
Working-programme (peak month) by $Q = Q_{max}$: 3-2-1				
100	1,554	3-2-1	2/12+4/12+1	1.015
83	1,295	3-2-1	1/12+4/12+1	1.015
67	1,036	2-1-1	1/12+1	0.852
33	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 2-1-1				
100	1,554	2-1-1	2/12+2	1.185
83	1,295	2-1-1	2/12+2	1.185
67	1,036	2-1-1	1/12+1	0.852
33	518	1-1-1	1	0.82
Working-programme (peak month) by $Q = Q_{max}$: 1-1-1				
100	1,554	1-1-1	4	1.72
83	1,295	1-1-1	2	1.12
67	1,036	1-1-1	2	1.12
33	518	1-1-1	1	0.82

The density of the product and the dimensions should allow for an efficiency or yield of 30 % of the irradiation absorption for an acceptable maximum/minimum dose ratio in the product (1.2 to 1.3/1).

With this yield and assuming that the minimum irradiation dose should be 100 krad, the number of Curies Co-60 for this application is calculated as follows :

$S = p_{max} \times 62.5$

S = the number of kCi Co-60

p_{max} = possible maximum number of tons/hour.

For the respective zones and for the various hour capacities according to working-programme and maximum production capacity the source strengths required are calculated in this manner and presented in table 62.

2. Investments.

In view of comparing the costs of irradiation for installations designed for maximum production capacity and for which no possibilities to expand are foreseen the investment for the irradiation facility, the biological concrete shielding and the conveyor-belt for loading und unloading has been assessed in relation to the maximum hour capacity.

Based on average figures for units of comparable types the data as shown in figure 13 were retained.

The cost of the Co-60 irradiation source was put at 22 BF per Ci, transport costs included.

Table 62 - Source strength according to the capacity per hour and maximum production capacity per working-programme.

(Source : Co-60 ; dose : 100 krad ; efficiency : 30 %).

Working-programme (peak month)	Zone I			Zone II			Zone III			Zone IV		
	P_{max} (tons/year)	tons/h	kCi	P_{max} (tons/year)	tons/h	kCi	P_{max} (tons/year)	tons/h	kCi	P_{max} (tons/year)	tons/h	kCi
	P_{max} = 100 % Q_{max} = 175 % $Q_{\bar{x}}$						P_{max} = 100 % Q_{max} = 150 % $Q_{\bar{x}}$					
3-2-1	3,724	1.32	82.5	4,174	1.48	92.5	1,941	0.69	43.1	2,590	0.92	57.5
2-1-1	3,724	1.98	123.7	4,174	2.22	138.7	1,941	1.03	64.4	2,590	1.38	86.2
1-1-1	3,724	3.97	248.1	4,174	4.45	278.1	1,941	2.07	129.4	2,590	2.76	172.5
	P_{max} = 80 % Q_{max} = 140 % $Q_{\bar{x}}$						P_{max} = 80 % Q_{max} = 120 % $Q_{\bar{x}}$					
3-2-1	2,979	1.05	66.9	3,339	1.18	73.7	1,553	0.55	34.4	2,072	0.75	45.6
2-1-1	2,979	1.58	98.7	3,339	1.77	110.6	1,553	0.83	51.9	2,072	1.10	68.7
1-1-1	2,979	3.17	198.1	3,339	3.55	221.9	1,553	1.65	103.1	2,072	2.21	138.1
	P_{max} = 60 % Q_{max} = 105 $Q_{\bar{x}}$						P_{max} = 60 % Q_{max} = 90 % $Q_{\bar{x}}$					
3-2-1	2,234	0.79	49.4	2,504	0.89	55.6	1,165	0.41	25.6	1,554	0.55	34.4
2-1-1	2,234	1.19	74.4	2,504	1.33	83.1	1,165	0.62	38.7	1,554	0.83	51.9
1-1-1	2,234	2.38	148.7	2,504	2.67	166.9	1,165	1.24	77.5	1,554	1.65	103.1

As regards the plant it is assumed that the irradiation cell will be built in an existing industrial complex at a cost of 2 million BF.

The respective investments in relation to the working-regimes and the annual capacity (P_{max}) are shown in tables 63-66.

3. Annual operating costs.

The manpower costs are already determined under point B.2 (tables 50 to 61).

The other costs were calculated pro rata the investment and according to the following scheme :

(a) Costs in relation to the irradiation source :
 Depreciation : 10 % (10 years) ;
 Interest : on average 7 % ;
 Reloading : 13 % ;
 Total : 30 % .

(b) Costs in relation to the irradiation unit and conveyor belt :
 Depreciation : 10 % (10 years) ;
 Interest : on average 7 % ;
 Maintenance and energy : 1 % ;
 Adjustments : 1 % ;
 Insurance : 0.2 % ;
 Total : 19.2 %.

(c) Costs in relation to the concrete shielding and building :
 Depreciation : 3.3 % (30 years) ;
 Interest : on average 7 % ;
 Maintenance : 0.5 % ;
 Insurance : 0.2 % ;
 Total : 11 %.

Table 63 - Investments, Zone I.

(Source : Co-60 ; dose : 100 krad).

Working-programme (peak month)	P_{max} (tons/year)	Amount in 10^6 BF					
		S	I	C	S	P	Total
Total landings irradiated							
3-2-1	3,724	1.81	5.5	5	1.1	2	15.41
2-1-1	3,724	2.72	6.5	7.5	1.2	2	19.92
1-1-1	3,724	5.46	8.5	14.5	1.3	2	31.76
80 % of the landings irradiated							
3-2-1	2,979	1.47	5	4	1.1	2	10.02
2-1-1	2,979	2.17	6	6	1.1	2	17.27
1-1-1	2,979	4.36	8	11.5	1.3	2	27.16
60 % of the landings irradiated							
3-2-1	2,234	1.09	4.5	3	1.1	2	12.14
2-1-1	2,234	1.64	5.5	4.5	1.1	2	14.74
1-1-1	2,234	3.27	7	9	1.2	2	20.07

S = source ; I = installation ; C = conveyer belt (except irradiator) ;
S = shielding ; P = plant.

Table 64 - Investments, Zone II.

(Source : Co-60 ; dose : 100 krad).

