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Final Report

HIGH RADIOPASTEURIZATION OF FOODS

Period September 21, 1956 to September 20, 1957

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QUARTERMASTER FOOD AND CONTAINER INSTITUTE
FOR THE ARMED FORCES, CHICAGO
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CONTRACT RESEARCH PROGRESS REPORT

QUARTERMASTER FOOD AND CONTAINER INSTITUTE
FOR THE ARMED FORCES, CHICAGO

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I. SUMMARY

This is the terminal report of research performed at the Fission Products Laboratory of The University of Michigan in the field of high radiopasteurization of foods and of investigations made with the cooperation of the Kelvinator Institute for Better Living of the Kelvinator Division of American Motors Corporation.

One of the ultimate technical objectives of research in the field of radiation preservation of food is the development of methods of sterilizing by irradiation to permit long-term storage of various food products of high quality. Unfortunately, various obstacles have limited success in reaching this goal. Many of the food items that would benefit most by the increased storage life, such as fresh meats and dairy products, are extremely susceptible to undesirable flavor change as a result of irradiation. Research has led to the dis-

covery of radiation-resistant microorganisms, which has necessitated the constant scaling up of the dose estimated necessary for radiation sterilization. These two major obstacles can be at least partly by-passed if food is radiation-processed without attempting to obtain sterilization. This has been found to be particularly true for refrigerated foods for which the shelf life may be increased several fold as a result of irradiation. Irradiation doses of about 1 megarep (0.93 megarads) will destroy all the microorganisms that might cause food poisoning except some of the more resistant spore formers, and these may be controlled by refrigeration. This dosage of radiation is also sufficient to destroy most vegetative food spoilage microorganisms, yeast, and mold.

Considerable difference in response of various foods to irradiation has been observed. One of the objectives of this research has been the investigation of various foods and food preparations to determine which foods and which combination of foods would be satisfactory products after receiving a radiation dose of 1 megarep (0.93 megarads). For example, certain food items such as cooked beef and cheese are very unsatisfactory when irradiated and tasted by themselves but produce satisfactory food products when irradiated after combination with other foods. Further study of some of these successful combinations may make it possible to separate food constituents which may be used to produce a larger variety of satisfactory food products. This in turn may lead to a more basic understanding of methods of preparing irradiated food products of high quality. It has also been observed that some of the products that are satisfactory after being given the 1-megarep dose of irradiation will also tolerate doses in the range considered for radiation sterilization. For example, a beef Chili Concarni has been found to be quite satisfactory after receiving a dose of 3 megarep (2.79 megarads). Thus, an indirect result of these studies will be an increase in the number of food items considered suitable for irradiation at the new radiation facility of the Quartermaster Corps.

During this year a new kitchen has been installed at the Fission Products Laboratory, with support from the Kelvinator Division of the American Motors Corporation and other industrial projects. This kitchen is particularly designed to accommodate both small batch and quantity irradiated food experiments and give greater validity to all experiments by permitting more exacting quality and quantity controls.

II. FRUITS

Definite and promising preservative effects of radiopasteurizing doses of gamma radiation have been demonstrated on some common fruit products. In many cases, the irradiated products have been highly satisfactory from the aesthetic and organoleptic points of view and have maintained this high degree of acceptability over extended periods of storage at 40°F. Similar nonirradiated control samples invariably deteriorated to less than acceptable quality in a much shortened storage period.

Radiation preservation of apples was first suggested by a local fruitgrower. Preliminary promising storage results were observed at doses as low as 50,000 rep (46,500 rads). A more extensive storage experiment is underway and is reported here.

Other local fruit products have been studied in a similar manner as they have become available. Care has been taken to acquire as good quality produce as could be obtained to minimize variations due to handling and storage.

Sterilizing levels of radiation have been shown[1] to result in unsatisfactory products, for the most part. The undesirable characteristics observed were an unappealing bleaching in color, and unappetizing softness of tissue, and a resulting exudation of fluid. The unpleasant flavor and odor characteristic of irradiated food were also almost invariably observed. Reduction of the irradiation treatment to one million rep (930,000 rads) or less, however, has been observed to minimize or eliminate these undesirable side effects.

APPLES

In the fall of 1955, Dr. Frederick Ludwig of Port Huron, Michigan, suggested an experiment utilizing gamma radiation as a means of preserving apples. He supplied the apples used in this work, culls that would not have been expected to keep for extended periods, even under the most favorable conditions. The varieties used were: Delicious, Golden Delicious, and Northern Spies. The radiation doses employed were 50,000, 100,000 and 200,000 rep (46,500, 93,000, 186,000 rads, respectively). The apples used for the major experiment had been held in cold storage from September to December 7. After irradiation at the Fission Products Laboratory they were returned to cold storage in Port Huron. Apples were individually packaged in polyethylene and sealed. One year from the harvest date, about half of the apples that had been irradiated at 50,000 and 100,000 rep were still crisp and juicy—in excellent condition (see Fig. 1). A slightly lower percentage of those apples irradiated at 200,000 rep were also in excellent condition. The spoilage of the remainder of the apples is reported to have been caused by rot and mold. All control apples had spoiled by the end of May.

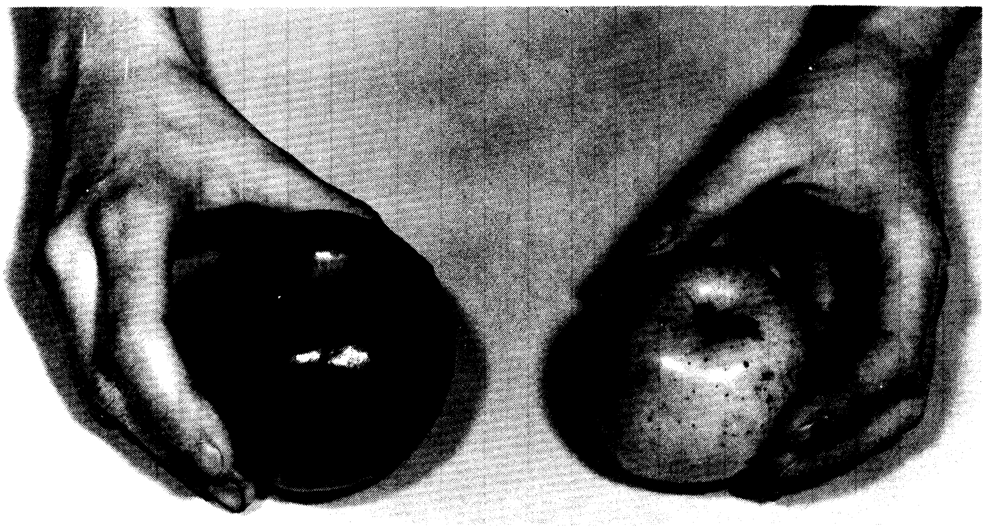

Fig. 1. Northern Spy (left) and Golden Delicious apples harvested in the fall of 1955, irradiated at 100,000 rep December 7, 1955, and photographed in January, 1957.

In a supplementary experiment wherein the apples were irradiated immediately after harvest prior to cold storage, the irradiated apples kept only slightly longer than the controls; however, only a few samples were employed in this experiment.

In the fall of 1956 the same varieties of apples were selected, Red Delicious, Golden Delicious, and Northern Spy, because they were used in the previous apple study and because of the susceptibility of these apple varieties to different physical disorders as listed in Table I.[2]

TABLE I

SUSCEPTIBILITY OF APPLE VARIETIES TO PHYSICAL DISORDERS

Variety	Water Core	Scald	Soft Scald	Bitter Pit	Miscellaneous
R. Delicious	Severe	Slight	None	Slight	Mealy breakdown
G. Delicious	Slight	Slight	Severe	None	Shriveling
Northern Spy	Slight	Slight	None	Severe	Spy spot, breakdown

The apples used in this experiment were of No. 1 quality, hand-picked and hand-graded with a known history. Because of the care taken in picking, grading, and handling these apples, it was expected that the control as well as the irradiated samples could be successfully stored for a greater length of time than is usual for these varieties of apples. This supposition has been proven correct. The normal cold storage season for Red Delicious and Golden Delicious apples varies from 90 to 120 days, with maximum storage at 180 days.[3]

The Red Delicious and Northern Spy apples selected for use in these experiments were grown by the Applecrest Farm at Northville, Michigan. They were brought down to storage temperature at the farm and then transferred to the University Food Service Storage where they were held for about three months at 35°F. Prior to irradiation these apples were packaged in perforated polyethylene squares and sealed with cellophane tape. All apples other than the control group received 100,000 rep (93,000 rads). The temperature in the radiation cave at the time of irradiation was 38°F. All apples were then returned to 35°F storage at University Food Service. There were no noticeable differences immediately after irradiation between the irradiated samples and the nonirradiated.

Seven months after harvest the first changes could be noticed in the Northern Spy apples. A total of eleven apples had spoiled. Fifty percent more Northern Spy control apples had spoiled than irradiated apples. Only one Delicious Apple had shown signs of deterioration at this time. This apple had been irradiated at 100,000 rep (93,000 rads) and had been bruised in handling. None of the control apples had deteriorated as yet. At the termination of this contract the apples used in these experiments are a year old. However, the results of the experiment are still inconclusive. The high quality of the fruit and the care taken in handling of the fruit is an important factor. Variety must also be considered as well as the time selected for irradiation after harvest.

Approximately 39% of the control Red Delicious apples have spoiled while only 17% of the irradiated apples of this variety have been lost. However, the results of the irradiation of Northern Spy apples were quite different after a year of storage. In this case 25% of the nonirradiated apples had rotted as well as 34% of the irradiated apples.

A second study was undertaken using Golden Delicious apples. These apples were purchased in October, packaged in tissue paper, and irradiated as soon as they were received with 25,000, 50,000 and 100,000 rep (23,250, 46,500, and 93,000 rads, respectively). They were then stored at 35°F at the University Food Service with the control apples.

After 4 months of storage, shriveling of the skin of the Golden Delicious apples was noted. Therefore, all apples, Red Delicious and Northern Spies as well as the Golden Delicious, were individually wrapped in perforated polyethylene squares and sealed with cellophane tape. This packaging procedure has reduced the loss of moisture and no further shriveling has been detected.

