TID-25211

OPERATIONS OF THE MARINE PRODUCTS
DEVELOPMENT IRRADIATOR

Annual Report, October 1, 1966—September 30, 1967

January 1968

Technological Laboratory
Bureau of Commercial Fisheries
Gloucester, Massachusetts
LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
OPERATIONS OF THE MARINE PRODUCTS DEVELOPMENT IRRADIATOR

Prepared by:

J.D. Kaylor*, E.J. Murphy**, J.B. Huff***, J.A. Holston****

for

Division of Isotopes Development
U.S. Atomic Energy Commission

Contract Number: At(49-11)-1889

Annual Report For The Period
October 1, 1966 to September 30, 1967

January, 1968

Bureau of Commercial Fisheries
Technological Laboratory
Gloucester, Massachusetts

* Supervisory Food Technologist
** Food Technologist
*** Health Physicist
**** Laboratory Director

This document is
PUBLICLY RELEASABLE

Authorizing Official
Date: 08/07/2007

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
SUMMARY

This report covers the work done by members of the Marine Products Development Irradiator of the Bureau of Commercial Fisheries Technological Laboratory, Gloucester, Massachusetts. The work was performed under Atomic Energy Commission Contract No. At(49-11)-1889 and covers continuing programs aimed particularly at establishing the commercial feasibility of irradiating fishery products to obtain an increased extension in shelf life.

A practical approach to the application of ionizing radiation to fish demands that the desired species be adequately available at a level of freshness high enough to justify the irradiation treatment. Our studies have shown that when certain criteria of freshness are applied to randomly chosen Boston haddock landings, 78 percent of this species are found to be of a suitable freshness level. This same study also showed that a recently developed objective method of assessing freshness of haddock exhibited a highly significant degree of correlation with subjective judgments made by highly skilled fish examiners. A breakdown also shows that winter trips are productive of higher quality fish than are summer trips, not so much because of the lower temperature, but because the trips are shorter.

Some of the most significant of our findings on the commercial feasibility of irradiating fillets are as follows:
Current distribution systems for fresh fish have been shown to be suitable for shipments of irradiated fillets. These systems ensure the delivery of a radiation-treated product of high quality under commercial conditions of shipment. Intensive organoleptic testing demonstrated an extension of shelf life of a minimum of 1 week with such extension at a high level of quality. Fillets processed under commercial conditions spoil in a normal recognizable manner by developing readily perceptible objectionable odors. Cod and haddock fillets of commercial origin, when irradiated, will routinely result in a reduction of bacterial numbers of one to two log cycles or of from 90 to 99 percent. This reduction of one to two log cycles was still observable even after the return of the fillets to Gloucester after shipment to distant points in the nation. The studies have shown that cod and haddock fillets when irradiated on a commercial scale respond well to the radiation treatment. Data obtained from our studies demonstrate that a radiation dose of 100 to 200 kilorads at the point of minimum absorption will provide a maximum of shelf life extension without undesirable changes in cod and haddock fillets.

Studies on four different methods of cooking irradiated fillets showed that there were few organoleptic differences noted in flounder, haddock and ocean perch fillets until 21 days of storage at 38°F. The study also showed a preference for certain methods of cooking.

ii
Other studies have shown that when commercially produced fresh-shucked eastern oysters are subjected to ionizing radiation at from 50 to 200 kilorads, the amount of free liquid that accumulates is above that legally permitted for nonirradiated fresh-shucked oysters. Reduction of bacterial numbers of oysters irradiated at 100 and 200 kilorads amounts to three or more log cycles.

Plans for modification of the present radioactive source to accommodate replenishment of the source with cobalt-60 of high specific activity have been made and a description of cost benefits from on-site loading techniques is presented.
IRRADIATOR PERSONNEL

John D. Kaylor
Program Leader

John B. Huff
Health Physicist

Edward J. Murphy
Food Technologist

William W. Lafond
Physical Science Technician

Jason Chamberlain
Physical Science Aid

Ralph K. Mayo
Physical Science Aid
ACKNOWLEDGMENTS

The authors wish to give special recognition with thanks to Mr. Leonard Galanter of the Radiation Engineering Section of the Radiation Division of the Brookhaven National Laboratory for his careful study of Section 7 and his suggestions on self absorption.

The authors wish to acknowledge the expertise of John C. Steele in his conduct of the summer and autumn part of the Fresh Fish Survey and the capable assistance given to him by Richard W. Cushman.

We also wish to give recognition to Joseph H. Carver for his cheerful willingness to undergo with us the rigors of the winter sampling campaign of the Fresh Fish Survey.

In general, we extend our sincere appreciation to all the professional laboratory personnel who gave of their time on weekends to participate in taste tests so there would be no hiatus in our schedule of the Commercial Benefit Shipping Studies. In particular, we wish to single out Mary Haskins for her faultless scheduling and preparation of the taste tests. The liaison and timing of the tests was of an exemplary order.

We wish also to recognize the contribution of Joseph M. Lee in keeping the MPDI in smooth running condition at all times. His skillful maintenance and repair work averted many operational difficulties.
To William W. Lafond go our thanks for the long hours of dosimetry and operational duties of the irradiator required in the Commercial Benefit Shipping Study.

Our sincere thanks also go to Mrs. Jean Knight and Mrs. Majorie Oakes, Clerk-Stenographer and Clerk-Typist, respectively, for their assiduous efforts in preparing this report.

To Jason Chamberlain and Ralph K. Mayo, students in the Co-operative Work-Study Program of Northeastern University, go our appreciation for their ever alert interest and willingness to participate in all phases of the MPDI program.
CONTENTS

<table>
<thead>
<tr>
<th>SUMMARY</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRRADIATOR PERSONNEL</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF TABLES AND LEGENDS</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF GRAPHS</td>
<td>xii</td>
</tr>
</tbody>
</table>

SECTION 0. GENERAL INTRODUCTION

0.1 PURPOSE OF THE MPDI 0-1
0.2 FOOD LAWS AND RADIATION 0-1
0.3 PROOF OF EFFECTIVENESS OF IRRADIATION 0-2

SECTION 1. PAST AND PRESENT WORK

1.0 INTRODUCTION 1-1
1.1 PAST WORK 1-1
1.2 PRESENT WORK 1-2

SECTION 2. FRESH FISH SURVEY

2.0 INTRODUCTION 2-1
2.1 BACKGROUND OF TRAWLER FLEET 2-2
2.2 PROCEDURE 2-2

2.2.1 Sampling
Before Discharge, Aboard Trawlers 2-2
After Discharge, Ashore 2-3

2.2.2 Objective Measurements
Electronic Fish Tester 2-4
Temperature Measurements 2-5
### 2.2.3 Subjective Measurements
Organoleptic Evaluations

### 2.3 RESULTS AND DISCUSSION

#### 2.3.1 Specific
- **Electronic Fish Tester**
- Temperature Measurements
- Organoleptic Examinations

#### 2.3.2 Correlations

<table>
<thead>
<tr>
<th>A. Per Trawler</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic vs. Organoleptic</td>
<td>2-14</td>
</tr>
<tr>
<td>Organoleptic vs. Temperature</td>
<td>2-14</td>
</tr>
<tr>
<td>Within Organoleptic</td>
<td>2-14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. All Trawlers Combined</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic vs. Temperature</td>
<td>2-15</td>
</tr>
<tr>
<td>Electronic vs. Organoleptic</td>
<td>2-15</td>
</tr>
<tr>
<td>Organoleptic vs. Temperature</td>
<td>2-16</td>
</tr>
<tr>
<td>Within Organoleptic</td>
<td>2-16</td>
</tr>
</tbody>
</table>

### 2.4 CONCLUSIONS

### 2.5 REFERENCES

---

### SECTION 3. COMMERCIAL BENEFIT SHIPPING STUDIES

#### 3.0 INTRODUCTION

#### 3.1 BACKGROUND DATA AND INFORMATION

#### 3.2 OBJECTS OF STUDIES

#### 3.3 PROCEDURE

<table>
<thead>
<tr>
<th>3.3.1 Long Distance Shipments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>General Shipments</td>
<td>3-9</td>
</tr>
<tr>
<td>Particular Shipment - Seattle, Jacksonville</td>
<td>3-16</td>
</tr>
</tbody>
</table>

#### 3.4 RESULTS

<table>
<thead>
<tr>
<th>3.4.1 Intra-agency Shipments</th>
<th></th>
</tr>
</thead>
</table>

#### 3.5 CONCLUSIONS

#### 3.6 REFERENCES
SECTION 4. PALATABILITY STUDY

4.0 INTRODUCTION 4-1
4.1 PROCEDURE 4-1
4.2 RESULTS 4-2

SECTION 5. IRRADIATED FRESH OYSTERS

5.0 INTRODUCTION 5-1
5.1 BACKGROUND INFORMATION 5-1
5.2 PROCEDURE 5-2
  5.2.1 Division of Work 5-2
  5.2.2 Objective Measurements 5-3
     Measurement of Free Liquid 5-3
     Measurement of pH 5-3
     Measurement of Bacteriological Activity 5-4
  5.2.3 Subjective Measurements 5-5
     Organoleptic Examinations 5-5
5.3 RESULTS AND DISCUSSION 5-6
5.4 CONCLUSIONS AND RECOMMENDATIONS 5-12
5.5 REFERENCES 5-13

SECTION 6. OPERATIONS AND SERVICES

6.0 INTRODUCTION 6-1
6.1 SCHEDULED WORK 6-1
  6.1.1 Present work 6-1
  6.1.2 Future Work 6-2
6.2 UNSCHEDULED WORK 6-5
SECTION 7. SOURCE REPLENISHMENT

7.0 INTRODUCTION 7-1
7.1 PRELIMINARY CALCULATIONS 7-1
7.2 SOURCE STRIP ORIENTATION 7-4
7.3 TENTATIVE PROCEDURE 7-9
7.4 CONCLUSIONS 7-11
7.5 REFERENCES 7-12

APPENDIX 1 ORGANOLEPTIC PROCEDURES AND EVALUATIONS
APPENDIX 2 MICROBIOLOGICAL METHODS AND MATERIALS
APPENDIX 3 GRAPHS OF SHELF LIFE, BACTERIAL REDUCTION AND TOTAL PLATE COUNTS OF BACTERIA
APPENDIX 4 FRESH FISH SURVEY ORGANOLEPTIC CRITERIA
LIST OF FIGURES

2.2.3-1 Fresh Fish Survey Score Sheet Form 2-8
1. Commercial Benefit Shipment, Jacksonville, Fla. 3-10
2. Commercial Benefit Shipment, Seattle, Wash. 3-11
3. Commercial Benefit Shipment, Jacksonville, Fla. Map Showing Routes of Commercial Benefit Shipping Studies 3-12
7.2.1-1 Proposed Source Holder for MPDI 7-5
7.2.1-2 Modified Source Frame for MPDI 7-7

LIST OF TABLES AND LEGENDS

Number | TABLE/LEGEND | PAGE
--- | --- | ---
2.3.1-1 | Freshness Survey of Boston Haddock | 2-10
2.3.1-2 | Seasonal Differences of Trawler Landings | 2-13
3.3.1-1 | Spoilage Characteristics of Irradiated Cod Fillets | 3-6
3.3.1-2 | Flow Chart of Experimental Design | 3-14
3.3.1-3 | Legend for Flow Chart | 3-15
3.4.1-1 | Bacterial Reductions--Cod and Haddock Fillets | 3-20
3.4.1-2 | Taste Panel Response to Odor | 3-25
3.4.1-3 | Taste Panel Response to Flavor | 3-26
5.3.1-1 | Per Cent Free Liquid Development of Irradiated Oysters | 5-7
5.3.1-2 | pH Measurements of Irradiated and Nonirradiated Oysters | 5-8
5.3.1-3 | Bacterial Reductions in Irradiated and Nonirradiated Oysters | 5-11
6.1.1-1 | Irradiation Services October 1, 1966, to September 30, 1967 | 6-3
LIST OF GRAPHS

1. Reduction of Total Bacteria - Haddock
2. Reduction of Total Bacteria - Cod
3. Shelf Life of Irradiated Cod Fillets
4. Shelf Life of Irradiated Haddock Fillets
5. Shelf Life of Irradiated Haddock Fillets Held at MPDI
6. Shelf Life of Irradiated Haddock Fillets Returned from Jacksonville
7. Shelf Life of Irradiated Haddock Fillets Held at MPDI
8. Shelf Life of Irradiated Haddock Fillets Tested at Seattle
9. Shelf Life of Irradiated Haddock Fillets Returned from Seattle
10. Shelf Life of Irradiated Haddock Fillets Held at MPDI
11. Shelf Life of Irradiated Haddock Fillets Returned from Jacksonville
12. Shelf Life of Irradiated Cod Fillets Held at MPDI
13. Shelf Life of Irradiated Cod Fillets Returned from Jacksonville
14. Shelf Life of Irradiated Cod Fillets Held at MPDI
15. Shelf Life of Irradiated Cod Fillets Tested at Seattle
16. Shelf Life of Irradiated Cod Fillets Returned from Seattle
17. Shelf Life of Irradiated Cod Fillets Held at MPDI
18. Shelf Life of Irradiated Cod Fillets Returned from Jacksonville
19. Total Plate Counts Haddock Fillets Held at MPDI
20. Total Plate Counts Haddock Fillets Returned from Jacksonville
21. Total Plate Counts Haddock Fillets Held at MPDI
22. Total Plate Counts Haddock Fillets Tested at Seattle
23. Total Plate Counts Haddock Fillets Returned from Seattle
24. Total Plate Counts Haddock Fillets Held at MPDI
25. Total Plate Counts Haddock Fillets Returned from Jacksonville
26. Total Plate Counts Cod Fillets Held at MPDI
27. Total Plate Counts Cod Fillets Returned from Jacksonville
28. Total Plate Counts Cod Fillets Held at MPDI
29. Total Plate Counts Cod Fillets Tested at Seattle
30. Total Plate Counts Cod Fillets Returned from Seattle
31. Total Plate Counts Cod Fillets Held at MPDI
32. Total Plate Counts Cod Fillets Returned from Jacksonville
33. Total Aerobic Counts Cod Fillets Nonirradiated
34. Total Aerobic Counts Cod Fillets Irradiated
35. Number Proteolytic Organisms Irradiated and Nonirradiated
36. Panel Estimates of Age of Nonirradiated Cod Fillets
37. Panel Estimates of Age of Irradiated Cod Fillets
SECTION 0.

GENERAL INTRODUCTION
CONTENTS

0.1 PURPOSE OF THE MPDI ........................................ 0-1
0.2 FOOD LAWS AND RADIATION .................................. 0-1
0.3 EFFECTIVENESS OF IRRADIATION .............................. 0-2
SECTION 0. GENERAL INTRODUCTION

0.1 Introduction

The purpose in establishing the Marine Products Development Irradiation (MPDI) at Gloucester, Massachusetts, by the U.S. Atomic Energy Commission (AEC) in cooperation with the Bureau of Commercial Fisheries of the Fish and Wildlife Service of the U.S. Department of the Interior was to determine if it is commercially feasible to irradiate fresh seafoods on a large scale and ship them by common carrier, under prevailing conditions of transportation, to distant markets and still retain a high degree of freshness for normal marketing practices.

0.2 FOOD LAWS AND RADIATION

Present food laws are restrictive and demand prior proof of safety and effectiveness in respect to what the law defines as food additives. Such strictures are designed for the protection of the consuming public and deserve the support of all food processors.

Radiation processing or treatment of foods constitutes a special type of food additive as now defined in the law. It states that a food that is intentionally subjected to irradiation is held to be adulterated unless such irradiation is in accordance with a special regulation that exempts it. Present food laws demand that a food additive be proved safe and...
that the additive (radiation) must accomplish the intended effect.

Proving the safety of irradiated seafoods does not come within the purview of the MPDI programs. This aspect will be treated by other researchers. Proving the effectiveness of irradiation applied to seafoods, however, is very much within the competence of the MPDI staff. Our principal efforts in the period covered in this report have been concerned with the effectiveness of radiation when applied to commercially produced fillets of cod and haddock. Supplementary to this was the proper and efficient operation of the irradiator itself.

0.3 EFFECTIVENESS

The effectiveness of the irradiation treatment was determined by shipping irradiated and nonirradiated fillets under commercial conditions over great distances; by sensory evaluations; and by microbiological tests. Throughout the entire effectiveness study and operating aspects of the MPDI, great emphasis was placed upon conducting them on a scale of truly commercial size. The information obtained from the effectiveness study and irradiator operations will aid in supplying the data needed to prepare a food additive petition for irradiated seafoods.
SECTION 1.

PAST AND PRESENT WORK
## CONTENTS

1.0 INTRODUCTION ........................................ 1-1  
1.1 PAST WORK ........................................... 1-1  
1.2 PRESENT WORK ......................................... 1-2
1. PAST AND PRESENT WORK

1.0 Introduction

The MPDI will have been in operation two and a half years at the end of the period covered in this report.