Working-programme (peak month)	P_{max} (tons/year)	Amount in 10^6 BF					
		S	I	C	S	P	Total
Total landings irradiated							
3-2-1	4,174	2.03	6	5.5	1.1	2	15.63
2-1-1	4,174	3.05	7	8	1.2	2	21.25
1-1-1	4,174	6.12	8.5	16	1.4	2	34.02
80 % of the landings irradiated							
3-2-1	3,339	1.62	5.5	4.5	1.1	2	14.72
2-1-1	3,339	2.43	6.5	6.5	1.15	2	18.58
1-1-1	3,339	4.88	8	13	1.3	2	29.18
60 % of the landings irradiated							
3-2-1	2,504	1.22	5	3.5	1.1	2	12.82
2-1-1	2,504	1.83	5.5	5	1.1	2	15.88
1-1-1	2,504	3.67	7.5	10	1.25	2	24.42

S = source ; I = installation ; C = conveyer belt (except irradiator) ;
S = shielding ; P = plant.

Table 65 - Investments, Zone III.

(Source : Co-60 ; dose : 100 krad).

Working-programme (peak month)	P_{max} (tons/year)	Amount in 10^6 BF					
		S	I	C	S	P	Total
Total landings irradiated							
3-2-1	1,941	0.95	4.5	2.7	1.1	2	11.25
2-1-1	1,941	1.42	5	4	1.1	2	13.52
1-1-1	1,941	2.85	6.5	8	1.2	2	20.55
80 % of the landings irradiated							
3-2-1	1,553	0.76	4	2	1.05	2	9.81
2-1-1	1,553	1.14	4.5	3	1.1	2	11.74
1-1-1	1,553	2.27	6	6	1.1	2	17.37
60 % of the landings irradiated							
3-2-1	1,165	0.56	4	1.5	1.05	2	9.11
2-1-1	1,165	0.85	4.5	2.5	1.05	2	10.9
1-1-1	1,165	1.70	5.5	4.5	1.1	2	14.8

S = source ; I = installation ; C = conveyer belt (except irradiator) ;
S = shielding ; P = plant.

Table 66 - Investments, Zone IV.

(Source : Co-60 ; dose : 100 krad).

Working-programme (peak month)	P_{max} (tons/year)	Amount in 10^6 BF					
		S	I	C	S	P	Total
Total landings irradiated							
3-2-1	2,590	1.26	5	3.5	1.1	2	12.41
2-1-1	2,590	1.90	5.5	4.5	1.1	2	15.0
1-1-1	2,590	3.79	7.5	10	1.25	2	24.54
80 % of the landings irradiated							
3-2-1	2,072	1.00	4.5	2.7	1.1	2	11.3
2-1-1	2,072	1.51	5	4	1.1	2	13.61
1-1-1	2,072	3.04	7	8	1.2	2	21.24
60 % of the landings irradiated							
3-2-1	1,554	0.76	4	2	1.05	2	9.81
2-1-1	1,554	1.14	4.5	3	1.1	2	11.74
1-1-1	1,554	2.27	6	6	1.15	2	17.42

S = source ; I = installation ; C = conveyer belt (except irradiator) ;
S = shielding ; P = plant.

Table 67 - Total operating costs (OC) and costs per kg, Zone I.
(Source : Co-60 ; dose : 100 krad).

P_{max}/Q_{max} (%)	Q/P_{max} (%)	Q (tons/year)	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg
			Working-programme 3-2-1		Working-programme 2-1-1		Working-programme 1-1-1	
100	100	3,724	4.41	1.18	5.70	1.63	9.04	2.43
	86	3,203	4.41	1.38	5.70	1.78	8.74	2.72
	80	2,979	4.41	1.48	5.70	1.92	8.74	2.94
	60	2,234	4.08	1.83	5.03	2.25	8.44	3.78
	50	1,862	4.08	2.19	5.03	2.70	8.14	4.37
	40	1,490	4.08	2.73	5.03	3.37	7.54	5.06
	20	745	4.02	5.39	4.97	6.67	7.54	10.12
80	100	2,979	4.02	1.35	5.14	1.73	7.73	2.60
	75	2,234	4.02	1.80	4.47	2.00	7.43	3.32
	63	1,862	3.69	1.98	4.47	2.40	7.13	3.83
	50	1,490	3.69	2.48	4.41	2.96	6.53	4.38
	25	745	3.63	4.87	4.41	5.92	6.53	8.76
60	100	2,234	3.62	1.62	3.93	1.76	6.42	2.87
	83	1,862	3.62	1.94	3.93	2.11	6.12	3.29
	67	1,490	3.29	2.21	3.93	2.64	5.52	3.70
	33	745	3.23	4.33	3.87	5.19	5.52	7.41

Table 68 - Total operating costs (OC) and costs per kg, Zone II.
(Source : Co-60 ; dose 100 krad).

P_{max}/Q_{max} (%)	Q/P_{max} (%)	Q (tons/year)	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg
			Working-programme 3-2-1		Working-programme 2-1-1		Working-programme 1-1-1	
100	100	4,174	5.16	1.23	5.99	1.43	9.53	2.28
	86	3,590	4.67	1.30	5.99	1.67	9.23	2.56
	80	3,330	4.67	1.40	5.99	1.80	9.23	2.77
	60	2,504	4.34	1.73	5.32	2.13	8.93	3.57
	50	2,087	4.34	2.08	5.32	2.55	8.63	4.13
	40	1,670	4.34	2.60	5.32	3.19	8.63	5.17
	20	835	4.28	5.12	5.26	6.30	8.03	9.62
80	100	3,339	4.25	1.27	5.43	1.63	8.17	2.45
	75	2,504	4.25	1.70	4.76	1.90	7.87	3.14
	63	2,087	3.92	1.88	4.76	2.28	7.57	3.63
	50	1,670	3.92	2.35	4.76	2.85	7.57	4.53
	25	835	3.86	4.62	4.70	5.63	6.97	8.35
60	100	2,504	3.85	1.54	3.91	1.56	6.84	2.73
	83	2,087	3.85	1.84	3.91	1.87	6.54	3.13
	67	1,670	3.52	2.11	3.91	2.34	6.54	3.39
	33	835	3.46	4.14	3.84	4.60	5.94	7.11

Table 69 - Total operating costs (OC) and costs per kg, Zone III.

(Source : Co-60 ; dose : 100 krad).