Of the three varieties of apples under study, the effect of irradiation is most noticeable when comparing irradiated and nonirradiated Golden Delicious apples (see Fig. 2). Prior to irradiation apples with stems were separated from

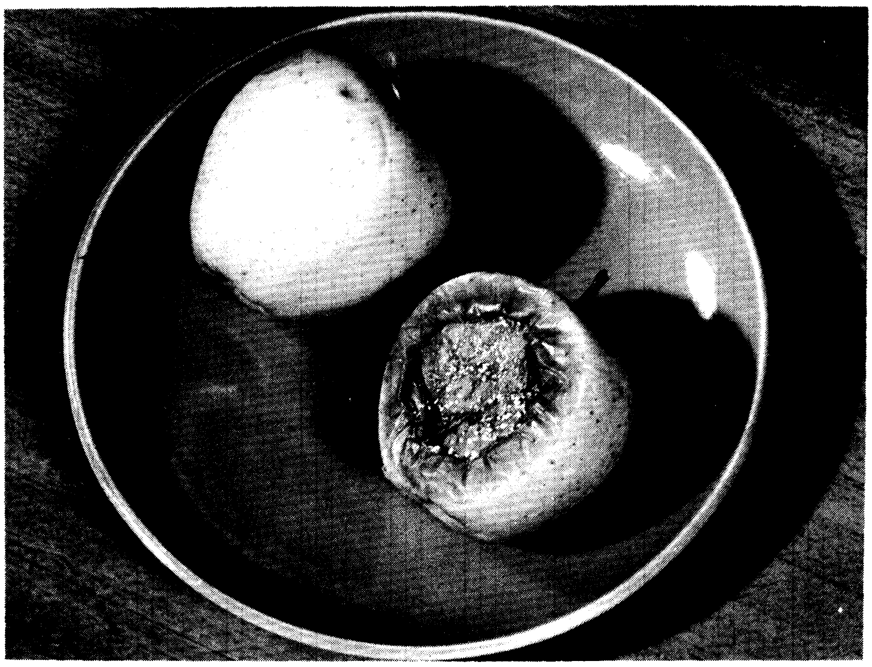

Fig. 2. Golden Delicious apple irradiated shortly after harvest at 100,000 rep shown with spoiled control apple seven months after harvest.

those apples without stems. Separate data have been maintained on each group. The most effective dose level for this variety appears to be 50,000 rep (46,500 rads). At this level of irradiation only 23% of those apples with stems and 15% without stems had spoiled after storage for one year. Fifty-one percent of the control apples with stems and 62% of the control apples without stems had spoiled during this period as listed in Table II.

The explanation for the greater success found in irradiation of Golden Delicious apples requires further study. These apples were irradiated earlier in their storage life than were the other varieties. These results are contrary to those reported by Dr. Ludwig in his first study, for he found those apples stored for several months before irradiation to keep for a much greater time than those irradiated shortly after harvest. The results found at 50,000 rep might also be attributed to variety or to other factors not yet explored.

The U. S. Department of Agriculture's Bureau of Agricultural Economics reports that prices based on the average mid-month price of Michigan apples (1937-52, excluding the war years of 1943-46) showed a net gain per crate of 33 cents above the price received for these apples in October.[4]

TABLE II

RESULTS OBTAINED WITH GOLDEN DELICIOUS APPLES
AFTER ONE YEAR'S STORAGE

Dose rep	% of apples spoiled (with stems)	% of apples spoiled (without stems)
0	51	62
25	41	21
50	23	15
100	41	21

Further investigation based on this figure into extending the storage life of apples by means of ionizing radiation is indicated. Although this project has terminated, data will be maintained on those apples in storage.

PEACHES

Three bushels of Elberta peaches were purchased from a local grower. These were sorted and the damaged peaches removed. One half of these whole and untreated peaches were irradiated to 50,000 rep (46,500 rads) and the remaining half were kept as controls. After irradiation the peaches were stored at 35°F at the University Food Service.

Little advantage could be found in irradiating this variety of peach at this level of irradiation. More samples would have to be employed to determine whether the seemingly slight increase in storage time to some of the irradiated peaches is significant.

Sliced H. J. Hale peaches were blanched by heating in a 50% brix syrup to which a small amount of ascorbic acid had been added. The peaches were packaged in polymylar envelopes and divided into five groups. One group was kept as a control while the others were irradiated at 250,000, 500,000, 750,000, and one million rep (232,000, 465,000 697,500, and 930,000 rads, respectively). All samples were stored at 40°F.

Immediately after irradiation the odor of the peaches was normal for cooked peaches, as was the flavor and coloring. There was no noticeable difference between the peaches irradiated at the various dose levels.

After 3 weeks of storage, 20% of the control samples had developed mold growth while the irradiated samples showed no signs of spoilage. After one month of storage, a slight fermented flavor was noticed in samples opened at each level of irradiation. The samples in the group irradiated to 250,000 and one million rep (232,000 and 930,000 rads, respectively) had a flat taste; the samples irradiated to 500,000 rep (465,000 rads) had slightly more flavor; and those at 750,000 rep (697,000 rads) were judged to have the best flavor of the four groups.

After 2 months of storage, the peaches irradiated at all levels were considered unacceptable because of a flat, fermented, and/or stale flavor.

RHUBARB

MacDonald Strawberry variety of rhubarb was purchased from a local grower, processed, packaged, and placed in the irradiation chamber within 5 hours of the time it was picked in the field. The rhubarb was cleaned and the stalks cut into inch-long pieces. It was combined with sugar at a ratio of 1-1/4 volumes of sugar to 8 volumes of rhubarb. No water was added. The product was cooked until it formed a sauce, but many pieces were still intact. Before irradiation the rhubarb sauce was a bright rose color, characteristic of the highest quality of this variety of rhubarb. The product was packaged in polymylar envelopes and irradiated at a rate of 153,000 rep (142,000 rads) per hour. After the samples had received approximately 300,000 rep (279,000 rads), they were examined for visible changes. The color, it was noted, had changed from bright rose to a muddy brown. At approximately 600,000 rep (557,000 rads) the samples were again examined. All samples this time were greenish brown. At the end of the total irradiation, 1×10^6 rep (930,000 rads) the color of the rhubarb was green with occasional fibers of pink. The color is typical of non-irradiated, cooked rhubarb of variety that has little red pigment. The consistency of the cauce when compared with the control was more liquid. The sauce was homogeneous; no whole pieces of rhubarb could be found.

The irradiated samples were stored with the control samples at 40°F. The first control sample had developed a growth of mold after 19 days of storage. The last control sample spoiled 12 days later. All irradiated samples were still in excellent condition.

After 4-1/2 months of storage, the flavor was very good and characteristic of freshly cooked rhubarb. Samples examined immediately after irradiation and on following examinations exhibited no off odor. No degrading of the product was apparent; however, the polymylar pouches had begun to delaminate.

PINEAPPLE

Cuban pineapples in good condition were cut into cubes after the rind was removed. One-half of the pineapple chunks was blanched, one-half was not. One-third of each of the above samples was kept as a control, one-third irradiated at 0.8 x 10^6 rep (744,000 rads), and one-third irradiated at 1.0 x 10^6 rep (930,000 rads). All samples were packaged in polymylar containers.

When tasted immediately after irradiation, and on subsequent flavor evaluations, the nonirradiated pineapple was invariably preferred. The pineapple was rated in order of acceptability: 1) unblanched controls; 2) blanched controls; 3) 0.8 x 10^6 rep (744,000 rads), unblanched; 4) 1 x 10^6 rep (930,000 rads), blanched. However, only the controls were considered acceptable. The unblanched samples which had received 0.8 and 1.0 million rep (0.744 and 0.93 x 10^6 rads, respectively) were described as having a sweet, sharp, bitter flavor as well as an off flavor not characteristic of pineapple. The off flavor was more pronounced in the samples which had received one million rep. The blanched product was described as flat with extreme off flavors. Storage did not improve the flavor of the irradiated products, nor did it change the order of preference.

After 2 months of storage the blanched and unblanched pineapple at both levels of irradiation were described as tasting flat with a sweet-sour flavor and a bitter after-taste. The texture of the unblanched pineapple had degraded until it could not be distinguished from the blanched product. At no time after irradiation could the blanched or unblanched pineapple be considered an acceptable product.

All the nonirradiated unblanched samples had spoiled after storage at 40°F for 8 days. The blanched controls lasted 4 days longer. At the same storage time the irradiated samples at both doses had not spoiled, but were definitely not a satisfactory product because of the off flavor observed.

CHERRIES

A quantity of locally grown Montmorency variety of cherries were purchased, and an experiment was undertaken using twelve different levels of radiation ranging from 25,000 rep (23,250 rads) to 1 megarep (930,000 rads). The cherries were purchased with stems intact. They were washed, and the damaged and overripe cherries were removed.

The irradiated samples were stored with the nonirradiated samples at 40°F. The first control samples spoiled in one week.

Of the various dose levels used, the samples irradiated to 250,000 rep (232,500 rads) had the least spoilage in the greatest number of days. At this level of irradiation 60% of the cherries lasted 26 days without discernible deterioration. Samples irradiated to doses lower than 250,000 rep (232,500 rads) lasted from 5 to 26 days. Most of the cherries spoiled in about two weeks. The samples irradiated at higher doses, 500,000 to 1,000,000 rep (465,000 to 930,000 rads), lasted from 2 to 2-1/2 weeks. Spoilage occurring between 5 and 21 days was attributed to mold and rot; spoilage after 21 days was attributed to fermentation.

III. VEGETABLES

Although several vegetable products have been reported to be acceptable organoleptically after receiving sterilizing doses of radiation, many other vegetable products have proven unsatisfactory.

A series of experiments has been undertaken, therefore, to investigate the possibility of extending storage life of some vegetable products at refrigeration temperatures. Radiation doses of 1×10^6 rep (930,000 rads) and less have been used in an effort to produce a significant preservative effect with minimal undesirable side effects.

The most promising of the products tested was beets, although an undesirable color change was observed.

ASPARAGUS

Martha Washington variety of asparagus was irradiated at two different dose levels, 8×10^5 rep (744,000 rads) and 1×10^6 rep (930,000 rads), and two different dosage rates, 153,000 rep/hr (142,000 rads/hr) and 80,000 rep/hr (74,500 rads/hr).

The treatment of the asparagus prior to irradiation was the same as in the asparagus packaging experiment. Polymylar envelopes were used for packaging. One group was irradiated to 1×10^6 rep (930,000 rads) and the other to 8×10^5 rep (744,000 rads). The samples were refrigerated with the controls at 40°F.

Group A - Dose: 1×10^6 rep (930,000 rads). Rate: 153,000 rep/hr (142,000 rads/hr) and 80,000 rep/hr (74,500 rads/hr).—After irradiation, the asparagus irradiated at the highest rate was slightly strong in flavor, the color was good, and the product was judged acceptable. Those packages irradiated at the lower dosage rate were judged unacceptable because they developed an extremely objectionable, strong flavor. After 3 weeks, mold was discovered on 17% of those samples irradiated at 153,000 rep/hr (142,000 rads/hr) and on 50% of the samples irradiated at 80,000 rep/hr (74,500 rads/hr).

After 6 weeks of storage, 16% of those samples irradiated at 153,000 rep/hr (142,000 rads/hr) and 17% of the samples irradiated at the lower dose rate were in good condition. After 7 weeks, all the irradiated samples showed breakdown and were discarded.