During this time we have directed most of our efforts toward providing the commercial feasibility of irradiation treatment to extend shelf life of seafoods. At the same time, we have gained valuable experience in the operation of an irradiator of unique design and capabilities.

1.1 Past Work

All the work of this unit in the period prior to that covered by this report was, of necessity, one of an exploratory and development nature. Our first concern was to determine to what extent the irradiator compared with design performance. We have now had enough experience to determine its operating potential and its limitations.

The outstanding feature of the MPDI design is its vertical labyrinth through which the product is conveyed into the cell for irradiation. In the interest of economy, the vertical labyrinth was chosen because it required considerably less floor space and less construction cost compared with horizontal labyrinths.

Despite the minor conveyor malfunctions for the first year and a half, the conveyor has now been made to operate reliably.
Jobs involving constant operation for over 30 hours without interruption can now be made.

A survey of commercial methods of handling fresh non-irradiated fillets has been completed. The primary emphasis in this study was to determine the temperature pattern of conventionally wrapped fillets in the chain of distribution under regular commercial shipping conditions. The data suggest that present commercial practices offer no obstacle to the future of irradiated seafoods.

1.2 Present Work

It is the declared policy of the Food and Drug Administration that petitions for clearance of irradiated foods will not be granted until, among other things, preliminary commercial-type shipping and storage studies have been completed. These studies for irradiated fillets require (1) objective criteria by which the products under study are to be measured, (2) sufficient size of sample, (3) records of radiation dose measurement, (4) attainment of the technical effect (extension of commercial shelf life), (5) statistical procedures to be used in evaluating the data, and (6) supporting microbiological data.

We have been granted permission by the Food and Drug Administration to perform shipping studies on commercially important seafoods such as fillets, clams, crabs, oysters, and shrimp. Labeling requirements have been met so that interstate shipments of irradiated investigational seafoods will be in

The main effort of the present work is directed at showing the commercial feasibility of irradiating commercial size shipments of fillets and shipping them under commercial conditions of transportation to destinations which would normally be extreme for distribution of fresh fish. These studies show that irradiated fillets may be shipped to any consuming area in the nation and still guarantee a shelf life that ensures no disruption to normal marketing practices.

We have also investigated the effect of gamma radiation on commercially packed fresh oyster meats. The purpose of this work was to show that radiation caused an unexpected increase of free liquid from the oyster meats.

An additional piece of work of an unscheduled nature was that of devising a method of using our present radioactive sources in combination with proposed additional sources of higher specific activity. The object of this addition would be to upgrade our source to its original design strength.
SECTION 2.

FRESH-FISH SURVEY

by

John D. Kaylor and Edward J. Murphy
2.0 INTRODUCTION 2-1

2.1 BACKGROUND OF TRAWLER FLEET 2-2

2.2 PROCEDURE 2-2

2.2.1 Sampling 2-2
   Before Discharge, Aboard Trawlers 2-3
   After Discharge, Ashore 2-4

2.2.2 Objective Measurements 2-4
   Electronic Fish Tester 2-5
   Temperature Measurements 2-6

2.2.3 Subjective Measurements 2-6
   Organoleptic Evaluations 2-7

2.3 RESULTS AND DISCUSSION 2-9

2.3.1 Specific 2-9
   Electronic Fish Tester 2-9
   Temperature Measurements 2-12
   Organoleptic Evaluations 2-12

2.3.2 Correlations 2-14
   A. Per Trawler 2-14
      Electronic vs Temperature 2-14
      Electronic vs Organoleptic 2-14
      Organoleptic vs Temperature 2-14
      Within Organoleptic 2-14
B. All Trawlers Combined
   Electronic vs Temperature
   Electronic vs Organoleptic
   Organoleptic vs Temperature
   Within Organoleptic

2.4 CONCLUSIONS

2.5 REFERENCES
SECTION 2. FRESH FISH SURVEY

2.0 Introduction

Very early in the MPDI program, we decided that if the irradiation treatment for extending the shelf life of fresh fillets offered much promise, we would logically be obliged to determine the freshness level of those species of fish that would be likely to be irradiated. Demersal fish constitute the most valuable fin fish in New England, Boston being the center for such landings. Haddock, followed by cod, is the species landed in greatest value and abundance in Boston. Because these two species are closely related biologically and are handled and processed identically, except for labeling, haddock was the species chosen to be studied.

If irradiation treatment of fillets is to be successful, much will depend upon the proportion of fish possessing a degree of freshness high enough to justify using the radiation-preservation treatment. Obviously, irradiation cannot be expected to improve the initial freshness of a fish any more than can any other method of food preservation. It can only prolong the freshness it possessed when it was irradiated. Ronsivalli and Slavin\(^1\) of this laboratory have shown that the fresher the fillets are when they are irradiated, the longer will be their extension of shelf life. The purpose of the work reported here, therefore, was to determine the proportion of haddock as landed at Boston that are of a freshness level high
2m+8agh to jusGify the irradiation treatment.

2.1 Background of Trawler Fleet

The Boston fishing fleet is divided into inshore vessels and offshore vessels. Our main concern was with the offshore vessels because they stay out on the fishing banks longer and because they land most of the fresh fish. The offshore fleet lands fish older than those landed by the inshore fleet. The freshness of fish is not always directly proportional to the days of caught age. Such factors as method of handling fish on deck, rapidity of stowing them and manner of icing them play an important part in the freshness level of the fish in any particular trip. All things being equal, however, we can reasonably expect to find a lower level of freshness in fish that are older in terms of days of caught age. For this reason we tried to sample, as much as possible, the large and medium size trawlers that customarily stay on the fishing banks for a longer period of time. The size classification of the vessels runs according to the gross tonnage. Large trawlers are classified as being more than 150 tons whereas the small trawlers are classified as being from 50 gross tons downward.

2.2 Procedure

2.2.1 Three major problems had to be overcome before one could assure that the sampling plan was practical. The first was to obtain a sample of such size that reliable conclusions could be drawn. The second was that of cost, partic-
ularly the cost of manpower. The third was that the fish were private property and that we had no legal or any right whatever to examine them.

Before starting the survey, we found that the sampling might best be done in the hold of the vessel before the fish were discharged. Sampling was to be done from each pen of the vessel. The sampling plan devised by one of the Bureau of Commercial Fisheries statisticians was as follows: for trips of 20,000 to 40,000 pounds, take sample of 25 or not less than 20 fish from each pen; for trips of 40,000 to 60,000 pounds, take 20 fish or not less than 15 from each pen; and for trips of 60,000 to 100,000 pounds, take 15 fish or not less than 10 fish from each pen. We tried this sampling plan for three trips each of Vessels 1 and 6 and part of one trip of Vessel 2 (Table 2.3.1-1) in the winter months and found that it was too hazardous, not only for ourselves who were doing the sampling but also for the lumpers who break down the pens and discharge the fish. We abandoned the on-ship sampling plan after one of the lumpers was killed in the same type of an accident that nearly killed one of us.

Although sampling in the hold of the trawler possessed some advantages, such as being able to arrive at swift judgments concerning the manner and method of stowage and icing of the catch, it contributed little over and above to that of recognizing which skippers ran a tight ship in respect to care
of their catch. Some captains pride themselves in being able
to catch fish. Other captains may not be as skillful in "get-
ting on fish" but are more conscientious in taking better care
of what they do catch.

Because the principal objective was to determine the
general level of freshness of haddock, rather than to determine
who did the best job or how it was accomplished, another method
of sampling was adopted. This method was performed on the
wharf itself rather than in the vessel. Wharf sampling was
done by taking, at random, a haddock dumped from the trawler's
canvas discharge basket into the weigh box on the wharf. At
the end of the examination, the sample fish was replaced in
the weigh box. This sequential sampling method was started
in August and continued into early November. Between both
sampling methods, the principal seasonal temperature extremes
were covered and 34 percent of the medium and large size
trawlers of the Boston trawler fleet were sampled.

The wharf-sampling plan had the advantage of reducing
costs. We found that two men sampling on shore could do the
work of four men required by on-ship sampling. An extra bonus
was that wharf sampling enabled the two-man crew to obtain
just about double the number of samples obtained by the four-
man crew.

2.2.2 Objective Measurements

No generally accepted objective test for freshness of
fishery products is available. Many methods have been proposed, but none can yet produce data equal in reliability to that obtained by trained inspectors. Recently, interest in the use of a novel objective method of assessing freshness has increased. A small, portable battery-operated electronic instrument for measuring freshness of fish was developed in the Federal Republic of Germany and has been tested in this country on various species of fish by Nelson\(^2\) and Carver\(^3\). The principle of the device is based upon the change in electrical conductivity of fish tissue as it degenerates with time. The instrument has a pair of carbon electrodes, arranged in forceps fashion, that are placed on opposite sides of the haddock at the lateral line below the second dorsal fin. Measurement is obtained by reading a dial that registers conductivity on a scale of from 0 to 99. The higher the reading, the fresher the fish.

We used this instrument to determine how the conductivity data obtained correlated with the judgment of expert fish examiners. The instrument is easy to operate and can be used by non-technical personnel and does not involve destructive sampling of the fish. A survey of this magnitude afforded a splendid opportunity to obtain thousands of measurements, each of which would be compared with many subjective judgments made at the same time on the same sample fish.

Icing practices in the holds of trawlers have probably
been the cause of more discussion and speculation in respect to freshness of landed fish than has any other phase of the fishing operation. This survey afforded an unparalleled opportunity to obtain thousands of temperature measurements of commercially caught haddock during winter, summer, and fall months. Measurements were made on each fish sample at that point of discharge from the hold of the vessel into weigh boxes on the wharf for all the samples taken during the summer and fall trips. Temperature measurements on winter-caught fish were made in the hold of the vessel prior to discharge.

We inserted stainless steel temperature sensing probes into each haddock sample immediately forward of the first dorsal fin through the thick fleshy portion down to and about half an inch along the side of the backbone. Each probe was connected to a Model 42 SF Tele-Thermometer (Yellow Springs Instrument Co.). This instrument had an accuracy of ±1°F. Each sample fish reading was allowed to come to equilibrium before the temperature was recorded.

2.2.3 Subjective Measurements

Assessment of freshness and other quality factors of fresh fish is more an art than a science, despite the desire of fish inspectors to be able to reduce freshness judgments to non-controversial objective measurements. In planning this survey, we developed criteria for freshness and other quality characteristics. They were reduced to four categories and they
were assigned numerals indicating their value. In this survey, only the very freshest or most perfect fish would be assigned a value of one for each organoleptic characteristic such as odor, texture, condition of eyes, etc., with the poorest rating being assigned a value of four. The reduction to four categories fitted in with a successful system used formerly in private industry, and it also was designed for use in automatic data processing equipment. Examiners on this survey were selected for their experience. Each examiner had not less than 25 years experience in the inspection and grading of fish and other seafood products, principally in private industry, but also in government service. Figure 2.2.3-1 illustrates the form used for both objective and subjective judgments. See Appendix 4 for an explanation of the criteria used for judging freshness and quality of fresh fish.
FIGURE 2.2.3-1 FRESH FISH SURVEY SCORE SHEET

Species _______ Vessel _______ Port _______ Trip No. _______ Lbs. _______ Length Trip _______

Broker _______ Refrig. _______ Captain _______ Analyst _______ Catch Area _______

<table>
<thead>
<tr>
<th>PEN NUMBER</th>
<th>SAMPLE NUMBER</th>
<th>FISH TESTER</th>
<th>FISH TEMP.</th>
<th>DAMAGE</th>
<th>SKIN</th>
<th>GILLS</th>
<th>TEXTURE</th>
<th>ODOR</th>
<th>EYES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.3 Results and Discussion

2.3.1 The survey was made in two different periods of the year. The first part of the survey was performed aboard the trawlers during the winter months of January and February. The second part was performed ashore during the late summer and early fall seasons. Thus the survey embraced most of the temperature extremes common to this fishery. It also permitted us to survey 34 percent of the offshore trawlers, from one to five times for each vessel.

Table 2.3.1-1 shows that, in every trawler sample, the electronic fish tester gave average readings of about 30 or below if the fish failed to pass the criteria of acceptance. The examiners judged that mature haddock exhibiting readings of 32 and higher were suitable material for irradiation almost without exception. They found that scrod haddock (immature) exhibiting readings of 40 and higher were suitable for irradiation almost without exception. Scrod haddock showing readings below 20 were always indicative of fish unsuitable for irradiation except for about 5 percent, which passed organoleptic inspection. Conversely, the examiners found that about 5 percent of the haddock with electronic readings of 40 or higher failed to pass organoleptic inspection. The only gray area concerned scrod haddock exhibiting readings of 32 to about 40. The examiners judged that 70 percent of the fish in this category would readily pass the minimum
### Table 2.3.1-1

<table>
<thead>
<tr>
<th>TRAWLER</th>
<th>DATE</th>
<th>SAMPLES</th>
<th>FISH TEMP</th>
<th>FISH DAMAGE</th>
<th>FISH SKIN</th>
<th>FISH EYES</th>
<th>GILLS</th>
<th>TEXTURE</th>
<th>ODOR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TESTER</td>
<td>TEMP.</td>
<td>DAMAGE</td>
<td>SKIN</td>
<td>EYES</td>
<td>GILLS</td>
<td>TEXTURE</td>
</tr>
<tr>
<td>1</td>
<td>Jan 12</td>
<td>63</td>
<td>45.0</td>
<td>32.2</td>
<td>1.1</td>
<td>2.0</td>
<td>1.9</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Jan 26</td>
<td>80</td>
<td>45.6</td>
<td>32.4</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Feb 8</td>
<td>90</td>
<td>50.9</td>
<td>32.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.7</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Sept 9</td>
<td>180</td>
<td>37.9</td>
<td>35.4</td>
<td>1.6</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Sept 22</td>
<td>160</td>
<td>28.7</td>
<td>35.4</td>
<td>1.8</td>
<td>2.2</td>
<td>2.5</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>Feb 9</td>
<td>32</td>
<td>43.9</td>
<td>32.2</td>
<td>1.0</td>
<td>1.0</td>
<td>1.1</td>
<td>1.5</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Aug 31</td>
<td>120</td>
<td>27.6</td>
<td>34.0</td>
<td>1.6</td>
<td>2.1</td>
<td>2.3</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Sept 13</td>
<td>180</td>
<td>37.5</td>
<td>34.7</td>
<td>1.6</td>
<td>1.9</td>
<td>2.1</td>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Oct 5</td>
<td>111</td>
<td>28.3</td>
<td>33.6</td>
<td>2.0</td>
<td>2.2</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Nov 1</td>
<td>65</td>
<td>33.4</td>
<td>35.3</td>
<td>2.0</td>
<td>2.2</td>
<td>2.4</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>3</td>
<td>Aug 30</td>
<td>180</td>
<td>--</td>
<td>34.0</td>
<td>1.6</td>
<td>2.1</td>
<td>2.3</td>
<td>2.6</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Sept 8</td>
<td>180</td>
<td>36.8</td>
<td>35.4</td>
<td>1.6</td>
<td>2.1</td>
<td>2.1</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Sept 28</td>
<td>160</td>
<td>30.4</td>
<td>33.9</td>
<td>2.2</td>
<td>2.0</td>
<td>2.4</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Oct 13</td>
<td>105</td>
<td>29.3</td>
<td>33.6</td>
<td>2.0</td>
<td>2.1</td>
<td>2.4</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Nov 3</td>
<td>65</td>
<td>29.8</td>
<td>34.6</td>
<td>1.8</td>
<td>2.3</td>
<td>2.6</td>
<td>2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
<td>Aug 26</td>
<td>60</td>
<td>--</td>
<td>36.2</td>
<td>1.7</td>
<td>2.1</td>
<td>2.4</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Oct 6</td>
<td>109</td>
<td>33.0</td>
<td>32.8</td>
<td>2.0</td>
<td>2.1</td>
<td>2.1</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>Oct 18</td>
<td>131</td>
<td>37.2</td>
<td>36.3</td>
<td>1.8</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Oct 28</td>
<td>15</td>
<td>42.6</td>
<td>34.0</td>
<td>1.7</td>
<td>1.4</td>
<td>1.4</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>5</td>
<td>Sept 7</td>
<td>160</td>
<td>34.3</td>
<td>36.3</td>
<td>1.5</td>
<td>2.1</td>
<td>2.2</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Sept 16</td>
<td>100</td>
<td>34.1</td>
<td>34.1</td>
<td>1.7</td>
<td>2.1</td>
<td>2.2</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Sept 27</td>
<td>100</td>
<td>30.4</td>
<td>34.3</td>
<td>1.9</td>
<td>2.1</td>
<td>2.4</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Oct 7</td>
<td>85</td>
<td>28.9</td>
<td>32.8</td>
<td>2.1</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Table 2.3.1-1 (cont'd.)