P_{max}/Q_{max} (%)	Q/P_{max} (%)	Q (tons/year)	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg
			Working-programme 3-2-1		Working-programme 2-1-1		Working-programme 1-1-1	
100	100	1,941	3.51	1.81	3.68	1.90	5.70	2.94
	86	1,669	3.01	1.80	3.68	2.20	5.70	3.41
	80	1,553	3.01	1.94	3.68	2.36	5.70	3.67
	60	1,165	3.01	2.59	3.68	3.80	5.10	4.38
	50	970	2.85	2.94	3.62	3.73	5.10	5.26
	40	776	2.85	3.67	3.62	4.66	5.10	6.57
	20	388	2.82	7.27	3.32	8.56	4.80	12.37
80	100	1,553	2.72	1.75	3.30	2.13	5.04	3.25
	75	1,165	2.72	2.34	3.30	2.84	4.44	3.81
	63	970	2.56	2.64	2.97	3.06	4.44	4.58
	50	776	2.56	3.30	2.97	3.83	4.44	5.72
	25	388	2.53	6.52	2.94	7.58	4.14	10.67
60	100	1,165	2.57	2.21	3.10	2.66	3.89	3.33
	83	970	2.57	2.65	2.77	2.86	3.89	4.01
	67	776	2.41	3.11	2.77	3.57	3.89	5.01
	33	388	2.38	6.13	2.74	7.06	3.59	9.25

Table 70 - Total operating costs (OC) and costs per kg, Zone IV.
(Source : Co-60 ; dose : 100 krad).

P_{max}/Q_{max} (%)	Q/P_{max} (%)	Q (tons/year)	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg	OC/year (10^6BF)	BF/kg
			Working-programme 3-2-1		Working-programme 2-1-1		Working-programme 1-1-1	
100	100	2,590	3.86	1.49	4.01	1.55	6.87	2.65
	86	2,227	3.86	1.73	4.01	1.80	6.87	3.08
	80	2,072	3.86	1.86	4.01	1.94	6.57	3.17
	60	1,554	3.54	2.28	4.01	2.58	6.57	4.23
	50	1,295	3.54	2.73	3.95	3.05	5.97	4.61
	40	1,036	3.20	3.09	3.95	3.81	5.97	5.76
	20	518	3.17	6.12	3.65	7.05	5.67	10.94
80	100	2,072	3.53	1.70	3.70	1.79	5.86	2.83
	75	1,554	3.03	1.95	3.70	1.98	5.86	3.77
	63	1,295	3.03	2.34	3.70	2.37	5.26	4.06
	50	1,036	2.87	2.77	3.64	3.51	5.26	5.08
	25	518	2.84	5.48	3.34	6.45	4.96	9.57
60	100	1,554	2.72	1.75	3.30	2.13	5.05	3.25
	83	1,295	2.72	2.10	3.30	2.55	4.45	3.44
	67	1,036	2.56	2.47	2.97	2.87	4.45	4.29
	33	518	2.53	4.88	2.94	5.67	4.15	8.01

According to the above mentioned assumption the total operating costs for the various alternatives as given in tables 67 to 70 can be determined.

4. Estimated cost price.

Tables 67 to 70 mention the estimated cost prices in relation to a yearly irradiated quantity.

The curve derived from these tables gives the irradiation costs in relation to the maximum annual capacity if the maximum amount is irradiated (fig. 15).

In the same way and under identical conditions the cost price is also calculated in relation to the maximum hour capacity (fig. 16).

From tables 67 to 70 and from the figures 15 and 16 it is possible to determine the proportional increase of the cost price in case the installation in the different zones is only dimensioned for a maximum capacity which lies 20 to 40 % lower than the maximum estimated landings (Q_{max}). The result is given in table 71.

Table 71 - Proportional increase of costs for lower maximum landings in relation to maximum capacity.

Annual Production capacity P_{max}/Q_{max} (%)	Working-programme	$100 \times \frac{\text{Price } (P_{max} = x\% \, Q_{max})}{\text{Price } (P_{max} = Q_{max})}$ (a)
80	3 - 2 - 1	114 (110 - 117)
	2 - 1 - 1	112 (108 - 114)
	1 - 1 - 1	107
60	3 - 2 - 1	130 (122 - 139)
	2 - 1 - 1	125 (119 - 131)
	1 - 1 - 1	117

(a) Average for the four zones with minimum and maximum.