Group B - Dose: 8 x 10^5 rep (744,000 rads). Rate: 153,000 rep/hr (142,000 rads/hr) and 80,000 rep/hr (74,500 rads/hr).—After irradiation, the asparagus irradiated at the higher rate in this group was brighter green, more flavorful, and had less off flavor than the asparagus irradiated at the lower dose rate.

In 10 days mold was found on the spears in 22% of the packages irradiated at a rate of 80,000 rep/hr (74,500 rads/hr), and in 15 days mold was found on the spears on 50% of the packages irradiated at the higher rate.

Twenty-five percent of the samples irradiated at 153,000 rep/hr (142,000 rads/hr) and 11% of the samples at the lower dose rate lasted 5 weeks. All these samples were discarded at the end of 6 weeks.

GREEN BEANS

A variety of fresh green beans known as Tender Green, with a known history, were purchased from a local grower. These beans were washed, blanched in boiling salted water for 2-1/2 minutes, cooled, drained, packaged in polymylar, and irradiated to a dose of 1 x 10^6 rep (930,000 rads). After irradiation these samples were held at refrigerator temperature with the control samples.

When examined after irradiation, the color of the green beans had bleached to a dull olive. The flavor was sweet, grassy, and not characteristic of green beans.

After one month of storage at 40°F some of the green beans had bleached to light green and others to a cream color. Translucent liquid had developed, the odor was unpleasantly sweet, and the flavor was not characteristic of green beans.

This experiment was repeated using the same variety of green beans. The beans received the treatment outlined in the previous experiment. After 2 weeks the control samples were discarded because they developed milky liquid and gas. After irradiation the flavor and appearance of these beans were similar to those of the green beans in the previous experiment using this variety. After 16 days of storage, mold was discovered on the beans in 90% of the packages. The remaining 10% broke down when heated.

Kentucky Wonder variety of green beans was used for another experiment. These beans were blanched for 6 minutes in boiling salted water, quenched in cold water, drained, packaged in polymylar envelopes, and irradiated to one megarep (930,000 rads). The controls and the irradiated samples were stored at 40°F.

Immediately after irradiation many of the beans had bleached to light green, while others were a dull olive color.

After 4 weeks of storage, the control samples were mushy and gas had developed in some of the packages. The irradiated samples were still firm. The color ranged from dull light green to dull medium green. No difference in color could be observed when the control samples were compared with those that had been irradiated.

After 5 weeks of storage, breakdown of the outer layers of the beans had begun. There was no further change in the color. They were discarded after 2 months.

BEETS

In all the experiments, fresh beets of the Detroit Dark Red variety were used. These beets were cooked, skinned, sliced, packaged in polymylar envelopes, and irradiated to 1 x 10^6 rep (930,000 rads). These samples of beets were stored with the nonirradiated samples at 40°F.

In the first experiment the cooked beets were irradiated without further treatment. Within 18 days the nonirradiated samples showed mold growth and breakdown while the irradiated samples showed no sign of mold or other evidence of degrading (see Fig. 3).

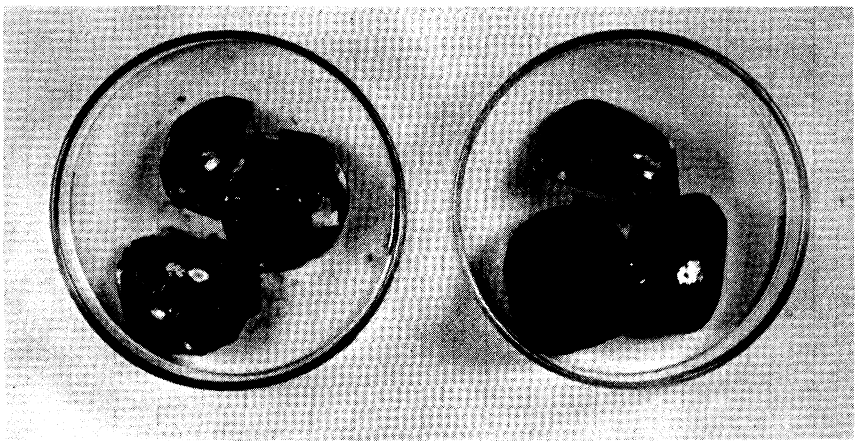

Fig. 3. Detroit Dark Red Beets, photographed after 33 days of storage. Left: control sample; right: sample irradiated to 1 megarep (930,000 rads).

Immediately after irradiation, these beets were considered less flavorful when compared with the controls, but 2 weeks later the freshly cooked beet flavor had returned to the irradiated samples.

After one month of storage at 40°F, the flavor of the beets was still fresh. However, they had lost their bright pigmentation and turned a dark maroon.

Various means were tried to develop a beet product that would prevent this darkening and retain its fresh appearance. Several Harvard Beet recipes were tried and the product irradiated to 1×10^6 rep (930,000 rads). The incorporation of a Harvard Beet sauce has helped the beets retain their original color. However, upon storage, the flavor of the vinegar from the sauce has penetrated into the beets and masked their flavor.

Those beets packaged without sauce retained excellent color and flavor for 4 months. During the fifth month of storage, the flavor became more sweet and flat than formerly and the outer layers of the beet had begun to slough off. The product could not now be considered salable. The polymylar packages started to delaminate at this period of storage.

BROCCOLI

A preliminary study of irradiated broccoli gave promising results; therefore, an intermediate experiment was performed to narrow the range of investigation by selecting the dosage and blanching time to be used for a future quantity storage experiment. The broccoli used in this experiment was locally grown and of excellent quality. It was processed within 16 hours after the time it was cut. Each group of broccoli, although processed on different days, was cut from the same field and held under the same conditions before and after treatment. Only one variety of broccoli was considered, Italian Green Sprouting. The two variables controlled in this study were blanching time and radiation dosage. Boiling, unsalted water was used for blanching. Group A was not blanched, Group B was blanched for 30 seconds, Group C for one minute, and Group D for 2 minutes. The preliminary study indicated that combining blanching time beyond 2 minutes with a pasteurizing dose of radiation yields a product that does not hold together. The dosages in all groups were 0, 0.5, 0.75, and 1 megarep (0, 0.465, 0.695, and 0.93 megarads, respectively). In each group 15 samples were packaged at each dosage range, making a total of 60 samples in each group.

The broccoli was washed and cut into uniform lengths of 3-1/2 inches. Those stems or flowers that appeared overly mature or undesirable for other reasons were discarded. The cut broccoli was placed in a wire blanching basket and immersed in rapidly boiling, unsalted water for the predetermined blanching time. After blanching, the basket of broccoli was immediately quenched in very cold water for approximately the same time used for blanching. When the temperature of the broccoli had been reduced to that of the water, it was removed and drained. Three spears of broccoli were packaged in each polymylar envelope, heat-sealed, and marked with the date of irradiation, the dosage, and group letter. After irradiation, the samples were stored at refrigeration temperature. Each sample was checked periodically to determine if any change in color, odor, flavor, texture, or general acceptability could be observed. The observations were made before and after cooking. The samples in each group, with blanching time constant but with dosage varying, were checked against each other and the control and rated accordingly. The possibility of using polyethylene bags as packaging material for broccoli was investigated, but it was found that the storage period of the product stored in polymylar was notably longer. Results of the intermediate broccoli experiment follow (also see Table III).

Group A (No Blanching).—The control samples were judged unacceptable after 7 days of storage. The samples of broccoli receiving 750,000 rep (695,000 rads) were stored for the longest period in this group (13 days) but were considered unacceptable at the sixteenth day. No mold could be detected on any sample.

Group B (30-Second Blanch).—The samples receiving 500,000 rep (465,000 rads) were considered good after 20 days of storage but unacceptable after 23 days. On the twenty-third day the nonirradiated sample was considered a fair product. After 35 days of storage, the controls were spoiled (exact date of spoilage was between 23 and 35 days) and 3 of the remaining 8 samples receiving 750,000 rep (695,000 rads) were spoiled; no mold was observed. The flavor of the unspoiled samples was considered good. All samples given one million rep (930,000 rads) dosage of radiation had spoiled.

Group C (One-Minute Blanch).—The nonirradiated samples were judged unacceptable after 13 days of storage. After this storage period the samples that received 500,000 rep (465,000 rads) were judged characteristic of broccoli; those receiving 750,000 rep (695,000 rads) were flat but had no off flavor. The samples that received one million rep (930,000 rads) had a strong taste with a definite off flavor. By the nineteenth day, all the 0.5 and 0.75 x 10^6 rep (0.475 x 10^6 and 0.695 x 10^6 rads, respectively) samples had spoiled; several showed mold growth. Two of the 14 samples at one megarep (0.93 megarads) showed breakdown but no mold growth. The unspoiled samples had a strong off flavor. The last of these samples had spoiled within 2 weeks.

Group D (2-Minute Blanch).—Nonirradiated samples were unacceptable after storage for 13 days. After this storage period 13 of 15 samples that had received 500,000 rep (465,000 rads) showed mold. At the end of this reporting period, the broccoli samples are 27 days old. The samples that received 750,000 rep (695,000 rads) are bright in color and taste slightly flat, but have no off flavor, show no mold, and no deterioration. The samples that received one million rep (930,000 rads) are more olive in color, limper in texture, and flatter in flavor than the 0.75 x 10^6 rep (0.695 x 10^6 rads) samples. An off flavor is quite evident but no spoilage is in evidence. The samples that received 750,000 rep (695,000 rads) are considered to be a good product.

TABLE III

INTERMEDIATE BROCCOLI EXPERIMENT

Group	Blanching Time(Sec)	Radiation Dosage (megarep)	(megarads)	No. of Samples	Percent of Acceptable Samples After Ten Weeks' Storage 1	2	3	4	5	6	7	8	9	10	Primary Reason for Unacceptable Rating
A	0	0	0	15	100	0	.	.	.	.	.	.	.	.	Flavor
A	0	0.50	0.465	15	100	0	.	.	.	.	.	.	.	.	Flavor
A	0	0.75	0.695	15	100	100	0	.	.	.	.	.	.	.	Flavor
A	0	1.0	0.930	15	100	0	.	.	.	.	.	.	.	.	Flavor
B	30	0	0	15	100	100	100	0	.	.	.	.	.	.	Disintegration
B	30	0.50	0.465	15	100	100	100	0	.	.	.	.	.	.	Disintegration
B	30	0.75	0.695	15	100	100	100	62.5	0	.	.	.	.	.	Disintegration
B	30	1.0	0.930	15	100	100	0	.	.	.	.	.	.	.	Disintegration, flavor
C	60	0	0	15	100	0	.	.	.	.	.	.	.	.	Disintegration
C	60	0.50	0.465	15	100	100	0	.	.	.	.	.	.	.	Disintegration, mold
C	60	0.75	0.695	15	100	100	0	.	.	.	.	.	.	.	Disintegration, mold
C	60	1.0	0.930	15	100	100	0	.	.	.	.	.	.	.	Flavor 86%, mold 14%
D	120	0	0	15	100	0	.	.	.	.	.	.	.	.	Disintegration
D	120	0.50	0.465	15	100	13.3	0	.	.	.	.	.	.	.	Mold
D	120	0.75	0.695	15	100	100	100	100	100	68	50	25	0	0	Mold
D	120	1.0	0.930	15	100	100	100	100	100	80	50	40	25	0	Mold

The broccoli blanched for 2 minutes and given 0.75 x 10^6 rep (0.695 x 10^6 rads) doses have been stored for a much longer period than any other group. The product receiving 0.75 x 10^6 rep (0.695 x 10^6 rads) is superior in color, flavor, and texture to that receiving a million rep (930,000 rads). When the blanching period was extended beyond 2 minutes and combined with an irradiation dosage of either 750,000 or a million rep (695,000 or 930,000 rads, respectively) the end product had an overcooked appearance and could not be heated for serving without breaking the product.