Freshness survey of Boston haddock

<table>
<thead>
<tr>
<th>TRAWLER</th>
<th>DATE</th>
<th>SAMPLES</th>
<th>FISH TESTER</th>
<th>TEMP.</th>
<th>DAMAGE</th>
<th>SKIN</th>
<th>EYES</th>
<th>GILLS</th>
<th>TEXTURE</th>
<th>ODOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Jan 18</td>
<td>46</td>
<td>36.0</td>
<td>32.4</td>
<td>1.3</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Feb 1</td>
<td>62</td>
<td>49.0</td>
<td>32.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Feb 10</td>
<td>80</td>
<td>48.0</td>
<td>33.7</td>
<td>1.0</td>
<td>1.0</td>
<td>1.8</td>
<td>1.9</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>Aug 21</td>
<td>160</td>
<td>--</td>
<td>36.0</td>
<td>1.6</td>
<td>2.1</td>
<td>2.9</td>
<td>2.9</td>
<td>2.6</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Sept 23</td>
<td>60</td>
<td>35.4</td>
<td>37.4</td>
<td>1.6</td>
<td>2.1</td>
<td>2.4</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Oct 11</td>
<td>107</td>
<td>38.5</td>
<td>34.6</td>
<td>1.9</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>8</td>
<td>Aug 25</td>
<td>172</td>
<td>--</td>
<td>34.2</td>
<td>1.8</td>
<td>2.1</td>
<td>2.4</td>
<td>2.5</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Sept 2</td>
<td>160</td>
<td>38.8</td>
<td>33.7</td>
<td>1.9</td>
<td>1.9</td>
<td>1.8</td>
<td>2.1</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Nov 4</td>
<td>120</td>
<td>43.6</td>
<td>36.6</td>
<td>1.8</td>
<td>2.0</td>
<td>1.7</td>
<td>1.7</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>9</td>
<td>Aug 27</td>
<td>120</td>
<td>--</td>
<td>36.1</td>
<td>1.6</td>
<td>2.3</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Oct 4</td>
<td>107</td>
<td>32.0</td>
<td>33.4</td>
<td>1.9</td>
<td>2.2</td>
<td>2.4</td>
<td>2.2</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>10</td>
<td>Oct 8</td>
<td>100</td>
<td>36.1</td>
<td>33.5</td>
<td>1.8</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Nov 2</td>
<td>71</td>
<td>27.0</td>
<td>33.2</td>
<td>2.1</td>
<td>2.3</td>
<td>2.5</td>
<td>2.6</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>11</td>
<td>Aug 24</td>
<td>150</td>
<td>--</td>
<td>34.9</td>
<td>1.9</td>
<td>2.1</td>
<td>2.4</td>
<td>2.9</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>12</td>
<td>Oct 14</td>
<td>100</td>
<td>36.1</td>
<td>34.0</td>
<td>2.1</td>
<td>2.1</td>
<td>2.0</td>
<td>2.1</td>
<td>2.1</td>
<td>1.9</td>
</tr>
<tr>
<td>13</td>
<td>Sept 1</td>
<td>160</td>
<td>32.0</td>
<td>33.9</td>
<td>1.6</td>
<td>2.1</td>
<td>2.3</td>
<td>2.5</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>14</td>
<td>Sept 3</td>
<td>92</td>
<td>38.6</td>
<td>33.0</td>
<td>1.3</td>
<td>1.8</td>
<td>1.7</td>
<td>2.0</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>15</td>
<td>Oct 15</td>
<td>100</td>
<td>38.6</td>
<td>--</td>
<td>1.9</td>
<td>2.1</td>
<td>1.8</td>
<td>1.8</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>16</td>
<td>Oct 22</td>
<td>80</td>
<td>42.9</td>
<td>34.1</td>
<td>1.8</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>17</td>
<td>Oct 21</td>
<td>16</td>
<td>36.6</td>
<td>35.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.4</td>
<td>1.2</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4594</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td>36.6</td>
<td>34.2</td>
<td>1.6</td>
<td>1.9</td>
<td>2.0</td>
<td>2.2</td>
<td>2.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>
requirements for quality, with a great likelihood of their passing when higher readings were obtained.

Table 2.3.1-1 shows the temperature measurements of all samples. The temperature of winter-caught fish, as seen in Table 2.3.1-2, is definitely lower than that of summer- and autumn-caught fish, but the difference is relatively small. It should be borne in mind that the "climate" in the fish hold is fairly constant, regardless of the temperature outside. A good example of this relation was the sampling in winter in the hold of the vessels. The temperature in the holds of the trawlers was in the mid-thirties, whereas the dock-side temperatures were in the low teens or lower. (It would have been impossible to have conducted the survey on shore as we did later in more clement weather.)

Sensory examinations formed the basis for all judgments of acceptance or rejection. Six subjective criteria (see Table 2.3.1-1) were used for recording purposes, but only the last four of these criteria (eyes, gills, texture and odor) were used to pass judgment on acceptance or rejection. Table 2.3.1-1 shows the results of sensory examinations and the number of trips failing to meet the minimum freshness requirements for irradiation treatment. Table 2.3.1-2 shows a breakdown of all trips according to seasons. Fish caught in the winter were superior in every category to fish caught in the summer or in the fall.

2-12
Table 2.3.1-2  
SEASONAL DIFFERENCES OF TRAWLER LANDINGS

<table>
<thead>
<tr>
<th>SEASON</th>
<th>TRIPS</th>
<th>SAMPLES</th>
<th>TESTER</th>
<th>TEMP.</th>
<th>DAMAGE</th>
<th>SKIN</th>
<th>EYES</th>
<th>GILLS</th>
<th>TEXTURE</th>
<th>ODOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>WINTER</td>
<td>7</td>
<td>453</td>
<td>45.5</td>
<td>32.6</td>
<td>1.0</td>
<td>1.3</td>
<td>1.5</td>
<td>1.8</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>SUMMER</td>
<td>15</td>
<td>2174</td>
<td>35.4</td>
<td>34.8</td>
<td>1.6</td>
<td>2.0</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>AUTUMN</td>
<td>21</td>
<td>1967</td>
<td>34.1</td>
<td>34.3</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>
2.3.2 When this survey was first undertaken, we were interested in determining what correlation, if any, the computer would find between electronic tester and temperature; electronic tester and organoleptic evaluation; organoleptic evaluation and temperature; and all six organoleptic factors, each one against the remaining five.

The data from each trawler trip were card punched and fed into a computer programmed to give correlations on a trip basis. The results were negative, as expected, on electronic tester versus temperature; they were equivocal on electronic tester versus organoleptic evaluation; and they were negative on organoleptic evaluation versus temperature. The results, however, of comparing any one of the six organoleptic factors against any of its remaining factors were significant but not to the degree the data was thought to show.

The failure of the computer to agree with our assessment of the data puzzled us. In view of the conflict, we requested the service of a statistician to examine the design of the experiment and to suggest improvements. The statistician pronounced the design good but that the computer had not been given the correct information. He suggested that instead of having the computer analyze each trip as a separate population that we have the computer digest all the information as one large population. The reason was that, although the design of the experiment was logical, the differences between the factors of
each trip were probably not large, and the computer could not "see" enough differences to measure and register them. On the other hand, differences between one trip and another were relatively wide as shown in Table 2.3.1-1, and the computer might be able to find correlations in a population of over 37,000 measurements with greater accuracy than, say, with Trawler 4 on its trip of 28 October with only 120 measurements.

Accordingly, all the data were re-programmed and fed back into the computer as one large population instead of as 34 separate populations representing as many trawler trips.

The results were strikingly different. This time the computer could "see" differences that only a skilled inspector could recognize before. (The human intellect is also a good computer and can make instant assessments of many variables almost simultaneously.)

The revised computer programming showed that our assumption was correct in that the data obtained with the electronic fish tester was not correlated with the temperature of the fish. With respect to the electronic fish tester data versus organoleptic evaluation, the computer showed that a highly significant correlation (indicating a value that is significantly larger than would be expected at the 1 percent level of probability) existed between the tester and all organoleptic factors except damage. This exception is understandable because the factor of damage is a random mechanical one associated with
handling and not with duration of holding as would apply to all other organoleptic factors.

The correlation between organoleptic evaluation and temperature was surprising because it showed a significant correlation. This correlation was not expected because the temperatures were quite uniformly low (Table 2.3.1-1) and the difference between winter and summer temperatures (Table 2.3.1-2) was relatively small. It was within the group of six factors of organoleptic evaluation that the highest degree of correlation was found. Although all were highly significant, the lowest of these correlations was found between damage and other organoleptic factors. This result supported the original choice of using only four factors (eyes, gills, texture, and odor) upon which to pass final judgment to accept or reject trips as shown in Table 2.3.1-1. Further, the computer agreed completely with what skilled inspectors have maintained are the two most reliable factors of all-gill appearance and odor.

Conclusions

A survey of fresh haddock landed on the Boston Fish Pier during the winter, summer, and autumn seasons of 1965 showed that 78.6 percent of the amount of haddock landed was of a freshness level high enough to justify the use of irradiation for extending the shelf life of haddock fillets in the fresh condition when held at ice temperature. The survey also showed that there was a highly significant correlation between an ob-
jective method of freshness assessment and the judgment of highly skilled fish inspectors.

2.5 References

2.5.1 Cited References


SECTION 3.

COMMERCIAL BENEFIT STUDIES
CONTENTS

3.0 INTRODUCTION  
3.1 BACKGROUND DATA AND INFORMATION  
3.2 OBJECTS OF STUDIES  
3.3 PROCEDURE  
3.4 RESULTS  
3.5 CONCLUSIONS

3-1  
3-1  
3-8  
3-9  
3-19  
3-28
SECTION 3. COMMERCIAL BENEFIT SHIPPING STUDIES

3.0 Introduction

All programs of the Marine Products Development Irradiator (MPDI) are directly aimed at establishing, on a large commercial scale, the feasibility of prolonging the shelf life of irradiation-treated seafoods at ice temperatures. To permit the necessary demonstrations of the commercial-scale feasibility of this radiation treatment, the Food and Drug Administration authorized this laboratory to engage in large-scale shipments of radiation-treated fish fillets. These commercial-benefit shipping studies were to be conducted under carefully controlled conditions to prevent any possibility of the irradiated food entering retail-food channels. Such studies, reported here, were to demonstrate the benefits, under commercial conditions, of treating cod and haddock fillets with ionizing radiation.

3.1 Background Data and Information

The total shelf life of normal fresh fillets after filleting and packaging and going through the regular channels of distribution, seldom equals 5 days. The shelf life of irradiated and commercially distributed fish fillets is defined in this report as the number of days, after irradiation, of marketable quality—that is, that period of time, in days, before the fillets would be considered the equivalent of FDA class 2 fish.
The aim of radiation treatment is to extend the commercial shelf life of fresh fillets, at a high level of quality, by a factor of 2. In certain cases, the extra shelf life provided by this preservation treatment would provide a total shelf life of from 10 to 12 days at the retail level. In other cases, it would provide for the longer shipping period required for new and more distant markets. This extension will help in eliminating the uneconomic but widespread commercial practice of under-buying in terms of both quantity and variety of fish.

Ordinary spoilage of fish fillets is caused principally by bacteria.\textsuperscript{2,3,4} The scientific literature\textsuperscript{5,6,7,8} states that laboratory-scale radiation processing of fillets, at dose levels of from 100 to 200 kilorads, destroys from one to two log cycles, or about 90 to 99 percent, of the incident bacteria, and this destruction of bacteria is reflected by an extended product shelf life.\textsuperscript{9} Among knowledgeable members of industry as among scientists,\textsuperscript{10} however, total bacterial counts alone are not considered to be a completely reliable index of freshness.

The degrees of reduction of bacterial loads, under commercial handling conditions, on haddock and cod fillets, as functions of radiation dose levels are presented in Graphs 1 and 2 of Appendix 3. The observations of the number of bac-
aterial survivors at each dose level are based on averaged multi-replicated total plate counts. (For information on methodology and for raw data on microbiological studies, see Appendix 2.)

The general trend for the total bacterial reduction as a function of radiation dose level for both cod and haddock fillets reflects an approximately straight-line relation above a dose level of 75 kilorads. In both curves, an initial or early "shoulder" appears reflecting ineffectiveness in microbial reduction until the from 75 to 100 kilorad range is reached. The graphs also demonstrate that dose levels greater than 100 kilorads are required to effect an assured reduction of more than 90 percent in the total microbial population.

The radiation dose level as used in this report means the averaged readings of 9 dosimeters placed in the plane of minimum absorbed dose. The dosimeters are inserted at the four corners of the plane and midway between each of the corners plus one dosimeter in the geometric center of the package.

Information on the shelf life of cod and haddock fillets as functions of minimal radiation dose level and of different storage temperatures (33°, 42°, and 46° F.) is presented in Graphs 3 and 4 of Appendix 3. Storage temperature is clearly the key factor in controlling the shelf life of fish fillets irradiated at 100 kilorads. At storage temperatures of 42° F. and 46° F., neither cod nor haddock fillets evidenced, under
laboratory conditions, a commercially desirable extension in shelf life at this dose level. The shelf lives of both cod and haddock fillets, when they were stored at 33°F., were considerably extended by irradiation at 100 kilorads. The shelf life curves, however, demonstrate an extremely adverse response as the storage temperature is increased. When one considers the possibilities for adverse storage temperatures at retail outlets, the minimal suitable dose for commercial operations must be 100 kilorads or above. These conclusions are in agreement with laboratory findings in which averaged optimum doses for cod and haddock fillets were found to be 150 to 250 kilorads, respectively. Neither of these doses caused any detectable quality changes in the product. This report deals with efforts made on a commercial basis rather than on a laboratory or experimental basis to show that the radiation dose proposed (100-200 kilorads when measured by averaging 9 dosimeters which had been placed in the plane of minimum absorption) accomplishes the intended technical effect.

Researchers have reported 11,12,13 that irradiated fish do not evidence, in laboratory testing, the typical fish-spoilage patterns—that is, they do not give rise to the objectionable amine-like odors normally associated with decomposed fish. Such studies were made on petrale sole fillets and involved dose levels of 100 to 500 kilorads. The Gloucester Laboratory of the Bureau of Commercial Fisheries studied the spoilage patterns of cod and haddock fillets irradiated to an
average of 150 kilorads. These studies show that commercial fillets of cod and haddock, treated at this level of gamma radiation, do undergo spoilage patterns, recognizable in both the raw and cooked states, which are similar in nature to those of untreated cod and haddock fillets. Table 3.3.1-1 presents the results of a typical study, at several storage temperatures, on the shelf life and spoilage characteristics of cod fillets, either nonirradiated or irradiated at an average 150 kilorads dose.

A second corroborative study involved a specially trained panel and microbiological testing for the occurrence of proteolytic bacteria in the irradiated fillets during the storage period on ice. Graphs 33-34 represent total aerobic plate counts for the temperature-storage studies described below, and Graph 35 represents the estimated number of proteolytic bacteria based on the total aerobic plate counts times the percent of proteolytic activity as determined by a gelatin plating method (Appendix 2). The individual samples were taken over a period of days from nonirradiated and irradiated cod fillets that were stored at 33°F, 37°F, 42°F, and 47°F. About 25 percent of the bacterial colonies from fresh, nonirradiated cod fillets showed proteolytic activity, and as storage time increased, the percentage of proteolytic colonies increased to about 50 to 60 percent. In the irradiated cod fillets, none of the observed colonies representing surviving bacteria showed proteolytic activity during
Table 3.3.1-1  Spoilage characteristics and laboratory shelf life of irradiated (averaged 150,000 rads) and nonirradiated cod fillets stored at different temperatures

<table>
<thead>
<tr>
<th>Sample</th>
<th>Storage temperature (°F)</th>
<th>Shelf life of product served steamed (days)</th>
<th>Evaluation of cooked product at end of shelf life</th>
<th>Comments of Panel</th>
<th>Evaluation of raw product at end of shelf life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiated in air-packed cans</td>
<td>33</td>
<td>36</td>
<td>Off odor, musty, old</td>
<td>Persistent fishy odor, slight discoloration</td>
<td>Opaque, defects, discolored, fishy odor</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>15</td>
<td>Ammonia, bitterness</td>
<td>Slight irradiation odor, slight fishy odor</td>
<td>Defects and discoloration, slight irradiation odor, fishy odor</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Irradiation taste, bitter, burnt taste</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>12</td>
<td>Ammonia, putrid, inedible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irradiated in bulk-packed 20-lb. cans</td>
<td>33</td>
<td>36</td>
<td>Spoiled, irradiation odor, irradiation flavor, ammonia</td>
<td>Slight discoloration, slight fishy odor, slight irradiation odor</td>
<td>Defects and discolored, fishy odor</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>15</td>
<td>Ammonia, putrid, irradiation odor</td>
<td>Defects and discolored, fishy odor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Musty, rancid</td>
<td>Slight fishy odor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>12</td>
<td>Ammonia, stale odor</td>
<td>Defects, discoloration, irradiation odor, decomposition odors</td>
<td></td>
</tr>
<tr>
<td>Nonirradiated packed in 30-lb. cans</td>
<td>32</td>
<td>15</td>
<td>Ammonia, putrid, sour inedible</td>
<td>Defects and discolored, persistent fishy odor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>12</td>
<td>Ammonia, inedible, putrid</td>
<td>Defects and discolored</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Ammonia, putrid, rancid, sour, bad</td>
<td>Defects, discolored, decomposition odors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>5</td>
<td>Ammonia</td>
<td>Decomposition odors</td>
<td></td>
</tr>
</tbody>
</table>

Taken from Slavin et al. (14)
the initial period of storage. After several days, about 1 to 3 percent of the colonies showed proteolytic activity. Probably very low, undetectable (less than 0.5% of total number of bacteria) levels of bacteria capable of proteolysis, survive the 150 kilorad dose level, and these slowly increase so that at about the time of organoleptic rejection they are at a detectable number. Apparently, the number of proteolytic bacteria on the cod fillets at the time of sensory rejection is about the same for irradiated and nonirradiated fillets. Thus, the objectionable odor characteristics of proteolysis are evident in the irradiated cod fillets although delayed due to the destruction of most of the proteolytic bacteria at the time of irradiation. (See Graphs 36 and 37. See also Appendix 1 - Organoleptic Evaluations for discussion of special conditions pertaining to this experimental study.) Other investigators have reported similar findings.5,15

The Bureau of Commercial Fisheries, during 1965, collected data on the temperature patterns occurring in nonirradiated fresh fish fillets as normally shipped in interstate commerce by common carriers. It was felt that unless the common commercial distribution practices were conducive to the efficient and safe distribution of irradiated seafoods, radiation processed fresh seafoods could not compete with unprocessed fresh seafoods. In the spring of 1966, the data amassed on product temperatures observed during shipments of fresh seafoods indicated that
present commercial shipping practices are more than adequate to ensure the safe distribution of irradiated fillets. The FDA sanctioned benefits-evaluation studies with irradiated and non-irradiated fillets were then initiated and carried out under commercial conditions.