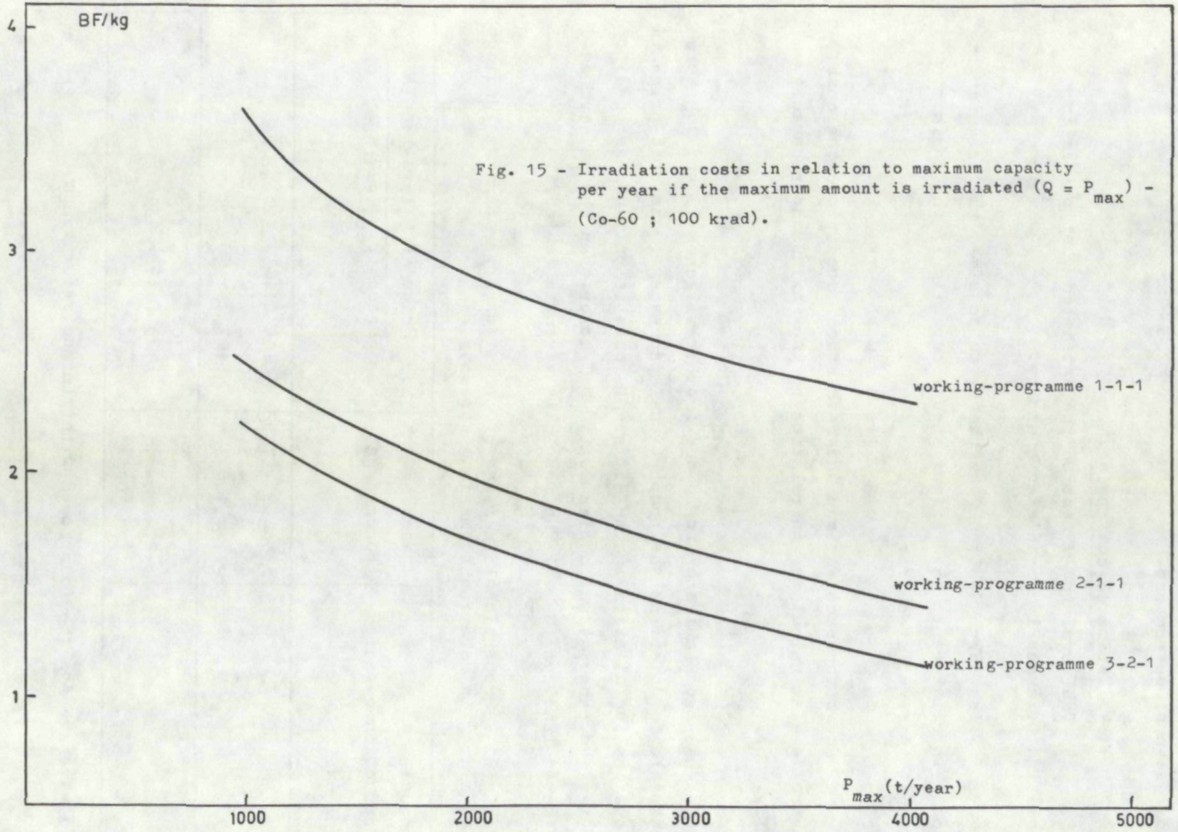


Fig. 15 - Irradiation costs in relation to maximum capacity per year if the maximum amount is irradiated ($Q = P_{max}$) - (Co-60 ; 100 krad).

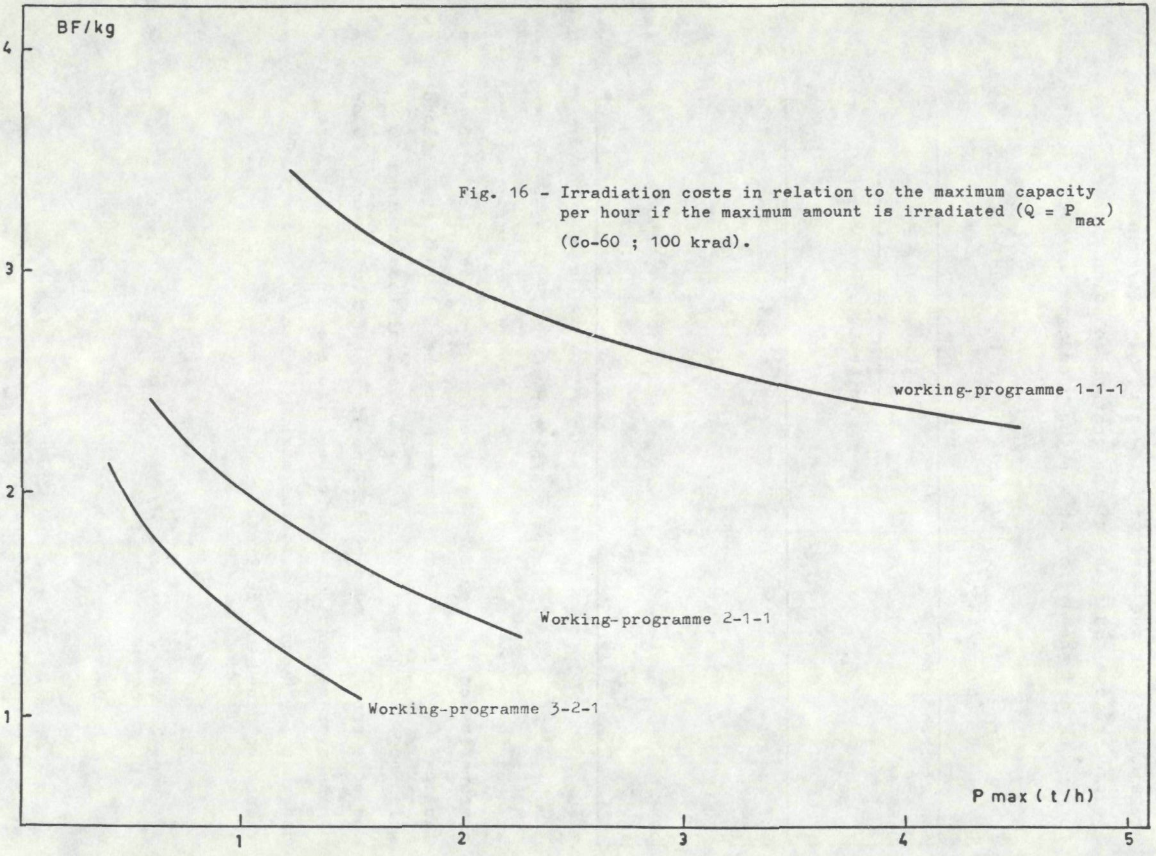


Fig. 16 - Irradiation costs in relation to the maximum capacity per hour if the maximum amount is irradiated ($Q = P_{max}$) (Co-60 ; 100 krad).

From the same tables and figures the effect of the fluctuations in the landings and the quantities to be irradiated (Q) which are smaller than the maximum calculated quantity can be deduced. The proportional increase of the cost price as an average for the four zones and the different working-programmes are given in table 72.

Table 72 - Effect of the fluctuations in the landings on the costs (percentage).

Annual irradiated Quantity Q/P_{max} %	$100 \times \frac{\text{Price } (Q = x \% P_{max})}{\text{Price } (Q = P_{max})}$
90	108
80	121
70	136
60	155
50	179

Finally, it is possible when taking the preceding figures as a basis to give per zone and for the three working-programmes the comparative cost price for the irradiation of the calculated average landings ($Q_{\bar{x}}$) of the last six years (table 46) in installations which are dimensioned for the maximum calculated landings (Q_{max}). The cost price can also be defined if systematically only 80 or 60 % of the average landings are to be irradiated in installations designed for 80 or 60 % of the maximum expected landings. The values obtained are mentioned in table 73.

Table 73 - Comparative costs in BF/kg for the irradiation of the average landings (source Co-60 ; dose 100 krad).