Results of this intermediate study indicate that the optimum duration of time for blanching broccoli which is to be irradiated is 2 minutes, and the optimum dosage is 750,000 rep (695,000 rads) (see Fig. 4 below).

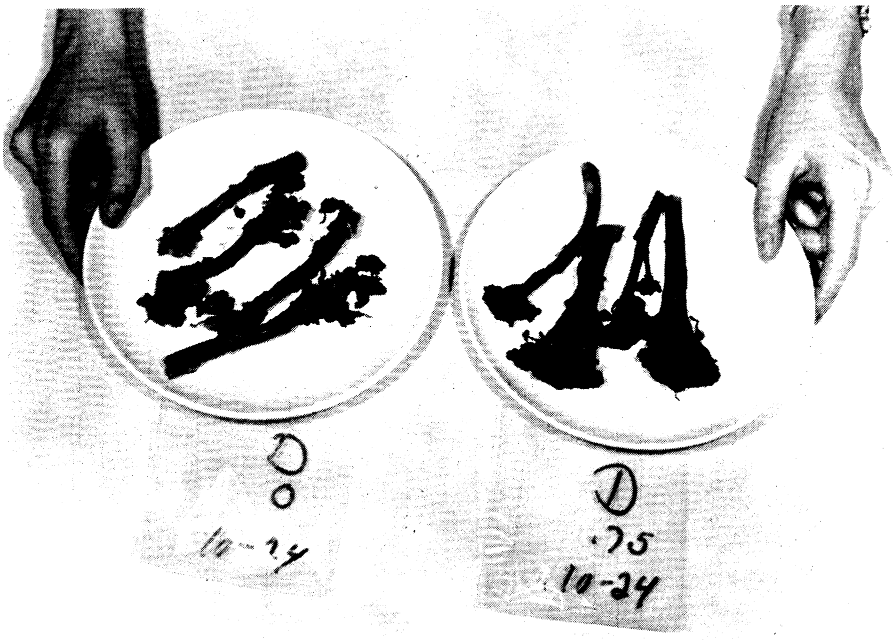

Fig. 4. Broccoli blanched 2 minutes, observed after 17 days of storage at refrigeration temperature. Left plate: not irradiated; disintegration and bleaching are evident. Right plate: broccoli that received 750,000 rep (695,000 rads) still in excellent condition.

BRUSSELS SPROUTS

Brussels sprouts were washed, trimmed, blanched in boiling water, chilled in cold water, drained, packaged in polymylar envelopes, and irradiated at 0.75 x 10^6 and 1 x 10^6 rep (695,000 and 930,000 rads, respectively). After irradiation the samples were held at 40°F. They were tasted immediately after irradiation and after a 2-week storage period. The product at both dosages had a strong acrid taste and was considered unacceptable.

Sample packages irradiated to one megarep (0.93 megarads) have been in storage for one year. The flavor of the brussels sprouts is strong and unappetizing. The color is olive with a grey cast and is similar to overcooked brussels sprouts. The odor of the product is acrid.

This experiment was repeated the following season with locally grown brussels sprouts with similar results. Immediately after irradiation to one megarep (0.93 megarads), the color of the brussels sprouts was bright green. The odor was strong and acrid. The flavor was sulfurous.

After 4 weeks of storage at 40°F, all control samples were judged unacceptable. The product was mushy and gas was evident in some packages.

The color of the irradiated brussels sprouts ranged from very light green to a darker, duller green after 2 months of storage. The flavor and odor had not noticably changed during this storage period.

PEAS

Fresh peas were irradiated at 0.75 and 1 x 10^6 rep (0.695 and 0.93 x 10^6 rads, respectively). One group of peas was blanched in boiling water for 1-1/2 minutes and a second group was blanched for 2-1/2 minutes. After blanching, the peas were chilled in cold water, drained, and packaged in polymylar envelopes. After irradiation, the samples were stored under refrigeration. The color of the irradiated samples could not be distinguished from the control. The peas were not graded and a difference in flavor was noticeable between the large peas, which were rather tough and starchy, and the small, tender peas. The flavor of the small peas seemed sweeter and more desirable than that of the control; after storage the larger peas developed a very slight off flavor.

Because the results of this preliminary experiment seemed promising, fresh peas, which had been flown in from California, were purchased on the Detroit market and used for a storage experiment ("A"). The peas were shelled, blanched in boiling water for 90 seconds, immediately chilled in cold water for about 3 minutes, drained, and packaged in polymylar envelopes. All samples other than the control were irradiated at one megarep (0.93 megarads). Between the shelling and blanching operations the product was held at refrigerator temperature. The temperature in the radiation cave during irradiation was 36-38°F. After irradiation the samples were stored at 40°F.

A second experiment ("B") was set up to duplicate the above pea-storage experiment (referred to here as "A"). The peas were purchased from the same source through the University Food Service. The peas were blanched in boiling water for 90 seconds, packaged in polymylar pouches, and irradiated at one million rep (0.93 million rads). All samples ("A" and "B") were stored together and have the same storage history except that batch "A" has been in storage a week longer than batch "B." Little is known of the histories of these two batches of peas prior to their arrival at the Laboratory.

At the end of 60 days, one-half of the 100 samples in batch "A" had spoiled. The peas broke down to a mushy consistency and mold developed in these packages. Group "B," prepared one week later (120 samples, 30 grams each), showed no degrading of any kind after 60 days of storage except a gradual bleaching from bright green to a less vibrant color.

After 4 months of storage, only 10 of the original 100 packages of peas (experiment "A") remain, and these could not be considered to be in good condition. While there is no evidence of mold, the peas appear mushy and have bleached to an ivory green color. No gas is evident in the bags. The peas in Pea Experiment "B" that were irradiated one week after those in Pea Experiment "A" are still firm after 4 months of storage. No samples have been lost and no degrading has been noted except bleaching which had continued to an olive green color.

After 7 months of storage, the peas in Experiment "A" had deteriorated further, having a strong odor and a flavor not characteristic of peas. Mold has been found on one of the remaining 9 packages.

None of the packages has spoiled in Experiment "B." As the experiment progressed, 10 samples were opened and examined, all the rest remain (110 samples). The smaller peas have bleached to an ivory-green while the larger peas have maintained an olive color. No mold has been found in any packages, and the peas are still firm. Small brown spots appeared on a few peas in 6 packages between the sixth and seventh months of storage. However, after 9 months of storage, the spots had not developed further and no new spots had appeared. About the seventh month of storage an off flavor developed in the peas and they became rather sweet.

All the remaining peas in Experiment "A" have become mushy and have been discarded. The peas in Experiment "B," which have shown no further change, remain in storage.

When peas became locally available, another experiment was started using Thomas Loitor's peas. These peas were fresh, young, and tender. The peas were shelled and divided into two groups. Each group was blanched in boiling salted water, one group for 1-1/2 minutes, the other for 2-1/2 minutes. Both groups were packaged in polymylar envelopes, irradiated to one million rep (930,000 rads) and refrigerated with the control at 40°F. Two and one-half weeks after irradiation, some of the peas had bleached to a light green. The peas blanched for a longer time retained their bright color longer. Those controls blanched 1-1/2 minutes had spoiled within 2-1/2 weeks. Of the controls blanched 2-1/2 minutes, 14% had spoiled at 2-1/2 weeks and a total of 72% had spoiled at 4 weeks.

After 4 weeks of storage, the irradiated peas were still firm, the color range was from light green to a darker bright green. There appeared to be no difference in the color of the peas or the number of samples spoiled after one month of storage due to blanching time.

After 3 months of storage, the color of the peas in each package ranges from ivory to bright green and olive. All colors appear in each package. A few packages have begun to delaminate. The flavor is unpleasantly sweet and not characteristic of peas.

CAULIFLOWER

Cauliflower heads were washed and cut into uniformly sized flowerettes. These were blanched in boiling water, chilled in cold water, drained, and packaged in polymylar envelopes. The samples received 0.75 x 10^6 and 1 x 10^6 rep (695,000 and 930,000 rads, respectively) and were held at refrigerator temperatures after irradiation. The color of the samples was good and the flavor of both the 0.75- and 1-megarep samples was considered within the range of acceptability, although the samples were rather flat in taste when compared with the control. If the product were well-seasoned and served with a suitable sauce, the end product might be desirable.

After 12 months of storage at 40°F, the cauliflower irradiated to one megarep (0.93 megarads) still has a good appearance although it has yellowed somewhat. The odor somewhat resembles pumpkin. The flavor is completely unacceptable.

IV. BAKED PRODUCTS

Premixed pastry products have been stored after irradiation to 1 megarep (0.93 megarads) for as long as 5 months with no loss of acceptability. A series of experiments was undertaken to evaluate the response of pastry made with three commercial cooking fats and oils.

Further studies were performed to determine whether irradiation should best occur before or after baking. Those products which were irradiated raw and baked after storage were clearly preferable to those baked prior to irradiation.

Two very satisfactory moist bread products have been developed. Such products might be expected to mold quickly if stored without irradiation, but have been stored satisfactorily at 40°F for as long as 6 months.

UNBAKED PASTRY SHELLS

A storage experiment was designed using the fat that gave the most satisfactory pastry in previous experiments (Fluffo). Three cups of sifted pastry flour were combined with one teaspoon of salt, one cup plus 2 tablespoons of Fluffo, and 9 tablespoons of cold water. The ingredients were combined by the standard method. The pastry was rolled out between lightly floured plastic sheets, cut into pieces, packaged in polymylar envelopes, and irradiated at one million rep (930,000 rads). These samples were stored with control samples at 40°F.

Storage data concerning these unbaked irradiated pastry shells are inconclusive. A preliminary experiment storage indicated that one hydrogenated fat, Fluffo (composed of vegetable and animal fats), could be stored for a greater length of time than another (all-vegetable) hydrogenated fat. The Crisco pastry "A" showed mold growth on all samples at 5 weeks, while the Fluffo pastry "B" was an excellent product at 2 months of storage.

