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TECHNICAL REPORT
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EFFECT OF LOW TEMPERATURE IRRADIATION ON CHEMICAL & SENSORY CHARACTERISTICS OF BEEF STEAKS

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F. L. Kauffman & J. W. Harlan

Swift & Co.
Research & Development Center
Chicago, Illinois 60609

Contract No. DA 19-129-AMC-164(N)

March 1969

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

FOOD LABORATORY
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FOREWORD

The availability of shelf-stable, highly acceptable meat items for use in military feeding systems is considered a necessity. The currently available thermally processed items do not fully meet requirements because of their limited utility, stability and acceptability. Radiation processing, or "cold" sterilization as it is frequently called, has the potentiality of yielding products that have good military utility, good storage stability, and good acceptability. Therefore, research to develop process criteria that can be used to produce irradiation sterilized meats is underway.

The work covered in this report was performed by Swift and Company Research Laboratories under Contract Number DA 19-129-AMC-164(N) during the period 22 July 1963 to 22 January 1966. It represents an investigation of the influence of variations in the quality of raw material (carcass grade) and variations in product temperature during irradiation on the acceptability and storage stability of irradiation sterilized beef steaks. Many factors, including irradiation flavor intensity, tenderness, free moisture and water binding capacity, soluble and insoluble collagen, total nitrogen and non-protein nitrogen, water soluble and insoluble carbonyl compounds, mercaptans, sulfides, and amino acids, were measured and used as indices for determining the effects of the irradiation treatments on the various grades of beef steaks.

Dr. F. L. Kauffman was the Project Officer and Official Investigator and Dr. J. W. Harlan was Collaborator in the research work for Swift and Company Research Laboratories. The U. S. Army Natick Laboratories' Project Officer was Dr. E. Wierbicki and the Alternate Project Officer was Dr. F. Heiligman, both of the Irradiated Food Products Division, Food Laboratory. The work was conducted under Project 7X84-01-002, Radiation Preservation of Foods.

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ABSTRACT

Irradiation flavor intensity, organoleptic tenderness, quantity of mercaptan, extractable non-protein nitrogen and soluble collagen were shown to be significantly affected at the 90% confidence level or better by animal grade, irradiation dosage, temperature of irradiation and storage time. Irradiation flavor intensity decreases substantially with decreasing temperatures. The water binding capacity was affected significantly by the animal grade and the storage time. The amount of 17 amino acids analyzed were not affected by the irradiation dose, irradiation temperature or the storage time.

The pH values, total moisture, free water and total nitrogen were slightly higher in the utility grade steaks than in the choice grade steaks.

OBJECTIVES

To correlate alterations in meat muscle tissue that occur during irradiation and storage with changes in radiation flavor intensity and radiation induced texture changes; to tell how these changes are influenced by the product temperature during irradiation; and to obtain insight on how to prepare satisfactory irradiation sterilized beef steaks.

INTRODUCTION

Investigations in this laboratory under Contract No. DA 19-129-QM-2000 showed that the intensity of the irradiation off-flavor developed in enzyme inactivated beef products is directly proportional to the temperature at which they are irradiated. Beef products sterilized at -196°C are markedly superior in acceptability to beef products irradiated at room temperature. Only slight improvement is needed in these low temperature irradiated beef ration items to make them as acceptable as similar non-irradiated items. A knowledge of the fundamental, physical and chemical effects of irradiation on cooked meat muscle tissue as a function of irradiation temperature should aid in attaining this additional degree of improvement.

The physical and chemical effects of ionizing radiation on meat, single proteins and protein constituents have been intensively studied at room temperature, both in solution and in the solid state using a wide variety of techniques and approaches. The effect of temperature on these interactions has been studied in a limited way by Patten and Gordy[4] using electron spin resonance to determine the nature and stability of free radicals formed on the gamma irradiation of amino acids and proteins. These studies showed that the free radicals of very long half life observed at -196°C after irradiation at -196°C differ from the shorter half life free radicals observed at room temperature following room temperature irradiation. However, they show that the free radicals observed in samples irradiated at -196°C and warmed to room temperature are the same as those observed following room temperature irradiation. Currently the only demonstrated difference between cooked meat irradiated at normal and low temperature is a difference in the intensity of irradiation flavor observed by a trained panel. It is worth noting that there has been no indication of a change in the nature of the irradiation flavor observed.

SELECTION OF EXPERIMENTAL MATERIAL AND ITS ALLOCATION IN THE STATISTICAL DESIGN

Center sections of boneless loin strips were selected as the most uniform meat samples available in sections suitable for preparation of steaks approximately 3/4 inch thick and 3 inches in diameter. Since the preparation of sufficient samples for evaluation at each of

14 combinations of temperature and irradiation dose at five different storage times plus an additional three combinations at 0 time would require 876 steaks (12 steaks at each condition are required for evaluation) with no replication and a pair of matched loins would yield only 240 steaks, the experimental design was established using matched whole loins at the extreme variable conditions of the experimental matrices in the 0 and 3 month storage period with random assignments of short loins to the intermediate conditions and to the test conditions of the 9, 15 and 24 month storage series. A few samples of the matched loins were carried into the 9th and 15th month. By replicating the initial and 3 month storage series an estimate of loin to loin variation was obtained for use in evaluation of the statistical significance of experimentally observed differences. Unirradiated control steaks were held in a freezer at -20°C.

EXPERIMENTAL

I. Preparation of Samples - U.S. Choice Grade Steaks

A fresh meat specialist from the laboratory was sent to the Swift and Company Plant at Rochelle, Illinois, and inspected several hundred sides of U.S. Choice beef. Two pairs of matched whole loins and 42 short loins were selected on the basis of uniformity in grade, marbling and size. The selected loins were then cut out and returned to the laboratory.

In the laboratory the ends (approximately 2") of the loins were cut off and the external connective tissue and fat cover removed. The loins were then sliced approximately 3/4 inch thick and 3 inches in diameter. Steaks were prepared from the slices. These steaks were then enzyme inactivated by heating on wire mesh racks to an internal temperature of 74°C as measured by multiple thermo-couples inserted in steaks at a constant relative humidity of 57%. The internal temperature of the steaks was 74°C or above 5 to 7 1/2 minutes, assuring complete enzyme inactivation in all samples. This thermal processing was done in a large smokehouse oven with temperature and humidity control equipment. The enzyme inactivated steaks were then packed into 200 x 300 cans, 3 steaks to the can. The cans were closed using a cycle of evacuation, nitrogen filling, evacuation and closing on a standard vacuum packaging machine. The cans were then allocated to the irradiation conditions and sent to Cook Electric Company, Morton Grove, Illinois, for Cobalt 60 gamma irradiation under one or more of the following conditions:

(1) Irradiation Dose in Megarad (Mrad):

Requested:	Received:
1.5	1.5 ± 10%
3.0	3.0 ± 10%
4.5	4.5 ± 10%
6.0	6.0 ± 10%

(2) Irradiation Temperature (in ^{o}C):

Requested:	Received:
+20	+20 to +30
-20	-20 ± 2
-80	-80 ± 2
-196	-194 ± 2

Irradiation dose rate varied from 0.1 to 0.409 Mrad per hour with most samples irradiated at the low dose rate.

Irradiation doses and irradiation temperatures, as used throughout this report, are "requested" doses and temperatures.

Samples for irradiation at +20^{o}C were held in a 4^{o}C cooler prior to irradiation as were samples for evaluation at 20^{o}C and no irradiation condition. The remainder of the samples were held at -20^{o}C prior to irradiation. After irradiation at the specified temperature the samples were all warmed to 15 to 20^{o}C and then stored at the above storage temperatures until the start of the 23^{o}C storage test.

II. Preparation of Samples - U.S. Utility Grade Steaks

Steaks were prepared from utility grade loins, enzyme inactivated, canned and coded for irradiation exactly as described above the U.S. Choice steaks. The loins were selected from cattle killed at Swift and Company Plant at Rochelle, Illinois.

III. Panel Training

U.S. Choice Beef Steaks 3/4 inch thick and 3 inches in diameter were prepared for panel training from two trimmed lean inside rounds. The steaks were broiled to an internal temperature of approximately 75^{o}C and vaccum packed in 200 x 300 cans. Cans prepared from each loin were given 0, 1.5, 3.0 and 4.5 megarads of irradiation at 20^{o}C.

Twenty members of the laboratory staff not experienced in irradiation flavor intensity evaluation were presented samples with and without irradiation flavor and the samples discussed openly at several sessions.

These people plus an additional 10 staff members previously trained were then presented with four randomized samples having received different levels of irradiation and their ability to detect and quantitate irradiation flavor determined. Panelists and alternates were then selected on the basis of performance on these tests. The above panelists were also trained for tenderness evaluation and texture description by open discussion of samples so that as nearly as possible specific descriptive terms would mean the same thing to each panel.

METHODS

I. Irradiation Flavor Intensity

An expert panel of eight persons was selected from an initial screening of fifteen members of the laboratory staff and trained to differentiate between levels of irradiation flavor intensity. Samples of beef irradiated with 0, 1.5, 3.0 and 4.5 megarads at ambient temperature were used for training this panel. Sufficient sessions were conducted to insure that the panel could distinguish between various quantitative levels of irradiation flavor and that it could effectively duplicate its responses. The scale used in these experiments had the following numerical and verbal designations concerning the amount of irradiation flavor.

1 - None
2 - Very little
3 - Little
4 - Moderate
5 - Much
6 - Very much

Panel sessions were conducted by warming product to serving temperature, then serving four or less samples in randomized order to each panel member. Panel scores were normalized for each sitting by tasting a control sample which had been irradiated at room temperature to a dose of 3.0 megarads. These samples usually were rated about 4.0 (moderate). The panel was checked at intervals on its ability to differentiate between samples receiving 0, 1.5, 3.0 and 4.5 megarads of irradiation at room temperature and was found to perform satisfactorily. Tests were run in duplicate or quadruplicate.

II. Organoleptic Tenderness

At the same time that the panel examined the steaks for irradiation flavor intensity it evaluated them also for tenderness. This was done on a ten point hedonic scale where a rating of one is extremely tough and a rating of ten is extremely tender. Tests were conducted in duplicate.

III. L. E. E. Kramer Shear Resistance Test

One inch squares were cut from beef steaks and placed in the shear-compression cell of the shear press. A series of 10 precision blades in the upper assembly mesh with grooves and shear bars in the sample cell box assembly by the application of force from a hydraulic unit. During the first phase of the downward stroke of the ram, the blades compress the sample and then the meat is sheared as the blades pass through the shearing bars in the lower cell box assembly. The compression-shearing action of the cell thus simulates the action of teeth in the chewing of food. The textural characteristics of the sample are evaluated by measuring the degree of deformation of the proving ring, resulting from the force required to compress and shear the sample in the test cell. Six replications were taken of each sample and recorded on a strip-chart.

IV. pH

The meat from the L. E. E. Kramer shear test was ground through an one-eighth inch plate and 50 grams blended with 150 ml. of distilled water in a Waring Blender for 1 minute. The meat adhering to the sides of the blending jar was scraped down and reblended for 30 seconds. The pH of the slurry was measured with a glass electrode pH meter.

V. Extractable Non-Protein Nitrogen

A 50 gram sample of the slurry prepared for pH measurement was mixed with 50 ml. of a 15% trichloroacetic acid solution. The mixture was allowed to stand for 30 minutes with occasional stirring. After filtering, nitrogen was determined on the filtrate by the micro-Kjeldahl method.

VI. Water Binding Capacity
(Adapted from method of Wierbicki, Tiede and Burrell[8])

Two 35 gram samples of the slurry prepared for pH measurement were weighed into 40 ml. centrifuge tubes. A Sorvall Centrifuge, model RC-2, with a SS-34 rotor was used at 4000 R.P.M. for 15 minutes at room temperature.

After centrifuging, the volume of the supernatant was measured in a graduate cylinder. The per cent swelling was calculated by the following formula:

$$\% \text{ Swelling} = 300 - (11.43 \times S), \text{ or}$$
$$= (26.25 - S) \times 11.43$$

Where; S = Volume of supernatant in ml per 35 grams of the meat slurry.

Fifteen ml of 40°C distilled water were added to each tube containing the meat residue, mixed, the tubes immersed in 40°C water for 15 minutes and centrifuged as before. The supernatants were removed and added to the supernatants of the first centrifugation. The volume was noted and the combined supernatants transferred quantitatively into a 500 ml autoclavable polypropylene Erlenmeyer flask by using an equal volume of 6 N sodium hydroxide. The resulting mixture was of 3 N sodium hydroxide concentration.

The Erlenmeyer flasks were covered with 50 ml polypropylene beakers, and placed into an autoclave operating at 15 lbs. pressure for 3 hours. After the hydrolysis, the hydrolysate was chilled and neutralized with concentrated hydrochloric acid to pH of 7.0. (The use of polypropylene flasks for hydrolysis instead of glass flasks eliminates the problem of precipitating silicic acid.) The neutralized hydrolysate was cooled, quantitatively transferred to a 250 ml volumetric flask and taken to volume with distilled water. The solution was filtered into polyethylene bottles for freezer storage.

The residues from the 40 ml centrifuge tubes were transferred quantitatively into 500 ml polypropylene Erlenmeyer flasks by using 6 N sodium hydroxide in the amount equal to the volume of the swollen meat, followed by 3 N sodium hydroxide solution. (The final mixture should have the concentration of 3 N sodium hydroxide.) The procedure used for hydrolysis, neutralization of the hydrolysate, quantitative transfer, dilution to volume, and filtration was the same as described above for the supernatant. Dilutions of these solutions must be made for the hydroxyproline and carbonyl determinations which are described elsewhere in this report.

VII. Total Nitrogen

The meat that was ground after conducting the L. E. E. Kramer shear test was used to determine total nitrogen by the official A.O.A.C. Kjeldahl method.

VIII. Total Moisture

The meat referred to in the determination of total nitrogen was also used for the total moisture analysis by the official A.O.A.C. air oven method.

IX. Free Moisture

(Adapted from a method of Wierbicki and Deatherage[7])

Apparatus

A Carver laboratory press, Fred S. Carver, Inc., Summit, N. J., with a reading gauge scaled from 0 to 600 p.s.i. in 10 p.s.i. increments.

Ott-Planimeter with vernier range of 0.01 square inch (Type 16).

Procedure

A 400 to 600 mg meat sample was weighed on a 9 cm Whatman No. 1 filter paper of constant moisture content obtained by holding the filter paper in a desiccator over saturated potassium chloride solution. The filter paper and meat were then placed between two 7 x 7 x 1/4 inch plexiglas plates and pressed immediately at a constant pressure of 500 p.s.i. for 1 minute. By pressing, the muscle material was squeezed to an almost circular film (meat film), while the expelled water was absorbed by the filter paper forming a circular brownish area (free moisture area).

Upon removal of the plexiglas the meat film area was carefully marked and the meat film removed. The filter paper was stored for the surface measurement with a planimeter.

$$\text{Per cent free water} = \frac{(\text{total area} - \text{meat film area}) \times 59.71 \times 100}{\text{total moisture (mg.) in muscle sample}}$$

X. Water Soluble and Total Collagen

(Adapted from methods by Neuman and Logan[3] and by Wierbicki and Deatherage[6])

Reagents

Standard solutions of hydroxy-l-proline containing
5, 10 and 15 gamma of hydroxyproline per ml
0.05 M copper sulfate solution
3.5 N sodium hydroxide
6 per cent hydrogen peroxide
3.0 N sulfuric acid
5 per cent p-dimethylaminobenzaldehyde in c.p.n.-propanol.

Procedure

One ml each of a limited number of unknowns were pipetted along with a water blank and the standard solutions into 18 x 150 mm test tubes. Into each test tube 1 ml each of 0.05 M copper sulfate solution, 3.5 N sodium hydroxide, and 6 per cent hydrogen peroxide was pipetted and mixed in succession.

The solutions were mixed occasionally during a 5 minute period and were then placed in a water bath at 80°C for 5 minutes with frequent mixing. (A Vortex Jr. mixer model K-500-J made by Scientific Industries, Inc., Queens Village, New York, was found to be highly efficient for all mixing.)

The heating and mixing destroy the excess of peroxide. Traces of peroxide which remain will decrease color formation and produce an orange-red hue. The tubes were chilled in an ice and water bath and 4 ml of 3.0 N sulfuric acid were added with mixing.

Two ml of p-dimethylaminobenzaldehyde solution were then added with mixing.

The tubes were placed in a water bath at 70°C for 16 minutes and then cooled in tap water. All time intervals must be strictly enforced. The optical density of the solution was determined by using a Beckman D.U. Spectrophotometer at 550 mu.

Calculations

Hydroxyproline was determined separately on the water soluble and insoluble hydrolysates of the meat swelling determinations. The results were corrected for tryptophan and tyrosine and calculated as collagen.

XI. Water Soluble and Insoluble Carbonyl Compounds (Adapted from a method by Lappin and Clark[1])

Reagents

a-ketoglutaric acid: Standard solutions containing 0.25×10^{-3}, 0.50×10^{-3}, 0.75×10^{-3} and 1.00×10^{-3} molar a-ketoglutaric acid.

Carbonyl-Free Methanol: To 500 ml of reagent grade methanol add about 5 grams of 2,4-dinitrophenylhydrazine and a few drops of concentrated hydrochloric acid. After refluxing for 2 hours, distill and redistill until a clear solution is obtained. Keep tightly stoppered.

2,4-dinitrophenylhydrazine Solution: Dissolve 0.100 gram of reagent grade 2,4-dinitrophenylhydrazine in about 85 ml of carbonyl-free methanol by heating. Cool the solution and add 10 ml of concentrated hydrochloric acid. Add sufficient carbonyl-free methanol to bring the volume to 100 ml.

Potassium Hydroxide Solution: Dissolve 50 grams of reagent grade potassium hydroxide in 200 ml of distilled water. Cool the solution and add sufficient carbonyl-free methanol to bring the volume to 500 ml.

Procedure

The unknown should not be more than 10^{-3} molar in carbonyl. In such dilute solutions the phenylhydrazone will not precipitate at room temperature. The solution must be neutral or very weakly acidic to prevent precipitation of potassium salts when the base solution is added.

To 1.0 ml of the water soluble and water insoluble beef samples which were hydrolyzed and neutralized, 1.0 ml of the 2,4-dinitrophenylhydrazine solution was added.

The tubes were loosely stoppered and heated in a water bath at 50°C for 30 minutes. After cooling, 5.0 ml of the potassium hydroxide solution were added. The almost black solution which resulted rapidly cleared to the characteristic wine-red color. Two water blanks, plus a series of standard solutions were analyzed with each set of unknowns.

The optical density of the solution was determined by using a Beckman DU Spectrophotometer. The instrument was standardized using a-ketoglutaric acid and a graph was constructed to allow direct reading of carbonyl concentration from the observed optical density of 530 mu. Also an adjustment was made for the background color.

XII. Mercaptans
(Adapted from a method by Sliwinski and Doty[5])

Reagents

Amine Solution: Dissolve 1.0 gram of N,N-dimethyl-p-phenylenediamine hydrochloride in 1 liter of concentrated hydrochloric acid. The solution should have an absorbance value of 0.04 or less at 500 mu. When protected from light, the solution is stable for at least 6 months.

Reissner Solution: Dissolve 67.6 grams of ferric chloride hexahydrate in distilled water, dilute to 500 ml and mix with 500 ml of a nitric acid solution containing 72 ml of boiled concentrated nitric acid (specific gravity 1.42). This solution is likewise stable.

Procedure

A small amount of antifoam A was sprayed into a 32 x 200 mm heavy walled test tube. In the tube was placed 30 grams of finely ground meat and 65 ml of distilled water. The meat was thoroughly dispersed by shaking the tube vigorously. A two-hole rubber stopper was fitted in the tube. In one hole a 6 mm (outside diameter) glass tube was inserted so that the end was within a few millimeters of the bottom of the test tube. In the other hole a short piece of glass tubing with an outside diameter of 10 mm was inserted for a Tygon tubing connection to the trapping tube. A water jacket was put around the Tygon tubing about 6 inches above the test tube to condense the water vapors being carried over with the effluent gas stream. A multiple system of tubes can be set up in this manner, using glass tubing through the condenser.