Zone	Landings irradiated (10^3) tons/year)	Maximum installation capacity (10^3 tons/year)	Working-programme		
			3-2-1	2-1-1	1-1-1
I	$Q\bar{x} = 2,1$	$Q_{max} = 3,7$	1,94	2,36	3,87
II	$Q\bar{x} = 2,4$	$Q_{max} = 4,2$	1,80	2,22	3,73
III	$Q\bar{x} = 1,3$	$Q_{max} = 1,9$	2,44	2,84	4,15
IV	$Q\bar{x} = 1,7$	$Q_{max} = 2,6$	2,13	2,50	3,79
I	$0,8\ Q\bar{x} = 1,7$	$0,8\ Q_{max} = 3,0$	2,25	2,69	4,15
II	$0,8\ Q\bar{x} = 1,9$	$0,8\ Q_{max} = 3,3$	2,11	2,53	4,00
III	$0,8\ Q\bar{x} = 1,0$	$0,8\ Q_{max} = 1,5$	2,68	3,08	4,43
IV	$0,8\ Q\bar{x} = 1,4$	$0,8\ Q_{max} = 2,1$	2,38	2,77	4,06
I	$0,6\ Q\bar{x} = 1,3$	$0,6\ Q_{max} = 2,2$	2,62	2,06	4,54
II	$0,6\ Q\bar{x} = 1,4$	$0,6\ Q_{max} = 2,5$	2,48	2,92	4,37
III	$0,6\ Q\bar{x} = 0,8$	$0,6\ Q_{max} = 1,2$	2,98	3,38	4,86
IV	$0,6\ Q\bar{x} = 1,0$	$0,6\ Q_{max} = 1,5$	2,68	3,08	4,43

D. Compared cost price with other irradiation sources.

In the literature only few recent data are available with comparable figures as regards different irradiation sources taking into account the same type of product, the same dose and the approximately identical production capacity. However, reference can be made to two detailed studies, the data of which have been used for comparative purposes.

It concerns figures for irradiation at a same dose and for installations with a comparable level of efficiency and adapted for the application intended. The capacity per hour is also comparable but the working-programme differs.

Although the number of working hours corresponds approximately, the examples concern an equally spread production. The capacities per hour determining the dimension of the installations are in the present calculations higher for the Co-60 installation for a possible identical annual production, as the high peak load during the peak month was taken into account.

In the first place the data of Hofmann (30) can be mentioned. These data allow the evaluation of the difference between irradiation with Co-60, C3-137 and an X-ray apparatus of 200 kV/2.5A.

For a 100 krad dose and an installation of a capacity of 2-3 tons per hour the figures are given in table 74.

Table 74 - Irradiation costs (dose : 100 krad).

Annual Production (10^3 tons)	Working hours per year	Co-60 (a)		Cs - 137		X-stralen	
		BF/kg	$\frac{a}{a}$	BF/kg	$\frac{b}{a}$	BF/kg	$\frac{c}{a}$
4- 6	2.000	2,0-3,1	1	2,0-3,7	1,12	1,3-1,5	0,55
8-12	4.000	1,1-1,6	1	1,1-1,8	1,07	0,8-1,0	0,67

Secondly, the data of Brynjolfsson (7) are available. These figures concern irradiation with Co-60 and with a linear accelerator of 10 MeV. For an identical dose of 100 krad and a capacity of 2-3 tons per hour the values obtained are given in table 75.

Table 75 - Irradiation costs (dose : 100 krad).

Annual Production (10^3 tons)	Working hours per year	Co-60 (a)		Lin. accelerator(b)	
		BF/kg	$\frac{a}{a}$	BF/kg	$\frac{b}{a}$
4 - 6	2.000	0,8 - 1,15	1	0,95-1,35	1,15
8 - 12	4.000	0,4 - 0,6	1	0,55-0,8	1,35

Due to the different approach and the difference in the basic data for investment and proportional operating costs the irradiation costs per kg are only indicative. It is a fact that the values lie distinctly lower because the annual quantities treated are much higher than those which for practical reasons were used in the present study.

The respective relations however are sufficiently important to indicate a trend. Roughly the application of Cs-137 would be about 12 % more expensive, X-rays would be a rather cheap technique whereas a linear accelerator would give a cost price about 15 % higher. As was mentioned in the discussions of the technological possibilities of irradiation it is not feasible to compare the different irradiation techniques without taking account of all criteria lying at the basis of the final option. A judgment on the applicability of one or other technique is in the present stage of development of irradiation procedures as important as a judgment on the costs.

It is also a fact that due to the unequal development level of the irradiation facilities as well as due to the lack of results of comparable pilot research carried out in adapted installations, the extrapolation of the differences obtained is not as yet justified.

Conclusions.

Shrimps (Crangon vulgaris Fabr.) are undoubtedly a product with guaranteed sales in the EEC, but it cannot be denied that processes aiming at extending shelf-life of this very perishable commodity can increase the demand.

In recent years, irradiation of shrimps has gained ample attention as regards scientific research, especially in Belgium, Germany (F.R.) and The Netherlands. This research was encouraged by the actions of the Eurisotop Office.

1. Extension of shelf-life.

Irradiation of shrimps extends shelf-life considerably. A dose of 100 krad seems to be optimal.

The extension of shelf-life depends upon the quality of the shrimps, salt content and storage temperature ; peeling is also of influence.

For irradiated peeled shrimps with a salt content of ca. 3.5 % and kept at 2° C, storage life averages 26 days against 15 days for the unirradiated ones. For the unpeeled shrimps this period is a few days shorter. For irradiated peeled shrimps with a salt content of ca. 1 % and kept at 4° C, the average storage life was 8 days against 3 days for the unirradiated ones.

The oxygen permeability of the packaging, which has an influence in the case of non-irradiated shrimps, does not appear to play a part with irradiated shrimps. Vacuum packaging however is not suitable in this case, the texture not being acceptable.

With peak landings, when the total quantity of shrimps cannot be irradiated the same day, the addition of a small amount of benzoic acid could be necessary. This acid has a synergistic effect with the irradiation. At a storage temperature of 4° C, the shelf-life is prolonged on an average from 8 to 17 days for peeled shrimps (1 % salt) and from 8 to 12 days for unpeeled shrimps.

2. Wholesomeness aspects.

Provided the storage temperature does not exceed 3-4° C, there appears to be no Clostridium botulinum-problem in irradiated shrimps.

Irradiation markedly decreases the number of Staphylococci, Enterococci and Enterobacteriaceae and thus improves hygienic quality of the shrimps.

Feeding experiments on rats did not indicate the wholesomeness of shrimps to be decreased by irradiation.