In accordance with the dose limits (averaged 100 and 200 kilorads) proposed, three benefits-evaluation studies, each involving shipments of fillets of cod and haddock, irradiated at dose levels of 0, 100, and 200 kilorads as determined by the average of 9 dosimeters in area of minimal absorption. These studies, coupled with information supplied by Graphs 1 to 4, were designed to test the assumption that the beneficial levels of radiation, under commercial conditions, would lie between 100 and 200 kilorads when averaged.

3.2 Objects of Studies

These studies were designed to determine the technical effect of irradiation on commercially processed and shipped fillets and to determine (1) if present commercial distribution and storage conditions are suitable for handling irradiated fresh fillets, (2) if fresh fillets can be irradiation-processed on a large commercial scale, (3) if an increase in distribution time or shelf life, or both, of irradiated fresh fish fillets can be realized under present commercial conditions of handling and shipping, (4) to what extent the consumer
would benefit, and (5) if the levels of irradiation used do not exceed the amount reasonably required to accomplish the intended effect.

3.3 Procedure

3.3.1 Fillets of cod and haddock were purchased on the open market, irradiated, placed aboard commercial interstate carriers and sent to states far beyond the present geographical limits of the East Coast fresh-fish market. Three such long-distance shipments (see Figures 1, 2, and 3 for records of product temperatures during the shipments) were made to points in the states of Washington and Florida (see map) and returned to the laboratory by air freight. Table 3.3.1-2 is a flow-chart representative of experimental handling of fillets during the studies. For each shipment, the test fillets were separated into two sets. One set, consisting of both irradiated and nonirradiated fillets, was retained as a control and evaluated at the Bureau of Commercial Fisheries Technological Laboratory, Gloucester, Massachusetts, throughout the test period. The other set, again consisting of irradiated and nonirradiated fillets, was shipped, under commercial conditions to either Seattle, Washington, or Jacksonville, Florida. A Bureau of Commercial Fisheries technologist traveled with each of the shipments to monitor shipping temperatures, to ensure that the irradiated products did not get into retail outlets and, at the destination
Figure 1. Temperatures of product and carrier during shipment to Jacksonville, Florida

February 1967
Figure 2. Temperatures of product and carrier during shipment to Seattle, Washington

February 1967
Figure 3. Temperatures of product and carrier during shipment to Jacksonville, Florida
March 1967

Product held in MPDI refrigerator for 72.5 hours

★-★ Product Temperature
★-★ Train Temperature
MAP SHOWING ROUTES OF COMMERCIAL BENEFIT SHIPPING STUDIES

Note:
Shaded section represents area to which fresh fillets are normally shipped

Broken lines represent routes to cities covered in Commercial Benefit Shipping Study.
Table 3.3.1-2 - Representative flow chart: experimental design intra-agency benefits-evaluation studies

Fish\(^1\) → Process\(^2\) → Deliver to MPDI\(^3\)

- 0 rads\(^4\): Held\(^6\) → TPC\(^8\) → Taste Tests\(^9\)
- Shipped\(^7\) → TPC\(^8\) → Taste Tests\(^9\)

- 100 Kilorads\(^5\):
  - Held\(^6\) → TPC\(^8\) → Taste Tests\(^9\)
  - Shipped\(^7\) → TPC\(^8\) → Taste Tests\(^9\)

- 200 Kilorads\(^5\):
  - Held\(^6\) → TPC\(^8\) → Taste Tests\(^9\)
  - Shipped\(^7\) → TPC\(^8\) → Taste Tests\(^9\)

- Returned by air-freight to MPDI

0 rads:
- TPC\(^8\) → Taste Tests\(^9\)

100 Krads:
- TPC\(^8\) → Taste Tests\(^9\)

200 Krads:
- TPC\(^8\) → Taste Tests\(^9\)
LEGEND FOR TABLE 3.3.1-2

1. Haddock and cod were purchased on the open market from normally available commercial supply. No special selection or culling for quality was performed. All such purchases were in several hundred-pound quantities.

2. Fish were processed into fillets under normal commercial operations. The fillets were packed into 10-pound fillet cans, and iced down for delivery to the laboratory.

3. The fish fillets, in 10-pound cans, were received at MPDI.

4. For each shipment, an appropriate number of 10-pound cans of each of the two species of fish fillets, selected at random from the supply, were used as controls. They were never irradiated.

5. For each shipment, an appropriate number of 10-pound cans of each of the two species of fish fillets were irradiated at either 100 or 200 kilorads. Dose was measured at the point of minimum absorption. (See Appendix 2 for detailed treatment).

6. For each shipment, a portion of each lot of each treatment (0, 100, 200 kilorads) was held in 33°F storage at the MPDI for concomitant testing with the lots which were shipped under commercial conditions and subsequently returned to the laboratory for testing.

7. Three such shipments of fish fillets, treated at 100 or 200 kilorads were made. Two shipments were made to Jacksonville, Florida and one to Seattle, Washington.

8. All samples, both those retained in the MPDI and those shipped to distant points and returned, were tested throughout their respective shelf-life for total bacterial counts according to accepted procedures.

9. All samples, both those retained in the MPDI and those shipped to distant points and returned, were tested for organoleptic acceptance throughout their respective shelf-lives using a minimum of twelve panelists for each test. All data were subjected to computer analysis by an outside independent agency, which analysis included Q tests, analyses of variance and regression curves.

10. An observer accompanied all shipments. At destination, he made arrangements for return of samples to the Gloucester Technological Laboratory.

3-15
point, to ship the test products back by air to Gloucester for subsequent bacteriological and organoleptic testing.

Two factors must be considered in assessing the intra-agency commercial benefits-evaluation studies. The first is that present handling methods maintain low temperatures of the product in commercial channels of distribution regardless of the season of the year. The second is that in winter, day-to-day variations in supply of some species of fish, due to storms at sea, posed problems in that only a relatively small quantity of fish might be available on the particular day specified in advanced planning with the Railway Express Agency for shipments via the railroad. Consequently, the fillets used in the three shipments discussed here were of mixed quality. Sometimes, despite all efforts, the desired amount of cod or haddock, was not obtainable. The winter shipments, therefore, contrary to expectations, posed the most critical tests of the usefulness of low-level radiation preservation.

One of the three long-distance benefits-evaluation shipments to Seattle on February 23, 1967 is presented as being representative. Commercially available fillets of haddock and cod were purchased on the open market on February 21 and irradiated in 10-pound fillet cans on February 22, 1967. The cans of irradiated fillets and nonirradiated fillets were randomly placed in barrels (ten 10-pound fillet cans per barrel), iced under normal conditions (1.5 parts of ice to 1.0 part of fish)
and shipped via the Railway Express Agency from South Station, Boston, Massachusetts, late in the evening of February 23, 1967. A Bureau of Commercial Fisheries technologist, with explicit instructions to observe conditions of handling and temperatures, but to take no corrective action, accompanied the shipment. An equal size sample of irradiated and nonirradiated fillets was held at the MPDI at 33 to 35° F.

Transfers of the samples between trains were made twice, once in Chicago and once in St. Paul, Minnesota. Owing to the seasonably cold weather, no reicing of the barrels was necessary from coast to coast. Figure 2 is a record of the constant product temperature observed during this shipment. The shipment arrived in Seattle, Washington, early in the morning of February 27, 1967, 5 days after irradiation, and was delivered by Railway Express Agency to the Bureau of Commercial Fisheries Seattle Technological Laboratory later the same morning. The shipment was then divided into two portions, one to be kept in Seattle for evaluation by the Seattle Laboratory and the other to be shipped by air freight back to the Gloucester Technological Laboratory. (The fillets shipped back to Gloucester from Seattle do not constitute an integral part of this study, as they would not under any imaginable circumstances reflect future industry practice. This was done, however, to assess the effect that the stress of additional commercial shipping might have on the fillets.) The return shipment left Seattle on

3-17
February 28 by air and was delivered in Gloucester on March 1, 1967, 8 days after irradiation. Similar treatment was given the two Florida shipments, also reported here, except that, in these two studies, all of the shipped fillets were returned directly to the Gloucester Laboratory for evaluation because no laboratory facilities were available for testing the fillets in Florida.

The sensory procedures used for this report involved evaluation as to appearance, odor, flavor, and texture by a panel trained in such evaluation on normal commercially available fish fillets. The evaluation system used was a modified hedonic system using a score of from 0 to 9 and providing space for separate evaluation as to appearance, odor, flavor, and texture. This modified hedonic scale was related quantitatively to specifically defined quality attributes and to the FDA system for organoleptic evaluation of fish fillets (Table 1, Appendix 1).

At each evaluation in Gloucester and Seattle, a minimum of 12 panelists participated. The samples of fish were steamed to bring the flesh tissue to a proper degree of cook. No other treatment was given, and no condiments of any nature were used. Individual panelists were provided with isolated booths, and they rated the test samples independently of each other. All the raw data was fed through a computer that had been programmed to apply Q-tests for the rejection of extremes.
among the panel members and for analysis of variance of each of the variables under study. The computer, after completing these steps, then applied regression analyses to arrive automatically at regression lines, which are presented in Graphs 5 to 18.

3.4 Results

3.4.1 Three, long distance, commercial-size shipments of irradiated and nonirradiated fish were made, using cod and haddock fillets irradiated at the MPDI in Gloucester. Table 3.4.1-1 summarizes these shipments and demonstrates the bacterial loads on the irradiated and on the nonirradiated control fillets before shipment and after return to the Gloucester BCF Laboratory. Irradiation, at the 200 kilorad treatment level, shows a reduction of at least two log cycles (or 99 percent) of bacterial numbers which persists even after commercial conditions of shipment to points more than double in distance than those currently being made by industry. The distances and durations involved in these shipments are unprecedented and clearly illustrate the benefits to be gained by irradiation of fish fillets.

Graphs 5 through 18 demonstrate that all of the irradiated fillets in these three shipments were of acceptable quality at all points of examination, including those tested after being returned to the Gloucester BCF Laboratory, and that, in contrast, all of the nonirradiated fillets were spoiled when
Table 3.4.1-1 Commercial benefit studies: haddock and cod fillets bacterial reductions

<table>
<thead>
<tr>
<th>Destination</th>
<th>Carrier</th>
<th>Pounds of samples</th>
<th>TOTAL PLATE COUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before shipping</td>
<td>Upon return to MPDI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date</td>
<td>Control</td>
</tr>
<tr>
<td>Jacksonville</td>
<td>train</td>
<td>300 haddock</td>
<td>2/13/67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300 cod</td>
<td></td>
</tr>
<tr>
<td>Seattle</td>
<td>train</td>
<td>540 haddock</td>
<td>2/22/67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>540 cod</td>
<td></td>
</tr>
<tr>
<td>Jacksonville</td>
<td>train</td>
<td>150 haddock</td>
<td>3/6/67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>150 cod</td>
<td></td>
</tr>
</tbody>
</table>
returned to Gloucester or, in three instances, within 1 or 2 days after being returned. These graphs demonstrate that, again in contrast to the nonirradiated fillets, the irradiated fillets continued to be of good quality for an additional 8 to 10 days after being returned to Gloucester.

The shelf lives of commercially handled and processed haddock fillets for the three shipments, as determined by sensory evaluation and computer-analysis of variances and regressions (Graphs 5 to 11), were 7, 15, and 18 days for irradiation levels of 0, 100, and 200 kilorads, respectively. The equivalent findings for cod fillets were 6, 16, and 20 days (Graphs 12 to 18). As was mentioned earlier, the necessary quantities of fish fillets were not always obtainable, which explains why some of the data shows depletion of samples prior to completion of specific tests. In all cases, however, the benefits of irradiation, as reflected in extended shelf life, were clearly demonstrated prior to the depletion of the samples. The studies conclusively demonstrate that the shelf life of commercial cod and haddock fillets, when irradiated with an averaged 100 kilorads dose of gamma radiation, can be doubled if product temperatures are maintained at from 33°F to 35°F throughout the distribution chain. Similarly, when commercially handled cod and haddock fillets are irradiated at an averaged 200 kilorads and held at 33°F to 35°F throughout the distribution chain, the shelf life of these fillets is about tripled.
Comparisons of the paired acceptance graphs for each shipment (that is, the MPDI-held controls and the REA-shipped lots) clearly showed that the stresses of commercial handling, transhipping, and re-icing reduce the shelf life of the shipped irradiated product by from 1 to 2 days. Similar conclusions cannot be drawn for the nonirradiated fish fillets because, usually, the nonirradiated fillets became spoiled while in transit. The precise time of acceptance relations, therefore, could not be established for comparison with the MPDI-held nonirradiated controls.

Graphs 19 through 32 reflect the bacteriological findings relative to these three shipments. All samples of fillets, both cod and haddock, for all three shipments upon initial pre-irradiation testing, had total plate counts of from 100,000 to 800,000 bacteria per gram. After irradiation (100 kilorads), these counts, for both haddock and cod fillets, were routinely reduced by about 90 percent (one log cycle). Upon subsequent testing, only one of the six (100 kilorad irradiated) lots tested (three shipments, two species) demonstrated any delay on outgrowth of the bacteria; all five other bacteriological patterns reveal rapid increases in numbers within 3 days. The over-all bacteriological patterns for these five lots of 100 kilorad irradiated fillets showed a trend parallel with the nonirradiated control samples. The bacterial numbers of these five lots, upon return to and subsequent testing at
Gloucester, demonstrated a bacterial population that was consistently two log cycles greater in number than was that of the similarly shipped fillets that had been irradiated at 200 kilorads.

However, on irradiation at the 200 kilorad level, all six lots of fish fillets (three shipments, two species) reflected a consistent reduction in bacterial populations of from 95 to 99 percent (of from 1.5 to 2.0 log cycles). Additional testing showed that each of the six lots exhibited a delay in microbial outgrowth during a period of 5 to 7 days. In three of the six lots, definite evidence of a devitalization of the surviving microbial population was found, as postulated by Shewan and Liston⁶. This devitalization took the form of further reductions in the microbial populations over a period of 2½ days post-irradiation.

These findings were based on the MPDI-held control samples of both nonirradiated and irradiated (100 kilorad and 200 kilorads) fillets of cod and haddock. Although the corresponding test fillets were in transit and thus unavailable for examination during this period of from 5 to 7 days, we observed that the shipped samples of 200 kilorad irradiated fillets, when returned to the Gloucester BCF Laboratory, were usually still comparatively low in terms of numbers of bacteria, whereas all of the 100-kilorad irradiated fillets usually exhibited a high bacteria count sooner than their corresponding MPDI-held
samples did, reflecting the stresses of commercial handling and distribution.

It should be emphasized that the return of the samples to Gloucester from a point that would normally be considered their commercial destination imposed an additional noncommercial stress on the product. The stresses that were set up on the returned samples, particularly those on the samples that had been shipped to Seattle, are readily evident in the quicker rise in bacterial counts. Stresses of this magnitude would not occur under any imaginable circumstances in commercial distribution. They are mentioned simply to demonstrate that even after shipment of over 6,000 miles by a combination of rail, air, and truck transport, during a period of nearly 9 days, the irradiated product was still of acceptable quality.