The test tube was connected to the trapping tube and to the nitrogen supply and placed in a water bath at 58°C. The trapping tube was a Folin-Wu sugar tube graduated at 6 and 12.5 ml, and it contained 6 ml of 5% mercuric acetate. The trapping tube was immersed in ice water to keep the trapping solution at 0° to 4°C.

The effluent gas stream from the meat slurry was fed into the trapping solution through a glass tube drawn into a capillary tip measuring approximately 1 mm.

Commercial high purity nitrogen was allowed to bubble through the meat slurry at a rate of 0.5 cubic foot per hour. After 4 hours of ebullition, the trapping tube was disconnected and the capillary tip broken off and added to the trapping tube (to retain the mercury mercaptide precipitate on the tip). One and one-half ml of the acid amine solution and 0.5 ml of the Reissner solution was added by means of the special cup described by Marbach and Doty[2]. The tube was stoppered, inverted and shaken for 10 minutes to mix the reagents. The special cup was rinsed into the tube and the solution diluted to 12.5 ml with distilled water, shaken and allowed to stand at room temperature for 30 minutes. The optical density was determined by using a Beckman DU Spectrophotometer at 500 mu.

The absorbance of a reagent solution containing no mercaptan was deducted from the sample reading and the amount of mercaptan calculated as methyl mercaptan, was determined from a standard curve prepared from known amounts of lead methyl mercaptide.

XIII. Sulfides

(Adapted from a method by Marbach and Doty[2])

Reagents

Amine Solution: Dissolve 5.0 grams of N,N-dimethyl-p-phenylenediamine hydrochloride in 1 liter of concentrated hydrochloric acid. The solution should have an absorbance value of 0.04 or less at 500 mu. When protected from light this solution is stable for at least 6 months.

Reissner Solution: Dissolve 67.6 grams of ferric chloride hexahydrate in distilled water, dilute to 500 ml, and mix with 500 ml of a nitric acid solution, containing 72 ml of boiled concentrated nitric acid (specific gravity 1.42). This solution is likewise stable.

Cadmium Hydroxide Suspension: Add sodium hydroxide solution (ca. 4N) in excess of a cadmium acetate solution and centrifuge down the white precipitate of cadmium hydroxide. Decant the supernatant, suspend the precipitate in distilled water, and again centrifuge down the cadmium hydroxide. Repeat the washing procedure until the pH of the cadmium suspension drops to 9.6.

Suspend the washed, wet precipitate in sufficient distilled water to make approximately 0.1 N cadmium hydroxide suspension.

Procedure

A small amount of antifoam A was sprayed into a 32 x 200 mm heavy walled test tube. In the tube was placed 30 grams of finely ground meat and 65 ml of distilled water. The meat was thoroughly dispersed by shaking the tube vigorously. A two-hole rubber stopper was fitted in the tube. In one hole a 6 mm (outside diameter) glass tube was inserted so that the end was within a few millimeters of the bottom of the test tube. In the other hole a short piece of glass tubing with an outside diameter of 10 mm was inserted for a Tygon tubing connection to the trapping tube. A water jacket was put around the Tygon tubing about 6 inches above the test tube to condense the water vapors being carried over with the effluent gas stream. A multiple system of tubes can be set up in this manner using glass tubing through the condenser.

The test tube was connected to the trapping tube and to the nitrogen supply and placed in a water bath at 65°C. The trapping tube was a Folin-Wu sugar tube graduated at 6 and 12.5 ml and it contained 5 ml of 0.1 N cadmium hydroxide suspension and 1 ml of 0.1 N sodium hydroxide. The trapping tube was immersed in ice water to keep the trapping solution at 0° to 4°C. The effluent gas stream from the meat slurry was fed to the trapping solution through a glass tube drawn into a capillary tip measuring approximately 1 mm.

Commercial high purity nitrogen was allowed to bubble through the meat slurry at a rate of 0.5 cubic feet per hour. After 2 hours of ebullition the trapping tube was disconnected and the capillary tip broken off and added to the trapping tube (to retain the cadmium sulfide precipitate on the tip). One and one-half ml of the amine solution and 0.5 ml of Reissner solution was added by means of a special cup. The tube was stoppered, inverted, and shaken for 10 minutes to mix the reagents. The cup was rinsed into the tube and the solution diluted to 12.5 ml with distilled water, shaken and allowed to stand at room temperature for 30 minutes. The optical density was determined by using a Beckman DU Spectrophotometer at 665 mu. The absorbance of a reagent solution containing no sulfides was deducted from the sample reading and the amount of sulfide calculated as hydrogen sulfide, was determined from a standard curve prepared from known amounts of sodium sulfide.

XIV. Amino Acid Analysis

A 15 gram sample of the slurry prepared for pH measurement was weighed into a 500 ml polypropylene Erlenmeyer flask and an equal amount of 6 N sodium hydroxide added. This mixture was hydrolyzed along with the samples for collagen and carbonyl determinations. After neutralization, dilution and filtration, a portion of the filtrate was used for analysis of the amino acids on a Spinco model 120 amino acid analyzer.

STATISTICAL ANALYSIS OF THE DATA

Multiple regression analysis was carried out on seven sets of data:

Irradiation flavor intensity

Organoleptic tenderness

Mercaptans

Water binding capacity

Water soluble collagen

Extractable non-protein nitrogen

Water soluble carbonyls

In each case, the response was analyzed as a function of animal grade, irradiation dosage in megarads, irradiation temperature (except for control) and storage time in months. For statistical purposes intial storage time was considered to be 0.25 months.

The data from the remainder of the tests were not analyzed statistically, but a general statement of the results are given for:

L. E. E. Kramer Shear Resistance

pH

Total Nitrogen

Total Moisture

Free Moisture

Total Collagen

Insoluble Carbonyls

Amino Acids

I. Irradiation Flavor Intensity and Organoleptic Tenderness

A total of 306 observations on flavor intensity were made. The essential data are shown in Tables 1 and 2. Multiple regression analysis showed the main effects of grade, dose and temperature as significant at the 90% confidence level or better with the interactions and quadratic terms $(\text{dose})^2$, $(\text{temperature})^2$, dose x temperature, temperature x time, grade x dose x temperature and dose x temperature x time as also significant at the same level. These variables accounted for almost 75% of the variability in the system. The relationships of the variables are shown in Figures I thru VI. The plots show changes of irradiation flavor intensity with storage time in months. Higher values represent a less desirable product. Each figure gives the flavor-time relationship at a selected irradiation dosage (2, 4.5 or 6 megarads) and one grade of cattle (utility or choice). The four irradiation temperatures (+20, -20, -80, -196°C) are shown on each Figure. These relationships were calculated using the regression equation obtained with significance at 90% or better.

Examination of the Figures for utility grade cattle shows that irradiation flavor intensity remains essentially constant or decreases with time. The rate of decrease seems to be a function of the dosage used. As the dosage was increased from 3 to 4.5 to 6 megarads, the initial irradiation flavor intensity shifts from lower ranges (2.7-3.2) to medium high ranges (3.2-3.8) to high ranges (3.2-4.2). The shift from 3 to 4.5 megarads results in a more pronounced flavor intensity than the 4.5 to 6 megarad shift. A linear change in flavor intensity at each temperature dose with time brings the ranges to 2.7-3.2 for 3 megarads, 2.9-3.3 for 4.5 megarads and 2.7-3.0 for 6 megarads. In all of the initial cases, the lowest temperature corresponds to the lowest flavor intensity range. As time of storage increases, the samples irradiated at -196°C with 4.5 and 6 megarads show considerably less decrease in irradiation flavor intensity and, consequently, end up slightly higher in relation to the samples irradiated at -80°C and even in relation to -20°C samples in case of 6 megarads irradiation.

As a summary of the utility grade flavor scores, increasing time lowers the irradiation flavor intensity depending upon the initial intensity. Increasing temperature of irradiation generally increases initial flavor intensity. Increasing the dosage increases the initial flavor intensity, but the 3 radiation levels differ very little from each other at 24 months. The 3 radiation dosages are all substantially higher in flavor intensity than the control (0 dose) at all times.

Examination of the Figures for choice grade show very similar responses to time, temperature and dose. The choice control is slightly lower in irradiation flavor intensity than the utility control and at 3 megarads the choice grade consistently is lower than utility at all temperatures and times. However, at 4.5 and 6.0 megarads, the choice grade is consistently higher in flavor intensity except at -196°C and -80°C. This shows the interaction between grade, dose and temperature.

Generally speaking the -196°C data remains the least affected by time, dose (excluding 0) or grade. The -196°C irradiated meat would therefore be indicated as a generally superior product, and is especially so at the shorter (less than two years) storage times.

A total of 306 observations were made on tenderness. The essential data are shown in Tables 3 and 4. Multiple regression analysis showed the main effects of grade, dose and time as significant at the 90% confidence level or better with the quadratic terms $(\text{temperature})^2$, $(\text{time})^2$ and the interactions grade by temperature, dose x time, temperature x time, grade x dose x time and dose x temperature x time, as also significant at the same level. The relationship between these variables is shown in Figures VII thru XII. Each dose (3, 4.5 and 6.0 megarads) and grade (choice or utility) is shown in a separate Figure. The four temperatures of irradiation are also shown in each Figure.

Examination of the Figures shows that the controls are consistently lower than any irradiated beef at all temperatures and times. This would indicate that the irradiation process does give a tenderizing phenomenon, even at the initial storage time. The choice grade is shown as much more tender (average of 1.89 units) than the utility grade. The higher temperatures of irradiation show greater tenderization except at 6 megarads. At 6 megarads, some crossing over of the temperature-tenderness curves takes place as time progresses.

Examination of Figures VII, VIII and IX pertaining to choice grade shows that tenderness increases on all irradiated beef with time. Initial tenderness of 6.5-7.5 is increased to 7.5-9.0 at 24 months. It should be noted that the tenderness is effected very slightly by the irradiation temperature at 6 megarads, but at 3 megarads very noticeable differences (with high temperature corresponding to high tenderness) in tenderness occur with temperature changes.

Figures X, XI and XII pertaining to utility grade beef show that the irradiated beef is more tender than the control, but at no time (except 24 months, 3 megarads, +20°C) does the tenderness get higher than 7 on a 10 point scale. The general effect of time (increasing tenderness with time) is not as clear cut with utility grade as with choice. The Figures for 3 megarads and 4.5 megarads show increases in tenderness with time, but at 6 megarads the tenderness is essentially equal at the initial and final times. Again, it can be noted that the irradiation temperature has a much more dramatic effect on tenderness at lower irradiation dosages. The higher temperatures again correspond to greater tenderization scores.

The choice grade is much more tender than utility. The choice grade also gains in tenderness with time at a more rapid rate than the utility grade. Increasing dosages in megarads generally increases tenderness over the control, but the 3 dosages studied do not differ in general magnitude from each other. Increasing the temperature of irradiation increases tenderness (especially at low dosage levels) and increasing time of storage generally increases tenderness (especially with choice grade).

The data matrix values used in the regression for irradiation flavor intensity and organoleptic tenderness were:

<u>Test Samples</u>

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 3, 4.5 and 6

3. Irradiation temperature; 2.93, 2.53, 1.93 and 0.77 (these correspond to +20°C, -20°C, -80°C and -196°C)

4. Storage time in months; 0.25, 3, 9, 15 and 24

Control Samples

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 0

3. Irradiation temperature; 0 entered as a missing variable

4. Storage time in months; 0.25, 3, 9, 15 and 24

The response was the average of panel members organoleptic scores. The models proposed for these two responses utilized main effects, two-way interactions, selected three-way interactions and some quadratic terms.

The data from both test and control samples were combined for one regression analysis. The limits on the ranges of variables in estimating a given response on any test samples are therefore:

1. Grade; 0 or 1

2. Irradiation dosage in megarads; 3 to 6 megarads

3. Irradiation temperature; 0.77 to 2.93°K/100

4. Storage time in months; 0.25 to 24

At no time can 0 dosage or 0 temperature be entered for test samples estimations, nor can any values outside the above stated ranges be validly used.

The regression equations resulting from these analyses are specific for the data in these test. Since the response is subjective in nature, use of these equations for estimations outside these particular experiments will be misleading and erroneous.

For these samples, the equation for estimating a response as a function of the variables would be as follows:

Irradiated Choice Grade:

$$
\begin{aligned}
\text{Irradiation flavor intensity} = & +1.07466 \\
& + .80875 \text{ (dose)} \\
& - .72678 \text{ (temp)} \\
& - .08307 \text{ (dose)}^2 \\
& + .19160 \text{ (temp)}^2 \\
& - .00533 \text{ (dose) (temp) (time)} \\
& + .09541 \text{ (dose) (temp)}
\end{aligned}
$$

Irradiated Utility Grade:

$$\text{Irradiation flavor intensity} = +1.33894 + .80875\,(\text{dose}) - .72678\,(\text{temp}) - .08307\,(\text{dose})^2 + .19160\,(\text{temp})^2 - .00533\,(\text{dose})(\text{temp})(\text{time}) + .08065\,(\text{dose})(\text{temp})$$

Control Choice Grade:

$$\text{Irradiation flavor intensity} = +1.07466$$

Control Utility Grade:

$$\text{Irradiation flavor intensity} = +1.33894$$

Irradiated Choice Grade:

$$\text{Organoleptic tenderness} = +6.25988 + .16175\,(\text{dose}) - .10276\,(\text{time}) + .10287\,(\text{temp})^2 + .00316\,(\text{time})^2 - .21433\,(\text{temp}) + .01911\,(\text{dose})(\text{time}) + .04967\,(\text{temp})(\text{time}) - .01128\,(\text{dose})(\text{temp})(\text{time})$$

Irradiated Utility Grade:

$$\text{Organoleptic tenderness} = +4.36648 + .16175\,(\text{dose}) - .10276\,(\text{time}) + .10287\,(\text{temp})^2 + .00316\,(\text{time})^2 + .01168\,(\text{dose})(\text{time}) - .01128\,(\text{dose})(\text{temp})(\text{time})$$

Control Choice Grade:

$$\text{Organoleptic tenderness} = +6.25988 - .10276\,(\text{time}) + .00316\,(\text{time})^2$$

Control Utility Grade:

$$\text{Organoleptic tenderness} = 4.36648 - .10276\,(\text{time}) + .00316\,(\text{time})^2$$

For flavor intensity or organoleptic tenderness, the data matrix for either choice or utility grade samples could be represented as follows:

Months		Test												Control
	Temp °C.	+20°			-20°			-80°			-196°			
	Megarads	3.0	4.5	6.0	3.0	4.5	6.0	3.0	4.5	6.0	3.0	4.5	6.0	
0.25		x	x	x	x	x	x	x	x	x	x	x	x	x
3		x	x	x	x	x	x	x	x	x	x	x	x	x
9		x	x	x	x	x	x	x	x	x	x	x	x	x
15		x	x	x	x	x	x	x	x	x	x	x	x	x
24		x	x	x	x	x	x	x	x	x	x	x	x	x

We can note from this that we have a "continuous" gradient of time for both test and control and that the test portion of the matrix is separate from control in temperature (no temperature for control temperature gradient for test) and also that we have no dosage gradients for controls. In order to incorporate the control data into the test data, we assigned a 0 temperature to the control, not that this implies an actual radiation temperature, but in reality assigns no irradiation temperature to the control. Thus we cannot use the 0 point of temperature for estimation purposes on test samples.

Irradiation flavor intensity and organoleptic tenderness were shown to be significantly affected by each of the independent variables studied. Both main effects and interactions were significant at the 90% confidence level or better.

II. Mercaptans

A total of 85 observations were made on mercaptans. The essential data are shown in Tables 5 and 6. Interactions found significant were dose x time, dose x temperature, grade x dose x temperature and $time^2$ x dose.

Figures XIII and XIV show the relationship of time and temperature for the two animal grades. The utility grade has higher volatile mercaptans than the choice grade. Samples irradiated (6 megarads) were higher in volatile mercaptans than were the controls, and higher radiation temperatures resulted in higher mercaptan values. The difference in temperatures was more accentuated for utility grade than for the choice grade.

Data matrix values used in the regression analysis for mercaptans were:

Test Samples:

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 6 megarads

3. Irradiation temperature; 0.79, 1.93, 2.53 and 2.93°K/100

4. Storage time in months; 0.25, 9, 15 and 24

Control Samples:

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 0

3. Irradiation temperature; 0 entered as a missing variable

4. Storage time in months; 0.25, 9, 15 and 24

The response was ppm (parts per million) volatile merceptans. The model proposed for the response utilized main effects, two-way interactions, selected three-way interactions and selected quadratic terms. The data from both test and control samples were combined for one regression analysis. The limits on the ranges of variables in estimating a response on any test sample are therefore:

1. Grade; 0 or 1

2. Irradiation dosage in megarads; 6

3. Irradiation temperature; 0.77 to 2.93°K/100

4. Storage time in months; 0.25 to 24

At no time can zero dosage or zero temperature be entered for test sample estimations, nor can any values outside the above ranges be validly used. The equations derived are specifically for this set of data and any use of these equations as estimations for other data will take a considerable risk. It must be remembered that almost 30% of the variability in this system was not accounted for.

The following equations were obtained for estimation of mercaptans.

Irradiated Choice Grade:

$$\text{ppm volatile mercaptans} = 0.15118 + .01626\,(\text{time}) + .05730\,(\text{temp}) - .000577\,(\text{time})^2$$

Irradiated Utility Grade:

$$\text{ppm volatile mercaptans} = 0.15118 + .01626\,(\text{time}) + .11370\,(\text{temp}) - .000577\,(\text{time})^2$$

Control Choice or Utility Grade:

ppm volatile mercaptans = 0.15118

The data matrix for mercaptans could be represented as follows for either choice or utility grade:

Months		Test				Control
	Temp °C	+20	-20	-80	-196	
	Megarads	6	6	6	6	
0.25		x	x	x	x	x
9		x	x	x	x	x
15		x	x	x	x	x
24		x	x	x	x	x

We can note that we have a common "continuous" gradient of time for both test and control samples, and that the test portion of the data matrix has a temperature gradient and a constant dosage of 6 megarads. In order to combine the test and control data for one regression analysis, we assign a 0 temperature and dose to the control samples. This does not imply an actual irradiation temperature, but in reality assigns no irradiation temperature to the control. The 0 dose can be considered as a 0 dosage, but we have no test samples with 0 dose. Thus we cannot use a 0 temperature for estimation purposes on test samples, nor can we use 0 dose.

All four independent variables (as interactions) significantly affected the amount of volatile mercaptans at the 90% confidence level or better. The variables account for 71% of the variability in the system. Utility grade steaks had generally higher amounts of mercaptans than did choice grade steaks.

III. Water Binding Capacity

A total of 133 observations were made on water binding capacity. The essential data are shown in Tables 7 and 8. The significant variables were: grade, time, grade x dose x time and temperature^2 x dose. Figures XV and XVI show the relationship between the variables. Choice grade was higher than utility at all times. The water binding capacity decreased in all cases with increased storage time. Increased temperature of irradiation increased the water binding capacity.

The data matrix values used in regression for water binding capacity were:

Test Samples:

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 6 megarads

3. Irradiation temperature; 0.77, 2.53 and 2.93^{o}K/100

4. Storage time in months; 0.25, 3, 9, 15 and 24

Control Samples:

1. Grade; 0 for utility, 1 for choice

2. Irradiation dosage in megarads; 0

3. Irradiation temperature; 0 entered as a missing variable

4. Storage time in months; 0.25, 3, 9, 15 and 24

The response is water binding capacity. The model prepared for the response utilized main effects, two-way interactions, selected three-way interactions and selected quadratic terms. The data from both test and control samples were combined for one regression analysis. The limits on the ranges of variables in estimating a response on any test sample are therefore:

1. Grade; 0 or 1

2. Irradiation dosage in megarads; 6

3. Irradiation temperature; 0.77 to 2.93^{o}K/100

4. Storage time in months; 0.25 to 24

The same restrictions apply to the equations found for water binding capacity as for mercaptans. The equations obtained for estimating water binding capacity in samples were:

Irradiated Choice Grade:

$$\text{Water binding capacity} = 78.72226 - 2.15904\ (\text{time}) + .74016\ (\text{temp})^2$$

Irradiated Utility Grade:

$$\text{Water binding capacity} = 68.20806 - 2.15904\ (\text{time}) + .74016\ (\text{temp})^2$$

Control Choice Grade:

$$\text{Water binding capacity} = 78.72226 - 1.61784\ (\text{time})$$

Control Utility Grade:

$$\text{Water binding capacity} = 68.20806 + 1.61784\ (\text{time})$$

The data matrix for water binding capacity is similar to the data matrix for mercaptans except that temperature 1.93 was not used for the water binding capacity data matrix. Comments on this data matrix are the same as for the mercaptan data matrix.