3. Costs aspects.

According to a number of options the costs for extending shelf-life vary between 2 BF and 5 BF per kg.

These costs depend however upon a number of technical and organizational factors which must be evaluated simultaneously.

In this respect, the most important cost-determining elements are : the choice of the type of irradiation and the production capacity of the installation ; the latter is influenced by the quantity to be irradiated.

As regards the quantities to be irradiated, three factors have to be taken into account, viz. the decentralization of the landings, their important fluctuations and the handling and selling conditions. In relation to the cost estimates these factors have led to setting up four zones and definite working-programmes.

The precise implantation of the irradiation installation must further be considered which means that transportation costs from the harbour to the plant was not taken into account.

For the estimation of the costs a Co-60 irradiator was chosen. However, a comparative study was made with other irradiation sources.

From the study it appears that, according to the circumstances, the application of Cs-137 would be about 10 % more expensive, X-rays would be a rather cheap technique whereas a linear accelerator would give a cost price about 15 % higher.

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Finally, three difficulties should be removed before introducing irradiation techniques of shrimps, viz. the evidence of wholesomeness to be demonstrated to the Governments, the industry and the consumers, the evidence that the extension of shelf-life compensates the increase of costs and the evidence that the feasibility on an industrial scale offers no exceptional difficulties and has reached a sufficient level of development.

To overcome these problems, a pilot-scale realisation is indispensable at the present moment.

This implies an optimalization study on conceptual design of source and facility, the product, packaging and the combination with other products to be irradiated.

The economic yield of the techniques must be evaluated for each individual case based on the costs calculated in the study.

A market study seems also necessary in order to determine the acceptability of the product by the consumer.

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SUPPLEMENT

Synthesis of the present status of fish irradiation research and perspectives for EEC actions

and spoilage micro-organisms and which, in conjunction with an airtight packaging, guarantees the commercial sterility of the product.

The three irradiation techniques are mainly characterized by the difference in irradiation dose. As a function of the nature of the product and the irradiation circumstances, the doses range from 0.05 to 1 Mrad for radurization, from 0.01 to 3 Mrad for radicidation and from 1 to 6 Mrad for radappertization.

The higher the irradiation dose the higher the risk for unacceptable organoleptic changes of the product and the higher the costs of the treatment. For this reason radappertization offers but few prospects for complete sterilization in the food sector. For the treatment of fishery products, it is radicidation and more particularly radurization which has been studied and applied. The reduction of the bacterial load obtained ensures the hygienic quality and increases the storage period of the treated product which remains just as fresh as before treatment.

The general advantages of the irradiation technique are :

- the treatment can be done on the product in its final package and stacking to a certain height is even possible ;
- the application of the irradiation dose causes no noticeable temperature rise ;
- radiation is a physical process offering an alternative for chemical additives.

The study on the use of ionizing radiation for the conservation of fish and fishery products has already been undertaken intensively some ten years ago. Many publications on this subject have been issued, especially during 1965-70. Moreover, several symposia and international meetings on this topic have been organized.

The purpose of this synthesis is to give a review of the present status of research and the perspectives for concrete realization and commercialization of this irradiation application. After a summary of the general and specific application possibilities on fish, the more practical problems concerning an industrial realization are given and the feasibility of common actions are exposed. Finally, some conclusions are presented.

1. General application possibilities of irradiation.

The use of ionizing radiation in food technology is based mainly on the bactericidal effect of the radiation used. As a function of the requirements and the imposed objectives three techniques can be distinguished to inhibit microbiological spoilage and further deterioration of food, viz. radurization, radicidation and radappertization.

Radurization is a treatment which aims at a sufficient reduction of the bacteriological contamination of the product in order to increase shelf life and to maintain the market value during the storage period. Radurization is mostly combined with cooling of the product, before, usually during and also after the irradiation.

Radicidation is a treatment to destroy pathogenic non-sporeforming micro-organisms or parasites, so that there is no potential danger for intoxication.

Radappertization is a treatment which eliminates all pathogenic

2. Concrete applications to fish.

Choice of the product.

The practical results of radurization of fish and fishery products may be different according to the species of fish used (e.g. fat or lean fish), the catching method and the handling of the fish aboard and ashore, the storage and selling conditions (either as a fresh product, whole fish or fillets and/or packed, or as a dried, salted or smoked product etc.). The treatment conditions must be elaborated for specific and concrete cases.

As EEC member countries are in the first place interested in an improvement of the hygienic quality and the extension of storage life of wet fish, this review deals chiefly with the radurization of the fresh product.

Irradiation conditions and advantages.

As a general principle it must be stated that the pre-irradiation quality of the fresh fish must be as good as possible in every respect, because the results, i.e. the improvements of quality and the extension of shelf life, are related to this initial quality.

Hence it follows that :

- irradiation must be carried out as soon as possible after catch ;
- handling (e.g. filleting, portioning, pre-packing) must be carried out under good hygienic conditions.

Moreover, radurization, especially for fish but also for other products must clearly be seen as a combination of irradiation and cooling. As fundamental condition for a possible application of radurization of fresh fish, it must be pointed out that, not only to prolong storage life and to maintain quality, but also to avoid the botulism hazard, the temperature of the irradiated product must be kept below 3° C.

The following advantages of the radurization of fish are generally recognized :

- the possibility to extend considerably the shelf life at normal refrigeration temperature of 0-1° C and to improve the quality ;
- the resulting prolongation of the period between catch and sale, offering the opportunity for a longer stay at sea, longer transport distances ashore and longer storage possibilities ;
- the product keeps its fresh character, which may contribute to a higher commercial value.

In practice three ways for irradiation of fresh fish exist, viz. on board, ashore and a combination of both.

The following specific advantages of irradiation at sea can be mentioned :

- irradiation takes place at optimal quality of the fish ;
- longer stays at sea resulting in bigger catches are possible ;
- fishing on more distant fishing grounds is possible ;
- a better utilization of the storage capacity can be realized ; the time of return to the home-port is thus of lesser importance in comparison as to when the fish is stored on ice.

As a consequence of the characteristics of the installations (installation possibilities) and also because of the technological and economical factors (cost price), it seems only to be worthwhile to install irradiation installations on board large ships. These ships operate in distant waters and realize bigger catches. The problem of storage life of the catches is indeed more acute for these ships.