Sensory evaluation showed that, in time, both the non-irradiated and the irradiated fillets exhibited objectionable spoilage odors and flavors. The only real difference between the two was that the irradiated fillets required more time to develop the spoilage odors and flavors. Tables 3.4-2 and 3.4-3 show the response of panel members of BCF Gloucester Laboratory during the evaluations of these shipments. Ratings below 5 reflect detection by trained panelists of fishy, ammoniacal, or sour odors. Such findings (below 5) were the basis for rejection for, as defined by FDA, "odor not intense by persistent and readily perceptible to the experienced examiner.
Table 3.4.1-2 Evaluation of sensory panel response to odor at end of shelf life in terms of objectionable characteristics

<table>
<thead>
<tr>
<th>Days Post-Irradiated</th>
<th>Control</th>
<th>100 Krads</th>
<th>200 Krads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Haddock</td>
<td>Cod</td>
<td>Haddock</td>
</tr>
<tr>
<td>6-8</td>
<td>4.0</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>9-11</td>
<td>2.4</td>
<td>1.2</td>
<td>5.6(^2)</td>
</tr>
<tr>
<td>12-14</td>
<td></td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td>15-17</td>
<td></td>
<td></td>
<td>4.7</td>
</tr>
<tr>
<td>18-20</td>
<td></td>
<td></td>
<td>3.5</td>
</tr>
<tr>
<td>21-23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Summation of averaged sensory test scores for 3 commercial-benefits studies after rejection on panelists by application of Q-tests. Ratings correspond to precisely defined organoleptic conditions in the fish (see Table 1 of Appendix 1). Each numerical rating reflects the weighted average of a total of 12 individual ratings.

2. The prior rating is added to demonstrate the reduction in score. A score below 5 in at least 2 consecutive tests demonstrates conclusively a drop to Food and Drug class 2 fish. Note that nonirradiated controls were all deemed unacceptable within eight days. Note also that 100 Krad-treated fish fillets were deemed unacceptable after 14 days while 200 Krad-treated fresh fillets were rejected after 18 to 20 days.
Table 3.4.1-3 Evaluation of sensory panel response to flavor at end of shelf life in terms of objectional characteristics

<table>
<thead>
<tr>
<th>Days Post-Irradiated</th>
<th>Control</th>
<th>100 Krads</th>
<th>200 Krads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Haddock</td>
<td>Cod</td>
<td>Haddock</td>
</tr>
<tr>
<td>6-8</td>
<td>4.1</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>9-11</td>
<td>2.7</td>
<td>1.2</td>
<td>5.6²</td>
</tr>
<tr>
<td>12-14</td>
<td></td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td>15-17</td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
<tr>
<td>18-20</td>
<td>3.6</td>
<td>3.2</td>
<td>4.6</td>
</tr>
<tr>
<td>21-23</td>
<td></td>
<td></td>
<td>3.1</td>
</tr>
</tbody>
</table>

1. Summation of averaged sensory test scores for 3 commercial-benefits studies after rejection of panelists by application of Q-test. Ratings correspond to precisely defined organoleptic conditions in the fish (See Table 1 of Appendix 1). Each numerical rating reflects the weighted average of a total of 12 individual ratings.

2. The prior rating is added to demonstrate the reduction in score. A score below 5 in at least 2 consecutive tests demonstrated conclusively a drop to Food and Drug class 2 fish. Note that nonirradiated controls were all deemed unacceptable within eight days. Note also that 100 Krad-treated fish fillets were deemed unacceptable after 14 days while 200 Krad-treated fresh fillets were rejected after 18 to 20 days.
who recognizes it as indicative of decomposition." Two consecutive findings of such a low level of acceptance were required in this study to establish conclusively the point of recognizable spoilage and the duration of marketable shelf life.

The possibility of maintenance of uniformly high level of quality of fish fillets during an extended shelf life, appeals to the industry. Producers anticipate that irradiation processing will help to smooth out the highs and lows of availability of fresh-fish supplies and will help to ensure a steadier market. Most retailers see no particular advantage in extending the shelf life for much more than 11 to 12 days over that of the nonirradiated fresh fish. Retailers claim that using irradiated seafoods would permit holding of the fillets after the traditional peak demand on Friday has passed rather than having to markdown the price or discard the fillets due to anticipated spoilage. The process would enable retailers to offer fresh fish throughout the week to a degree greater than is now possible. Producers also claim that these savings can be passed along to consumers. Spokesmen for eight of the largest chain supermarkets in the nation state that they could, and would, sell irradiated fresh seafoods in areas where fresh seafoods are not sold now.
3.5 Conclusions

1. Commercial radiation-processed fish fillets spoil in a normal, recognizable manner—that is, through the development of readily perceptible objectionable odors. These odors are apparent in both the raw and the cooked fish. The spoilage odors, although not identical with the fishy amine-like odors, are similar in nature and occur, under commercial conditions, after about 18 days of ice storage, post-irradiation. In the event of mishandling, the shelf life is shortened proportionately, and spoilage is again evidenced by the development of objectionable odors.

2. Cod and haddock fillets of commercial origin, after being irradiated at 100 and 200 kilorads routinely result in a reduction of bacterial numbers of from one to two log cycles or from 90 to 99 percent. Usually, this reduction of one to two log cycles was still observable even after the return of fillets to Gloucester following shipment to distant points in the nation.

3. The data presented here, and in particular, those that relate an extension of shelf life to radiation dose level and to variable product temperatures in transit and in storage, demonstrate that the optimum radiation dose for preserving these products under the most extreme anticipated commercial conditions is 100 to 200 kilorads as determined by averaging 9 dosimeters at the point of minimum dose absorption to ensure
maximum beneficial effect without undesirable changes in the product. The shipping distances used in the tests were much greater than those in present use. Because the presently used systems and distances will undoubtedly be used in the application of the proposed new process, no difficulty should be encountered.
3.6 References

3.6.1 Cited References


3.6.2 Uncited References

SECTION 4.

PALATABILITY STUDY
CONTENTS

4.0  INTRODUCTION  4-1
4.1  PROCEDURE     4-1
4.2  RESULTS       4-2
SECTION 4. PALATABILITY STUDY

4.0 Introduction

The material presented in this section is a resume only of work performed by the Department of Nutrition of the University of Massachusetts, therefore the data which would normally be presented is omitted in a summary of this kind.

All of the sensory panel work done with fishery products irradiated in the MPDI has been performed by members of the Technological Laboratory of the Bureau of Commercial Fisheries in Gloucester, Massachusetts. To check these findings, we considered it desirable to have an outside, independent trained panel to perform taste tests on three species of irradiated fillets. If an independent panel found irradiated fillets to be acceptable, then the Gloucester panel could not be considered to be biased, whether consciously or unconsciously. Accordingly, a series of sensory tests were made by the Department of Nutrition and Food of the School of Home Economics of the University of Massachusetts, Amherst, Massachusetts.

4.1 Procedure

The project, carried out for a period of one year, was designed to give information on the influence of gamma radiation on fish fillets stored up to 3 weeks at 380 F. and subsequently cooked by four different methods. Fillets of flounder, haddock and ocean perch were purchased by MPDI personnel for various Gloucester fillet producers and represented
regular commercial production on the day they were purchased. One half the amount of each purchase of each species was irradiated at 250,000 rads at the MPDI and the other half was frozen for control samples. Four common methods of cooking recommended by the Bureau of Commercial Fisheries were used. They were broiled, oven-baked, pan-fried, and steamed. Irradiated fillets prepared by each of these methods were evaluated by comparing them with a thawed, control sample similarly prepared. Frozen controls were stored at -20° F. and thawed for about a day at 38° F., the same temperature at which the irradiated fillets were held throughout each test period.

The panel consisted of seven participants who evaluated each cooked sample for appearance, odor, flavor, and texture. The conventional nine-point hedonic scale was used to arrive at judgments. The statistical design used was a split-split plot. This design was chosen to give information on the cooking and on the effect of irradiation and of days of storage.

4.2 Results

Few differences were found in cooked samples of flounder, haddock or ocean perch until 21 days of storage at 38° F. for the irradiated samples. The study also showed and rated the order of preference of method of cooking as being (1) pan-fried, (2) broiled, (3) baked, and (4) steamed.
SECTION 5.

EFFECT OF GAMMA RADIATION ON FREE LIQUID DEVELOPMENT, pH, AND BACTERIAL SUPPRESSION IN FRESH SHUCKED EASTERN OYSTERS

by

John D. Kaylor and Alexander Movahed
CONTENTS

5.0 INTRODUCTION 5-1
5.1 BACKGROUND INFORMATION 5-1
5.2 PROCEDURE 5-2
  5.2.1 Division of Work 5-2
  5.2.2 Objective Measurements 5-3
    Measurement of Free Liquid 5-3
    Measurement of pH 5-3
    Measurement of Bacteriological Activity 5-4
  5.2.3 Subjective Measurements 5-5
    Organoleptic Examinations 5-5
5.3 RESULTS AND DISCUSSION 5-6
  5.3.1 Objective Results 5-6
  5.3.2 Subjective Results 5-12
5.4 CONCLUSIONS AND RECOMMENDATIONS 5-12
5.5 REFERENCES 5-13
SECTION 5. EFFECT OF GAMMA RADIATION ON FREE LIQUID DEVELOPMENT, pH, AND BACTERIAL SUPPRESSION IN FRESH SHUCKED OYSTERS

5.0 Introduction

While conducting an experiment aimed at determining certain aspects of the shelf life of commercially produced fresh shucked Eastern oysters (Crassostrea virginica), it was observed that irradiated samples seemed to have a greater content of free liquid than did nonirradiated control samples of the same lot. This phenomenon was considered to be of sufficient importance to conduct an experiment to determine principally what, if any, relation exists between low-level radiation treatment of fresh shucked oysters and the development of free liquid. It was also desired to determine the influence, if any, of radiation on other characteristics described here.

5.1 Background Information

When oysters are opened under commercial conditions, contamination of the oyster meats with grit, bits of shell, and other foreign material is virtually unavoidable. To clean the meats, oyster processors, as standard practice, wash the shucked oyster meats with fresh potable water or with salt water containing less than 0.75 percent salt by any of several methods. This aspect of the production of fresh shucked oysters has been of some concern to processors and regulatory officials for many years.
The contact time of the oysters with fresh or salt water, the conditions of draining, and the percent of liquid by weight after draining are subject to standards of identity enforced by the Food and Drug Administration. The purpose is to protect the consumer from adulteration of oysters by the addition of an excess amount of water.

The loss of body fluid or "bleeding" of the Eastern oyster is a matter of serious economic concern to the oyster industry. The extent of this phenomenon will vary from one geographic source to another. If irradiation treatment, when applied to prolong the shelf life of commercially produced, shucked fresh oysters, results in the expression of additional liquid, a serious problem could arise in respect to the application of present standards for drained weight of oysters.

5.2 Procedure

5.2.1 This investigation was conducted jointly by a quality control laboratory of private industry and by the Bureau of Commercial Fisheries. The plan called for the control laboratory to supervise the packing of the oysters according to good commercial practice and to test for free liquid. The Bureau was responsible for irradiation services, and for microbiological, pH, and organoleptic tests. Both laboratories performed their respective tests on the same day on duplicate samples irradiated at 0, 50, 100, and 200 kilorads and subsequently held at 33°F to 37°F throughout the
testing period.

Fresh Chesapeake oyster shell stock was commercially shucked, blown, drained, and sealed in half pint, transparent-plastic-topped metal cans in April, 1967, in an oyster plant in Virginia. After being sealed, the cans were packed in ice and shipped under commercial conditions to Boston, where they were subsequently delivered in ice to the Marine Products Development Irradiator (MPDI) for irradiation treatment within 3 days of production.

5.2.2 Measurement of free liquid was obtained for each half pint can by obtaining the percent of liquid by weight from the contents of each weighed can when they were drained on a stainless steel skimmer. Perforations of the skimmer were 1/4 of an inch in diameter and less than 1 1/4 inches apart. After being weighed, the contents of each can were distributed evenly over the draining surface and were drained for 5 minutes.

Measurement of pH was made by means of a Beckman Expanded Scale pH Meter, Model 76. The meter was adjusted each time before use, and duplicate samples were run after the cans were aseptically opened for microbiological analysis. Because of the small size of the container, the electrodes of the pH meter could be placed directly into the cans containing the liquid and oysters. No attempt was made to grind the oyster

1. The use of trade names is merely to facilitate descriptions; no endorsement is implied.
meats, as the liquid was considered to be a reliable enough index of the pH when in contact with the meats.\(^{(2)}\)

Microbiological assay procedures were as follows:

**General**


Homogenates are prepared by weighing 50 grams of material into a sterile Oster Blender jar, adding 450 ml of sterile diluent (buffered peptone water), and blending for 2 minutes. Subsequent decimal dilutions are made in 9 or 99 ml sterile, diluent blanks. Melted sterile agar media are then poured into inoculated petri plants.

**Specific**

**Total Aerobic plate count (TPC):**

Eugon agar (BBL) plus 0.5% yeast extract (BBL) medium used. The incubation is at 20° C. for 5 days before plate count.

Brilliant green, 2% Bile Salt Broth (BBL or
Difco) is inoculated by 3 or 5 tube MPN method, incubated at 37°C for confirmation of coliform. The second set of tubes are incubated at 45.5°C (water bath) for E. coli determination.

**Salmonellae**

Selenite Cystine Broth (BBL or Difco) tubes are inoculated by 3 or 5 tube MPN method. After 24 hours at 37°C incubation, all tubes are streaked onto Brilliant Green Agar (BBL, plus Sulfadiazine), XL Agar (BBL), XLBGagar (XL base agar + brilliant green), or Bismuth Sulfite agar (BBL), or combinations of the above. Suspect colonies after incubation are inoculated into Triple Sugar Iron agar (Difco) and Lysine iron agar (BBL). Further confirmation is obtained by polyvalent serological testing.

**Staphylococcus (G+, coagolase +):**

Tellurite Glycine Agar (BBL) prepoured plates are inoculated by spreading 1 ml of inoculum on the surface with "hockey sticks". Plates are incubated at 37°C (mostly marine micrococi colonies are apt to appear) and 43°C (suggested by Dr. Robert Levin, University of Massachusetts, for specific staphlococcus).

**5.2.3** At this laboratory, organoleptic examinations of
fishery products are made daily on cooked seafoods of one kind or another. In this particular experiment, however, we wished to obtain the judgments of panelists on raw oyster meats in order to determine if the objective measurement of pH had correlated with its sensory assessment. Regrettably, some panelists could not bring themselves to taste raw oyster meats without condiments. For this reason, we lack sufficient organoleptic data of statistical value.

5.3 Results and Discussion

5.3.1 Table 5.3.1-1 shows that gamma radiation has an effect on the development of free liquid in shucked oysters under the conditions of geography and season that apply in this particular experiment. The amount of free liquid developed in the sealed cans is almost proportional to the irradiation dose level.

For about two decades, a pH value of 5.8 or above has been considered to be a reliable index of the freshness of shucked Eastern oysters. Proponents of this cut-off point have generally been associated with regulatory or purchasing agencies. Industry members are usually more cautious and tend to qualify endorsement of the 5.8 cut-off point with the conditional stipulation that such a pH value should be supported by skilled organoleptic assessment. It is interesting to note that, in the absence of skilled organoleptic testing, the pH values reported in Table 5.3.1-2 show a gradual lowering that seems to
TABLE 5.3.1-1  Percent by weight of free liquid development of irradiated and nonirradiated fresh shucked eastern oysters stored at 37°C F.

<table>
<thead>
<tr>
<th>Days Post Irradiation</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9</td>
<td>5.95</td>
<td>9.9</td>
<td>11.2</td>
</tr>
<tr>
<td>4</td>
<td>2.77</td>
<td>6.67</td>
<td>10.8</td>
<td>13.5</td>
</tr>
<tr>
<td>7</td>
<td>1.0</td>
<td>6.0</td>
<td>10.8</td>
<td>12.5</td>
</tr>
<tr>
<td>11</td>
<td>1.0</td>
<td>10.0</td>
<td>6.2</td>
<td>15.6</td>
</tr>
<tr>
<td>15</td>
<td>10.0</td>
<td>14.4</td>
<td>14.4</td>
<td>16.2</td>
</tr>
<tr>
<td>18</td>
<td>15.0</td>
<td>20.0</td>
<td>21.0</td>
<td>23.0</td>
</tr>
<tr>
<td>22</td>
<td>18.0</td>
<td>17.5</td>
<td>24.5</td>
<td>15.0</td>
</tr>
<tr>
<td>25</td>
<td>17.5</td>
<td>18.0</td>
<td>19.0</td>
<td>20.5</td>
</tr>
<tr>
<td>29</td>
<td>19.5</td>
<td>21.0</td>
<td>23.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>
Table 5.3.1-2: pH measurements on duplicate samples of irradiated and nonirradiated fresh shucked eastern oysters stored at 330°F.