However, in a second storage experiment using unbaked pastry shells prepared with shortening "B", 8% of the pastry samples supported green mold after 6 weeks of storage. After 2 months of storage, mold was found on a total of 14% of the samples. More mold gradually appeared on the samples until at 5-1/2 months 40% of the samples supported some mold growth.

After 3 months of storage, the texture of the pastry after baking was slightly chewy but the shell was still judged to be of very good quality. This quality was maintained through 5-1/2 months of storage. At 4-1/2 months of storage one polymylar envelope was delaminating and yellow-orange spots had appeared on many samples. At 5-1/2 months, the orange spots had appeared on most samples. This was not a mold growth, but appeared as if a yellow fat had been used in making the pastry and the mixture had not been homogeneous. Up to this time the texture of the raw product had always appeared normal. However, now a greasy, slightly rancid odor was noticed. The product appeared slightly carmelized after baking, and while the first flavor of the baked product was good, a biting after-taste could be noticed. After this date the product degraded rapidly and could no longer be considered satisfactory. Control samples had spoiled by the nineteenth day of storage.

Pastry prepared for another experiment using both of the above shortenings and a vegetable oil were stored for 10 months without any sign of mold or other visual evidence of degrading in any samples. The flavor of all samples after baking, however, was unacceptable at 10 months. All had a stale flavor and a biting aftertaste. The results are summarized in Table IV.

TABLE IV

FLAVOR ACCEPTABILITY OF IRRADIATED PASTRY

	Storage, months	Hydrogenated Fat "A"	Hydrogenated Fat "B"	Vegetable Oil
Product baked prior to irradiation	0	Poor	Poor	Fair - good
	5	Poor	Poor	---
	10	Poor	Poor	Poor
Product baked after irradiation + storage	0	Excellent	Excellent	Poor
	5		Excellent	
	10	Poor	Poor	Poor

BAKED PASTRY SHELLS

Pastry prepared according to the procedure described above was baked, packaged in polymylar envelopes, and irradiated to one megarep (0.93 megrads). The products were judged immediately after irradiation and after 10 months of storage and were considered unacceptable. The flavor was strong and biting and the odor was rancid. No sample had shown mold or other noticeable signs of deterioration during storage.

BREADS

The baked products that have been developed include a Banana Bread and an Apricot Bread. These two fruit breads have proved to be very satisfactory irradiated products.

Banana Bread.—The bread prepared according to the recipe given in Table V was packaged in polymylar envelopes and irradiated to 1×10^6 rep (930,000 rads), and stored with the nonirradiated samples at 40°F. This product, when tasted immediately after irradiation, was found to have very little banana flavor. However, after being stored at 40°F for several days, the banana flavor again developed.

The nonirradiated samples developed mold growth in 35 days. At the end of 4 months of storage the irradiated samples show no signs of mold or other

TABLE V

RECIPE FOR BANANA BREAD

3 ripe bananas	2 c flour
3/4 c sugar	1 t salt
2 eggs, beaten lightly	1 t soda

Mash bananas. Add eggs, sugar, and sifted flour with salt and soda. Mix. Place in greased pans. Bake 1 hr at 325°F.

evidence of degrading. The flavor is excellent, the bread is moist and has an even texture.

Apricot Bread.—Apricot bread was prepared from the recipe given in Table VI, packaged in polymylar envelopes, irradiated to 1 x 10^6 rep (930,000 rads), and stored with the nonirradiated samples at 40°F.

TABLE VI

RECIPE FOR APRICOT BREAD

1-1/2 c dried apricots	1 c whole wheat flour
1-1/2 c boiling water	1-1/2 c pastry flour
1 c sugar	1 t soda
1 t salt	1 t orange extract
1 egg, well beaten	

Chop apricots. Add water, sugar, and salt. Cool. Add orange extract. Add other ingredients (sifted flours and soda). Place in greased floured pans. Bake 1-1/2 hr at 350°F.

Immediately after irradiation and on subsequent organoleptic evaluations, the irradiated apricot bread was found to be free of any flavor change.

A quantity of this bread has been prepared, irradiated to one million rep (930,000 rads), and stored at 40°F. It was examined and tasted periodically for spoilage and flavor change.

After 4 months of storage there has been no change in the irradiated samples of bread. The flavor is excellent and the apricot flavor is easily distinguishable. The bread is moist and has an appetizing appearance (see Fig. 5).

Fig. 5. Apricot Bread irradiated to one megarep (0.93 megarads) shown after 3 months of storage, and apples after 11 months of storage.

SOFT MOLASSES COOKIES

A recipe was developed for a moist cake-like cookie that had a pleasant flavor, odor, and texture after irradiation at one million rep (930,000 rads). These cookies, packaged in polymylar envelopes, were stored for a year at 40°F. However, it was found that by decreasing the moisture level slightly, this product might be kept almost as long without irradiation when stored under the same conditions.

SANDWICHES

A preliminary inquiry was initiated in which sandwiches and their components were packaged and irradiated at 750,000 and one million rep (690,750 and 930,000 rads, respectively). A group of sandwiches made with rye bread with salami, boiled ham, sharp cheddar cheese or Swiss cheese as a filling were stored for a year at 40°F. Along with these, samples of the meats and cheeses were packaged separately. After one year of storage, the bread was slightly stale but had not lost a great deal more moisture than observed immediately after irradiation. The Swiss cheese and the ham sandwiches appeared quite dry; however, the ham and Swiss cheese packaged individually had retained a good color. The texture of the ham appeared normal while the Swiss cheese was rather oily. The flavor had not essentially changed during the year of storage. Flavorwise, the ham and salami were still acceptable. The flavor of the Swiss cheese, unacceptable when examined immediately after irradiation, seems to have improved somewhat. The cheddar cheese is still not acceptable.

The cheddar cheese and salami sandwiches were somewhat more successful in regard to normal color and texture retention. The separately packaged salami had an appearance very much like the salami in the sandwich. The cheddar cheese in the sandwich appeared more desirable than that in the individual package because of the oily appearance of the individually packaged cheese.

Several commercially available condiments usually used in sandwiches have received some investigation. These include mustard, ketchup, chili sauce, barbecue sauce, mayonnaise, salad dressing, and pickle relish. Of these, a mayonnaise-type salad dressing, a prepared mustard, and a pickle relish were selected in which a flavor change was not discernible at one megarep (0.93 megarads). In breads of full flavor, no irradiation off flavor could be detected; however, a drying effect after irradiation was evident in all samples.

Obtaining a good irradiated sandwich presents a complex problem, for a very slight irradiation flavor in one component of a sandwich might be readily acceptable when tasted alone, but the cumulative flavor produced when the several items composing the sandwich are combined, results in an end product that is quite unpalatable. Therefore the study was discontinued after this preliminary investigation except for storage of the samples for one year because it was felt that the investigation of the many variables of this problem were beyond the scope of this contract.

V. PRECOOKED PRODUCTS

A variety of precooked savory items has been developed which have no undesirable properties after irradiation. For the most part these items contain numerous flavorful ingredients. At this time the evidence is not clear as to whether a genuine protective effect is brought about by some of the ingredients or whether the generally strong flavor of the final product is sufficient to mask undesirable effects. There are some indications of a protective effect.

An outstanding example of such a successful product is the beef swirl. This item is concocted primarily of chopped beef and grated cheese, both of which exhibit strong undesirable flavor and odor upon irradiation alone. Other successful products include Chile Concarni, Shrimp Creole, Chicken Curry, and Hot Potato Salad.

The striking success of these precooked entrée items has made possible the development of several interesting and well-balanced irradiated meals. Figures

6 and 7 illustrate two of these irradiated meals. The meals shown are Beef Goulash with noodles, green beans, and asparagus salad; and Chicken Supreme with baked potato, peas, and salad, with baked apple for dessert.

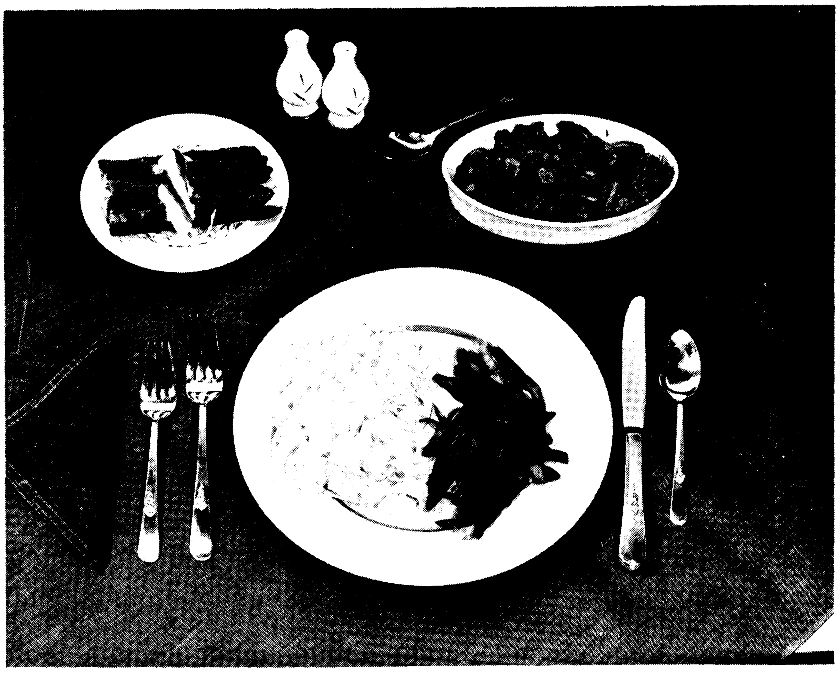

Fig. 6. Irradiated meal consisting of Goulash, green beans, and an asparagus salad.

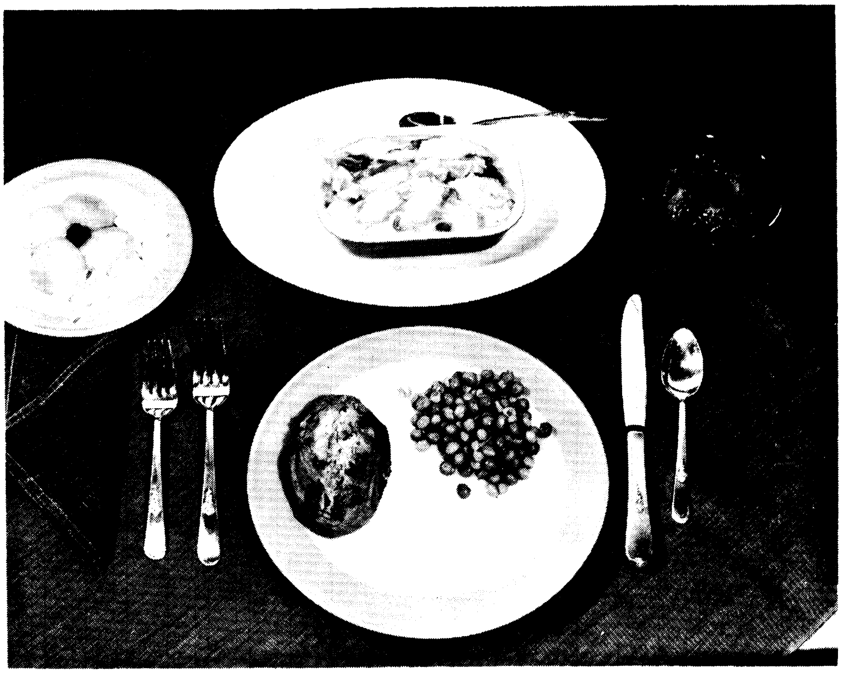

Fig. 7. Irradiated meal of Chicken Supreme, baked potato, garden peas, peach salad, and baked cinnamon apple.