The most significant factors in determining water binding capacity were found to be grade and time. Interactions involving dose and temperature were also significant at or above the 90% CL. The significant variable accounted for over 59% of the variability in the system.

IV. Soluble Collagen

The essential data for soluble collagen are shown in Tables 9 and 10. The significant variables were grade, grade x dose, dose x time, dose x temperature, and time^2 x dose. A total of 136 observations were made. Figure XVII shows the relationships of the variables. Only 0 (control) and 6 megarads were studied, along with time, grade and temperature.

The soluble collagen in choice grade was about 10% higher than soluble collagen in utility grade in all cases. With irradiated beef, soluble collagen increased with time (over 10% from one week to 24 mos). Increasing temperature linearly increased the soluble collagen.

The data matrix, restrictions and general comments on soluble collagen are the same as for water binding capacity. The equations for estimation of the response are as follows:

Irradiated Choice Grade:

$$\text{Soluble collagen} = 14.56183 + 1.36356\,(\text{time}) + 1.38834\,(\text{temp}) - .03348\,(\text{time})$$

Irradiated Utility Grade:

$$\text{Soluble collagen} = 3.95794 + 1.36356\,(\text{time}) + 1.38834\,(\text{temp}) - .03348\,(\text{time})^2$$

Control Choice Grade:

Soluble collagen = 14.56183

Control Utility Grade:

Soluble collagen = 3.95794

The most significant factors in determining soluble collagen was animal grade. Interactions containing the other three independent variables were also significant at or above the 90% confidence level. The variables used accounted for over 77% of the variability in the system.

V. Total Collagen

The per cent total collagen determined is shown in Tables 11 and 12 for selected samples. No statistical analysis was made and no obvious trends were observed.

VI. Extractable Non-Protein Nitrogen

The data for extractable non-protein nitrogen are shown in Tables 13 and 14. So little variability was accounted for with regression analysis (set up in a similar way to the previous regressions) that the resulting equations would be misleading in estimating a response. Therefore, no equations or graphs are presented. The variables found to be significant were; temperature, temperature^2, grade x temperature, grade x dose x temperature and grade x dose x time. With these high order interactions as significant it is impossible to make any blanket statement about the direction of effects of the variables.

All independent variables significantly affected the response at the 90% confidence level or better. Each variable was only significant as part of an interaction except temperature. A very small (about 18%) amount of the variability was accounted for by the significant variables.

VII. Soluble Carbonyls

Some of the samples for soluble carbonyl analyses were contaminated with acetone in the initial and 3 month periods and those data are not reported in Tables 15 and 16. Because of the uncertainty of the validity of the remaining data at the initial and 3 month periods, none was used in the statistical analyses. The interactions shown as significant were grade x time and dose x temperature. Examination of the data (56 observations with partial replication) showed 9 month and 24 month values to be roughly equivalent. The utility grade observations replicated at 15 months were more spread apart than the values of all other data. With this example in mind, we must assume that until more complete replication is carried out on this experiment, no statement as to the magnitude and/or direction of effects can be made.

Two-way interactions, which include all four independent variables account for 30% of the variability in this system. Examination of the data itself showed very poor replication of points that were actually replicated.

VIII. Insoluble Carbonyls

The data for insoluble carbonyls are shown for selected samples in Tables 17 and 18. There appears to be an increase of insoluble carbonyls with storage time. This is more apparent in the utility grade steaks than in the choice grade steaks. It should be noted that the frozen control also increases in the same properties as do the irradiated samples.

IX. L. E. E. Kramer Shear Resistance Readings

A correlation coefficient was calculated between expert panel tenderness scores and L. E. E. Kramer shear resistance readings. The correlation coefficient was calculated to be -0.63, which is comparable to previous studies made in our laboratories. The averages of six L. E. E. Kramer shear resistance readings for each sample are given in Tables 19 and 20.

X. pH

The pH readings for each sample are given in Tables 21 and 22. There was little apparent change in pH during storage. The only apparent difference noted was that the pH of the utility grade steaks was slightly higher (avg. of 6.0 vs 5.8) than that of the choice grade steaks.

XI. Total Nitrogen

The per cent total nitrogen for all samples is shown in Tables 23 and 24. The only effect noted was that the amount of nitrogen was somewhat higher (avg. of 4.8 vs 4.4) in the utility grade steaks than in the choice grade steaks. This is undoubtedly due to the fact that more fat was present (and less protein) in the choice grade steaks.

XII. Total Moisture

The per cent moisture for all samples is shown in Tables 25 and 26. The only effect noted was that the amount of moisture was higher in the utility grade steaks than in the choice grade steaks. This is undoubtedly due to the fact that the utility grade steaks had less fat than the choice grade steaks.

XIII. Free Moisture

The average data for four determinations for per cent free moisture from selected samples are given in Tables 27 and 28. The only effect noted was a somewhat higher percentage of free moisture in the utility grade steaks than in the choice grade steaks.

XIV. Hydrogen Sulfide

The levels of hydrogen sulfide present were too low to detect with any degree of accuracy in both the irradiated and control samples. Therefore, this determination was discontinued after the early periods and no data are reported.

XV. Amino Acids

Amino acid analyses were made on an alkaline hydrolysis of selected samples. The results for 17 amino acids are shown in Tables 29 to 62 as indicated below:

Table No	Amino Acid
29-30	Lysine
31-32	Histidine
33-34	Aspartic Acid
35-36	Threonine
37-38	Serine
39-40	Glutamic Acid
41-42	Proline
43-44	Glycine
45-46	Alanine
47-48	Half Cystine
49-50	Valine
51-52	Methionine
53-54	Iso-leucine
55-56	Leucine
57-58	Tyrosine
59-60	Phenylalanine
61-62	Allo iso-leucine

Because of the alkaline hydrolysis the arginine was destroyed and could not be analyzed.

The histidine peaks on the charts of the amino acid analyzer were small and some were poorly resolved. Therefore, no conclusions can be made concerning them.

Tyrosine values for the initial storage period were in error and are not reported.

No obvious trends were noted in any of the amino acids resulting from either irradiation or storage.

XVI. Matched Loin Study

In the experimental design, two matched full loins from each grade of beef were used at the extreme variable conditions of the experimental matrices in the early storage periods, with random assignments of short loins to the intermediate conditions and to the test conditions of the longer storage times. Thus effects of processing variable extremes were determined on samples from the same loin. By replicating the initial and the 3 month storage series, an estimate of loin to loin variation was obtained for use in evaluating the statistical significance of experimentally observed differences. In addition samples of full loin #2 for each grade were held for 96 hours at -196°C after irradiation to ascertain of holding at low temperature resulted in an improved product.

An analysis of variance was performed on each of the organoleptic, physical and chemical properties investigated at the initial and 3 month storage periods to estimate the importance of loin to loin variation. The loin to loin variations were found to be small in all instances and were not significant at the 95% confidence level.

XVII. Post Irradiation Holding at Low Temperature

No appreciable changes were noted in product irradiated at -196°C and warmed immediately and that held for 96 hours at that temperature before warming.

FIG. I.

IRRADIATION FLAVOR INTENSITY
CHOICE GRADE
3 MEGARADS

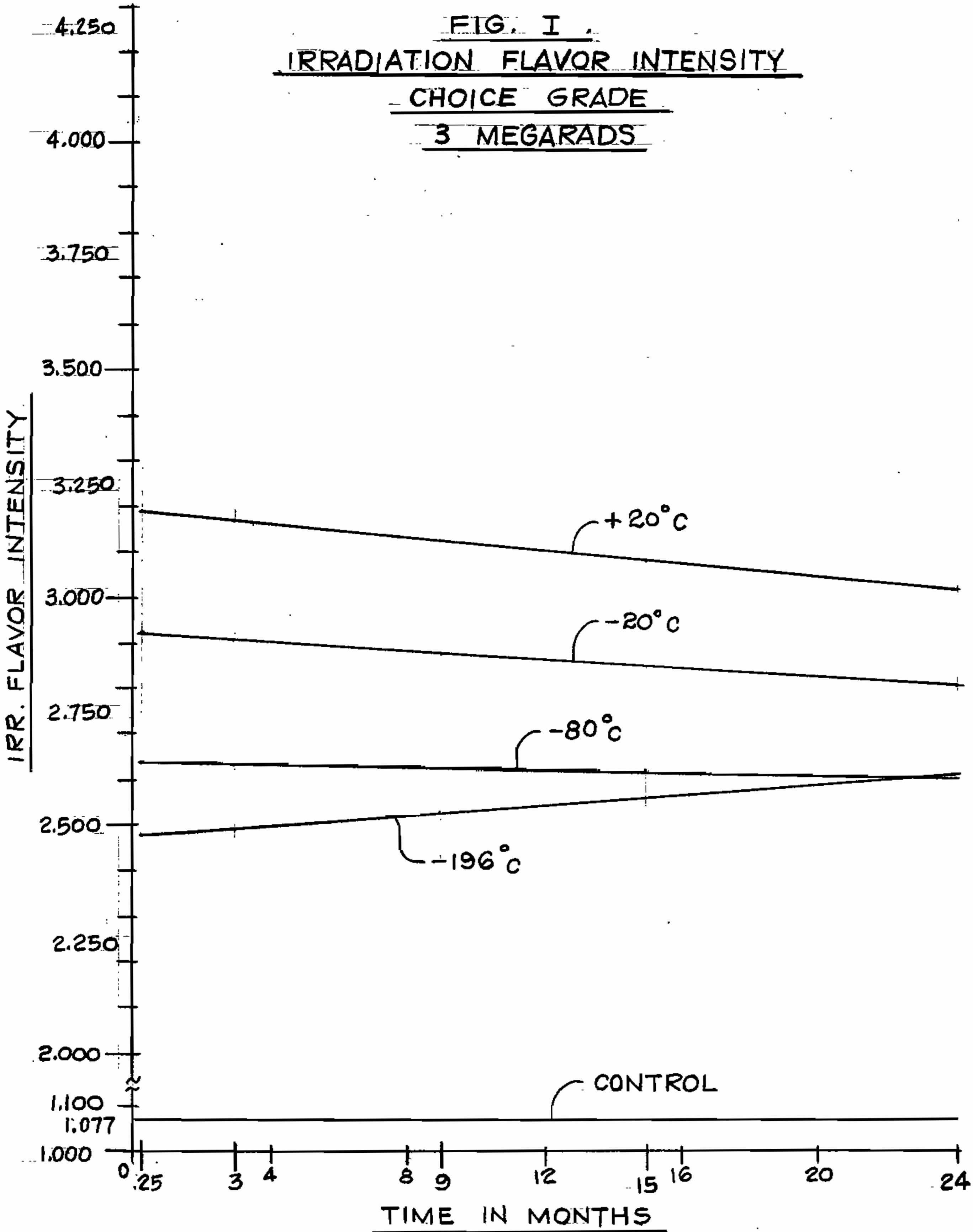
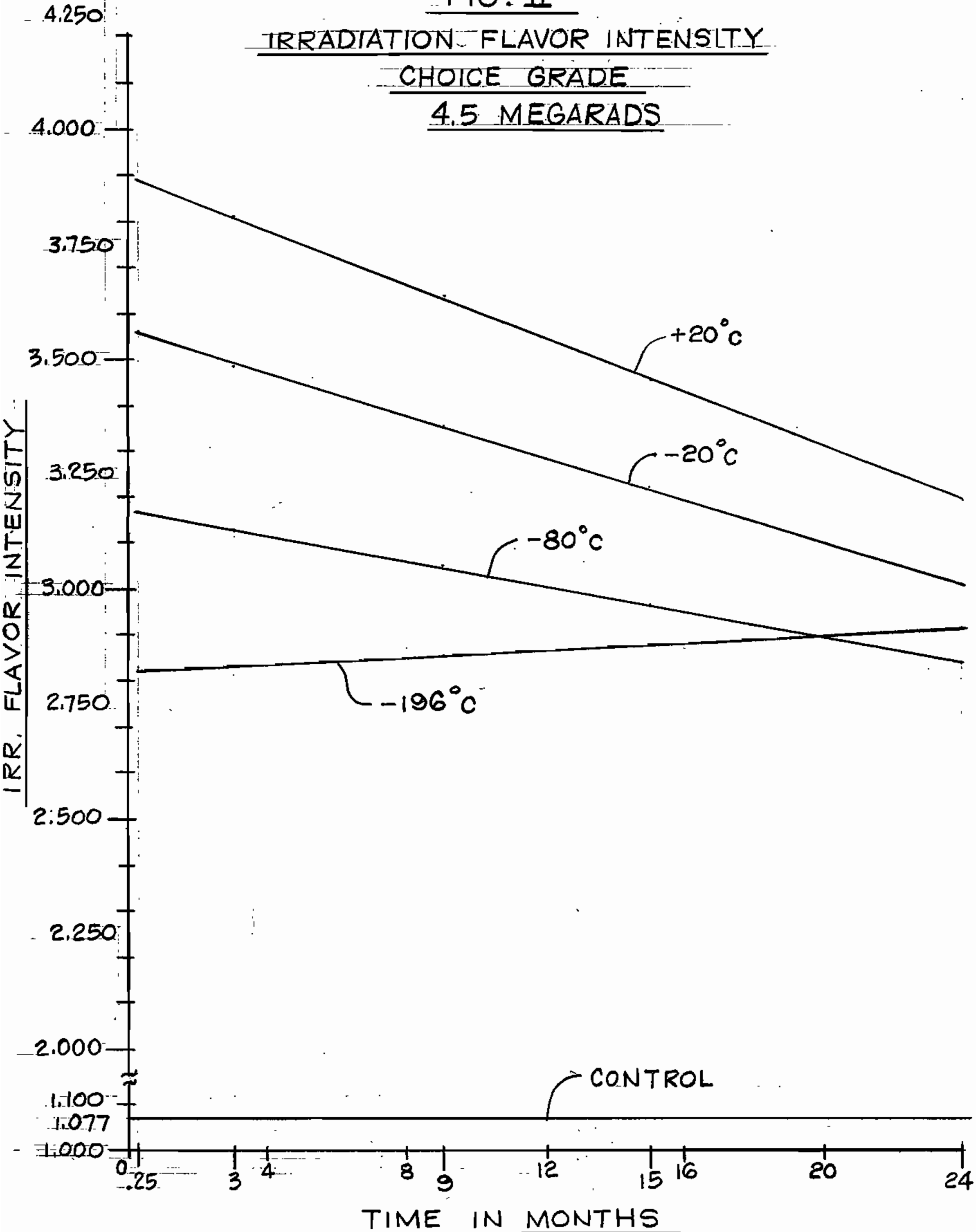


FIG. II

IRRADIATION FLAVOR INTENSITY

CHOICE GRADE

4.5 MEGARADS



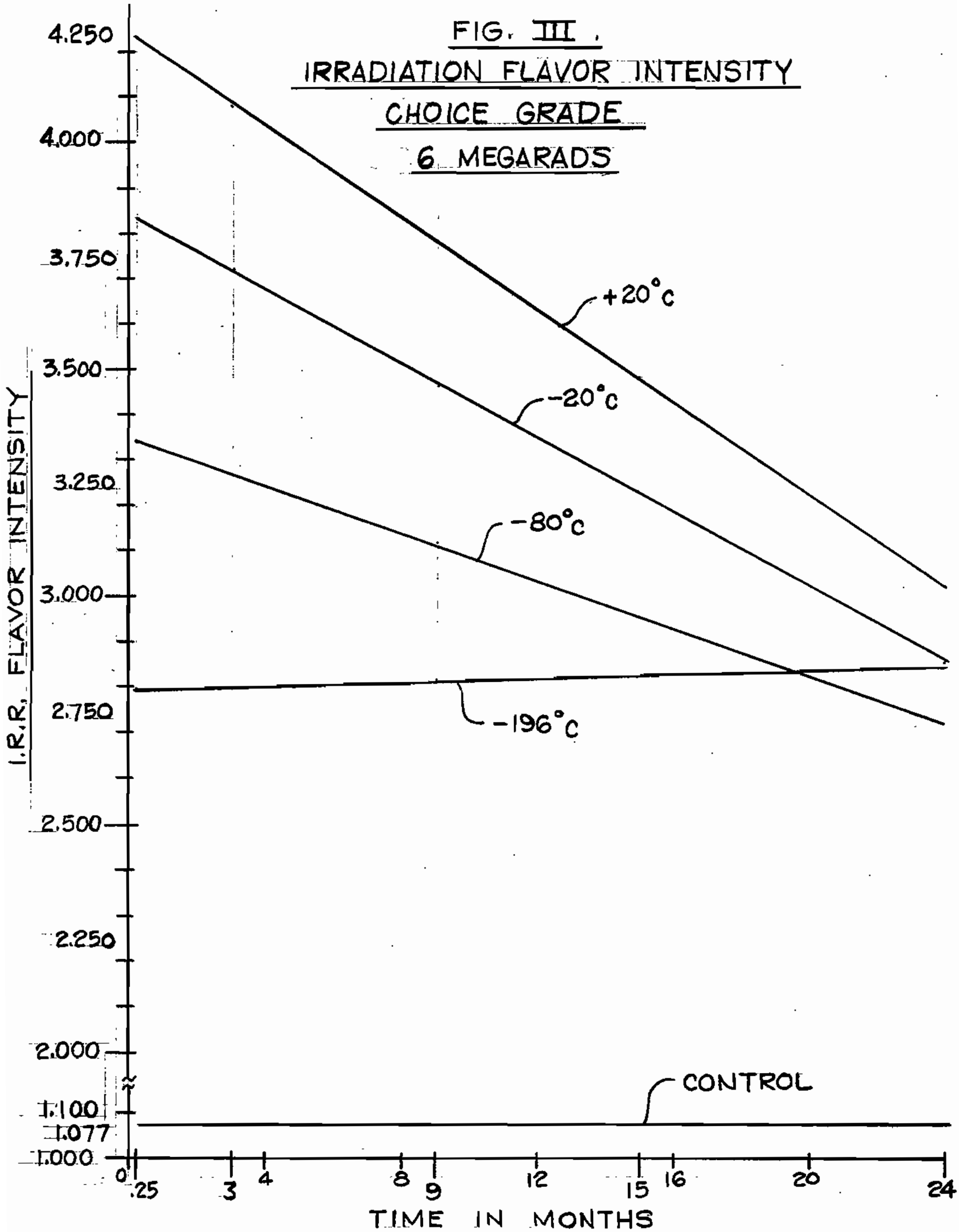


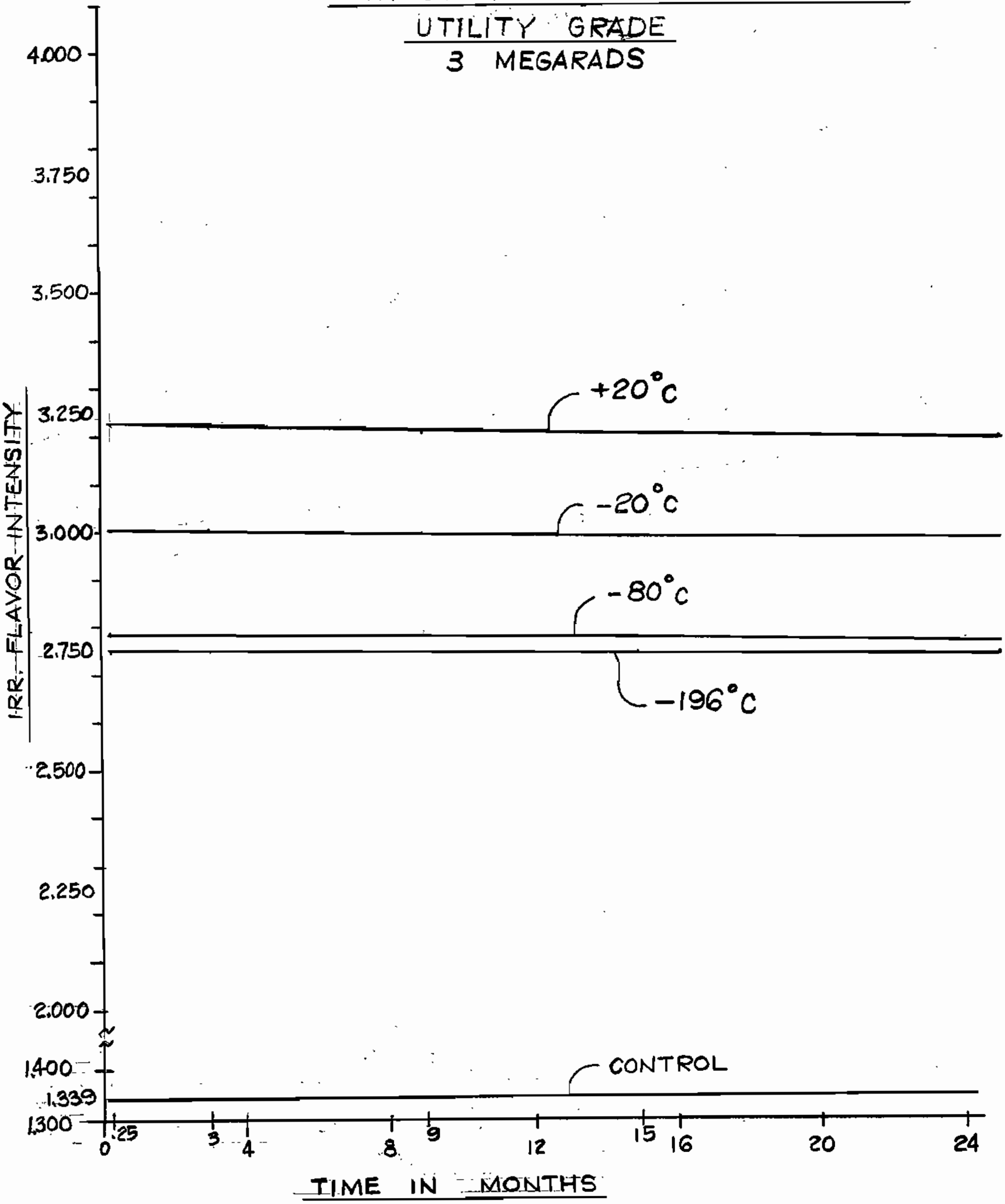
FIG. III.
IRRADIATION FLAVOR INTENSITY
CHOICE GRADE
6 MEGARADS
I.R.R. FLAVOR INTENSITY
4.250
4.000
3.750
3.500
3.250
3.000
2.750
2.500
2.250
2.000
1.100
1.077
1.000
+20°C
-20°C
-80°C
-196°C
CONTROL
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