The irradiation ashore is indicated when near waters are fished and when the distances to the sales points are great. It offers the following specific advantages :

- a reduction of losses due to spoilage ;
- the extension of existing markets ;
- the spreading of the supply with a stabilizing effect on prices ;
- smaller transport and handling costs by simplification of distribution ;
- better adaptation to modern distribution techniques and new presentation methods.

A combination of a first irradiation at sea followed by a second dose during processing ashore is also feasible. This procedure has even the advantage that the successive irradiation doses can be lower than a single dose ashore, resulting in principle in lower irradiation costs. In practice however, the length of the journey and the size of the ship will be the factors justifying a combined irradiation at sea and ashore.

- Installations.

The irradiation installations must be related to the option chosen.

For irradiation on board special precautions must be taken concerning the security and the stability of the apparatus. There can be limitations as to the capacity and weight of shielding. In this respect X-ray apparatus could offer certain advantages, explaining the intensive research (e.g. in the F.R. of Germany) in this field.

The installations ashore have in general the advantage of a simpler construction and a larger capacity and offer the possibility for applications to other products ; this influences favourably the utilization factor and the operation costs. As irradiation source in non-mobile installations, radio-isotope-gamma radiation sources are more indicated, although after adaptation of the form and the dimensions of the product (layer thickness), high-energetic electron generators may also be considered.

3. Practical problems for industrial realization.

The practical problems which presently arise in the irradiation of fresh fish, can be summarized as follows :

3.1. Acceptability.

Considering the acceptability and the clearance, much will depend on the results of the research on the wholesomeness of irradiated food products. This research is carried out on a fundamental basis in different countries and is co-ordinated by the "International Project in the Field of Food Irradiation" at Karlsruhe.

The administrative decision allowing the commercialization of irradiated fishery products, will however have to be taken in each member country. Except for experimental quantities of shrimps (in the Netherlands) no licence has been given until now in any EEC member country, nor in other countries.

Considering the import and export position of some countries, the clearance procedure will have to be generalized and a harmonized system for requesting and granting a licence is to be recommended. The same should be applied to the control requirements.

3.2. Technical feasibility.

In view of a technical realization of the irradiation of fresh fish, the following factors are of special importance :

- Product.

The species to be irradiated, as well as the form of its presentation are to be examined concretely.

The irradiation problems differ according to the species, because the radiation sensitivity of the species to radurization doses is not the same.

On the other hand, there is also a difference whether whole fish or fillets are irradiated and whether the fish is irradiated prepacked or not.

Determinant is also whether the process is carried out on species of great consumption, and/or if the market price of the species can bear the irradiation costs.

- Pre-irradiation quality.

Besides the species, the initial quality plays also an important rôle. The better the quality, the longer the storage life.

When irradiating at sea the quality consitutes no problem but problems may arise when irradiating ashore. In this case the fish should be maximum one week old.

Irradiation ashore after thawing and conditioning of fish frozen at sea, may also be considered. The use of this frozen fish may contribute not only to the solution of the quality problem but can also permit a levelling off of the fluctuations of landings and avoid the discontinuous operation of the installation.

Also regarding the initial quality, the handling of the fish (low temperature, hygienic filleting, duration of filleting and packaging) is of exceptional importance.

- Storage and selling conditions.

The further handling conditions after irradiation are also important parameters.

A storage at low temperature is recommended. The lower the temperature the longer the storage period.

The low storage temperature must also be correlated to the botulism hazard. It is known that from the different serotypes of Clostridium botulinum, the spores of the type E also germinate at relatively low temperatures in food products. In order to avoid the danger of toxin production, the temperature should not exceed 3° C. A control of temperature during storage is thus required.

- Packaging material.

The irradiation is only meaningful if the fish is not recontaminated after treatment ; packaging of radurized and ready-to-cook fish seems indispensable.

Packaging must : (a) protect the product against recontamination ; (b) be resistant to radiation ; (c) withstand wet content or environment for at least four weeks and prevent loss of moisture by evaporation ; (d) have a low oxygen permeability and (e) be readily available at reasonable price.

- Irradiation installation.

The choice of the irradiation installation depends on whether irradiation is achieved at sea, ashore or is a combination of both.

- Product.

The species to be irradiated, as well as the form of its presentation are to be examined concretely.

The irradiation problems differ according to the species, because the radiation sensitivity of the species to radurization doses is not the same.

On the other hand, there is also a difference whether whole fish or fillets are irradiated and whether the fish is irradiated prepacked or not.

Determinant is also whether the process is carried out on species of great consumption, and/or if the market price of the species can bear the irradiation costs.

- Pre-irradiation quality.

Besides the species, the initial quality plays also an important rôle. The better the quality, the longer the storage life.

When irradiating at sea the quality consitutes no problem but problems may arise when irradiating ashore. In this case the fish should be maximum one week old.

Irradiation ashore after thawing and conditioning of fish frozen at sea, may also be considered. The use of this frozen fish may contribute not only to the solution of the quality problem but can also permit a levelling off of the fluctuations of landings and avoid the discontinuous operation of the installation.

Also regarding the initial quality, the handling of the fish (low temperature, hygienic filleting, duration of filleting and packaging) is of exceptional importance.

- Storage and selling conditions.

The further handling conditions after irradiation are also important parameters.

A storage at low temperature is recommended. The lower the temperature the longer the storage period.

The low storage temperature must also be correlated to the botulism hazard. It is known that from the different serotypes of Clostridium botulinum, the spores of the type E also germinate at relatively low temperatures in food products. In order to avoid the danger of toxin production, the temperature should not exceed 3° C. A control of temperature during storage is thus required.

- Packaging material.

The irradiation is only meaningful if the fish is not recontaminated after treatment ; packaging of radurized and ready-to-cook fish seems indispensable.

Packaging must : (a) protect the product against recontamination ; (b) be resistant to radiation ; (c) withstand wet content or environment for at least four weeks and prevent loss of moisture by evaporation ; (d) have a low oxygen permeability and (e) be readily available at reasonable price.

- Irradiation installation.

The choice of the irradiation installation depends on whether irradiation is achieved at sea, ashore or is a combination of both.

In any case attention should be paid to the whole operating system and particularly to the optimum scale (throughput per hour), design and engineering, efficiency, verstility, location for stationary units, etc.