BARBECUED PORK CHOPS

Barbecued Pork Chops were prepared in quantity according to the recipe given in Table VII to determine the shelf life of the product. All samples were sealed individually in polymylar envelopes. All irradiated samples received one million rep (930,000 rads); however, two dosage rates were employed. One set of samples received 35,000 rep (32,500 rads) per hour, the other, 153,000 rep (142,000 rads) per hour. They have been stored with control samples at 40°F.

TABLE VII

RECIPE FOR BARBECUED PORK CHOPS

8 pork chops, 3/4 inch thick	1/3 c bottled neat sauce
1/2 c minced onions	1 t dry mustard
3 tb hydrogenated fat	3 dashes Tabasco
1-1/2 c chili sauce	1 tb Worcestershire sauce
	1 t salt

Brown pork chops on both sides in fat trimmed from chops. Cook onions in fat until tender. Add remaining ingredients to cooked onions and mix well. Pour barbecue sauce over pork chops. Cover: simmer 1 hr or until tender. Remove cover and cool.

The pork chops have been observed for signs of bacterial decay and molding and evaluated periodically for product acceptability. After 2 months of storage at 40°F, all irradiated samples were still in good condition. The flavor was good, as was the color. However, the texture was somewhat less desirable than it was immediately after irradiation. The product seemed more dry. This dryness was first noted after 25 days of storage and was evident even after the pork chop was warmed in the barbecue sauce in which it had been stored. This difference is small when considering the total product.

Barbecued Pork Chops may still be considered a good product after 9 months of refrigerated storage. The only spoilage that has been observed was in those packages in which a bone had punctured the package. All control samples showed excessive moisture and had a decided spoiled odor at 13 days. Of the original 150 chops, all remain except those mentioned above or those removed for organoleptic examination. Except for dryness, those remaining are still good.

STEW

Many variations of recipes for Beef Stew have been tried. It is hoped that a formula can be devised so that the food components in the liquid protect the beef against developing a radiation flavor. Spices in varying amounts and combinations have been tried. An unpleasant flavor was observed when rosemary was used as a spice, even in small amounts. The "Beef" Stew judged to have the best flavor was made with 1/2 beef, 1/4 pork, and 1/4 veal. The only spices used were salt, pepper, and bay leaves. The vegetables were judged to be most acceptable when cut into large pieces and cooked slightly so that they were still somewhat crisp when packaged. The stew containing only carrots, potatoes, and onions as vegetables was liked best.

This stew has been stored at 40°F for 5-1/2 months. The pieces of vegetable and meat are still firm. Although the vegetables have become slightly flat, no off odor is exhibited. No off flavor can be detected in the meat, but it is rather tasteless. No signs of degradation are apparent. The stew is not as flavorful as might be desired.

GOULASH

As an outgrowth of the studies of a Beef Stew recipe that would withstand irradiation, a recipe for Hungarian Goulash was developed. The meat used is 1/2 beef, 1/4 pork, and 1/4 veal. Spices are salt, pepper, and paprika. Other ingredients are onions, garlic, tomato juice, and mushrooms. This is an excellent meat dish with no irradiation flavor at one million rep (930,000 rads). When all beef was substituted for the beef-pork-veal combination, no off flavor was detected in the mixture at one megarep (0.93 megarads); however, the flavor of the product made with three different meats was preferred. Control samples of this product spoiled after 20 days of storage. The irradiated product appeared unchanged in color, texture, and flavor after 3 months of storage at 40°F. Although this project had terminated, data will be maintained on this product.

CHILI CONCARNI

The recipe given in Table VIII for Chili is one of the most successful products developed during this project.

TABLE VIII

RECIPE FOR CHILI CONCARNI

1 lb ground beef	1-1/3 c tomatoes
2-1/2 c kidney beans	1 6-oz can tomato paste
1-1/4 c onions, minced	3 tb hydrogenated fat

Brown onions and meat in 3 tb fat. Add remaining ingredients and cook 10 minutes. Make a paste and blend in the following:

2 tb chili powder	3 tb water
1 tb flour	1 t salt

Cook over low heat 45 minutes, stirring frequently.

Chili has been prepared from the above recipe, packaged in polymylar and irradiated at one, two, three, and six million rep (0.93, 1.86, 2.79, and 5.58 million rads, respectively).

When irradiated to one million rep (930,000 rads) the Chili developed no irradiated flavor and was considered an excellent product. When given a dose of two million rep (1,860,000 rads), a slight bleaching of the product was evident, but no distinguishable difference was found in the flavor of the Chili. At three million rep (2,790,000 rads), there was still no evidence of an irradiated flavor, though the Chili was considered less flavorful than that irradiated to one and two million rep (0.93 and 1.86 million rads, respectively). However, a decidedly unpleasant irradiation flavor was present in the beef of the Chili irradiated to six million rep (5.58 million rads). The mixture was much more bland; the total product had bleached considerably.

SHRIMP CREOLE

A simple creole sauce has been developed (see Table IX) in which no flavor change can be detected at one million rep radiation dosage. This sauce, combined with short-grained rice which was cooked separately, makes an excellent Spanish rice. The mixture was packaged in polymylar envelopes and irradiated at 0.75 and 1×10^6 rep (0.698 and 0.98×10^6 rads, respectively). It was tasted immediately after irradiation and again after a storage period of 2 weeks under refrigeration. The product at both doses was judged very good when informally tasted, being free of radiation flavor change. After 12 months, samples are still in storage and are in good condition.

TABLE IX

RECIPE FOR CREOLE SAUCE

1/4 c finely chopped onion
2 c canned tomatoes
1 t salt
1/8 t pepper
1/2 t A-1 sauce
few drops Tabasco sauce

Blend all ingredients together and simmer for 15 minutes.

The recipe given in Table IX has been repeated with variations including the following recipe for Shrimp Creole.

Fresh frozen shrimp were cooked for 4 minutes in boiling, salted water and added to the above recipe for Spanish Rice. This product was packaged and irradiated at one million rep (930,000 rads). The resulting dish masks or inhibits the slight irradiation flavor found in shrimp irradiated without sauce at this dose.

In January of 1957, Shrimp Creole was prepared in quantity and has been in refrigerated storage for more than 9 months. During the storage period, the samples have gradually exhibited an increasing amount of almost clear liquid. However, when the product is heated, the liquid is absorbed and again becomes part of the mixture. Through 6 months of storage the flavor of the Creole gradually became somewhat more bland. However, after the sixth month the mixture began to take on the flavor of the shrimp and the entire product had a fishy odor and flavor after 9 months of storage. The grains of rice are less distinct, although the product is not soggy after it has been warmed through preparatory to eating. The shrimp appears whole and in good condition when viewed in the polymylar container; however, when touched with a fork, the shrimp falls apart and is reduced to a uniform mushy consistency.

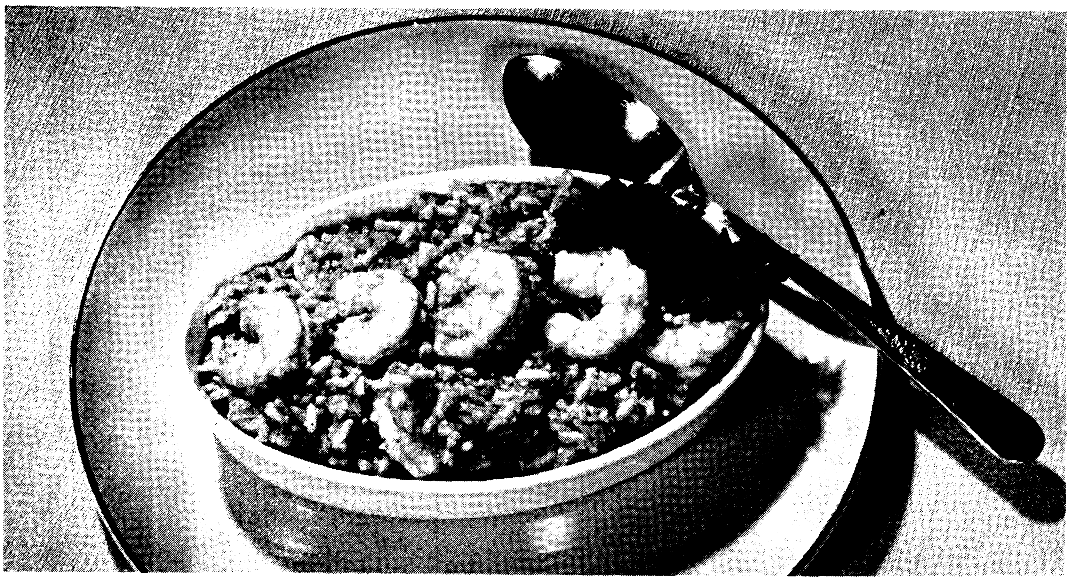

Fig. 8. Shrimp Creole irradiated at one megarep (0.93 megarads) and stored at 40°F shown after 4 months of storage.

RAW PORK CHOPS

Untreated, raw pork chops purchased from the University Food Service were packaged in polymylar envelopes and irradiated at one million rep (930,000 rads) without further treatment. The prok chops have been stored for 2 months at 40°F. The color of the pork chops immediately after irradiation was a vibrant pink. The irradiated pork chops have retained this color for 2 months at 40°F. A slight amount of drip is discernible. When the irradiated pork was compared with the nonirradiated samples immediately after irradiation, the irradiated pork exhibited a fresher appearance. The nonirradiated pork was greyer and darker than the pink irradiated pork. The control samples gradually turned more grey and lost all their pink cast. By the eleventh day, the control pork chops were slimy, showed some mold, and were judged to be spoiled. There has been little discernible change in the irradiated pork chops. At this time they are 6 months old, still bright and appearing fresh. Figure 9 shows irradiated and nonirradiated raw pork chops after 60 days of refrigerated storage.