FIG. IV

IRRADIATION FLAVOR INTENSITY

UTILITY GRADE

3 MEGARADS



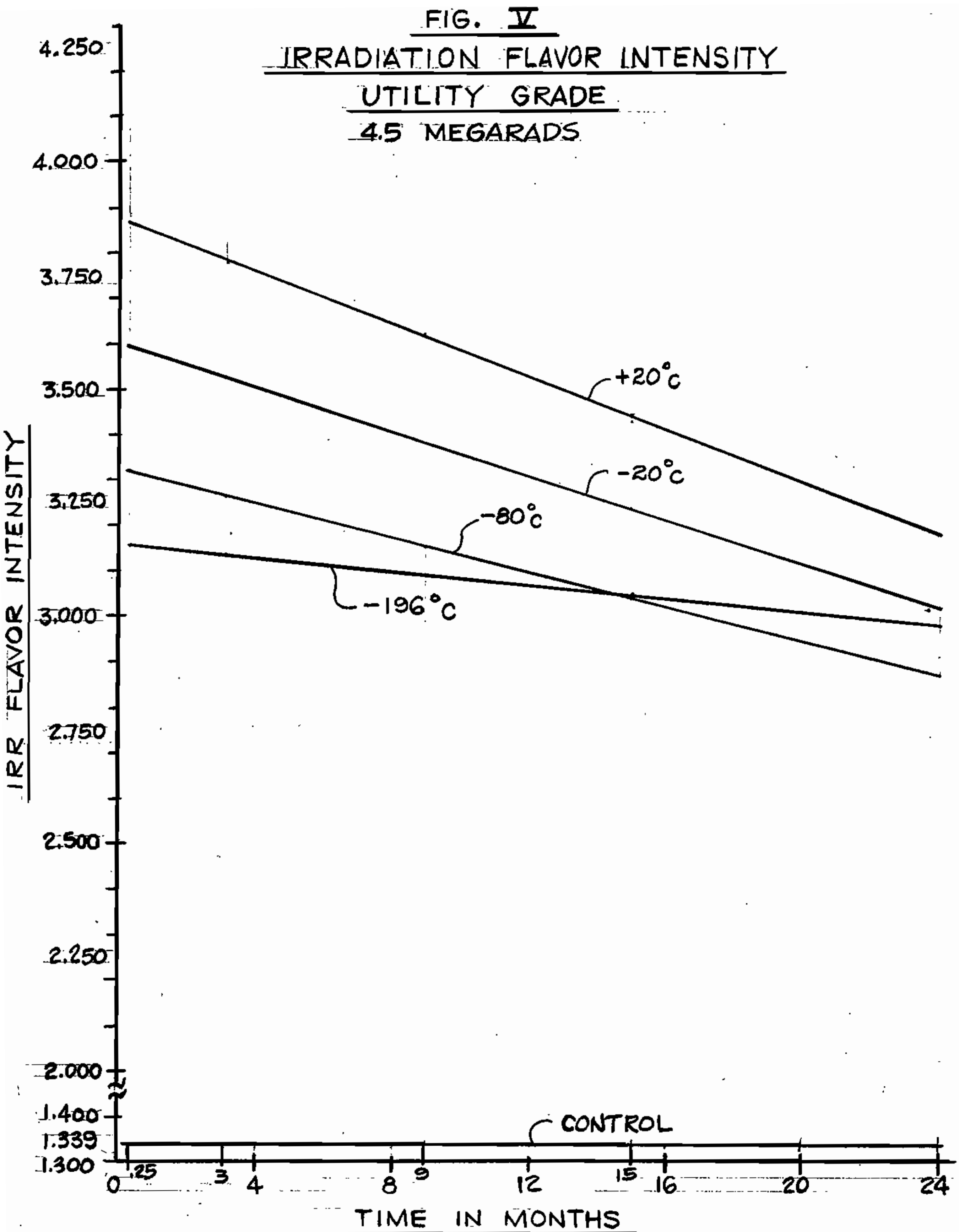


FIG. V
IRRADIATION FLAVOR INTENSITY
UTILITY GRADE
4.5 MEGARADS
IRR FLAVOR INTENSITY
4.250
4.000
3.750
3.500
3.250
3.000
2.750
2.500
2.250
2.000
1.400
1.339
1.300
+20°C
-20°C
-80°C
-196°C
CONTROL
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

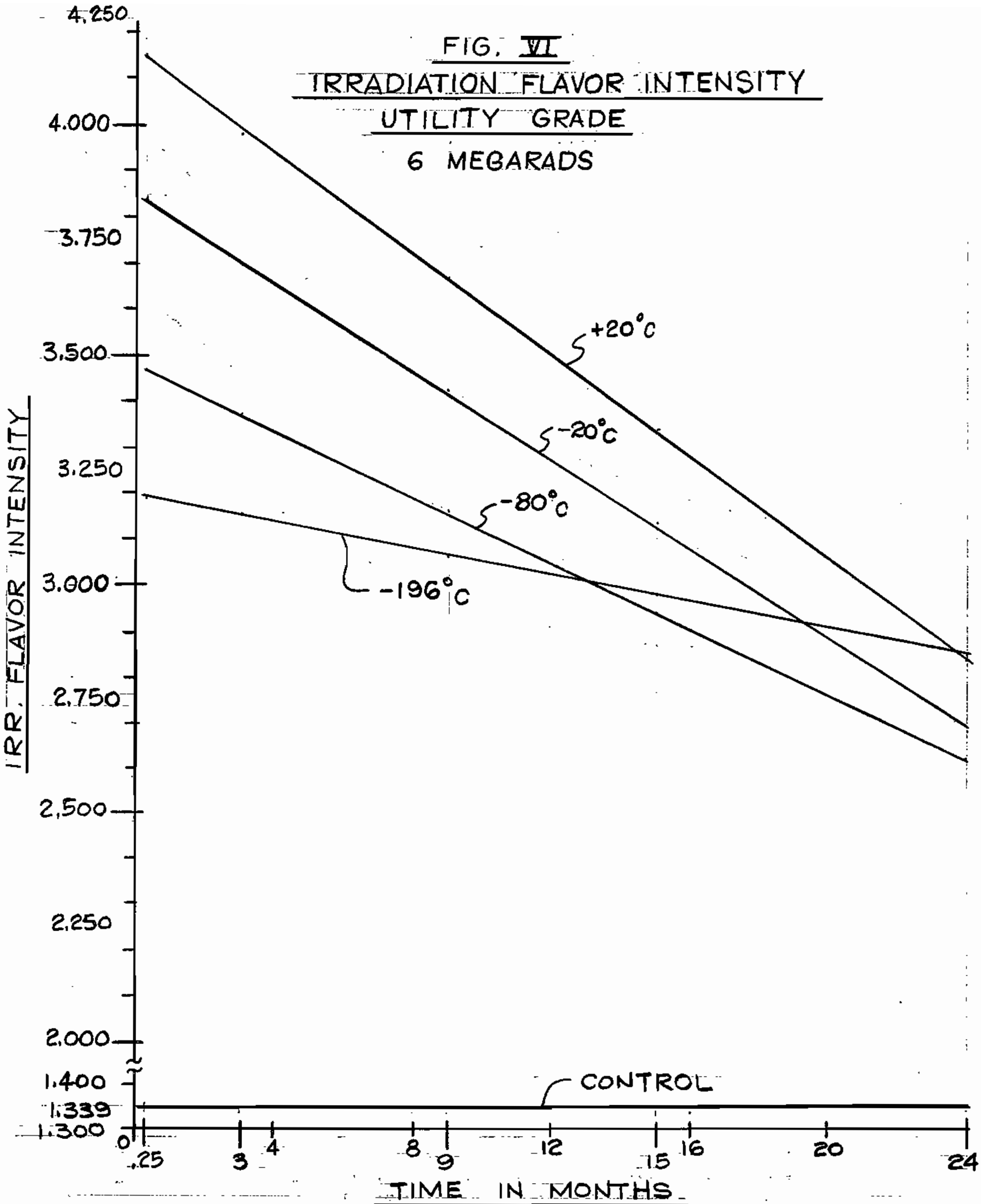


FIG. VI
IRRADIATION FLAVOR INTENSITY
UTILITY GRADE
6 MEGARADS
IRR. FLAVOR INTENSITY
4.250
4.000
3.750
3.500
3.250
3.000
2.750
2.500
2.250
2.000
1.400
1.339
1.300
0
+20°C
-20°C
-80°C
-196°C
CONTROL
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

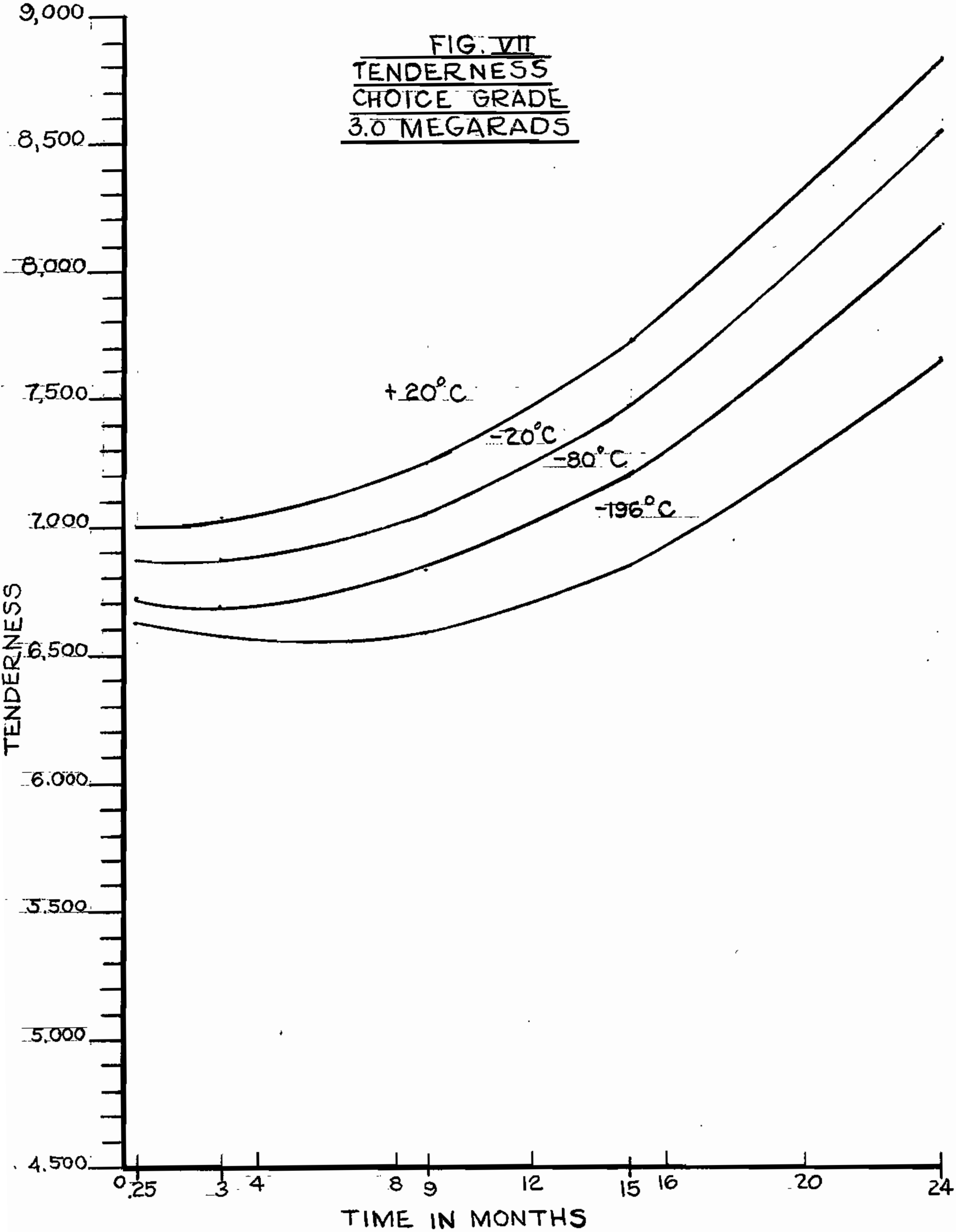


FIG. VII
TENDERNESS
CHOICE GRADE
3.0 MEGARADS
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
TENDERNESS
+20°C
-20°C
-80°C
-196°C
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

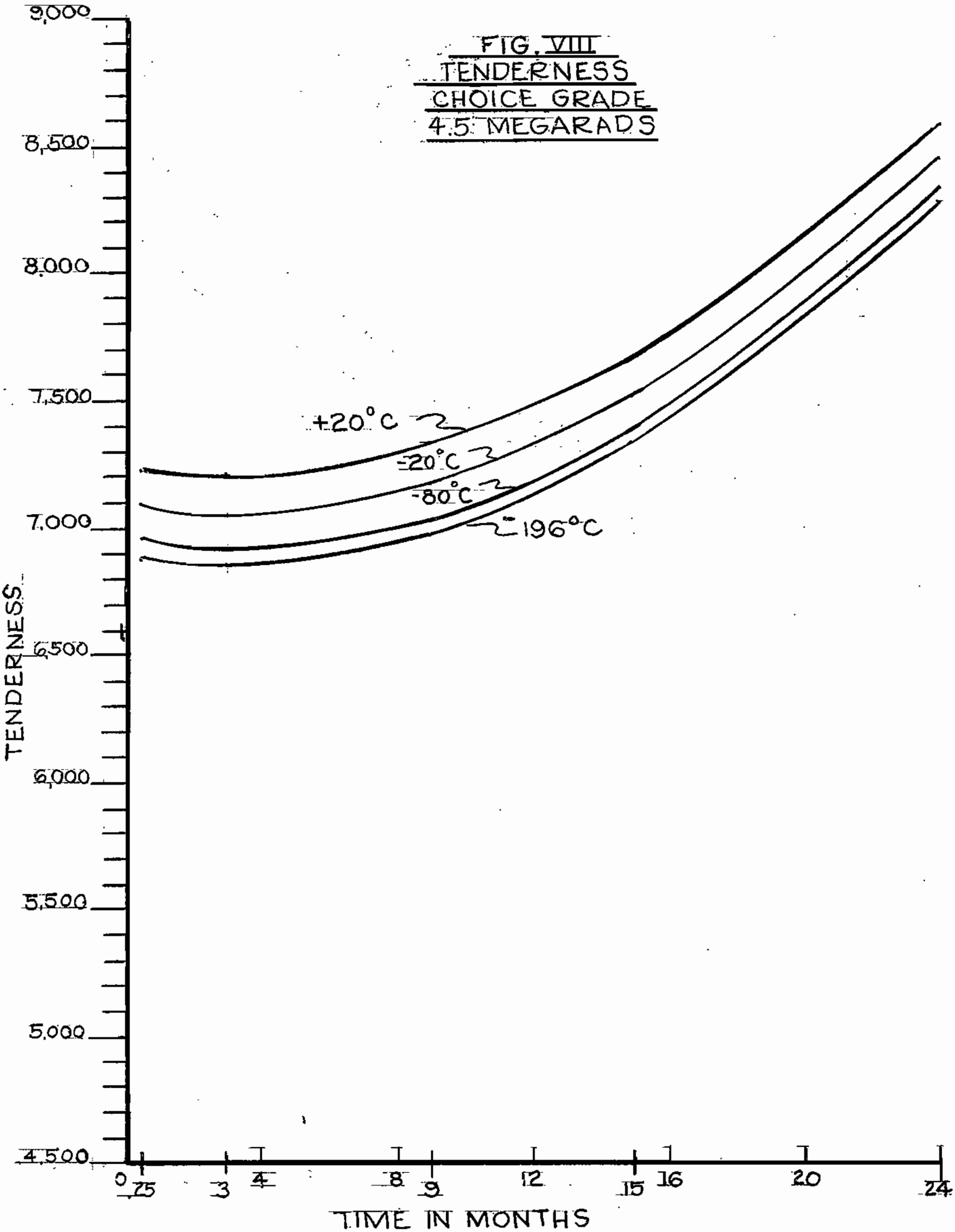


FIG. VIII
TENDERNESS
CHOICE GRADE
4.5 MEGARADS
+20°C
-20°C
-80°C
-196°C
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
TENDERNESS
0
.75
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