<table>
<thead>
<tr>
<th>KIlorad Dose Level</th>
<th>Days Post Irradiation</th>
<th>pH Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>6.6; 6.6</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>6.3; 6.3</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>6.3; 6.3</td>
</tr>
<tr>
<td>200</td>
<td>1</td>
<td>6.3; 6.3</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>6.3; 6.3</td>
</tr>
<tr>
<td>50</td>
<td>4</td>
<td>6.3; 6.2</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>6.1; 6.3</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>6.3; 6.3</td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>6.3; 6.1</td>
</tr>
<tr>
<td>50</td>
<td>7</td>
<td>6.0; 6.0</td>
</tr>
<tr>
<td>100</td>
<td>7</td>
<td>6.2; 6.2</td>
</tr>
<tr>
<td>200</td>
<td>7</td>
<td>6.1; 6.2</td>
</tr>
<tr>
<td>0</td>
<td>11</td>
<td>5.9; 5.7</td>
</tr>
<tr>
<td>50</td>
<td>11</td>
<td>6.0; 5.9</td>
</tr>
<tr>
<td>100</td>
<td>11</td>
<td>6.0; 6.0</td>
</tr>
<tr>
<td>200</td>
<td>11</td>
<td>6.0; 6.0</td>
</tr>
<tr>
<td>0</td>
<td>15</td>
<td>5.8; 5.9</td>
</tr>
<tr>
<td>50</td>
<td>15</td>
<td>5.9; 5.8</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>200</td>
<td>15</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>0</td>
<td>18</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>50</td>
<td>18</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>100</td>
<td>18</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>200</td>
<td>18</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>0</td>
<td>22</td>
<td>5.8; 5.8</td>
</tr>
<tr>
<td>50</td>
<td>22</td>
<td>5.8; 5.8</td>
</tr>
<tr>
<td>100</td>
<td>22</td>
<td>5.9; 5.9</td>
</tr>
<tr>
<td>200</td>
<td>22</td>
<td>5.8; 5.8</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>5.8; 5.7</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>5.8; 5.7</td>
</tr>
<tr>
<td>100</td>
<td>25</td>
<td>5.9; 5.8</td>
</tr>
<tr>
<td>200</td>
<td>25</td>
<td>5.9; 5.8</td>
</tr>
</tbody>
</table>
TABLE 5.3.1-2 (Cont'd.)

pH Measurements on duplicate samples of irradiated and nonirradiated fresh shucked eastern oysters stored at 33° F.

<table>
<thead>
<tr>
<th>Kilorad Dose Level</th>
<th>Days Post Irradiation</th>
<th>pH Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29</td>
<td>5.5; 5.5</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>5.7; 5.7</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>5.8; 5.8</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>5.8; 5.8</td>
</tr>
<tr>
<td>0</td>
<td>31</td>
<td>5.5; 5.3</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>5.7; 5.7</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>5.7; 5.7</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>5.7; 5.7</td>
</tr>
</tbody>
</table>
reflect function of time, whether or not the oysters have been irradiated. This relation would seem to suggest the influence of acid-forming bacteria, perhaps such as Lactobacillus, which is resistant to radiation up to about 300 kilorads. This dose is well above the maximum dose level given to any samples in this experiment. For this reason, we plan to study the course of pH in samples of oysters irradiated at dose levels high enough to inactivate acid-forming bacteria.

If bacterial suppression were the only factor to be considered in obtaining clearance for irradiated seafoods, irradiated fresh shucked oysters would serve as a model. Table 5.3.1-3 shows that the 200 kilorad samples exhibit a total plate count of less than 100 compared with a count of over 1,000,000 for the control sample at Day Eleven of post irradiation or after 14 days total shelf life. This shelf life represents about the maximum commercial shelf life at store level. When this shelf life is doubled, we still have a four log cycle reduction between the two samples. Table 5.3.1-3 also shows that Salmonella and Shigella organisms importance are of no significance either in irradiated or nonirradiated samples, indicating that the oysters must have been produced under good sanitary conditions.

Although the bacteriological results are very good, it must be remembered that these results are obtained under controlled laboratory conditions and do not necessarily reflect
TABLE 5.3.1-3  Bacterial growth in irradiated and nonirradiated fresh shucked eastern oysters stored at 33° F.

<table>
<thead>
<tr>
<th>Kilorad Dose Level</th>
<th>Days Post Irradiation</th>
<th>Total Plate Count</th>
<th>Coliforms (37°C)</th>
<th>E. coli (45.5°C)</th>
<th>Salmonella</th>
<th>Shigella</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0.27 x 10^6</td>
<td>67</td>
<td>neg.</td>
<td>neg.</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>0.57 x 10^6</td>
<td>59</td>
<td>0.2</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>4</td>
<td>est. 11 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>est. 2 x 10^2</td>
<td>0</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>0.21 x 10^6</td>
<td>1.4</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>7</td>
<td>est. 8 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>7</td>
<td>est. 28 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>7</td>
<td>est. 4 x 10^2</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>11</td>
<td>1.1 x 10^6</td>
<td>60</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>11</td>
<td>1.1 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>11</td>
<td>est. 16 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>11</td>
<td>est. 6.5 x 10</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>15</td>
<td>4.5 x 10^6</td>
<td>0.3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>15</td>
<td>12 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>1 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>15</td>
<td>9.0 x 10</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>18</td>
<td>7 x 10^6</td>
<td>35</td>
<td>1.3</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>18</td>
<td>17 x 10^4</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>18</td>
<td>est. 8 x 10^2</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>18</td>
<td>est. 1.3 x 10^2</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>22</td>
<td>2 x 10^7</td>
<td>24</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>22</td>
<td>1.1 x 10^5</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>22</td>
<td>3.5 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>22</td>
<td>est. 6.5 x 10^2</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>6.2 x 10^7</td>
<td>13.4</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>0.9 x 10^6</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>25</td>
<td>est. 30 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>25</td>
<td>est. 20 x 10^3</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>0</td>
<td>29</td>
<td>23 x 10^8</td>
<td>67</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>50</td>
<td>29</td>
<td>8 x 10^6</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>100</td>
<td>29</td>
<td>16 x 10^4</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
<tr>
<td>200</td>
<td>29</td>
<td>0/gm</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
<td>neg.</td>
</tr>
</tbody>
</table>
what would happen under commercial conditions of processing, shipping, holding, and displaying at the retail level. Experience with other seafoods has shown that radiation treatment of commercially handled samples results in a shorter shelf life than is obtained with duplicate laboratory-held samples.

5.4 Conclusions and Recommendations

Irradiation treatment of fresh shucked oysters from this particular producing area at this particular season resulted in expression of free liquid that was above that allowed for normal, nonirradiated fresh shucked oysters. It is recommended that tests be made of similarly produced oysters from other major producing centers to determine if the same pattern holds. It is also recommended that such work include samples of unwashed oysters to determine if the same effect is obtained.

The lowering of pH seems to be a function of time with relatively little difference between nonirradiated control samples and those irradiated at levels of from 50 to 200 kilorads. It is recommended that dose levels high enough to suppress lactic acid bacteria be used in order to determine whether the lowering of pH is due to organisms of this nature or is due to spoilage organisms.

Gamma radiation exerts a profound effect upon bacterial suppression at the 200-kilorad level for a duration that has promising commercial prospects, despite the controlled conditions of this experiment. It is recommended that if future
work is to be conducted, that it be designed to consider the radiation treatment of fresh shucked Eastern oysters at levels high enough to suppress lactic acid forming bacteria as stated above, and under actual commercial conditions.

5.5 References


SECTION 6.

OPERATIONS AND SERVICES

by

John D. Kaylor
CONTENTS

6.0 INTRODUCTION 6-1
6.1 SCHEDULED WORK 6-1
  6.1.1 Present Work 6-1
  6.1.2 Future Work 6-2
6.2 UNSCHEDULED WORK 6-5
6.0 Introduction

Throughout this annual report, emphasis has been placed on the primary object of the Marine Products Development Irradiator and its associated programs. This is a developmental unit in the truest sense of the word since there was no precedent to guide us. The mission of the MPDI therefore, is best accomplished by proving the effectiveness of irradiation treatment of seafoods and thereby aiding in the approval for this method of food preservation.

6.1 Scheduled Work

6.1.1 Work during this period consisted mainly of the design and collection of all the data as reported in Section 3 of this report entitled "Commercial Benefit Shipping Studies". We have shown that commercially produced cod and haddock filets purchased on the open market can be commercially irradiated and shipped under prevailing conditions of commercial transportation to extreme distances and still exhibit an extension in shelf life that about doubles that of similarly treated nonirradiated control samples. Future studies of different seafoods will, in general, follow the basic plan of Section 3.

We have also shown that even where exceptionally vigorous standards of quality are the criteria for judging the freshness level of haddock as landed at Boston, the supply of
raw material that will justify using irradiation treatment to obtain shelf life extension is ample. The data are reported in Section 2.

The MPDI has rendered a host of irradiation services for research and for industry. In this current period, the MPDI has irradiated many tons of products as can be seen in Table 6.1.1-1. Its production capacity, however, is large when compared with the amount of material it has irradiated. This imbalance is necessarily caused by the lack of clearances of foods for general sale to the public. When restrictions on the general use of irradiation for fisheries and other food products are eased, MPDI output can be expected to increase.

6.1.2 All work planned for the MPDI program is directly or indirectly aimed toward one object—the practical commercialization of radiation treatment to prolong the shelf life of fresh seafoods. The purposes of future work to be undertaken are to:

1. Survey, at purchaser level, the temperatures of cod and haddock. This work is to complement the work reported in the 1966 Annual Report dealing with temperatures encountered in the channels of distribution.

2. Engage in test shipments of irradiated and non irradiated shrimp in order to establish an acceptable and meaningful protocol. This work is aimed at determining the technical effects of irradiation of shrimp when performed under commer-
<table>
<thead>
<tr>
<th>Product</th>
<th>No. of Jobs</th>
<th>Unit</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentines</td>
<td>1</td>
<td>30 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Clams, hard</td>
<td>1</td>
<td>10 pounds</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Clams, soft shucked</td>
<td>7</td>
<td>27,900 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>clams, surf</td>
<td>1</td>
<td>15 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Clams, surf</td>
<td>1</td>
<td>35 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Cod fillets</td>
<td>30</td>
<td>2,183 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Cod fillets</td>
<td>1</td>
<td>5 pounds</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Cod fillets</td>
<td>1</td>
<td>8 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Crabment</td>
<td>6</td>
<td>296 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Culture, bacterial</td>
<td>1</td>
<td>---</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Dosimeters</td>
<td>1</td>
<td>---</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Electrical cable</td>
<td>1</td>
<td>---</td>
<td>Sterilize Industry</td>
</tr>
<tr>
<td>Fish oil</td>
<td>3</td>
<td>---</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Fish sausage</td>
<td>1</td>
<td>21 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Flounder fillets</td>
<td>22</td>
<td>1,446 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Flounder fillets</td>
<td>2</td>
<td>70 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Gypsy Moth</td>
<td>19</td>
<td>31,069 pupae</td>
<td>Sexual Sterilization</td>
</tr>
<tr>
<td>Gypsy Moth food</td>
<td>1</td>
<td>12 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Haddock fillets</td>
<td>31</td>
<td>2,060 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Haddock fillets</td>
<td>20</td>
<td>1,189 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Haddock fillets</td>
<td>1</td>
<td>5 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Haddock heads</td>
<td>1</td>
<td>3 pounds</td>
<td>Sterilize Research</td>
</tr>
</tbody>
</table>

October 1, 1966 to September 30, 1967
<table>
<thead>
<tr>
<th>Product</th>
<th>No. of Jobs</th>
<th>Unit</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haddock heads</td>
<td>2</td>
<td>5 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Haddock, whole</td>
<td>3</td>
<td>320 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Ham</td>
<td>1</td>
<td>455 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Herring, pickled</td>
<td>3</td>
<td>58 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Ketchup</td>
<td>1</td>
<td>60 pounds</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Lobster</td>
<td>1</td>
<td>15 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Lobster</td>
<td>1</td>
<td>12 pounds</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Mackerel fillets</td>
<td>1</td>
<td>5 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Mackerel fillets</td>
<td>1</td>
<td>50 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Ocean Perch</td>
<td>1</td>
<td>50 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Ocean Perch</td>
<td>3</td>
<td>26 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Oysters, shucked</td>
<td>7</td>
<td>118 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Plates, Bacterial</td>
<td>3</td>
<td>***</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Salmon (lox)</td>
<td>1</td>
<td>20 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Scallops, calico</td>
<td>1</td>
<td>10 pounds</td>
<td>Pasteurize Industry</td>
</tr>
<tr>
<td>Scallops, sea</td>
<td>7</td>
<td>230 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Scallops</td>
<td>2</td>
<td>40 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Shrimp, cocktail</td>
<td>3</td>
<td>9 pounds</td>
<td>Sterilize Research</td>
</tr>
<tr>
<td>Shrimp</td>
<td>20</td>
<td>288 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Snapper fillets</td>
<td>1</td>
<td>5 pounds</td>
<td>Pasteurize Research</td>
</tr>
<tr>
<td>Sole fillets</td>
<td>23</td>
<td>830 pounds</td>
<td>Pasteurize Research</td>
</tr>
</tbody>
</table>

\[
\begin{array}{c|c|c|c}
\text{Product} & \text{No. of Jobs} & \text{Unit} & \text{Purpose} \\
\hline
\text{Haddock heads} & 2 & 5 pounds & Pasteurize Research \\
\text{Haddock, whole} & 3 & 320 pounds & Pasteurize Research \\
\text{Ham} & 1 & 455 pounds & Sterilize Research \\
\text{Herring, pickled} & 3 & 58 pounds & Sterilize Research \\
\text{Ketchup} & 1 & 60 pounds & Pasteurize Industry \\
\text{Lobster} & 1 & 15 pounds & Pasteurize Research \\
\text{Lobster} & 1 & 12 pounds & Pasteurize Industry \\
\text{Mackerel fillets} & 1 & 5 pounds & Sterilize Research \\
\text{Mackerel fillets} & 1 & 50 pounds & Pasteurize Research \\
\text{Ocean Perch} & 1 & 50 pounds & Pasteurize Research \\
\text{Ocean Perch} & 3 & 26 pounds & Sterilize Research \\
\text{Oysters, shucked} & 7 & 118 pounds & Pasteurize Research \\
\text{Plates, Bacterial} & 3 & --- & Pasteurize Research \\
\text{Salmon (lox)} & 1 & 20 pounds & Sterilize Research \\
\text{Scallops, calico} & 1 & 10 pounds & Pasteurize Industry \\
\text{Scallops, sea} & 7 & 230 pounds & Pasteurize Research \\
\text{Scallops} & 2 & 40 pounds & Sterilize Research \\
\text{Shrimp, cocktail} & 3 & 9 pounds & Sterilize Research \\
\text{Shrimp} & 20 & 288 pounds & Pasteurize Research \\
\text{Snapper fillets} & 1 & 5 pounds & Pasteurize Research \\
\text{Sole fillets} & \frac{23}{239} & \frac{830}{35,929} \text{ pounds} & Pasteurize Research \\
\end{array}
\]

6-4
cial conditions of operation.

3. Obtain the complete microbiological history ir-
radiated shrimp used in these shipping studies. Such studies
will include total plate count, coliforms, and *E. coli*.

4. Prepare an analysis of the MPDI, covering operational
experience to date, costs of operation, design changes deemed
desirable in the light of operating experience and estimated
costs for such changes, and preparation of this information in
a form suitable as a separate AEC publication so as to provide
industry the basis for a truly commercial irradiator.

6.2 Unscheduled Work

6.2.1 Table 6.1.1-1 shows that many of the irradiation
services rendered were of a nature that don't lend themselves
to scheduling. Such outside requests, however, do not fall
into the category of unscheduled work. This classification is
reserved for projects that involve planning and experimenta-
tion and that entail much time and effort to accomplish. Ex-
amples of such projects are found in Sections 5 and 7 that
arose out of necessity.

Section 5, for example, shows that gamma radiation can
influence the amount of free liquid released from freshly
shucked oysters to the point where the sale of the product
would be in violation of present legal restrictions. The rem-
edy may lie in reducing the contact time with water to effect
the conventional cleaning. An alternative may lie in the use of unwashed oysters—a practice that has been found to be commercially feasible in some areas.

Section 7 stresses the savings to be made on the first replenishment of the radioactive source and even greater savings on subsequent replenishments. These are improvements that help to lower the cost to a level that will be more attractive to all potential users.
SECTION 7.

SOURCE REPLENISHMENT

by

John B. Huff
CONTENTS

7.0 INTRODUCTION 7-1
7.1 PRELIMINARY CALCULATIONS 7-1
7.2 SOURCE-STRIP ORIENTATION 7-4
7.3 TENTATIVE PROCEDURE 7-9
7.4 CONCLUSIONS 7-11
7.5 REFERENCES 7-12
SECTION 7. SOURCE REPLENISHMENT

7.0 Introduction

The Marine Products Development Irradiator (MPDI) uses a cobalt-60 source. The source consists of 96 strips of encapsulated cobalt-60 assembled to form a plane 11 inches wide by about 4 feet long. The source plane is horizontal while it is being used, but it is stored under water in a vertical position when not in use. The machinery used to automatically move the source into irradiating position has been described by Miller and Herbert (1).