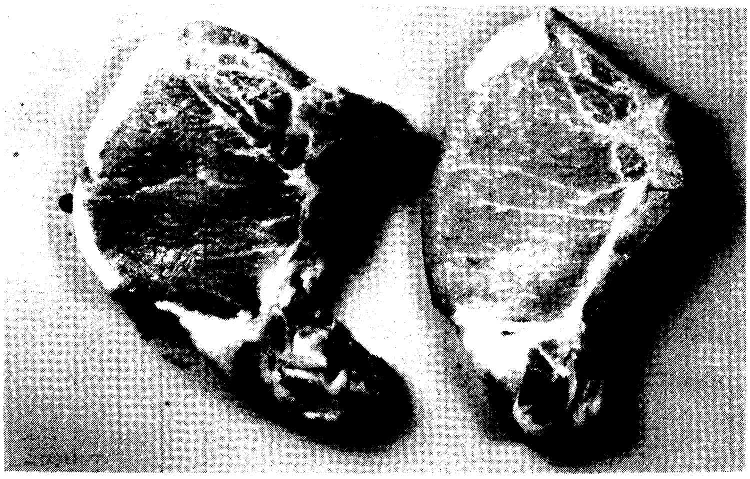

Fig. 9. Nonirradiated pork chop (left) with pork chop irradiated to 1 x 10^6 rep (930,000 rads)(right) after storage at 40°F for 60 days.

The flavor of the chop when broiled differs from a nonirradiated chop; however, this difference is not displeasing. The flavor and odor might be described as slightly smoky and rather like fresh ham. After broiling to the "well-done" stage, the center of the pork remained a decided pink color. The outside of the chop browned normally.

CHICKEN CURRY

The following recipe given in Table X was developed for Chicken Curry that has no flavor of irradiation after receiving one million rep. Storage at 40°F for 4 months did not markedly change this product.

TABLE X

RECIPE FOR CHICKEN CURRY

1 medium sized stewing chicken, cooked and diced	1/4 c chicken fat
1 c tomato juice	1/3 c flour
2 c chicken stock	1/2 t Worcestershire sauce
1/2 c chopped onion	Salt and pepper
1/2 c chopped celery	1-1/2 tb curry powder
	4 c cooked rice

Brown onion and celery in hot fat. Add the flour and blend. Add the stock and cook until thick. Add the tomato juice, Worcestershire sauce, seasonings, chicken, and rice. Package.

CITY CHICKEN

Another product that appears to withstand the effects of irradiation is City Chicken prepared according to the recipe given in Table XI. After irradiation this product had been stored for 8 months at 40°F. It is still an acceptable product although the flavor is somewhat more flat than when examined shortly after irradiation.

TABLE XI

RECIPE FOR CITY CHICKEN

	Gravy
1/4 c all-purpose flour	1/4 c melted fat
1 t salt	1 bay leaf, crushed celery tops
1/4 t pepper	1/2 c sliced onions
1/4 t thyme	2 c water
1/4 t sage	2 tb all-purpose flour
8 city chickens (veal and pork cubes threaded on wooden skewers)	1/3 c water
	1 t salt

Mix together 1/4 c flour, salt, pepper, thyme, and sage. Dredge meat in flour mixture. Brown meat in fat. Add bay leaf, celery tops, onions, and water. Cover and cook over low heat about 30 min. Remove meat. Blend flour with 1/3 c water. Pour flour paste gradually into water, stirring constantly. Cook until smooth and thickened. Cool. Package city chicken and gravy separately.

CHICKEN SUPREME

Chicken Supreme was prepared according to the recipe given in Table XII, the product packaged in polymylar envelopes, and irradiated to 1 x 10^6 rep (930,000 rads). The irradiated samples were refrigerated at 40°F with the control samples.

TABLE XII

RECIPE FOR CHICKEN SUPREME

2 c cooked chicken, cut up	2 tb flour (all purpose)
3 c chicken stock	1/3 c water
1 pt sliced mushrooms (sautéed)	1/4 t pepper
2 c cooked noodles	1 t salt
1/4 c sliced pimento	

Remove fat from the chicken stock. Sautee mushrooms in oil, and add along with other ingredients (pimento and noodles) to the chicken stock. Blend flour with water. Gradually add to mixture, stirring constantly. Season with salt and pepper. Cook until thickened.

When tasted immediately after irradiation the Chicken Supreme was judged to be an excellent product. Each ingredient was flavorful, the noodles were still intact, and the flavor of the chicken and mushrooms was excellent.

The first controls spoiled at 27 days; at that time the irradiated samples were still good. The irradiated samples continued to be flavorful with an attractive appearance and characteristic odor and were stored at 40°F. However, after 4 months of storage a rancid flavor could be detected in the product. As the meat used to prepare this dish for the storage experiment was from fat hens, it seems likely that, if lean meat were used, less rancidity might be detected after storage. No other evidence of degrading in the product could be noted.

BEEF SWIRLS

The Beef Swirls were prepared in quantity for a storage experiment following the recipe given in Table XIII. All irradiated samples and controls were sealed in polymylar envelopes. Group A received 1 x 10^6 rep (930,000 rads) at a rate of 153,000 rep/hour (142,000 rads/hr). Group B received 1 x 10^6 rep (930,000 rads) at a rate of 35,000 rep/hour (32,500 rads/hr). They were then stored with control samples at 40°F. A decided odor was detected in all control samples checked at the end of 16 days of storage at 40°F. All samples of control Beef Swirls were soft and some envelopes were very highly inflated. Although the samples were considered spoiled, those that were not gaseous were observed until the twenty-first day when all samples exhibited mold. All bags were very inflated. In previous experiments the control samples were considered to be spoiled at 10 days.

TABLE XIII

RECIPE FOR BEEF SWIRLS

2-1/2 c small bread cubes	2 t salt
2 c grated Cheddar cheese	1/4 t pepper
1 c chopped green pepper	1 can condensed tomato soup
1/2 c grated onions	1 egg, beaten
1 t Worcestershire sauce	2 lb ground beef

Combine bread cubes, cheese, green pepper, onions, Worcestershire sauce, salt and pepper, and 1/2 c tomato soup. Mix lightly, but thoroughly. Blend in 1/2 c tomato soup and egg with beef. Pat meat mixture out evenly into a rectangle 1/4 inch thick. Spread stuffing evenly over meat. Roll up as for a jelly roll and cut into 1-1/2-inch slices. Arrange in a shallow baking dish. Pour remaining tomato soup over meat slices. Bake at 325°F, 40-45 min. Cool before packaging.

The irradiated Beef Swirls were also observed for obvious signs of bacterial action or molding and evaluated for acceptability during the storage run. After 2-1/2 months of storage at 40°F, the irradiated Beef Swirls began to show the first signs of deterioration. No mold was found; however, the flavor changed gradually. This flavor was described as being more salty than formerly. Occasional samples exhibit a more intense flavor than the nonirradiated samples of the batch that has been stored in the frozen state. The total product was still described as "good."

Some samples showed a considerable amount of drip after 3 months of storage. The product was less firm than formerly. The flavor was still considered "good." The color of the tomato paste in some of the samples had bleached from bright tomato red to orange or a dull pink. Beef Swirls irradiated at a rate of 35,000 rep/hr (32,500 rads/hr) were compared with those irradiated at 153,000 rep/hr (142,000 rads/hr) after 3 months of storage. All samples showed an increase in the amount of drip. When the two groups were compared organoleptically, those samples irradiated at 35,000 rep/hr (32,500 rads/hr) were judged to have a slightly stronger flavor than any of those samples irradiated at the higher dose rate. No difference in color or odor was detected when comparing the two groups. No irradiated samples had spoiled after 3 months of storage.

After 4 months of storage, some of the packages of beef swirls developed a mushy consistency. The color of the tomato paste in some samples ranged from orange to dull pink. An occasional package had a slightly strong flavor, but generally the flavor was normal.

By the end of the fifth month of storage, gas was developing in some of the packages. In these packages the swirls were beginning to break down, considerable quantities of liquid was forming, and the flavor of those samples opened ranged from flat to strong. Few were characteristic of the product after 7 months of storage.

At this point in storage the tomato paste on the surface of the Beef Swirls had bleached, some samples to light pink or orange and some to grey. A great deal of drip was evident in all samples. The beef has been reduced to a mushy consistency. The odor was strong and unpleasant.

Although the recipe contains a high percentage of cheese, a flavor change could not be detected in the cheese, the beef, or the total product after receiving one million rep (930,000 rads). The dose was increased to two and three million rep (1,860,000 and 2,790,000 rads, respectively). At the highest dose some bleaching of the product was evident; however, no irradiation flavor could be detected by organoleptic examination.

When the cheese and the beef were irradiated separately, each developed a decided off odor and flavor at one million rep (930,000 rads).

Nine separate batches of beef swirls were then prepared. One batch was made exactly according to the recipe given in Table XIII; the other excluded one ingredient in each batch, i.e., bread cubes, cheese, green pepper, onions, Worcestershire sauce, all spices, tomato soup, and egg. All samples were packaged in polymylar bags and irradiated to one million rep (930,000 rads). These samples were examined organoleptically immediately after irradiation and again after a storage period. These informal taste tests indicated that the best product was the complete product; the worst was the batch from which the tomato soup had been omitted, which was the only product with an irradiation off flavor.

To determine whether the protective ingredient was contained in the soup mixture or in the tomato within the mixture, the product was made with tomatoes and tomato juice. Both products prepared with these ingredients were very satisfactory after irradiation.

Batches of Beef Swirls lacking one component were irradiated to 3 megarep (2,790,000 rads). The only batch at this level to exhibit unfavorable irradiation flavor change was the product lacking tomatoes. Much more work is indicated to try to determine which fraction of the tomato acts as a protective agent, if indeed it is a protector.

HOT POTATO SALAD

Potato Salad has been proven to be another satisfactory menu item. The potatoes used in the recipe were only partially cooked. Ingredients include bacon, onion, sugar, cider vinegar, wheat flour, salt, and pepper. No discoloration of the product, which had received one million rep (930,000 rads) could be perceived after storage for 4 months at 40°F. Sensory examination showed that the potatoes had become somewhat rubbery and grainy in texture after 4 months of storage. While the flavor was considered somewhat less desirable than a batch of freshly prepared nonirradiated potato salad, the potato salad was still considered a satisfactory product when served warm. Six months of storage showed no further change in the product.

VI. PACKAGING

The packaging material that has been used most often in experiments with cooked food preparations is a polyethylene-mylar laminated envelope. This material has been a very good container for this type of food up to about 4 months of storage at 40°F. Between 4 and 5 months after irradiation to about one megarep (0.93 megarads) delamination begins to occur. Often there is no indication of spoilage in the product (rhubarb, beets, unbaked pastry, shrimp creole, chicken curry, etc.) when this delamination takes place. Cooked foods packaged in polymylar invariably last longer than the same material packaged in polyethylene. However, polyethylene has proven to be the best material tested for packaging some types of irradiated raw produce. Three experiments were set up to determine the length of storage time for foods packaged in several materials.

ASPARAGUS

To determine whether a difference in an irradiated product might occur because of the packaging material used, Martha Washington variety of asparagus was packaged in three different kinds of packaging material: polyethylene, polymylar, and aluminum foil-mylar.