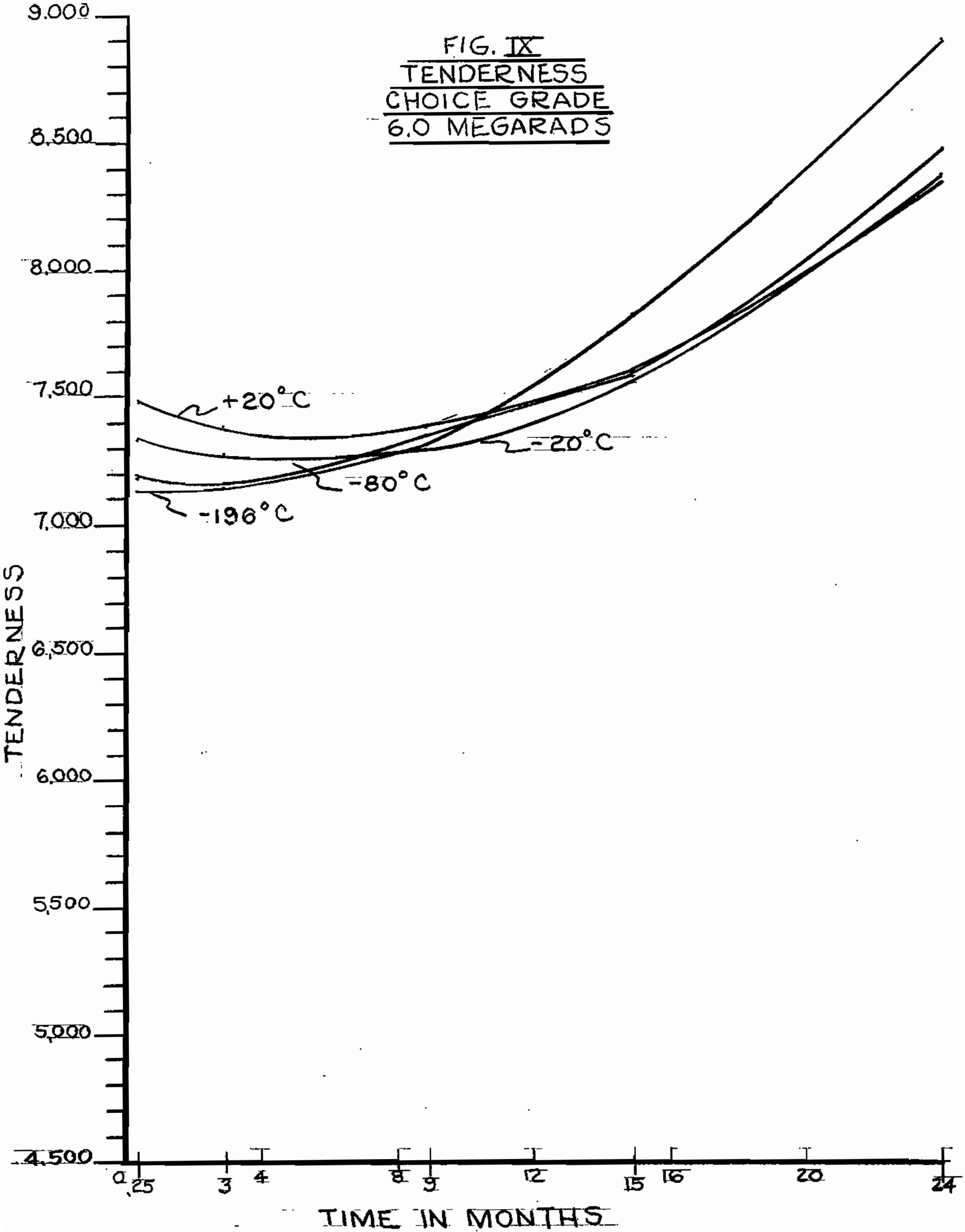


FIG. IX
TENDERNESS
CHOICE GRADE
6.0 MEGARADS
9.000
8.500
8.000
7.500
7.000
6.500
6.000
5.500
5.000
4.500
TENDERNESS
+20°C
-20°C
-80°C
-196°C
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

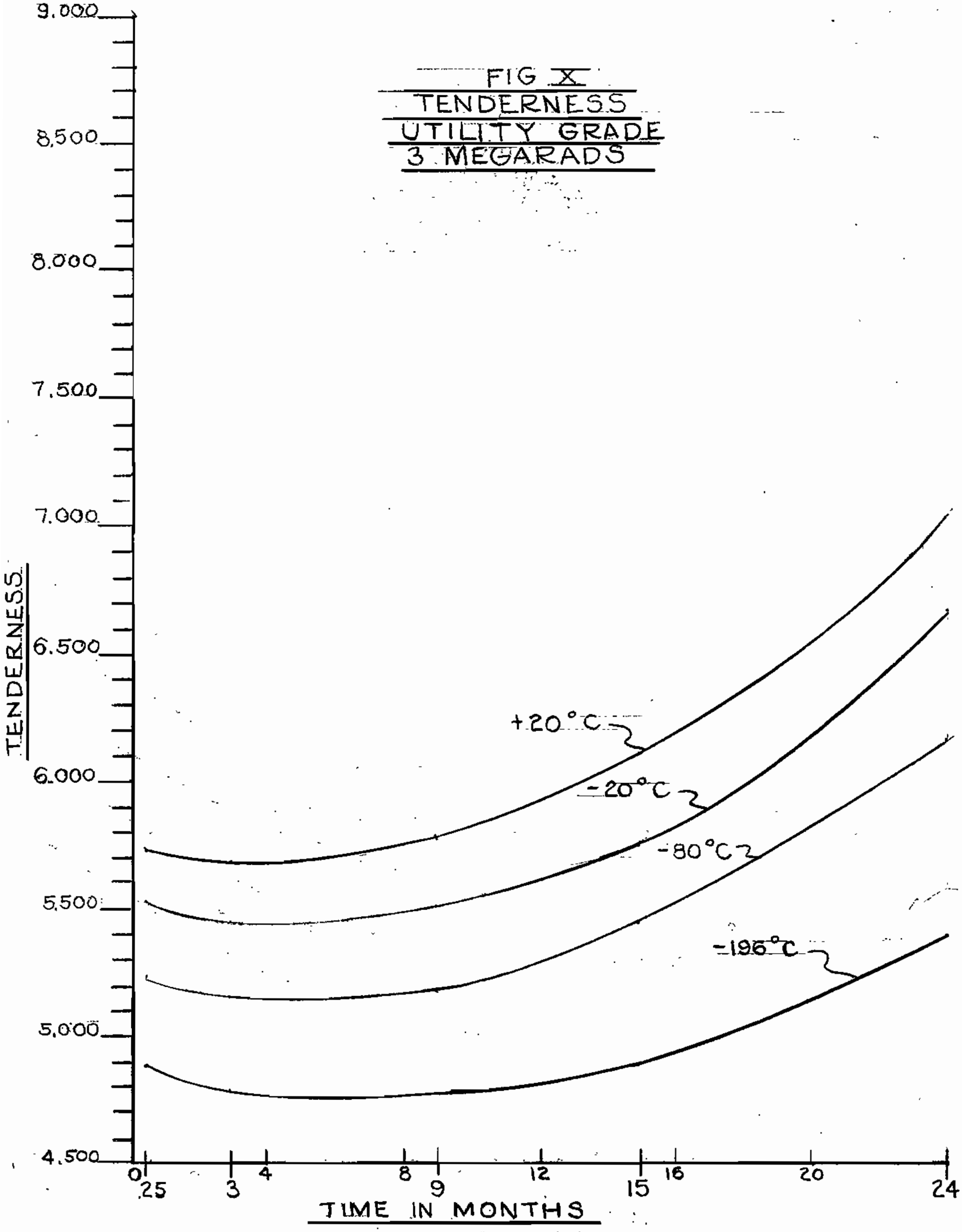


FIG X
TENDERNESS
UTILITY GRADE
3 MEGARADS
TENDERNESS
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
+20°C
-20°C
-80°C
-196°C
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

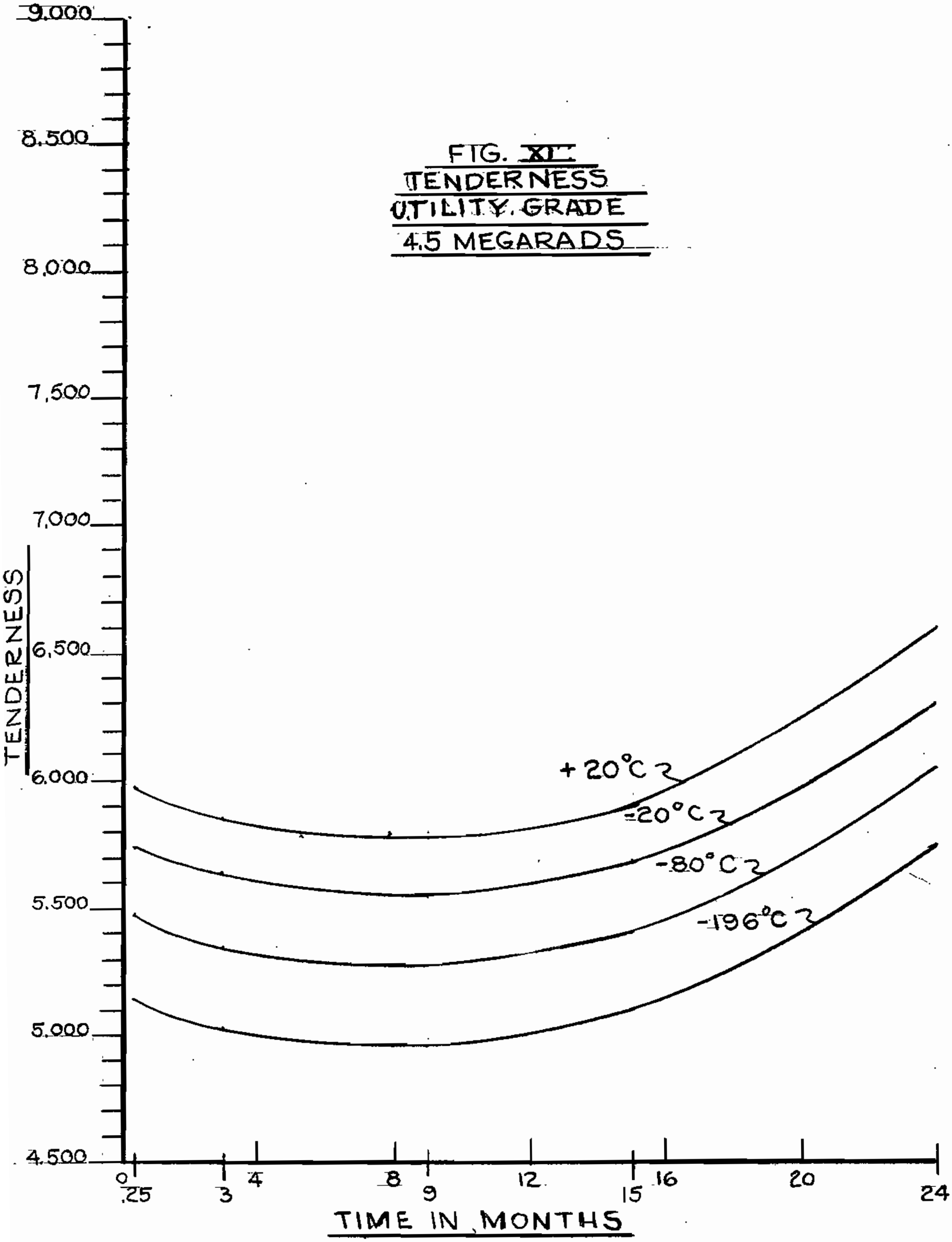


FIG. XI
TENDERNESS
UTILITY GRADE
4.5 MEGARADS
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
TENDERNESS
+20°C
-20°C
-80°C
-196°C
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

FIG. XII
TENDERNESS
UTILITY GRADE
6.0 MEGARADS

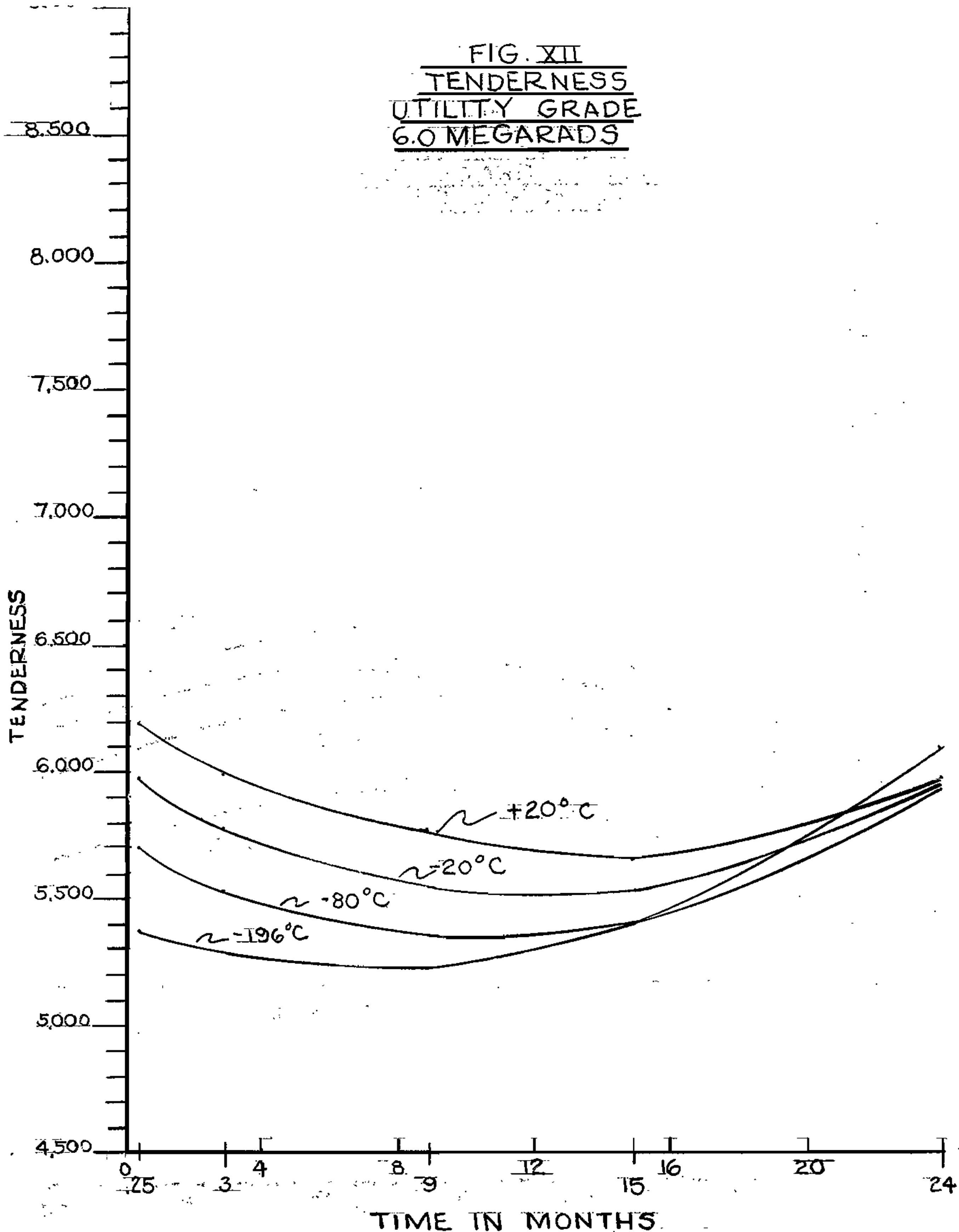
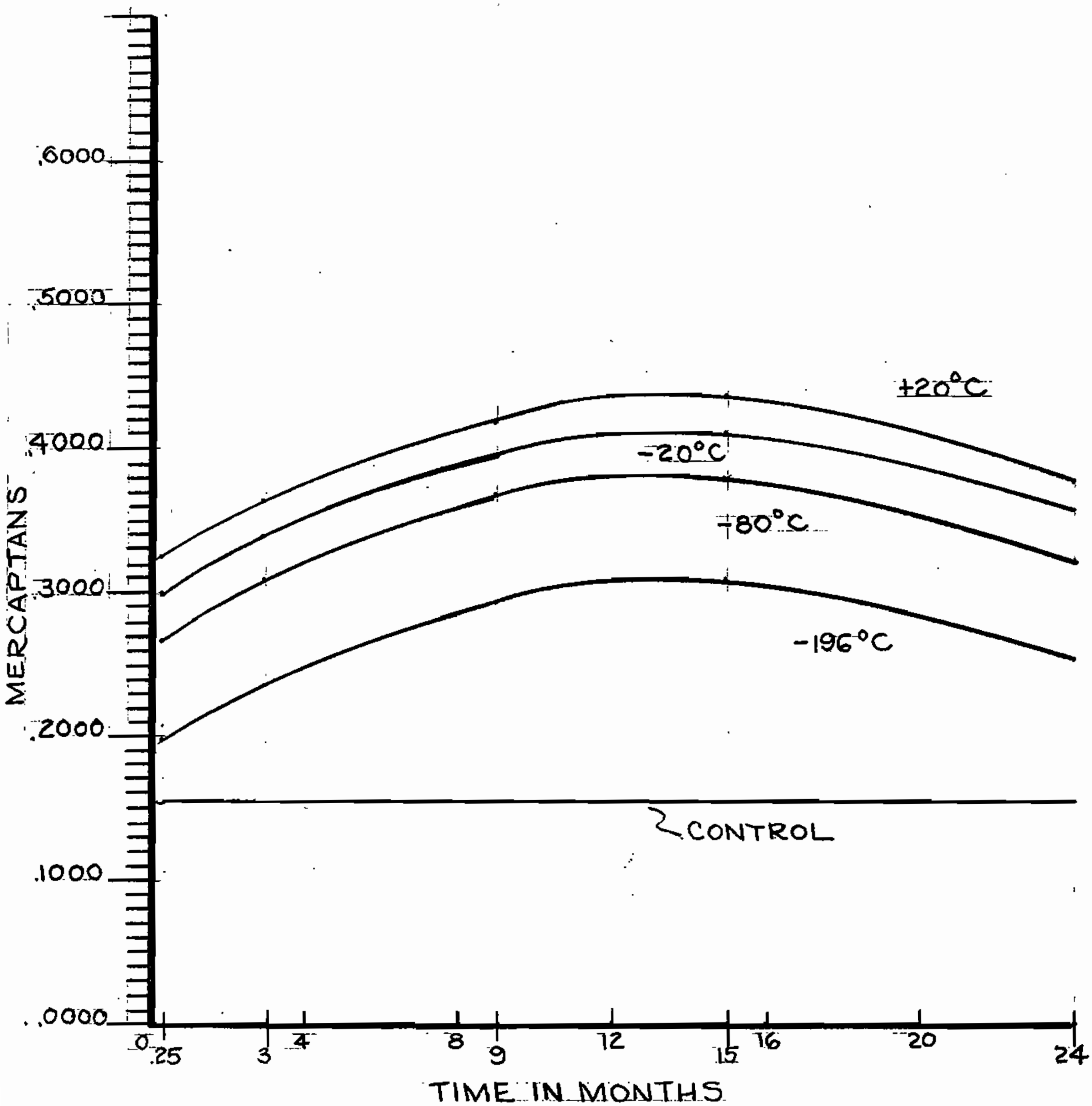