Related to the irradiation facilities is the choice of source, viz. Co-60 or Cs-137 as gamma sources and X-rays or accelerated electrons as machine sources. This choice is influenced especially by the density, form and dimensions of the product (layer thickness, small or voluminous unit packages versus bulk irradiated products), length of processing time (dose rates) and also by the continuity of operation, the annual throughput etc.

- Irradiation dose.

The dose to be used is function of the composition of the fish (lean or fat fish), the presentation form (whole fish or fillets, pre-packed or not), the desired shelf life and the distances to the sales points.

The dose is principally different when a combined treatment on board and ashore is chosen.

The dose applied is about 100 to 200 krad tending to 200 krad. A combined irradiation could consist of 50 krad (at sea) and 100 to 150 krad (ashore). In all case, the dose must be determined by practical experiments.

- Quality control and quality indicators.

In function of the organoleptical, chemical and microbiological changes which may appear and in conjunction with the nature and the amount of micro-organisms present, the quality assessment methods must be defined.

The quality assessment methods (organoleptical, chemical and microbiological) may give rise to problems as differences may appear due to the fish species, the season and the catching ground, while other factors such as dose administrated and temperature also play a rôle.

Indicators for dose, storage temperature, market life etc. must also be defined and should be internationally harmonized.

3.3. Economic feasibility.

As regards the economic feasibility the commercial point of view must first of all be considered. This results in the question : does the industry see real benefits in irradiation, in other words, what is the commercial value (costs, benefits) compared to other conservation methods, more specifically in comparison with classical ice-cooling and deep-freezing.

In the second place, the (re)organization in the production and distribution sector (e.g. concentration of industries) must be taken into account.

In the third place, a market strategy for irradiated products (education of the consumer, distribution, marketing in general) must be elaborated because the general public may be reluctant to purchase irradiated foods. In this connection, the acceptability with respect to the eating quality (external aspect, odour, texture) is a very important factor.

Evaluating the costs and the benefits, the specific technical options shall again be taken into consideration : irradiation at sea, ashore or a combined system, the fish species, the quantity, the handling etc. The costs shall be evaluated against the extension of shelf life and the optimal length of this period, in competition with other conservation techniques, the application and development of which play an important rôle. As a matter of fact all these elements differ from country to country.

4. Status of research in the member countries and feasibility of common research programmes.

In order to obtain information on research programmes and on the feasibility of common research, a questionnaire was sent to the institutes or organisations dealing with irradiation of fish in the EEC member-countries. Replies were received from the Institute for Fishery Products (IJmuiden), United Kingdom Atomic Energy Authority (Harwell), Bundesforschungsanstalt für Fischerei, Institut für Biochemie und Technologie (Hamburg), Bundesforschungsanstalt für Ernährung, Institut für Strahlentechnologie (Karlsruhe), Ministry of Agriculture and Fisheries (Dublin), Rijksstation voor Zeevisserij (Oostende) and Nationaal Instituut voor Radio-elementen (Fleurus).

4.1. Past experiments in the EEC-member countries.

Since the start of scientific research in that field in the early sixties (*) only a limited number of experiments were performed on radurization of wet fish in the EEC member-countries.

During the IRAD-action sponsored by the Eurisotop Office in 1967, a series of experiments with prepacked plaice was carried out in Belgium. Shelf life of irradiated fish was prolonged by 3 days.

In the Netherlands the keeping quality of whole and filleted cod (prepacked or not) and plaice was evaluated after irradiation at 100 krad. Shelf life was approximately doubled by radurization.

(*) Fresh-water fish, molluscs,shellfish and processed fishery products are not taken into consideration in this synthesis.

In the Federal Republic of Germany, several series of irradiation trials were conducted on board the R.V. Walter Herwig on cod, haddock, saithe and mainly redfish. An X-ray irradiator was used. The results were rather deceiving as concerns increase of shelf-life although an inhibition of bacterial growth of up to six days was noticed.

In the United Kingdom, some trials were conducted on several sea-fish species, but research was carried out mainly in the field of wholesomeness. Several series of toxicity tests were conducted and special attention was also paid to the botulism hazard in irradiated fish. These studies showed the safety of irradiated fish to be guaranteed.

4.2. Present and future programmes.

In Belgium, no experiments on irradiation of wet fish are actually being carried out. A project for future research on prepacked cod, whiting plaice and skate is being considered.

The Netherlands will finish their present programme on irradiation of prepacked cod and plaice fillets in 1975. No further experiments are planned.

In the Federal Republic of Germany the continuation of the studies on fish depends on the outcome of present experiments at sea and on the interest shown by the fishing industry.

In the United Kingdom currently no work is going on relating to the irradiation of fish nor is it intended to start any in the foreseeable future.

In Ireland, no experiments were carried out and no research is planned in the immediate future.

4.3. Feasibility of EEC research programmes.

The United Kingdom is not in favour of an EEC programme on fish irradiation. This country is of the opinion that enough work has been done on the technological aspects of fish irradiation and that it is not worthwhile to proceed further in this direction until the question of wholesomeness of irradiated fish (and irradiated food in general) has been resolved. This is the aim and object of the "International Project in the Field of Food Irradiation" based at Karlsruhe. Because wholesomeness testing is now so expensive, the United Kingdom feels that any EEC work ought to be properly integrated with the work of this International Project to which all member-countries of the EEC already subscribe.

Belgium, the Netherlands and the Federal Republic of Germany could consider a common technological programme on irradiation of fish. Due to cut backs of staff and funds however, they are not prepared to carry out such a programme without substantial financial support from the CEC.

Furthermore, it is their opinion that such programme can only give the best practical results if clearance is given in the member countries for sale of irradiated fish. This problem should be dealt with by priority and could also form a basis for a further common action.

Ireland is not in a position to say if it would be possible to set up an EEC programme but if one were set up, she would like to participate in its deliberation so as to keep in close contact with its work and to be kept informed of developments.

5. Conclusions.

Radurization of fish has been proved to increase shelf-life of wet fish significantly and to offer interesting commercial possibilities.

However, further technological research, especially on pilot-scale, is still necessary to optimalize the irradiation techniques. Most EEC member countries are willing to co-operate in this field provided that substantial funds are made available. They feel however that the question of wholesomeness of irradiated fish and its clearance for sale should be resolved first.

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