During the period covered by this report, plans were made for the replenishment of the MPDI source, since it had been in use for about 3 years. These plans included some modifications for the source master frame, and specifications for a set of new subframes that were designed to extend the capability of the irradiator. The proposed new design was based upon a few calculations and experiments, which are outlined below.

7.1 Preliminary Calculations

Since the present source, consisting of six subframes completely fills the source elevator, some redesign is required to utilize the existing source material. It appears possible to rotate the source strips 90°; this will approximately double the number of source-strips that the elevator will hold.

The MPDI source strips, when encapsulated, are 13.5" long,
0.8" wide, and 0.156" thick. In the present configuration, the
source strips are placed back-to-back so that the double thick-
ness is 0.312". If a \(\frac{1}{4}\)-inch thick plate of iron were to cover
each side of the existing source, the total thickness would be
about 0.8", which would also be the thickness of the source if
the strips were rotated 90°. Thus, if we calculate the shield-
ing effect of \(\frac{1}{4}\)" steel plate, it should give a reasonable ap-
proximation of the self-absorption in the reoriented source.
The data needed for the calculation are shown in Table 7.1-1.

TABLE 7.1-1

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x = 0.25 \text{ inch or } 0.25 \times 2.54 \text{ cm or } 0.635 \text{ cm iron} )</td>
<td>2, p.144</td>
</tr>
<tr>
<td>Absorption Coefficient = (\mu/\rho=0.052 \text{ cm}^2/\text{g @ 1.25 MeV} )</td>
<td>2, p.88</td>
</tr>
<tr>
<td>(\rho = 7.85 \text{ g/cm}^3 )</td>
<td></td>
</tr>
<tr>
<td>(\mu = 0.52\rho=0.052 \times 7.85 =0.408/\text{cm} )</td>
<td></td>
</tr>
</tbody>
</table>

The intensity of radiation (1) penetrating the iron, as a
fraction of the intensity impinging on the shield (\(I_0\)), is
given by the formula

\[
I = I_0e^{-\mu x}
\]

\[
I = I_0e^{-0.408 (0.635)}
\]

\[
I = 0.68 I_0
\]

This simplified calculation, in which buildup and other
factors are disregarded, shows that the reoriented source strips
should be 68% as effective as they now are. It appears advis-
able, however, to leave some space, say 0.025 inch, between the reoriented strips, so that some air will circulate to cool them. In that case self-absorption will be less, because the assembly will be less dense than the iron plate used in the calculation.

These preliminary calculations were based upon a source decay time of 3 years, since the replenishment date could not be predicted. After three years of decay, a cobalt-60 source will have 67% of its original activity. If it can be used in any array that is 68% effective, the 3-year-old MPDI source should be equivalent to 250 X 0.67 X 0.68 or 113.9 kCi of new source material. Its dollar value is thus in the order of $57,000, based upon an estimated replacement cost of 50 cents per curie, to which can be added shipping costs and other expenses involved in procuring new source material. The length of time that source material is kept has a direct bearing on the cost of maintaining a cobalt-60 source. The curies that decay during use produce the gamma energy required for processing. Hence, the useful curie content is found by subtracting the amount discarded from the amount purchased. Cobalt-60 will yield 25% of its potential energy in 26 months, 50% in 63 months, and 75% in 126 months. A source used for 126 months, then, will yield 3 times the ergs of energy that would be obtained in 26 months, and the cost, on a simple energy-yield basis, is 3 times as much for the shorter use-time. Long use-times are feasible.
if freshly installed cobalt-60 has high specific activity and if space is available in the source-frame to periodically add new source material without discarding the old. The preliminary calculations thus indicated that it would be economically desirable to reorient the old source strips to make room in the source-frame for new cobalt-60.

7.2 Source-Strip Orientation

The structural cross-members of the MPDI elevator source-frame are $1\frac{1}{4}$ inches thick. The six subframes are only $\frac{3}{4}$ inch thick, but the guides that support them extend about $\frac{1}{4}$ inch more on each side, so that the present sub-assembly is about 1 inch thick. If the source strips were reoriented, as proposed, the present guide system would add too much thickness. Hence, it was proposed that new subframes be fabricated with grooved edges to fit guides made of round rods. These subframes will be only 1 $1/8$ inches thick, which is somewhat thinner than the angle-irons that form the top and bottom of the master frame. The proposed subframes are shown in Fig. 7.2-1; they are described as follows:

The subframes consist essentially of two channels that face each other so that they will support the ends of the source strips. Mounted between the channels are two grooved bars. One bar is fixed, but the other one can be removed to install the source strips. The strips can be installed under water; with one side removed and the subframe held in a fixture
Fig. 7.2-1. Proposed source holder for MPDI.
so that the channels are vertical, individual source strips can be slipped into place with suitable underwater tools. The fixture should be sufficiently precise to also align the holes for the retaining pins when the side is re-installed. The personnel at this laboratory have performed some under-water assembly jobs (4); on the basis of this experience, the steps outlined here are considered feasible.

Stainless steel bar stock can be used to retain the strips back-to-back in the old configuration or to adjust the subframe to use shorter strips, such as the Brookhaven National Laboratory Standard Strip, for example. Future adjustments of this kind can apparently be made in our shop with ordinary tools. Section A-A in Fig. 7.2-1 shows a subframe partially loaded with strips in both the old and the new array. New, high specific-activity strips should be used back-to-back, because there will be less total self-absorption with the partially-spent strips in the less favorable positions.

Eight subframes should be fabricated. Two subframes should be loaded with only four strips each, these strips being old cobalt-60 from our existing source. These low-activity subframes can be used to obtain doses in the 20,000 rad range, which is about one-fourth of our present lower limit. An even number of subframes must be used in order that source intensity will be uniformly distributed about the symmetrical center-line, Fig. 7.2-2; nonsymmetrical loading increases the maximum/minimum ratio. With 8 strips loaded in two new subframes, 88 old strips
Fig. 7.2-2. Modified source-frame for MPDI
remain for loading symmetrically with new source material in the other six subframes.

Each source strip is about 0.156 inch thick. The net width of the channels is 7". If the strips were spaced 0.025 inch, the distance between centers should be 0.181 inch. Thus, each subframe should hold 7/0.181 or 38 strips. Strips installed in the old array are 0.8 inch wide; a double layer, 8 strips wide, should thus require 6.4 inches. Thirty-eight old strips could thus be mounted in each of the first two subframes, and each of the four remaining subframes could hold 16 new source-strips together with 3 old source-strips (6.4 inches plus (3 X 0.181)) inches. Refer to Section A-A, Fig. 2.2-1 for the proposed method of mounting old and new strips in the same subframe. It can be seen that, alternately, 44 strips could be assembled in one subframe, by using a space of 0.003" between strips; the 88 remaining strips would then fill two subframes, leaving four empty subframes for new source material. But self-absorption will be at a maximum with the reoriented source strips assembled so close to each other; spacing should be adjusted to use all of the room not required for new source material, which will, in turn, depend upon the specific activity of the new source material.

It follows that as many as 64 new source strips could be used under this proposal. In an attenuation test, a ½ inch iron plate was supported one inch from the MPDI source; dosi-
meter readings showed that the iron absorbed 39% of the energy. This is more absorption than was calculated in the preliminary consideration. In this configuration, many photons penetrate the iron at an oblique angle, so that the distance traversed is more than \( \frac{1}{2} \) inch. If we assume, however, that the new configuration is even half as efficient as the old, the relative source strength of 88 old strips can be estimated as follows. If replenishment is scheduled for 3 years after the first MPDI dosimetry measurements, then 67% of the activity should remain. Only part of the original source will be used: this fraction is 88/96. On the basis of these assumptions, the re-oriented old source should have 0.5 \( \times \) 0.67 \( \times \) 88/96, or 0.3 of startup capability. Assuming further that the new source strips are equivalent in intensity to that of the original ones at startup time, the fraction that they will contribute is 64/96 or 0.67 of startup capability. The replenished source should thus provide 97% of the original MPDI capability; but new source material should not be lower in specific activity than the original source was. Since a capability equal to startup conditions is acceptable, the following procedure for making the modifications is proposed.

7.3 Tentative Procedure

1. The new 1 1/8 inch subframes should be fabricated as an early step. It is recommended that a local machine shop do this work so that its mechanics can adjust clearances for easy
underwater assembly. These mechanics should also be prepared to install the guide rods (Fig. 7.2-2) when the change-over is made.

2. Shims for spacing the old source-strips can be made from strips of stainless steel sheet, 2 x 0.75 x 0.025 inches, or of other thickness, as required. These strips can be bent into a "U" shape to slip over the ends of the source-strips. They should exert some tension when installed, so that they will not fall off before the source-strip is placed in the subframe. With these shim-clips installed on alternate source-strips, the spacing should be as planned. The shim-clips will be locked in place when the subframes are closed.

3. A few special-purpose underwater tools will be required. These can probably be designed and fabricated in the MPDI shop.

4. New underwater storage buckets will be required for the new subframes. The storage buckets should be so designed that underwater irradiation in the rotating pressure cooker is as efficient as possible. About half of our jobs are presently done with this system. It should be possible to array the six high-level subframes hexagonally around the submerged pressure cooker at predetermined, but adjustable, distances from its axis.

5. Since the MPDI is a development irradiator, dosimetry measurements should be taken to compare the new configuration with the old. From these data it would be possible to forecast
the economics of using source material that has decayed to a specified activity. Similarly, it would be desirable to compare two different spacings, such as 0.025 inch and 0.050 inch, for example, by actually measuring the yield of gamma energy. No more than a day should be required to assemble the strips with another set of shims and then take the readings. Such a test, however, should be scheduled as a step in the modification procedure; after the source has been assembled and its dosimetry has been established, it is undesirable to change the geometry of the assembly.

7.4 Conclusions

The proposed modifications are apparently justified by the money saved on the first source replenishment; relative savings should be greater on subsequent additions of cobalt-60, since little shop work would then be required. With the cost of radioactive shipments rising, any development of techniques for on-site loading or extending the useful life of source material should result in lower processing costs.
7.5 References


APPENDIX 1

ORGANOLEPTIC PROCEDURES AND ORGANOLEPTIC EVALUATIONS TO DETERMINE BACTERIAL SPOILAGE OF IRRADIATED AND NONIRRADIATED COD AND HADDOCK FILLETS
ORGANOLEPTIC PROCEDURES

The organoleptic procedures employed for this study involved evaluation of the characteristics of appearance, odor, flavor, and texture by a consumer-oriented panel on normal commercially available fish fillets.

Generally, a minimum of 12 panelists participated. All fillets were steamed to the proper degree of cook. No other treatment was used; no condiments of any nature were used. This procedure consistently exposed the fillets to the most severest testing conditions, because fillets removed from fish not more than 24 hours out of the water, seldom receive an average rating exceeding 7 (good) when performed under such rigorous conditions.

The evaluation system used was a modified Hedonic system employing a score of from 0 to 9 and providing space for separate evaluations of appearance, odor, flavor, and texture. A copy of the form is attached.

This modified Hedonic scale was related quantitatively to specifically defined quality attributes and to the FDA system for organoleptic evaluation of fish fillets (See Table 1).

Panelists evaluated samples in individual booths, and arrived at their scores independently of each other. The raw data were placed in a computer for Q-test for the rejection of extreme organoleptic ratings of panelists, and analysis of variance of each of the variables under study, and, the

I-1
Range test was applied when these values were significant. The computer, after completing these steps, then applied regression analyses to arrive automatically at regression lines, which were reproduced in Graphs 5 through 18.

Objective

The objective of the study was to determine the shelf life and the change in quality of nonirradiated and radiation-treated (150 kilorads) cod fillets stored at 33° F. to 47° F. and to compare these data with data on the total plate count and proteolytic bacteria count of the samples.

Methods

Freshness was determined on the basis of the odor of the raw samples by a special, trained panel of six staff members selected from the laboratory staff as a result of numerous experiments that showed that each of the selected panelists was able to determine the storage age (in ice) of cod fillets within ± 2 days with a reproducibility of 85 percent. As a group, the panel average for determining the age (in ice) of cod fillets within ± 2 days, thus far, has been 95 percent.

In training, testing, and selecting the panelists, participants were asked daily to evaluate cod fillets of varying quality. Fish were obtained 24 to 48 hours after capture, commercially filleted, packed in plastic pouches, and placed within 30 pound fillet cans which, in turn, were stored in ice.
<table>
<thead>
<tr>
<th>Hedonic Scale</th>
<th>Bureau of Commercial Fisheries Nomenclature</th>
<th>Food and Drug Administration Nomenclature</th>
<th>Odor</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 Excellent</td>
<td>Seafresh fresh odor characteristic of species</td>
<td>Neutral, faint sweet flavor characteristic of species</td>
<td>0</td>
</tr>
<tr>
<td>8 Very Good</td>
<td>Faint seafresh odor</td>
<td>Increase of sweet and characteristic flavor of species</td>
<td>0</td>
</tr>
<tr>
<td>7 Good</td>
<td>Neutral or no odor</td>
<td>Decrease of sweet and characteristic flavor of species</td>
<td>1</td>
</tr>
<tr>
<td>6 Fair</td>
<td>Very slightly fishy</td>
<td>Loss of flavor, very slightly fishy or musty</td>
<td>1</td>
</tr>
<tr>
<td>5 Borderline</td>
<td>Slightly fishy</td>
<td>Neutral or slightly fishy</td>
<td>2</td>
</tr>
<tr>
<td>4 Slightly Poor</td>
<td>Strongly fishy, fleeting NH₃</td>
<td>Fishy or incipient spoilage</td>
<td>2</td>
</tr>
<tr>
<td>3 Poor</td>
<td>Slight but persistent NH₃ fruity, sour, oniony or slightly yeasty</td>
<td>Strongly fishy, sour acid, sulfide, slight but persistent NH₃</td>
<td>2</td>
</tr>
<tr>
<td>2 Very Poor</td>
<td>Stale or &quot;rancid&quot; strong NH₃, moderately yeasty</td>
<td>Salty, bitter, sulfide, strong NH₃</td>
<td>3</td>
</tr>
<tr>
<td>1 Inedible</td>
<td>Strongly yeasty, nauseating, putrid fecal, indole, H₂S excessive NH₃, revolting or sickly sweet</td>
<td>Nauseating, revolting, bitter, sulfide or excessive NH₃</td>
<td>3</td>
</tr>
</tbody>
</table>
Every 2 or 3 days, fillets were removed so that, eventually, the participants had presented to them fish that had been held for varying storage times in ice. Spoiled samples of known age were also included. At first, the testers were told the storage age of each sample given to them to help them associate the iced age of the sample with their own individual indices for quality. (At this stage there was considerable discussion and exchange of ideas among the testers.) Eventually the staff members were given unidentified samples along with known samples. They were asked to estimate the age of the unknown samples. The responses of each staff member, over about 30 separate tests, were recorded and plotted against the known values. Six of the panelists showed an uncommon ability to estimate the iced age of the fillets within a narrow range, 85 percent of the time. More important, when the responses of the six panelists were averaged, the values consistently fell within the narrow range, ± 2 days. The panel's reliability depends on the exceptional capabilities of its members as well as on the consistent training it receives and on the known samples that are made available for it to use as references.

Discussion
In the experiment reported here, the panel did not know the treatment to which the samples were subjected. Their responses, to the quality and shelf life of all samples
tested, are shown in Graphs 36 and 37. It can be seen that the values supplied by the panel for the nonirradiated samples stored at 33° F., shown by the triangle-points, do not differ from the actual values by more than 2 days, up to the time the samples were spoiled. As expected, the slopes of points assigned to samples stored at higher temperatures increased as a function of the storage temperature. This type of graph can be used to show that the quality of cod fillets stored for 3 days at 47° F. is equivalent to the quality of cod fillets stored about 10 days on ice. In addition, the panel indicated that the irradiated samples eventually developed recognizable objectionable odors similar to those found in spoiled nonirradiated samples.

Ordinarily, nonirradiated samples of fish are considered to be spoiled by sensory evaluation when the total plate count reaches 10^6 to 10^7 organisms per gram. The total plate count of itself is recognized to be only a partly reliable indicator of the freshness of nonirradiated fish. There is no evidence to show that total counts alone have any legally acceptable degree of reliability as an indicator of the freshness of non-irradiated fish.

The proteolytic bacteria number 10^7 to 10^8 organisms per gram when the nonirradiated samples became spoiled and about 10^6 to 10^7 organisms per gram when the irradiated samples became spoiled. Thus it appears reasonable to expect that the number
of proteolytic bacteria in irradiated fish at the time of spoilage should be fewer than the number of proteolytic bacteria in nonirradiated fish when it is considered spoiled.

It would also seem reasonable to postulate that irradiated fish spoil with the development of objectionable odors similar and recognizable as those developed by spoiled nonirradiated fish. The only difference is that the odor development is delayed in the case of irradiated fish due to a lowering or partial destruction of the proteolytic bacteria.
APPENDIX 2

MICROBIOLOGICAL METHODS AND MATERIALS
Microbiological Methods and Materials

The microbiological analysis of experimental fillets consisted of total aerobic plate counts performed on samples of fillets selected from commercially packed cans (irradiated or nonirradiated). The aseptic techniques and procedures employed are those prescribed in the American Public Health Association publications entitled "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes" Tenth Edition, and "Standard Methods for the Examination of Dairy Products" Eleventh Edition. Further details of the media employed, selection and handling of fillets, and incubation of plates are described herein.