FIG XIII
MERCAPTANS
CHOICE GRADE BEEF
6.0 MEGARADS



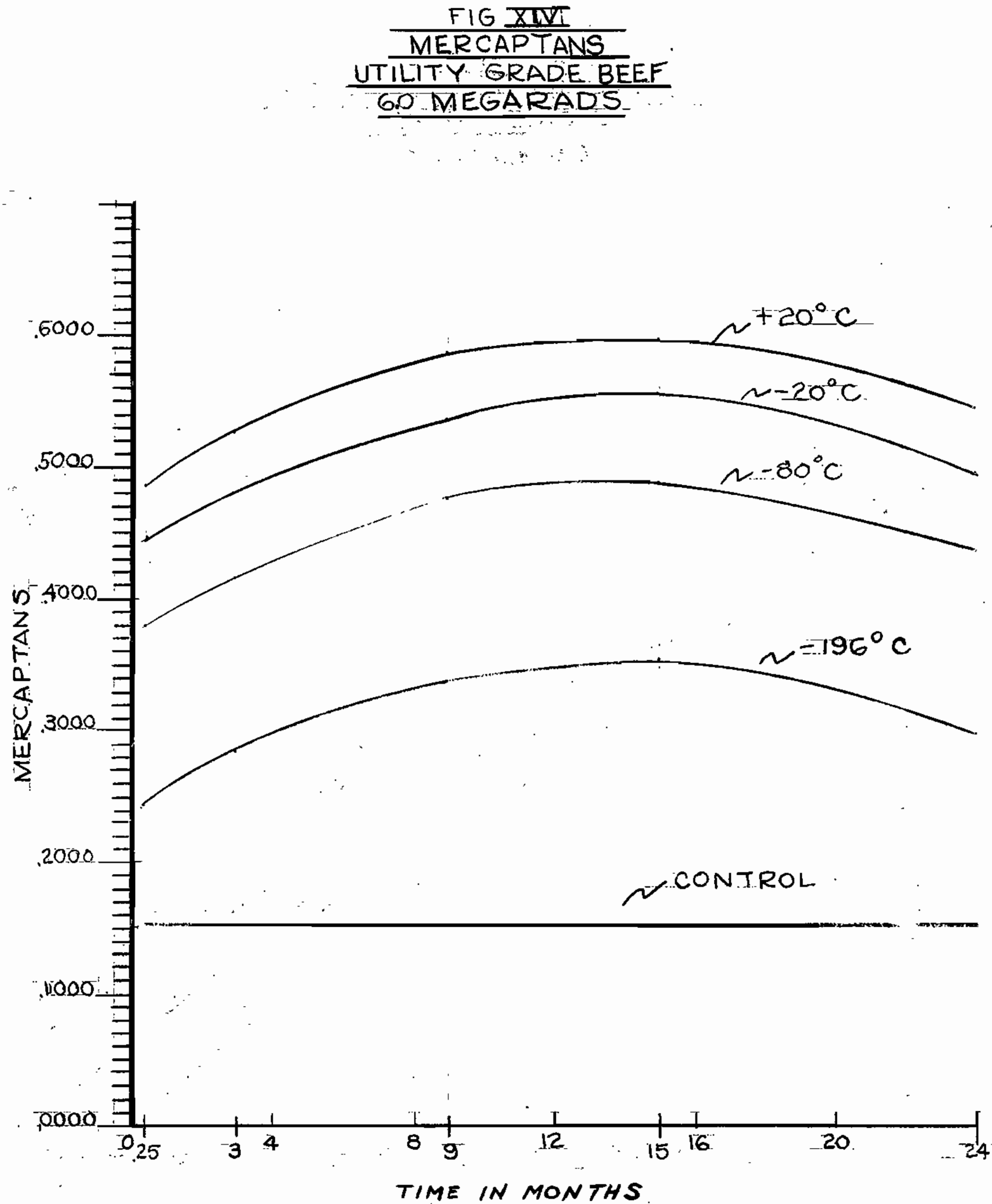


FIG XLVI
MERCAPTANS
UTILITY GRADE BEEF
60 MEGARADS
+20°C
-20°C
-80°C
-196°C
CONTROL
MERCAPTANS
.6000
.5000
.4000
.3000
.2000
.1000
.0000
0
.25
3
4
8
9
12
15
16
20
24
TIME IN MONTHS

FIG. XV
WATER BINDING CAPACITY
CHOICE GRADE
6.0 MEGARADS

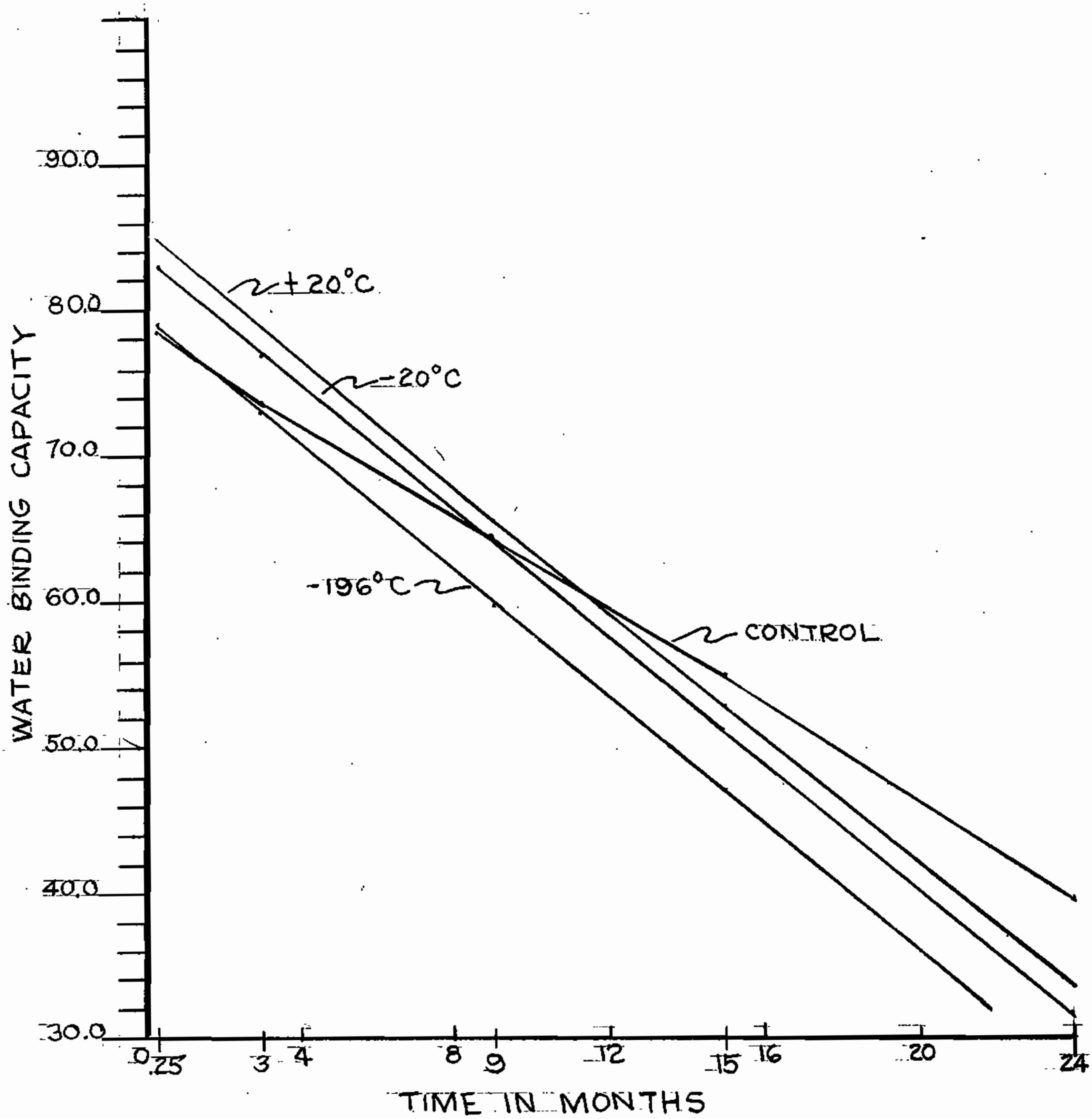


FIG XVI

WATER BINDING CAPACITY

UTILITY GRADE

6.0 MEGARADS

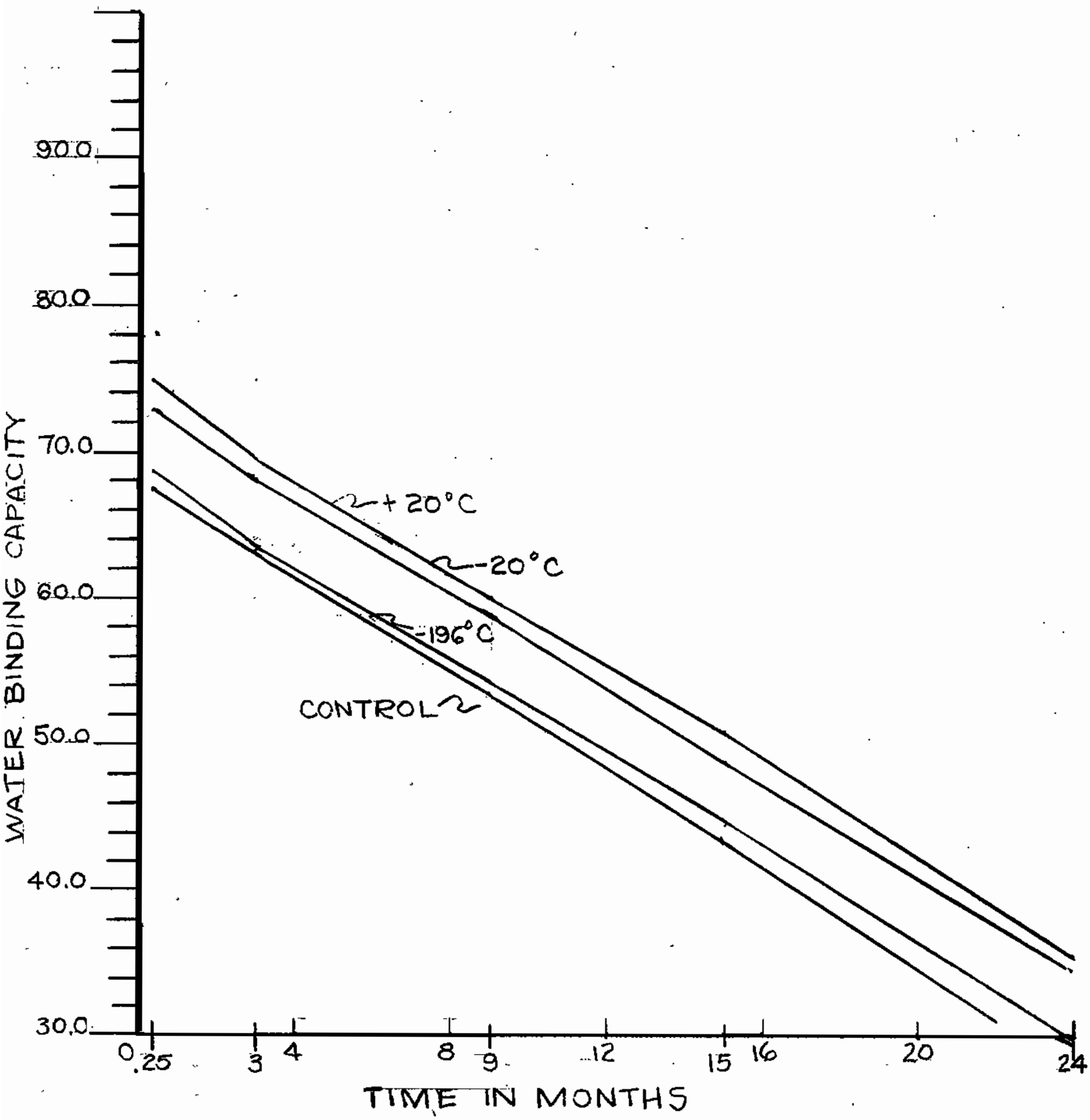


FIG. XVII

SOLUBLE COLLAGEN

CHOICE & UTILITY GRADES

6.0 MEGARADS

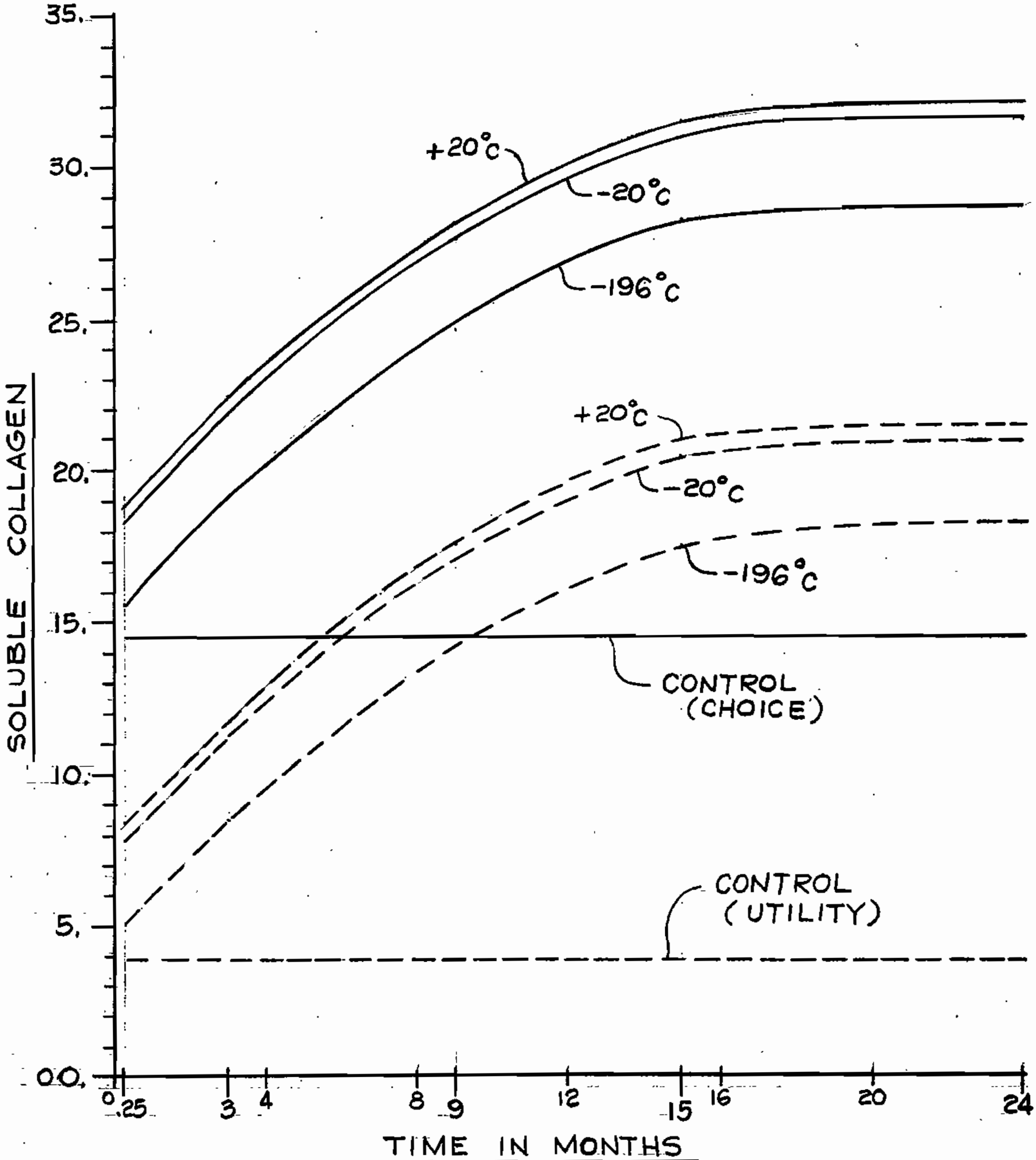


TABLE 1

IRRADIATION FLAVOR INTENSITY SCORES OF CHOICE GRADE BEEF
(Score of 1 = none; 6 = very much)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	1.2*	1.3*	1.1	1.1	
	1.1**	1.4**			
	1.1				
	1.1				
	1.1				
	1.0				
	1.3*				
	1.2**				
Mrads at +20°C					
3.0	3.6	3.3	2.9	3.7	3.3
3.0	3.1	3.0			
4.5	3.5	3.6	4.7	3.2	2.8
4.5	3.6	6.2			
6.0	4.3*	3.9*	3.8	3.3	3.4
6.0	4.3**	3.7**			
Mrads at -20°C					
3.0	2.7	3.0	2.7	2.8	2.5
3.0	2.6	2.9			
4.5	3.5	3.8	3.6	3.0	2.5
4.5	4.0	4.0			
6.0	3.9	2.9	3.3	3.9	2.8
6.0	3.7	3.6			
Mrads at -80°C					
3.0	2.6	2.9	2.3	2.7	2.9
3.0	3.0	2.7			
4.5	3.1	3.1	2.9	2.9	2.9
4.5	2.8	3.1			
6.0	2.8	4.0	3.8	3.1	3.1
6.0	3.4	3.4			
Mrads at -196°C					
3.0	1.9	2.0	2.6	2.7	3.0
3.0	2.0	2.0			
4.5	2.5	2.0	2.3	2.7	2.6
4.5	3.1	2.8			
6.0	2.2*	3.0*	2.7	3.4	2.3
6.0	3.1**	3.4**			
6.0***	2.9*	2.9*	2.8*	2.7*	
6.0***	2.7**	3.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 2

IRRADIATION FLAVOR INTENSITY SCORES OF UTILITY GRADE BEEF
(Score of 1 = none; 6 = very much)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	1.1*	1.1*	1.2	1.0	
	1.2**	1.3**			
	1.5				
	1.7				
	1.0				
	1.1				
	1.1*				
	1.1**				
Mrads at +20°C					
3.0	4.0	3.4	3.6	3.3	3.4
3.0	3.4	2.1			
4.5	3.0	4.4	3.0	3.3	3.2
4.5	3.9	3.8			
6.0	4.3*	4.4*	3.2	2.9	2.8
6.0	4.5**	3.8**			
Mrads at -20°C					
3.0	3.3	2.5	2.9	3.3	2.5
3.0	3.0				
4.5	4.1	3.2	3.5	3.4	3.0
4.5	3.6	3.1			
6.0	4.1	3.9	3.1	3.5	3.2
6.0	3.6	3.1			
Mrads at -80°C					
3.0	3.0	1.7	2.6	3.1	2.8
3.0	2.0	3.6			
4.5	3.0	3.0	3.1	2.8	2.7
4.5	3.1	2.9			
6.0	3.7	3.3	3.4	3.1	2.4
6.0	4.0	3.1			
Mrads at -196°C					
3.0	3.4	3.1	2.9	2.9	2.8
3.0	2.3	3.6			
4.5	3.7	3.3	2.8	3.4	3.2
4.5	4.0	3.0			
6.0	2.7*	3.0*	2.9	2.7	2.7
6.0	3.5**	2.8**			
6.0***	3.1*	3.4*	3.4*	2.6*	
6.0***	3.3**	2.6**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 3

ORGANOLEPTIC TENDERNESS SCORES OF CHOICE GRADE BEEF
(Score of 1 = very tough; 10 = extremely tender)

Irradiation	Storage Time in Months 0	3	9	15	24
None	7.1*	5.9*	4.6	4.7	
	6.8**	6.5**			
	6.8				
	6.2				
	5.1				
	6.0				
	6.5*				
	6.4**				
Mrads at +20°C					
3.0	7.6	7.7	6.7	7.1	9.0
3.0	6.6	6.7			
4.5	7.4	7.7	8.3	7.0	8.4
4.5	6.9	8.1			
6.0	8.1*	8.3*	7.9	7.6	8.8
6.0	7.5**	8.0**			
Mrads at -20°C					
3.0	6.4	7.3	6.7	7.1	8.0
3.0	5.5	7.4			
4.5	7.0	8.6	7.5	5.7	8.2
4.5	6.8	7.0			
6.0	5.2	7.7	7.4	8.2	7.7
6.0	6.8	8.2			
Mrads at -80°C					
3.0	7.3	7.0	6.7	7.3	9.6
3.0	6.3	7.2			
4.5	7.3	8.3	7.0	6.4	9.0
4.5	6.3	7.4			
6.0	7.3	7.4	8.1	7.3	9.1
6.0	6.8	6.8			
Mrads at -196°C					
3.0	7.8	6.6	7.7	7.0	8.9
3.0	6.0	6.8			
4.5	6.3	6.6	8.1	6.5	8.4
4.5	6.0	6.3			
6.0	7.3*	7.2*	8.4	7.4	8.5
6.0	6.7**	7.5**			
6.0***	6.0*	7.9*	8.7*	6.4*	
6.0***	6.7**	7.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 4

ORGANOLEPTIC TENDERNESS SCORES OF UTILITY GRADE BEEF
(Score of 1 = very tough; 10 = extremely tender)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	5.3*	4.6*	2.3	2.5	
	4.1**	3.7**			
	3.4				
	4.3				
	3.4				
	3.8				
	5.2*				
	4.1**				
Mrads at +20°C					
3.0	5.9	5.6	3.8	6.1	6.9
3.0	6.1				
4.5	6.4	7.7	4.7	6.6	7.8
4.5	6.9	5.2			
6.0	6.4*	7.0*	6.3	5.7	7.1
6.0	6.6**	4.5**			
Mrads at -20°C					
3.0	6.4	5.5	4.7	5.5	6.7
3.0	4.0	5.1			
4.5	4.9	5.2	4.3	5.1	4.9
4.5	5.1	5.0			
6.0	5.7	5.4	5.9	4.0	5.3
6.0	4.3	4.6			
Mrads at -80°C					
3.0	5.7	3.1	5.2	6.6	6.2
3.0	5.4	3.7			
4.5	5.5	6.1	7.0	5.3	5.2
4.5	5.9	6.1			
6.0	5.1	6.2	4.0	6.1	6.4
6.0	5.8	4.7			
Mrads at -196°C					
3.0	4.4	5.9	5.4	6.6	5.8
3.0	3.8	6.0			
4.5	5.1	5.0	6.1	5.1	6.5
4.5	6.0	6.6			
6.0	5.9*	6.6*	4.1	5.5	4.6
6.0	3.9**	5.0**			
6.0***	6.1*	6.0*	6.3*	5.5*	
6.0***	4.8**	4.1**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 5