The asparagus was washed, trimmed, and the stalks sorted into small and large sizes. The small stalks were blanched in boiling salted water for 3 minutes, and the larger stalks were blanched for 4 minutes.

The asparagus was apportioned, packaged in the three above-mentioned packaging materials, irradiated to 1 x 10^6 rep (930,000 rads), and stored at 40°F with nonirradiated packages in each packaging material.

Immediately after irradiation there was no noticeable difference in the samples. The color of each sample appeared to be the same, bright dark olive. The odor was slightly acrid, the flavor was flat, and considered not acceptable.

A. Polyethylene.—After 10 days the controls had soured and disintegration had begun; these samples were discarded. The irradiated samples had developed a sweet taste. After 17 days all irradiated samples showed breakdown and excess liquid was found in the packages. These samples showed complete breakdown after 22 days.

B. Polymylar.—After 10 days the control sample packages showed milky liquid, and breakdown was just beginning. These controls developed mold growth in 17 days. After 10 days the flavor of the irradiated samples had not changed. They were still off flavor and slightly acrid. After 17 days the irradiated asparagus in polymylar envelopes was still firm; no mold was evidenced. These samples were discarded after 27 days because of breakdown. No mold had developed.

C. Aluminum Foil-Mylar.—After 10 days the control samples had a slight souring odor, disintegration was beginning, and the stems were slightly slimy. After 10 days the color of the irradiated samples were good, the flavor of the product had improved, and was judged acceptable and characteristic of asparagus. After 20 days these samples were still found to be acceptable, the stalks were still firm, and there was no breakdown. These samples lasted 36 days.

The asparagus packaged in aluminum foil-mylar was judged to have the best flavor of the samples in the three different packaging materials. The flavor of the irradiated samples packaged in polyethylene was preferred over that of the polymylar-packaged samples. There was little discernible difference in color between the polyethylene and polymylar samples; the aluminum foil-mylar samples appeared a more brilliant green. The aluminum foil-mylar samples lasted a week longer than the polymylar samples, and 2 weeks longer than the polyethylene samples.

SPINACH

American variety spinach was purchased locally and irradiated to one megarep (930,000 rads) and 0.1 megarep (93,000 rads). The spinach was washed and the damaged leaves were removed. The spinach was then packaged without further treatment. One-half of the spinach was packaged in polyethylene, and the other half was packaged in polymylar envelopes. These samples were irradiated to one megarep (930,000 rads) and to 0.1 megarep (93,000 rads) and refrigerated with the control samples at 40°F.

Polyethylene.—After 12 days of storage at 40°F, the control samples showed a slight amount of bleaching, and very slight rotting of the leaves. These controls were generally in good condition. The samples irradiated to 1×10^5 rep (93,000 rads) showed breakdown and slight bleaching, while all the samples receiving one million rep (930,000 rads) showed extreme breakdown and were discarded.

After 18 days of storage, the envelopes of the control samples contained a slight amount of brownish liquid and had an unpleasant odor. The samples receiving 1×10^5 rep (93,000 rads) exhibited more breakdown and had a strong off odor. After 25 days the controls and the irradiated samples were mushy and were discarded.

Polymylar.—At the end of 12 days of storage at 40°F, the control samples were in good condition. The leaves were crisp and the flavor was normal. The samples irradiated to 1×10^5 rep (93,000 rads) were wilted and were milder in flavor. Those samples that had received one million rep (930,000 rads) appeared almost as if cooked and had an off flavor. Two-thirds of the one million rep (930,000 rads) samples were discarded.

After 18 days of storage all control samples were judged to be spoiled. Sixty-six percent of the 1×10^5 rep (93,000 rads) samples had spoiled, and all the megarep (930,000 rads) samples were spoiled. After 25 days of storage all the 1×10^5 rep (93,000 rads) samples had spoiled.

During this storage period, the controls and samples receiving 1×10^5 rep (93,000 rads), packaged in polyethylene, retained a more appetizing appearance than the controls packaged in polymylar or any of the samples that had received 1×10^6 rep (930,000 rads).

The samples irradiated to 1×10^6 rep (930,000 rads) and packaged in polyethylene were all discarded after 12 days, while the samples receiving the same dose and packaged in polymylar were acceptable up to 18 days after irradiation.

For a second experiment, more spinach was purchased from the same source and given the same preliminary treatment as in the above experiment. In this experiment, however, the spinach was blanched 90 seconds in boiling water, and quenched in cold tap water. This spinach was packaged in polymylar envelopes, irradiated to 1×10^6 rep (930,000 rads), and kept with the controls at 40°F.

In this group the control samples were judged not acceptable after 12 days, due to off flavor. The samples irradiated to 1×10^6 rep (930,000 rads) were considered to be in good condition after 12 days. The leaves were distinct, the color was bright dark green, the flavor was sweet but still resembled spinach. A slight off flavor was beginning to develop.

At the end of 18 days of storage, there was a slight bleaching of the irradiated samples, the flavor was judged to be flat, unpleasant and not characteristic of cooked spinach.

After 33 days, the flavor of the irradiated samples was not improved. The samples were discarded because the polyethylene-mylar laminated bags had separated although no further change in the samples could be noted.

CHERRIES

Montmorency Cherries were packaged in envelopes of four materials: polyethylene, polyethylene-coated mylar, polyethylene-coated cellophane, and aluminum-foil-coated mylar.

After irradiation to one million rep (0.93 million rads) and storage at 40°F for 30 days, the samples were compared (see Figs. 10 and 11).

Polyethylene.—The cherries packaged in the polyethylene envelopes had progressed in their life cycle toward maturity. These cherries had ripened and the color was darker; most of the stems had fallen off. The flavor was sweet and characteristic of ripe cherries. The odor was normal.

Polyethylene-Coated Mylar.—Gas was present in all packages. The color of the cherries had changed little during the month's storage. The flavor was bitter and not characteristic of cherries.

Aluminum-Foil-Coated Mylar.—Some gas was present in all samples in which the seal had not broken. Most of the cherries were brown and fermenting. The flavor was flat and did not resemble cherries.

Polyethylene-Coated Cellophane.—Samples in this group had bleached to a lighter color. The flavor was strong and slightly bitter. The fruit was on the borderline of acceptability but did not approximate the quality of the cherries packaged in polyethylene.

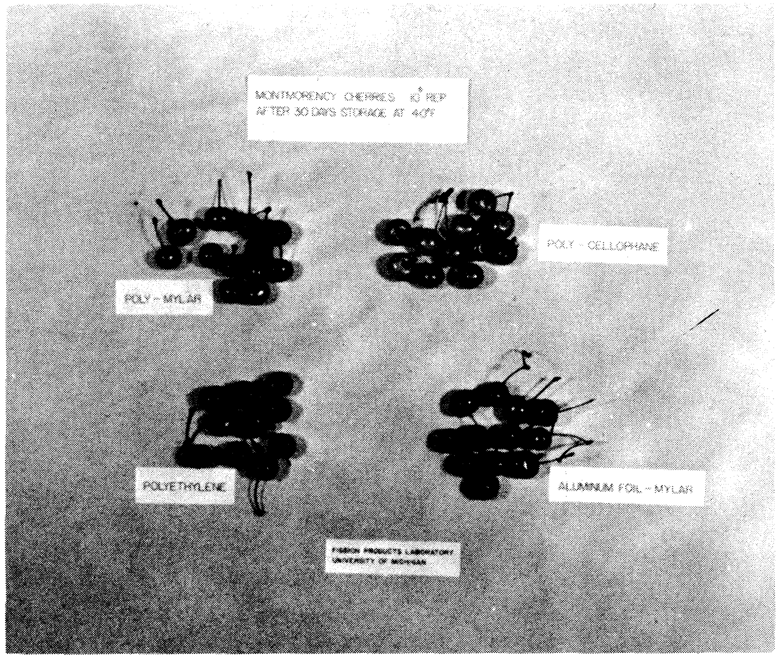

Fig. 10. Montmorency Cherries irradiated to one megarep (0.93 megarads) packaged in different packaging materials after 30 days at 40°F.

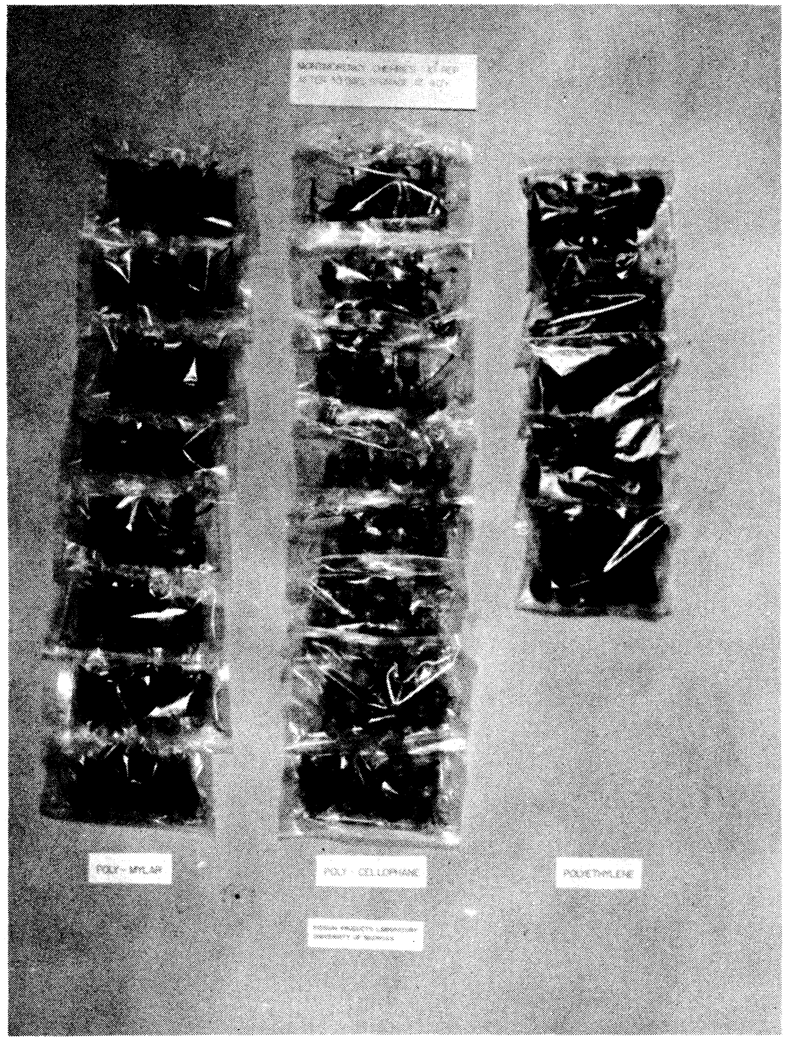

Fig. 11. Montmorency Cherries irradiated to one megarep (0.93 megarads) showing difference in color in cherries packaged in various packaging materials after 30 days at 40°F.

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