Methods Employed

A. Growth medium: Eugonagar, *BBL, modified with the addition of 0.5 percent yeast extract (BBL). Prepared according to manufacturer's directions and bottled and sterilized (autoclaved 1210 C., 15 minutes) in 100 and 200 ml. quantities for use.

B. Media for dilution Blanks:

0.1 percent Trypticase (BBL)
0.125 percent KH$_2$PO$_4$ Stock Solution
(Stock Solution, 42.5 gm. KH$_2$PO$_4$/L)
0.1 - 0.2 percent NaOH to adjust pH to 7.2 ± 0.1
This preparation (the above) represents a modification of the original formula by the omission of

* Baltimore Biological Laboratories, Co., Baltimore, Maryland.
Antifoam (Dow Corning). The 9 ml. dilution blanks are prepared in screw cap tubes (18 x 150 mm), 99 ml. in flasks or pyrex bottles. The diluent blanks are sterilized (autoclave) at 121°C. for 15 minutes.

Selection and Handling of Examined Samples

Each 10 pound commercially packed can of fillets was removed from its 33°C. storage area on the day of examination and carefully opened. Using aseptic techniques (flamed tongs, scissors, scalpels), representative cellophane packages from different parts of the can, were unwrapped and portions of fillets were placed in sterile containers. Usually, from 2 to 4 fillets, depending upon size comprised one sampled selection. From these samples, 50 grams of fillet cross sections were aseptically removed, weighed, and placed in a sterile blender container (**Oster cup) followed by the addition of 450 ml. of sterile diluent. The mixture was blended for 2 minutes; the resulting homogenate represented a 1:10 dilution of a given sample. Decimal dilutions of this homogenate were prepared for plating.

Petri plates were poured with melted Eugonagar (45°C.), solidified, and incubated at 20°C. for 5 days after which the outgrown colonies were counted on a Quebec Colony Counter. The data were recorded as the number of viable bacteria per gram of fish.

** John Oster Mfg. Co., Milwaukee, Wisconsin

II-2
At least one sample of fillets selected from a 10 pound can being examined was used for the data collected. For the bacterial counts to determine survival curve data and for that which would represent the bacterial load the first day of irradiation for each shipment, two samples were taken, and their counts were averaged for each determination. After microbiological samples were removed, the remaining portion was used for the sensory panel evaluation.

Proteolytic Analysis

A method has been adapted from that of Dr. Robert Levin, University of Massachusetts, for the detection of proteolytic activity, based on the lysis of gelatin. The following medium is prepared:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eugon Broth (BBL)</td>
<td>30 gm</td>
</tr>
<tr>
<td>Gelatin</td>
<td>100 gm</td>
</tr>
<tr>
<td>NaCl</td>
<td>5 gm</td>
</tr>
<tr>
<td>Yeast Extract</td>
<td>5 gm</td>
</tr>
<tr>
<td>H₂O</td>
<td>1000 ml</td>
</tr>
</tbody>
</table>

This nutrient gelatin medium is dispensed in pyrex tubes, 2.5 ml per tube, and sterilized.

To assay for proteolytic activity, 0.1 ml of a dilute fish homogenate preparation (previously described in this Appendix), was spread on the surface of solidified, sterile Eugonagar (BBL) in a petri plate. The inoculum was spread using sterile glass spreaders ("hockey sticks"). The Eugonagar surface is then overlayed with 2.5 ml of the above described gelatin medium and placed in a refrigerator (at about...
4° C.) for 20 to 30 minutes to solidify the gelatin prior to inverting the petri plate for incubation at 20° C. for 5 days. After incubation, the surface of the petri plate is flooded with a solution of 2NHCl containing 15 percent HgCl₂. The HgCl₂ solution causes the gelatin to form a milky precipitate except where colonies of micro-organisms have dissolved the gelatin. Thus, clear zones around colonies indicate proteolytic activity.

The percentage of proteolytic colonies for a given sample is determined:

\[
\% \text{ proteolytic activity} = \frac{\text{colonies with clear zones}}{\text{total colonies on plate}}
\]

The percentage of proteolytic active colonies is multiplied by the total number of micro-organisms for that same sample (total plate count method) to give a numerical answer for the number of proteolytic micro-organisms.
APPENDIX 3

GRAPHS OF SHELF LIFE, BACTERIAL REDUCTION, AND TOTAL PLATE COUNTS OF BACTERIA
Graph 1

Reduction of total bacteria as a function of irradiation dose level (haddock fillets).

Log No.
Bacteria per gram

Irradiation Dose Level (Kilorads)
Graph 2

Reduction of total bacteria as a function of irradiation dose level (cod fillets).

Log No. Bacteria per gram vs. Irradiation Dose Level (Kilorads)
GRAPH 3

SHELF LIFE OF IRRADIATED AND NONIRRADIATED COD
FILLETS AS A FUNCTION OF STORAGE TEMPERATURE
AND RADIATION DOSE

--- 0 RADS
--- --- 100,000 RADS

POST IRRAD. STORAGE TEMP. OF

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>33°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46°</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GRAPH 4

SHELF LIFE OF IRRADIATED AND NONIRRADIATED HADDOCK PILLETS
AS A FUNCTION OF STORAGE TEMPERATURE AND RADIATION DOSE

TIME (days)
Graph 5

Shelf-life of bread: Effects of palm oil and 

Non-Irradiated, 25°C, 54% RH, 50% rh, 20% rh

--- CONTROL

--- 100 K ILS

--- 200 K ILS

Score of shelf-life, compared with 0 (best) and 10 (worst).
Contrasts with results of shelf-life studies
following irradiation to dose levels of 50, 100,
and 200 K ILS.
Graph 6: Shelf-life of haddock fillets (3105) irradiated and non-irradiated, held at 33°-35°F. after rail shipment to Jacksonville, Florida and return.

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 2.
Shelf-life of haddock fillets (3106)/irradiated and non-irradiated, held at 33° - 35°F., at Marine Products Development Irradiator, Gloucester, Massachusetts.2/

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix I. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix I.

3/ Contrast these with graphs 3 and 9 which detail results of shelf-life studies following shipment to BCF, Seattle laboratory and return.
Shelf-life of haddock fillets (3120), irradiated and non-irradiated, held at 33° - 35°F., after rail shipment to BCF, Seattle laboratory.

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.
Graph 9. Shelf-life of haddock fillets (3107), irradiated and non-irradiated, held at 33° - 35°F, after rail shipment to BCF Seattle laboratory and return.

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix I. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix I.
Shelf-life of haddock fillets (312a) irradiated and non-irradiated, held at 33° - 35°F., at Marine Products Development irradiator, Gloucester, Massachusetts.

Score of 4 corresponds with FDA class 2 fish.

Code refers to organoleptic raw data in Appendix 1.

Contrast with graph 11 which details results of shelf-life studies following second shipment to Jacksonville, Florida and return.

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.

3/ Contrast with graph 11 which details results of shelf-life studies following second shipment to Jacksonville, Florida and return.
Shelf-life of salted haddock fillets, irradiated and non-irradiated, held at 33° - 35°F., after second rail shipment to Jacksonville, Florida and return.

**1/** Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

**2/** Code refers to organoleptic raw data in Appendix 1.
Shelf-life\(^1\) of cod fillets (3112)\(^2\) irradiated and non-irradiated, held at 33\(^\circ\) - 35\(^\circ\)F., at Marine Products Development Irradiator, Gloucester, Massachusetts.\(^2\)

**GRAPH 12**

---

**CONTROL**

---

100 KRADS

---

200 KRADS

---

MARKETABLE

---

UNMARKETABLE

---

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.

3/ Contrast with graph 13 which details results of shelf-life studies following shipment to Jacksonville, Florida and return.
Graph 13

Sheelf-life$^1$ of cod fillets (311)$^2$, irradiated and non-irradiated, held at 33° - 55° F., after rail shipment to Jacksonville, Florida and return.

10
9
8
7
6
5
4
3
2
1

0
5
10
15
20
25
30

TIME (days)

Score

Control
Unmarketable
7th Day

100 KRRAS
200 KRRAS

Graph 13

Likewise

Unmarketable

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.
Graph 14: Shelf-life of cod fillets (311A), irradiated and non-irradiated, held at 33° - 35°F., at Marine Products Development Irradiator, Gloucester, Massachusetts.

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.

3/ Contrast these with graphs 15 and 16 which detail results of shelf-life studies following shipment to BOP Seattle laboratory and return.
Graph 15

Shelf-life of cod fillets (3122), irradiated and non-irradiated, held at 35° - 35°F., after rail shipment to BCF Seattle laboratory.

---

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix I. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix I.
1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.
Graph 17

Shelf-life of cod fillets (3128) irradiated and non-irradiated, held at 33°-35°F, at Marine Products Development Irradiator, Gloucester, Massachusetts.

---

1/ Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

2/ Code refers to organoleptic raw data in Appendix 1.

2/ Contrast these with graph 18 which details results of shelf-life studies following second shipment to Jacksonville, Florida and return.
Graph 18

Shelf-life\textsuperscript{1/} of cod fillets (3129)\textsuperscript{2/}, irradiated and non-irradiated, held at 23° - 35°F., after second rail shipment to Jacksonville, Florida and return.

\begin{itemize}
    \item Control
    \item 100 Krad
    \item 200 Krad
\end{itemize}

 Interruption in lines indicates samples in transit.

100 Krad Declared Inedible Raw State 17th Day

MARKETABLE

UNMARKETABLE

\textsuperscript{1/} Shelf-life determined on hedonic scale (0-9). Relationship with accepted FDA organoleptic system defined in Table 1, Appendix 1. Score of 4 corresponds with FDA class 2 fish.

\textsuperscript{2/} Code refers to organoleptic raw data in Appendix 1.
Total plate counts\(^1\). Haddock held at MPDI at 338-358°F. (February 13, 1967)\(^2\).

CONTROL
100 KRADS
200 KRADS

1. Total Number of viable bacteria determined by procedure described in Appendix 2.

2. Compare with Graph No. 20 which details total plate counts of haddock shipped to Jacksonville, Florida (returned samples).

1. Procedure, see Appendix 2.

2. Compare with Graph No. 19 which details the total plate counts of haddock held at MPDI at 330-350F.
Total plate counts\(^1\): Haddock held at MPDI at 33\(^\circ\)-35\(^\circ\)F. (February 22, 1967)

1. Procedure, see Appendix 2.

2. Compare with Graph Nos. 22 and 29 which detail the total plate counts of haddock shipped to Seattle, Washington.

1. Procedure, see Appendix 2.

2. Compare with Graphs 21 and 29 which detail the total plate counts of haddock held at MPDI or shipped to Seattle (returned samples).
Total plate counts\(^1\): Haddock shipped to Seattle, Washington (February 22, 1967) returned samples\(^2\).

1. Procedure, see Appendix 2.

2. Compare with Graphs 21 and 27 which detail the total plate counts of haddock either held at MPDI or shipped to Seattle, Washington (Seattle BGF Lab data).
Total plate count: Haddock held at MPDI at 33°-35°F. (March 6, 1967).

1. Procedure, see Appendix 2.
2. Compare with Graph no. 25 which details the total plate counts of haddock shipped to Jacksonville, Florida.
Total plate count\(^1\): Haddock shipped to Jacksonville, Fla. (March 6, 1967) returned samples\(^2\).

1. Procedure, see Appendix 2.

2. Compare with Graph No. 24 which details total plate count of haddock held at MPDI at 33\(^\circ\)-35\(^\circ\)F.
Total plate counts: Cod held at MPDI at 33°-35°F. (February 13, 1967).

1. Procedure, see Appendix 2.

2. Compare with Graph No. 27 which details the total plate count of the cod shipped to Jacksonville, Florida. (Returned samples)
Total Plate Counts: Cod shipped to Jacksonville, Fl. (February 13, 1967) returned samples.

1. Procedure, see Appendix 2.

2. Compare with Graph No. 26 which details the total plate count of cod held at MPDI 33°-35°F.
Total plate counts: Cod held at MPDI at 33°-35°F. (February 22, 1967). 

GRAPH 28

Log No.

Bacteria per gram

1. Procedure, see Appendix 2.

2. Compare with Graph No. 29 which details the total plate counts of cod shipped to Seattle, Washington.
Log No.

Bacteria per gram

CONTROL
100 KRADS
200 KRADS

Graph 29

Days Post Irradiation

Total plate counts\(^1\): Cod shipped to Seattle, Washington (February 22, 1967)
Seattle BCF Lab data.

1. Procedure, see Appendix 2.

2. Compare with Graph No. 28 which details the total plate counts of cod either held at MPDI or shipped to Seattle, Washington, returned samples.
Total plate counts\(^1\): Cod shipped to Seattle, Washington (February 22, 1967) returned samples\(^2\).

1. Procedure, see Appendix 2.

2. Compare with Graph no. 28 and 29 which detail the total plate count of cod either held at MPDI or shipped to Seattle, Washington. (Seattle BCF Lab data).

---

**GRAPH 30**

- **CONTROL**
- **100 KRADS**
- **200 KRADS**

**Days Post Irradiation**

**Log No.**

<table>
<thead>
<tr>
<th>Bacteria per gram</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
Total plate count: Cod held at MPDI at 33°-35°F. (March 6, 1967).

1. Procedure, see Appendix 2.

2. Compare with Graph no. 32 which details total plate count of cod shipped to Jacksonville, Florida. (returned samples)
Total plate count: Cod shipped to Jacksonville, Fla. (March 6, 1967) returned samples.

1. Procedure, see Appendix 2.

2. Compare with Graph 31 which details total plate count of cod held at MPDI at 330-350F.
Total aerobic plate counts for non-irradiated cod fillets stored at various temperatures.
Graph No. 34

Total aerobic plate counts for cod fillets irradiated at 150 krad and stored at various temperatures.
Graph No. 35

Number of proteolytic microorganisms appearing during storage at various temperatures of unirradiated and irradiated cod fillets.

Key

Nonirradiated

Storage Temp.

- - - - - - 47°

Irradiated

- - - - - - 47°
Panel estimates of age of nonirradiated cod fillets stored at 33, 37, 42, and 47°F.

Graph 36

Panel estimates of age (days)

Actual Age (days)

R = Unanimous rejection by panel.

This panel was trained to detect changes in the post mortem quality of fish stored in ice. They, therefore, define quality as equivalent to days stored in ice.
Graph 37

*Panel estimates of age of cod fillets irradiated at 150 kilorads and stored at 33, 37, 42, and 45°F.

R = Unanimous rejection by panel.

*This panel was trained to detect changes in the post mortem quality of fish stored in ice. They, therefore, define quality as equivalent to days stored in ice.
APPENDIX 4

FRESH FISH SURVEY

ORGANOLEPTIC CRITERIA
ORGANOLEPTIC CRITERIA

Damage

Score               Description
1. No physical damage. Skin intact.
2. Slight damage or suffusion of blood under the skin. Minor breaks in skin surface.
3. Fork holes or torn flesh evident. Belly blown with some viscera visible in whole fish.
4. Badly torn or mutilated. Belly blown with some viscera protruding in whole fish.

Skin Surface

1. Skin surface has high sheen, not faded. Moderate amount of clear, evenly distributed slime. Whole appearance bright as though alive.
2. Skin surface somewhat faded in lustre. Slime heavier and beginning to become opaque.
4. Skin very faded. Very dull. Scales loose and fall upon handling. Slime thick, opaque, knotted or ropy.

Eyes

1. Clear, bright, slightly protruding to bulging (depending upon species), black pupil, transparent cornea.
2. Cornea slightly cloudy, somewhat dull, not protruding. Pupil tending to be cloudy.
3. Dull, flat or unusually sunken. Pupil definitely cloudy

IV-1
or milky. Cornea opaque.

4 Dull, sunken. Cornea discolored reddish or yellowish.
   Pupil opaque.

Gills

1 Bright red to bright pink (depending on species). Free from slime. No odor.
2 Less color intensity. Dull red to pink. Slightly slimy. May have slight odor.
3 Pink to pale pink. Slimy. Odor 3 classification below.
4 Faded pink to discolored, tan, yellow or grayish or brown. Odor 4 classification below.

Texture

1 Flesh very firm and elastic (in rigor mortis - body rigid).
2 Flesh beginning to lose elasticity. Indented finger marks disappear, but more slowly.
3 Flesh moderately soft. Resiliency lost. Pressure marks remain.
4 Flesh very soft and limp. Pits readily on pressure.

Odor

1 Odor characteristic of freshly caught fish.
2 Practically no odor. Neutral or very faint hint of fishy odor at most.
3 Slight, persistent fish odor.
4 Strong fishy, ammoniacal, or other definite odors associated with decomposition in varying degrees.