VOLATILE MERCAPTANS IN CHOICE GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months 0	3	9	15	24
None	0.24*	0.40*	0.14	0.07	0.16
	.15**	0.19**			
	.13				
	.15				
	.15				
	.26*				
	.18**				
Mrads at +20°C					
3.0	.62	.31	.46		
3.0	.33				
4.5	.50	.37	.35		
4.5	.32	.32			
6.0		.57*	.47	.56	.30
Mrads at -20°C					
3.0	.26	.27	.31		
3.0	.23				
4.5	.26		.29		
4.5	.19				
6.0	.28		.36	.37	.39
6.0	.23				
Mrads at -80°C					
3.0	.27		.34		
3.0	.53				
4.5	.27		.29		
4.5	.16				
6.0			.27	.37	
6.0	.37				
Mrads at -196°C					
3.0	.22		.27		
3.0	.30				
4.5	.23		.29		
4.5	.29				
6.0	.24*	.41*	.27	.29	.31
6.0	.23**				
6.0***	.27*	.44*	.29*	.34*	
6.0***	.21**	.30**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 6

VOLATILE MERCAPTANS IN UTILITY GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None			0.31	0.12	0.10
	0.06**				
	0.19				
Mrads at +20°C					
3.0			.54		
4.5			.55		
6.0	0.50*		.82	.80	.67
Mrads at -20°C					
3.0			.31		
4.5			.35		
6.0	.30		.39	.40	.43
Mrads at -80°C					
3.0			.38		
4.5			.38		
6.0			.44		
Mrads at -196°C					
3.0			.33		
4.5			.41		
6.0			.34		.26
6.0	.14**				
6.0***			.32*	.34	
6.0***	.13**				

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 7

WATER BINDING CAPACITY OF CHOICE GRADE BEEF
(% Swelling - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	81*	58*	81	55	30
	70**	72**			
	92				
	78				
	89				
	61				
	56*				
	57**				
Mrads at +20°C					
3.0	75				
3.0	67				
4.5	84				
4.5	85				
6.0	99*	90*	82	37	46
6.0	77**	63**			
Mrads at -20°C					
3.0	111				
3.0	88				
4.5	93				
4.5	63				
6.0	85	74	68	38	34
6.0	71	74			
Mrads at -80°C					
3.0	58				
3.0	67				
4.5	78				
4.5	63				
6.0	87				
6.0	74				
Mrads at -196°C					
3.0	88				
3.0	74				
4.5	91				
4.5	58				
6.0	99*	71*	65	42	41
6.0	70**	70**			
6.0***	89*	66*	62*	35*	
6.0***		84**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 8

WATER BINDING CAPACITY OF UTILITY GRADE BEEF
(% swelling - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	82*	69*	62	46	35
	40**	70**			
	84				
	54				
	43*				
	67**				
Mrads at +20°C					
6.0	68*	65*	82	48	41
6.0	71**	69**			
Mrads at -20°C					
6.0	81	79	71	23	28
6.0	56	76			
Mrads at -196°C					
6.0	56*	67*	76	18	43
6.0	61**	72**			
6.0***	53*	65*	66*	21*	
6.0***	70**	75**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 9

SOLUBLE COLLAGEN IN CHOICE GRADE BEEF
(% of total collagen - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	15*	14*	9	8	7
	11**	9**			
	11				
	19				
	11*				
	12**				
Mrads at +20°C					
3.0	12				
6.0	15*	18*	26	28	32
6.0	16**	28**			
Mrads at -20°C					
3.0	20				
4.5	20				
6.0	16	24	22	25	36
6.0	23	31			
Mrads at -80°C					
3.0	11				
4.5	21				
6.0	48				
Mrads at -196°C					
3.0	9				
4.5	14				
6.0	15*	20*	33	23	33
6.0	9**	24**			
6.0***	18*	28*	33*	21*	
6.0***	15**	16**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 10

SOLUBLE COLLAGEN IN UTILITY GRADE BEEF
(% of total collagen - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	2.6*	2.9*	3.5	2.4	2.6
	2.5**	2.7**			
	3.0				
	3.3				
	2.1*				
	3.2**				
Mrads at +20°C					
6.0	8.4*	8.4*	19.3	11.7	17.8
6.0	7.3**	11.1**			
Mrads at -20°C					
6.0	7.0	20.2	30.0	15.6	25.8
6.0	12.3	11.6			
Mrads at -196°C					
6.0	4.1*	5.1*	15.6	18.8	20.0
6.0	5.6**	8.7**			
6.0***	4.4*	8.0*	21.1*	14.3*	
6.0***	4.8**	9.5**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 11

PERCENT TOTAL COLLAGEN IN CHOICE GRADE BEEF
(Avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	0.75*	0.50*	0.59	0.48	0.63
	.50**	.57**			
	.50				
	.49				
	.55*				
	.44**				
Mrads at +20°C					
3.0	.75				
6.0	.61*	.46	.49	.60	.54
6.0	.91**	.67			
Mrads at -20°C					
3.0	.44				
4.5	.55				
6.0	.67	.84	.54	.61	.74
6.0	.56	.78			
Mrads at -80°C					
3.0	.67				
4.5	.77				
6.0	.57				
Mrads at -196°C					
3.0	.73				
4.5	.46				
6.0	.66*	.54*	.48	.69	.70
6.0	.71**	.71**			
6.0***	.70*	.55*	.53*	.53*	
6.0***	.53**	.29**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 12

PER CENT TOTAL COLLAGEN IN UTILITY GRADE BEEF
(Avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	0.87*	0.53*	0.57	0.66	0.58
	.67**	.68**			
	.75				
	.52				
	.77*				
	.69**				
Mrads at +20°C					
6.0	.54*	.60*	.65	.80	.51
6.0	1.03**	.75**			
Mrads at -20°C					
6.0	.76	.51	.62	.61	.61
6.0	.50	.65			
Mrads at -196°C					
6.0	.50*	.53*	.66	.68	.57
6.0	.68**	.65**			
6.0***	.54*	.86*	.85*	.74*	
6.0***	.80**	.77**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 13

EXTRACTABLE NON-PROTEIN NITROGEN IN CHOICE GRADE BEEF
(% of total nitrogen)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	10*	10*	9	9	9
	10**	9**			
	9				
	11				
	11				
	11				
	9*				
	9**				
Mrads at +20°C					
3.0	9	9	9	9	10
3.0	10	10			
4.5	9	10	10	10	9
4.5	10	10			
6.0	11*	10*	11	11	11
6.0	11**	10**			
Mrads at -20°C					
3.0	9	9	9	10	11
3.0	9	9			
4.5	9	9	9	10	9
4.5	9	9			
6.0	10	9	9	10	11
6.0	9	10			
Mrads at -80°C					
3.0	10	10	10	10	11
3.0	9	9			
4.5	10	10	9	10	11
4.5	10	9			
6.0	9*	10*	10	10	11
6.0	9**	11**			
6.0***	11*	10*	10*	10*	
6.0***	9**	10**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 14

EXTRACTABLE NON-PROTEIN NITROGEN IN UTILITY GRADE BEEF
(% of total nitrogen)

Irradiation	Storage Time in Months 0	3	15	24
None	9*	10*	9	9
	10**	10**		
	9			
	12			
	9			
	9			
	9*			
	10**			
Mrads at +20°C				
3.0	11	11	10	10
3.0	10	10		
4.5	9	10	11	10
4.5	9	11		
6.0	9*	10*	9	10
6.0	11**	11**		
Mrads at -20°C				
3.0	9	9	10	11
3.0	9	10		
4.5	9	9	10	8
4.5	10	10		
6.0	9	9	10	9
6.0	10	10		
Mrads at -80°C				
3.0	10	9	9	9
3.0	9	9		
4.5	10	10	11	9
4.5	10	9		
6.0	9	9	10	9
6.0	9	10		
Mrads at -196°C				
3.0	10	9	12	10
3.0	10	10		
4.5	10	9	10	10
4.5	9	9		
6.0	10*	10*	8	9
6.0	9**	10**		
6.0***	10*	11*	10*	
6.0***	9**	10**		

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 15

SOLUBLE CARBONYLS IN CHOICE GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	1.8**	1.4**	1.3	0.5	0.7
	1.4				
	1.1				
	1.4**				
Mrads at +20°C					
3.0	1.5				
4.5	1.4				
6.0			1.4	0.6	1.0
Mrads at -20°C					
3.0	0.9				
4.5	1.0				
6.0	1.4				
6.0	1.7		1.3	0.9	0.9
Mrads at -80°C					
3.0	1.2				
4.5	1.4				
6.0	1.0				
Mrads at -196°C					
6.0	1.3*		1.1	0.6	0.7
6.0	1.5**	1.5**			
6.0***			1.1*	0.6*	
6.0***	1.5**	1.6**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 16

SOLUBLE CARBONYLS IN UTILITY GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	1.0*	0.9*	0.5	1.1	0.8
	2.1**				
	1.4				
	1.3				
	.9*				
Mrads at +20°C					
4.5	1.0*	1.5*	1.3	2.4	1.1
Mrads at -20°C					
4.5	1.1	2.4	.9	1.5	1.2
6.0	2.2				
Mrads at -196°C					
6.0	1.2*	1.4*	.9	1.4	0.8
6.0		2.3**			
6.0***	1.2*	1.3*	.8	2.3	
6.0***		1.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 17

INSOLUBLE CARBONYLS IN CHOICE GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	17*	9*	16	15	20
	14**	11**			
	11				
	12				
	13				
Mrads at +20°C					
3.0	18				
6.0	14*	9*	17	16	19
6.0	12**				
Mrads at -20°C					
3.0	12				
4.5	15				
6.0	16	17	17	17	22
6.0	11				
Mrads at -80°C					
3.0	13				
4.5	13				
6.0	11				
Mrads at -196°C					
3.0	14				
4.5	15				
6.0	12*		16	17	20
6.0	15**	15**			
6.0***			17*	16*	
6.0***	11**	10**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 18

INSOLUBLE CARBONYLS IN UTILITY GRADE BEEF
(Parts per million - avg. of 2 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	7.7*	9.0*	14.6	19.3	19.4
	9.3**	11.2*			
	8.4				
	10.2				
	8.5*				
	9.3**				
Mrads at +20°C					
6.0	8.5*	8.9*	15.3	20.9	22.1
6.0		9.1**			
Mrads at -20°C					
6.0	10.2	11.8	14.8	17.4	20.7
6.0	10.2	9.3			
Mrads at -196°C					
6.0	8.7*	12.0*	14.9	18.6	21.2
6.0	10.6**	8.5**			
6.0***	8.8*	9.8*	16.2*	18.6*	
6.0***		8.4**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 19

L. E. E. KRAMER SHEAR RESISTANCE READINGS OF CHOICE GRADE BEEF
(Avg. of 6 readings)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	16*	22*	38	36	13
	16**	26**			
	23				
	19				
	26				
	21				
	19*				
	25**				
Mrads at +20°C					
3.0	16	9	28	16	14
3.0	15	23			
4.5	30	9	12	16	14
4.5	14	18			
6.0	9*	9*	14	12	11
6.0	16**	10**			
Mrads at -20°C					
3.0	44	22	23	12	13
3.0	25	26			
4.5	30	21	21	17	14
4.5	24	28			
6.0	49	15	24	10	23
6.0	23	18			
Mrads at -80°C					
3.0	18	23	23	20	9
3.0	19	36			
4.5	24	22	24	20	8
4.5	24	28			
6.0	15	15	17	16	10
6.0	25	30			
Mrads at -196°C					
3.0	25	23	24	19	16
3.0	32	24			
4.5	22	31	17	19	12
4.5	25	26			
6.0	18*	19*	11	13	19
6.0	21**	23**			
6.0***	17*	15*	11*	14*	
6.0***	22**	21**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 20

L. E. E. KRAMER SHEAR RESISTANCE READINGS OF UTILITY GRADE BEEF
(Avg. of 6 readings)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	30*	35*	47	41	51
	35**	56**			
	42				
	41				
	34				
	35				
	31*				
	12**				
Mrads at +20°C					
3.0	39	33	30	21	23
3.0	35	33			
4.5	32	17	31	27	14
4.5	31	44			
6.0	16*	28*	21	22	17
6.0	23**	22**			
Mrads at -20°C					
3.0	44	44	39	27	16
3.0	38	34			
4.5	45	38	27	45	27
4.5	32	41			
6.0	34	28	22	43	24
6.0	37	42			
Mrads at -80°C					
3.0	26	57	22	23	22
3.0	24	48			
4.5	33	37	19	27	23
4.5	38	25			
6.0	40	31	37	29	20
6.0	28	44			
Mrads at -196°C					
3.0	47	27	28	32	22
3.0	41	38			
4.5	42	35	19	24	21
4.5	28	37			
6.0	28*	31*	26	33	22
6.0	13**	39**			
6.0***	32*	39*	15*	36*	
6.0***	15**	48**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 21

pH READINGS OF CHOICE GRADE BEEF

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	5.5*	5.6*	5.6	5.5	5.7
	5.6*	5.8**			
	5.7				
	5.6				
	5.6				
	5.7				
	5.7*				
	5.5**				
Mrads at +20°C					
3.0	5.8	5.9	5.9	5.8	5.9
3.0	5.8	5.9			
4.5	5.8	6.0	5.9	5.7	5.9
4.5	5.8	5.9			
6.0	5.8*	5.9*	5.8	5.8	5.7
6.0	5.8**	6.0**			
Mrads at -20°C					
3.0	5.8	5.9	5.9	5.7	5.9
3.0	5.7	5.9			
4.5	5.8	5.9	5.9	5.7	6.0
4.5	5.8	5.9			
6.0		5.9	5.9	5.7	5.9
6.0	5.8	6.0			
Mrads at -80°C					
3.0	5.8	5.9	5.9	5.8	5.9
3.0	5.8	5.9			
4.5	5.8	5.9	5.9	5.7	5.9
4.5	5.8	6.0			
6.0	5.8	5.9	5.9	5.7	5.9
6.0	5.8	5.9			
Mrads at -196°C					
3.0	5.8	6.0	5.9	5.6	5.7
3.0	5.8	5.9			
4.5	5.8	5.9	5.8	5.7	5.9
4.5	5.8	5.9			
6.0	5.8*	5.9*	5.9	5.8	5.7
6.0	5.8**	5.9**			
6.0***	5.8*	5.9*	5.9*	5.8*	
6.0***	5.8**	5.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 22

pH READINGS OF UTILITY GRADE BEEF

Irradiation	Storage Time in Months 0	3	9	15	24
None	5.9*	5.8*	6.3	5.6	5.8
	5.9**	6.0**			
	5.9				
	5.8				
	5.8				
	5.8				
	5.9*				
	5.9**				
Mrads at +20°C					
3.0	5.9	6.0	6.0	6.0	6.0
3.0	5.9	6.0			
4.5	5.9	5.9	6.1	6.4	6.0
4.5	5.9	6.0			
6.0	6.0*	5.9*	6.0	5.9	6.0
6.0	6.0**	6.1**			
Mrads at -20°C					
3.0	5.9	6.0	6.0	6.0	5.9
3.0	6.0	6.1			
4.5	6.2	5.9	6.0	5.9	5.9
4.5	5.9	6.0			
6.0	6.0	6.0	6.0	6.2	6.4
6.0	6.0	6.0			
Mrads at -80°C					
3.0	5.9	6.1	5.9	6.0	5.9
3.0	6.0	6.2			
4.5	6.1	5.8	5.9	6.0	6.0
4.5	6.4	6.1			
6.0	6.3	6.3	6.0	6.1	6.1
6.0	5.9	6.1			
Mrads at -196°C					
3.0	5.9	5.9	6.0	5.9	5.9
3.0	5.9	6.0			
4.5	6.0	6.0	6.0	6.4	6.0
4.5	5.9	5.9			
6.0	5.9*	6.0*	6.0	5.9	6.0
6.0	5.9**	6.1**			
6.0***	5.9*	6.0*	5.9*	6.0*	
6.0***	5.9**	6.1**			

* Loin #1

** Loin #2

*** Held at -196°C for 96 hours after irradiation

TABLE 23

PER CENT TOTAL NITROGEN IN CHOICE GRADE BEEF

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	4.5*	4.3*	4.7	4.2	4.4
	4.5**	4.7**			
	4.3				
	4.2				
	3.7				
	4.0				
	4.5*				
	4.7				
Mrads at +20°C					
3.0	4.5	4.5	4.7	4.6	4.7
3.0	4.3	4.4			
4.5	4.5	4.3	4.1	4.7	4.9
4.5	4.2	4.5			
6.0	4.5*	4.5*	4.0	4.4	3.9
6.0	4.5**	4.7**			
Mrads at -20°C					
3.0	4.5	4.8	4.5	4.3	4.5
3.0	4.3	4.3			
4.5	4.6	4.5	4.4	4.4	4.2
4.5	4.3	4.6			
6.0	4.6	4.4	4.3	4.5	4.2
6.0	4.5	4.3			
Mrads at -80°C					
3.0	4.5	4.6	4.6	4.0	4.3
3.0	4.4	4.8			
4.5	4.6	4.4	4.4	4.6	4.4
4.5	4.2	4.7			
6.0	4.5	4.5	4.5	4.5	3.9
6.0	4.4	4.4			
Mrads at -196°C					
3.0	4.2	4.2	4.3	4.3	4.4
3.0	4.6	4.6			
4.5	4.6	4.7	4.0	4.8	5.0
4.5	4.3	4.6			
6.0	4.1*	4.6*	4.2	4.6	4.3
6.0	4.5**	4.7**			
6.0***	4.3*	4.5*	4.4*	4.6*	
6.0***	4.6**	4.6**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 24

PER CENT TOTAL NITROGEN IN UTILITY GRADE BEEF

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	4.4*	4.4*	4.6	5.0	4.7
	4.2**	4.8**			
	4.6				
	4.3				
	4.8				
	4.9				
	4.6*				
	4.4**				
Mrads at +20°C					
3.0	4.5	4.6	4.9	4.9	4.7
3.0	4.9	4.9			
4.5	4.9	4.5	4.9	4.5	5.3
4.5	5.1	4.5			
6.0	4.4*	4.5*	4.7	4.8	5.0
6.0	4.7**	4.7**			
Mrads at -20°C					
3.0	5.2	5.0	4.9	4.9	5.1
3.0	4.9	4.8			
4.5	4.9	5.0	4.7	5.1	5.5
4.5	4.9	4.8			
6.0	4.9	5.0	4.6	5.1	4.9
6.0	4.5	5.2			
Mrads at -80°C					
3.0	4.8	5.0	4.8	5.0	5.0
3.0	4.9	5.0			
4.5	4.7	4.8	5.0	4.4	5.0
4.5	4.8	5.0			
6.0	5.0	4.9	5.0	4.5	4.8
6.0	5.0	4.7			
Mrads at -196°C					
3.0	4.8	4.8	5.0	4.6	5.1
3.0	4.6	4.0			
4.5	4.7	5.3	4.8	4.8	5.1
4.5	4.8	4.8			
6.0	4.3*	4.4*	5.0	5.4	5.2
6.0	4.6**	4.7**			
6.0***	4.3*	4.3*	4.6*	4.7*	
6.0***	4.7**	4.7**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 25

PER CENT MOISTURE IN CHOICE GRADE BEEF

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	60*	54*	62	57	60
	61**	58**			
	54				
	61				
	59				
	56				
	59*				
	60**				
Mrads at +20°C					
3.0	60	57	61	61	60
3.0	57	60			
4.5	57	59	57	61	61
4.5	55	57			
6.0	60*	60*	58	61	54
6.0	61**	61**			
Mrads at -20°C					
3.0	58	58	62	56	55
3.0	59	56			
4.5	61	58	57	60	59
4.5	56	60			
6.0	59	56	61	60	58
6.0	58	53			
Mrads at -80°C					
3.0	59	58	60	60	57
3.0	59	61			
4.5	59	56	56	62	59
4.5	52	59			
6.0	59	59	58	60	56
6.0	58	59			
Mrads at -196°C					
3.0	55	55	59	60	58
3.0	59	59			
4.5	61	62	56	61	60
4.5	59	58			
6.0	56*	59*	56	60	58
6.0	61**	60**			
6.0***	58*	60*	59*	61*	
6.0***	61**	61**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 26

PER CENT MOISTURE IN UTILITY GRADE BEEF

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	60*	61*	65	66	66
	63**	65**			
	64				
	66				
	60*				
	63**				
Mrads at +20°C					
3.0		64	64	66	64
3.0		65			
4.5		64	66	67	65
4.5		66			
6.0	62*	62*	66	67	64
6.0	65**	63**			
Mrads at -20°C					
3.0		64	65	66	65
3.0		65			
4.5		64	64	66	64
4.5		64			
6.0	65	62	65	66	65
6.0	67	65			
Mrads at -80°C					
3.0		69	66	66	65
3.0		67			
4.5		62	64	67	65
4.5		65			
6.0		64	65	65	66
6.0		66			
Mrads at -196°C					
3.0		66	64	66	65
3.0		64			
4.5		65	65	67	64
4.5		66			
6.0	63*	63*	66	66	64
6.0	64**	63**			
6.0***	61*	61*	62*	65*	
6.0***	64**	61**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 27

FREE MOISTURE IN CHOICE GRADE BEEF
(% of total moisture - avg. of 4 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	43*	40*	48	45	41
	42**	34**			
	39				
	40				
	44				
	38				
	53*				
	47**				
Mrads at +20°C					
3.0	41				
3.0	50				
4.5	31				
4.5	38				
6.0	39*	34*	46	42	40
6.0	33**	30**			
Mrads at -20°C					
3.0	39				
3.0	44				
4.5	49				
4.5	40				
6.0	48	32	51	42	32
6.0	38	30			
Mrads at -80°C					
3.0	35				
3.0	37				
4.5	37				
4.5	24				
6.0	31				
6.0	37				
Mrads at -196°C					
3.0	40				
3.0	31				
4.5	47				
4.5	35				
6.0	39*	35*	49	40	32
6.0	49**	36**			
6.0***	46*	38*	47*	45*	
6.0***	41**	35**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 28

FREE MOISTURE IN UTILITY GRADE BEEF
(% of total moisture - avg. of 4 determinations)

Irradiation	Storage Time in Months				
	0	3	9	15	24
None	54*	48*	44	48	54
	44**	41**			
	47				
	50				
	47*				
	45**				
Mrads at +20°C					
6.0	54*	47*	44	44	40
6.0	47**	35**			
Mrads at -20°C					
6.0	44	37	39	44	35
6.0	50	41			
Mrads at -196°C					
6.0	45*	43*	47	46	38
6.0	46**	38**			
6.0***	46*	48*	48*	41*	
6.0***	50**	30**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 29

LYSINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	15.6*	15.8	15.1	16.3
	16.3**			
	14.8			
	14.5*			
	15.2**			
Temp of Irrad °C				
+20	16.6*	14.4	15.0	14.1
+20	14.1**			
-20	14.9	14.9	14.4	16.0
-20	15.0			
-196	16.8*	15.3	15.6	15.1
-196	15.1**			
-196***	15.6*	15.4*	14.6*	
-196***	15.3**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 30

LYSINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	14.5*	14.8	14.9	15.9
	15.7**			
	14.3			
	15.1			
	15.0*			
	14.7**			
Temp of Irrad °C				
+20	14.0*	14.9	15.0	15.4
+20	15.3**			
-20	14.8	14.1	14.7	14.6
-20	14.9			
-196	15.6*	14.4	15.1	14.8
-196	15.9**			
-196***	15.0*	14.0*	15.0*	
-196***	15.0**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 31

HISTIDINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.3*	1.1	0.6	
	1.2**			
	1.6			
	0.8*			
	1.5**			
Temp of Irrad °C				
+20	1.2*	0.8	0.4	
+20	1.2**			
-20	1.0	0.8	0.5	0.8
-20	1.2			
-196	1.1*	1.0	0.6	0.4
-196	1.2**			
-196***	1.3*	0.9*	0.5	
-196***	1.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 32

HISTIDINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.6*	1.1	0.9	0.9
	1.6**			
	1.5			
	1.4			
	1.5*			
	1.5**			
Temp of Irrad °C				
+20	1.4*	1.0	0.9	0.8
+20	1.1**			
-20	1.3	0.7	0.9	0.7
-20	1.6			
-196	1.4*	1.2	0.9	0.6
-196	1.4**			
-196***	1.5*	1.1*	1.0*	
-196***	1.4**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 33

ASPARTIC ACID CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS

(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	11.5*	11.5	11.7	10.8
	11.7**			
	11.3			
	11.6*			
	11.3**			
Temp of Irrad °C				
+20	11.4*	10.6	11.4	11.4
+20	11.6**			
-20	11.7	11.2	11.1	11.6
-20	11.6			
-196	11.4*	12.0	11.7	10.8
-196	11.4**			
-196***	11.3*	11.2*	11.2*	
-196***	11.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 34

ASPARTIC ACID CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	10.6*	10.8	11.2	11.3
	11.2**			
	10.9			
	10.7			
	11.0*			
	10.9**			
Temp of Irrad °C				
+20	11.4*	10.8	11.1	11.6
+20	11.7**			
-20	11.1	11.2	10.8	10.8
-20	11.1			
-196	11.3*	10.8	11.1	10.5
-196	11.2**			
-196***	10.9*	11.1*	11.0*	
-196***	11.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 35

THREONINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	0.4*	0.7	0.4	0.3
	0.3**			
	0.2			
	0.3*			
	0.4**			
Temp of Irrad °C				
+20	0.4*	0.2	0.4	0.3
+20	0.2**			
-20	0.5	0.2	0.5	0.3
-20	0.5			
-196	0.4*	0.2	0.3	0.2
-196	0.5**			
-196***	0.4*	0.2*	0.4*	
-196***	0.6**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 36

THREONINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	0.3*	0.1	0.3	0.3
	0.3**			
	0.3			
	0.2			
	0.3*			
	0.2**			
Temp of Irrad °C				
+20	0.3*	0.2	0.1	0.2
+20	0.2**			
-20	0.3	0.2	0.2	0.3
-20	0.3			
-196	0.3*	0.2	0.3	0.2
-196	0.2**			
-196***	0.4*	0.3*	0.2*	
-196***	0.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 37

SERINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.4*	1.4	2.0	1.7
	1.6**			
	1.6			
	1.5*			
	2.3**			
Temp of Irrad °C				
+20	2.4*	1.4	2.0	1.8
+20	1.5**			
-20	2.2	1.4	2.1	1.7
-20	2.5			
-196	2.3*	1.5	2.0	1.8
-196	2.2**			
-196***	2.2*	1.4*	2.2*	
-196***	2.3**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 38

SERINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.3*	1.7	1.9	2.0
	2.1**			
	2.2			
	1.8			
	1.9*			
	1.6**			
Temp of Irrad °C				
+20	2.3*	1.8	1.8	1.9
+20	1.9**			
-20	2.3	1.6	1.8	2.0
-20	1.9			
-196	2.1*	1.7	1.7	1.6
-196	1.5**			
-196***	2.2*	1.8*	1.7*	
-196***	1.7**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 39

GLUTAMIC ACID CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	19.5*	10.2	18.0	18.2
	17.8**			
	19.2			
	18.8*			
	19.7**			
Temp of Irrad °C				
+20	18.3*	18.8	18.0	18.6
+20	18.3**			
-20	19.1	18.3	18.1	19.6
-20	19.9			
-196	19.0*	19.7	18.6	18.3
-196	19.1**			
-196***	19.2*	18.9*	17.8*	
-196***	20.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 40

GLUTAMIC ACID CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	19.5*	18.4	17.6	18.6
	19.7**			
	20.0			
	19.8			
	20.4*			
	19.3**			
Temp of Irrad °C				
+20	20.4*	18.7	17.0	18.9
+20	20.2**			
-20	19.8	18.9	18.4	19.0
-20	20.6			
-196	20.9*	18.7	18.5	19.2
-196	19.9**			
-196***	19.7*	19.0	18.3	
-196***	20.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 41

PROLINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	4.7*	4.5	4.3	4.5
	4.3**			
	5.0			
	5.2*			
	4.8**			
Temp of Irrad °C				
+20	4.8*	4.1	4.4	4.6
+20	4.5**			
-20	4.6	4.6	4.4	4.4
-20	4.0			
-196	4.9*	4.3	3.9	5.0
-196	4.3**			
-196***	4.8*	4.4*	4.2*	
-196***	4.4**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 42

PROLINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	5.1*	4.3	4.8	4.2
	4.3**			
	4.8			
	4.6			
	5.1*			
	4.7**			
Temp of Irrad °C				
+20	4.5*	4.4	4.4	4.1
+20	4.6**			
-20	4.6	4.4	4.7	5.1
-20	4.4			
-196	4.1*	4.6	4.5	4.9
-196	4.8**			
-196***	4.7*	4.8	4.5	
-196***	5.0**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 43

GLYCINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	9.4*	8.6	9.1	9.1
	9.7**			
	9.1			
	9.2*			
	8.7**			
Temp of Irrad °C				
+20	9.1*	8.4	9.0	9.1
+20	9.7**			
-20	9.4	8.3	9.4	9.0
-20	10.2			
-196	9.4*	8.3	9.1	9.0
-196	9.5**			
-196***	9.1*	8.3*	9.2*	
-196***	9.3**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 44

GLYCINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	9.1*	8.3	8.3	8.8
	8.6**			
	8.6			
	8.6			
	8.6*			
	8.7**			
Temp of Irrad °C				
+20	8.8*	8.3	8.8	8.5
+20	8.7**			
-20	8.4	8.7	8.9	9.0
-20	7.7			
-196	8.4*	8.6	8.1	8.6
-196	8.6**			
-196***	8.8*	8.8	8.7	
-196***	8.8**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 45

ALANINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	11.1*	10.7	10.9	10.7
	11.3**			
	11.7			
	11.8*			
	10.5**			
Temp of Irrad °C				
+20	11.0*	10.8	11.0	11.7
+20	11.0**			
-20	11.1	10.6	11.3	10.8
-20	11.4			
-196	11.1*	10.3	11.0	11.2
-196	10.7**			
-196***	10.9*	10.5*	11.3*	
-196***	10.6**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 46

ALANINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	10.3*	10.0	10.8	10.9
	10.4**			
	10.0			
	10.7			
	10.5*			
	10.8**			
Temp of Irrad °C				
+20	10.6*	10.4	10.8	10.8
+20	10.8**			
-20	10.6	10.9	10.8	10.8
-20	10.7			
-196	9.6*	10.5	10.5	11.1
-196	10.9**			
-196***	10.4*	10.4*	11.1*	
-196***	11.1**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 47

HALF CYSTINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.1*	1.4	0.9	0.9
	1.3**			
	0.9			
	1.3*			
	0.9**			
Temp of Irrad °C				
+20	1.2*	1.3	0.8	1.0
+20	1.3**			
-20	0.9	1.4	1.2	1.0
-20	1.6			
-196	0.7*	1.2	0.9	0.9
-196	1.6**			
-196***	1.2*	1.4*	1.0*	
-196***	1.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 48

HALF CYSTINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.3*	1.4	1.3	0.7
	1.2**			
	1.4			
	1.3			
	1.1*			
	1.5**			
Temp of Irrad °C				
+20	1.3*	1.6	1.5	1.0
+20	1.2**			
-20	1.2	1.6	1.7	1.0
-20	1.3			
-196	1.0*	1.6	1.6	1.1
-196	1.3**			
-196***	1.4*	1.4	1.2	
-196***	1.4**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 49

VALINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.6*	2.6	2.3	2.5
	2.1**			
	2.4			
	2.3*			
	2.2**			
Temp of Irrad °C				
+20	2.4*	2.7	2.3	2.6
+20	2.3**			
-20	2.2	2.6	2.5	2.4
-20	2.3			
-196	2.4*	2.3	2.4	2.6
-196	2.2**			
-196***	2.5*	2.7*	2.4*	
-196***	2.3**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 50

VALINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.8*	2.6	2.4	2.2
	2.6**			
	2.9			
	2.8			
	2.7*			
	3.0**			
Temp of Irrad °C				
+20	2.6*	2.6	2.4	2.4
+20	2.9**			
-20	2.7	2.6	2.5	2.4
-20	2.8			
-196	2.6*	2.7	2.5	2.5
-196	2.8**			
-196***	2.8*	2.6*	2.5*	
-196***	2.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 51

METHIONINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.8*	2.8	3.0	3.1
	2.7**			
	2.7			
	2.7*			
	2.8**			
Temp of Irrad °C				
+20	2.7*	3.2	2.9	3.2
+20	2.7**			
-20	2.8	3.2	2.8	2.8
-20	2.6			
-196	2.9*	3.0	3.1	3.0
-196	2.8**			
-196***	2.9*	3.0*	3.0*	
-196***	2.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 52

METHIONINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	2.8*	2.4	3.1	3.0
	2.9**			
	2.7			
	2.7			
	2.6*			
	2.9**			
Temp of Irrad °C				
+20	1.8*	3.4	2.9	3.0
+20	2.5**			
-20	2.4	3.0	3.2	3.3
-20	2.5			
-196	2.9*	3.1	3.1	3.2
-196	2.7**			
-196***	2.7*	2.9*	2.9*	
-196***	2.8**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 53

ISOLEUCINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	0.8*	0.8	0.8	0.9
	0.7**			
	0.8			
	1.0*			
	0.8**			
Temp of Irrad °C				
+20	0.9*	0.8	0.8	0.9
+20	0.9**			
-20	0.7	0.8	0.8	0.8
-20	0.7			
-196	0.8*	0.8	1.0	0.8
-196	0.8**			
-196***	0.9*	0.8*	0.8*	
-196***	0.8**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 54

ISOLEUCINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.1*	0.8	0.8	0.7
	0.9**			
	0.8			
	0.9			
	0.8*			
	1.1**			
Temp of Irrad °C				
+20	1.1*	0.9	0.9	0.9
+20	0.8**			
-20	0.9	0.8	0.9	0.9
-20	1.0			
-196	0.9*	0.9	0.7	0.9
-196	0.9**			
-196***	0.9*	0.9*	0.8*	
-196***	0.9**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 55

LEUCINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	8.7*	8.9	8.7	9.0
	8.0**			
	8.6			
	8.2*			
	8.7**			
Temp of Irrad °C				
+20	8.7*	9.0	9.0	8.8
+20	8.3**			
-20	8.6	8.7	8.5	8.3
-20	8.2			
-196	8.8*	8.3	8.7	8.7
-196	8.2**			
-196***	9.0*	8.2*	9.3*	
-196***	8.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 56

LEUCINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	9.2*	8.5	8.7	9.1
	9.0**			
	9.2			
	8.9			
	8.6*			
	9.2**			
Temp of Irrad °C				
+20	9.7*	8.8	9.0	8.7
+20	9.1**			
-20	8.8	8.9	8.8	8.8
-20	9.2			
-196	9.0*	8.8	8.8	8.5
-196	9.0**			
-196***	8.6*	8.8*	8.7*	
-196***	9.2**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 57

TYROSINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated		3.1	3.9	3.8
Temp of Irrad °C				
+20		4.0	3.8	4.1
-20		3.9	3.6	3.5
-196		3.5	3.8	4.2
-196***		3.8*	4.0	

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 58

TYROSINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated		3.9	4.0	3.8
Temp of Irrad °C				
+20		3.6	3.7	3.9
-20		3.9	4.0	3.8
-196		3.9	3.9	4.2
-196***		3.6*	3.9*	

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 59

PHENYLALANINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	4.0*	4.4	4.1	4.3
	3.7**			
	3.9			
	3.9*			
	4.0**			
Temp of Irrad °C				
+20	3.8*	4.4	4.0	4.2
+20	3.6**			
-20	4.2	4.2	4.1	3.8
-20	3.3			
-196	4.2*	3.6	3.6	4.5
-196	3.7**			
-196***	3.8*	4.0*	4.2*	
-196***	3.7**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 60

PHENYLALANINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	3.7*	4.1	3.9	4.0
	3.9**			
	3.9			
	4.1			
	3.8*			
	4.2**			
Temp of Irrad °C				
+20	3.8*	4.1	4.0	4.2
+20	4.0**			
-20	4.2	4.2	4.1	3.9
-20	4.1			
-196	3.9*	4.1	4.3	4.7
-196	4.1**			
-196***	4.0*	4.1	4.2	
-196***	3.8**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 61

ALLOISOLEUCINE CONTENT OF CHOICE GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	0.8*	1.3	1.1	1.2
	1.0**			
	1.2			
	1.0*			
	1.0**			
Temp of Irrad °C				
+20	1.1*	1.2	1.1	1.3
+20	1.1**			
-20	1.1	1.2	1.1	1.0
-20	0.9			
-196	1.2*	1.2	1.2	1.1
-196	1.0**			
-196***	1.2*	1.2*	1.1*	
-196***	1.1*			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

TABLE 62

ALLOISOLEUCINE CONTENT OF UTILITY GRADE BEEF IRRADIATED AT 6 MEGARADS
(% of total amino acids after hydrolysis)

	Months Stored			
	0	9	15	24
Non-Irradiated	1.4*	1.2	1.1	1.1
	1.3**			
	1.3			
	1.4			
	1.4*			
	1.6**			
Temp of Irrad °C				
+20	1.3*	1.2	1.1	1.1
+20	1.3**			
-20	1.2	1.2	1.2	1.2
-20	1.3			
-196	1.2*	1.2	1.1	1.2
-196	1.3**			
-196***	1.2*	1.2*	1.2*	
-196***	1.4**			

* Loin #1
** Loin #2
*** Held at -196°C for 96 hours after irradiation

SUMMARY

Beef steaks from two different grades of animal were irradiated at three different levels (3.0, 4.5 and 6.0 Mrad) and at four different temperatures (+20, -20, -80 and -196°C) and stored at 23°C for two years. Organoleptic, physical and chemical analyses were made at intervals. Multiple regression analysis was carried out on data from several variables. Irradiation flavor intensity, organoleptic tenderness, quantity of mercaptans, extractable non-protein nitrogen and soluble collagen were shown to be significantly affected at the 90% confidence level or better by animal grade, irradiation dosage, temperature or irradiation and storage time. The most significant factors in determining water binding capacity were found to be grade and time.

Although not analyzed statistically, the pH, moisture, free moisture, and nitrogen content were somewhat higher in the utility grade steaks than in the choice grade steaks. No obvious trends in the amount of 17 amino acids were noted.

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13. ABSTRACT

Irradiation flavor intensity, organoleptic tenderness, quantity of mercaptan, extractable non-protein nitrogen and soluble collagen were shown to be significantly affected at the 90% confidence level or better by animal grade, irradiation dosage, temperature of irradiation and storage time. Irradiation flavor intensity decreases substantially with decreasing temperatures. The water binding capacity was affected significantly by the animal grade and the storage time. The amount of 17 amino acids analyzed were not affected by the irradiation dose, irradiation temperature or the storage time.

The pH values, total moisture, free water and total nitrogen were slightly higher in the utility grade steaks than in the choice grade steaks.

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Irradiation	8					
Storage	8				6	
Beef	8,9		9		9	
Military rations	4					
Irradiated			0		0	
Testing	8					
Chemical analysis	8					
Physical properties	8					
Water-binding properties	8					
Quality					6	
Irradiation dosage					6	
Irradiation temperature					6	
Acceptability					7	
Irradiation flavor					3,7	
Tenderness					7	