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LOW DOSE IRRADIATION AT NATICK

Irradiated Food Products Group
Radiation Preservation of Food Division

June 1977

UNITED STATES ARMY
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This report was presented at the FAO/IAEA Advisory Group Meeting on Low Dose Irradiation of Agricultural Products 27-31 October 1975, Rio de Janeiro, Brazil. It includes highlights of the Army's program for food irradiation at Natick using doses below 10 kGy. The program encompassed application to white potatoes for sprout inhibition during storage, to wheat flour for disinfestation of insects, and to chicken for radurization and radicidation.

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PREFACE

This report was presented at the FAO-IAEA Advisory Group Meeting on Low Dose Irradiation of Agricultural Products, 27-31 October 1975, Rio de Janeiro, Brazil. It includes results of low dose irradiation of white potatoes for sprout inhibition during storage, wheat flour for insect disinfestation, and chicken for radurization or radicidation.

The authors express appreciation to Dr. L.W. Smith, Jr. for the entomology aspects of insect disinfestation of flour, Mr. J. J. Killoran for the packaging of the flour and chicken, Mrs. L. J. Baker Rice for conducting the consumer and expert panel testing at Natick, Mrs. Miriam H. Thomas for the vitamin analysis data, Mrs. N.J. Kelley for the bread scores and baking tests, and Mr. R. Sidney Kahan for participating in the chicken studies.

These studies were undertaken as research projects by the Irradiated Food Products Group, Radiation Preservation of Food Division, Food Engineering Laboratory.

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LOW DOSE IRRADIATION AT NATICK

Introduction

The United States Army began its food irradiation program in 1953 at the Quartermaster Food and Container Institute for the Armed Forces (QMF&CI) in Chicago, Illinois. Between 1953 and 1961, the Army's program encompassed all aspects of food irradiation for civilians and the military. The Army's activities were part of the National Food Irradiation Program which was established under the President's "Atoms for Peace" program following President Eisenhower's address to the United Nations General Assembly in New York City in 1953.

In 1961 the Army was joined by the United States Atomic Energy Commission (AEC) in carrying out the National Food Irradiation Program. Since then, the Army has given primary emphasis to radappertization (doses above 10 kGy while the AEC was concerned with applications to food involving irradiation at doses below 10 kGy. When the Army and AEC were mutually interested in a specific application of ionizing radiation to food such as radurized and radicidized chicken, they undertook a cooperative effort.

The Army's food irradiation activities between 1953 and 1961 in exposing food to ionizing radiation at doses below 10 kGy have been summarized in two reports.[1,2] Among the food studied were meats (fresh and cured), poultry, marine products, white potatoes, onions, vegetables, fruits, cereals, and spices. The Army Medical Department conducted studies to prove wholesomeness of oranges, cabbage, wheat flour, and white potatoes.

[1] Low dose radiation monograph. QMF& CI Report No. 42-60. Quartermaster Food and Container Institute for the Armed Forces, U.S. Army, Chicago, Illinois. December 1960.

[2] Preservation of food by low-dose ionizing energy, U.S. Army Quartermaster Research and Engineering Command, Natick, Massachusetts, U.S. Army, January, 1961

In 1960, the Army decided to build a food irradiation laboratory at the Natick Research and Development Command, Natick, Massachusetts (referred to as "Natick" in this report). When construction was completed in 1962, the Army moved its food irradiation activities from the QMF&CI in Chicago to Natick.

This report covers some of the highlights of the Army's program for food irradiation at Natick using doses below 10 kGy. Details are reported in other publications.[3,4,5,6,7,8] The program encompassed applications to white potatoes for sprout inhibition during storage, to wheat flour for disinfestation of insects, and to chicken for radurization and radicidation.

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[3] Irradiation of white potatoes for sprout inhibition with Cobalt-60. The Army petition for clearance and approval to the Food and Drug Administration, U.S. Army Natick Laboratories, Natick, MA. 1963.

[4] Wadsworth, C. K. and E. Wierbicki. Production tests and evaluations of irradiated potatoes. Technical Report, U.S. Army Natick Research and Development Command, Natick, Massachusetts (in preparation).

[5] Wierbicki, E., F. Heiligman, J. J. Killoran, M. H. Thomas, N. J. Kelley, and L. W. Smith. Production tests and evaluations of irradiated wheat flour, Technical Report, U. S. Army Natick Research and Development Command, Natick, Massachusetts (in preparation)

[6] Previte, J. J., Y. Chang and H. M. El-Bisi, 1970. Effects of radiation pasteurization on Salmonella. I. Parameters affecting survival and recovery from chicken. Canadian J. Microbiol., 16: 465.

[7] Previte, J. J., Y. Chang, W. S. Scrutchfield, and H. M. El-Bisi, 1971. Effects of radiation pasteurization on Salmonella. II. Influence of repeated radiation-growth cycles on virulance and resistance to radiation and antibiotics. Canadian J. Microbiol., 17: 105

[8] Previte, J.J., Y. Chang and H. M. El Bisi, 1971. Effects of radiation pasteurization on Salmonella. III. Radiation lethality and frequency of mutation to antibiotics resistance. Canadian J. Microbiol., 17: 385.

White Potatoes

The QMF&CI and the Army Medical Department completed the technology and wholesomeness studies on white potatoes irradiated to inhibit sprouting during storage before the Army moved the food irradiation program to Natick. Those involved in the earlier work contributed to preparing a petition which Natick submitted to the U.S.Food and Drug Administration (FDA) for approval in 1963.[9] The FDA issued regulations approving the exposure of white potatoes to gamma radiation from cobalt-60, 50-100 Gy on June 30, 1964; from cesium-137, 50-100 Gy on October 2, 1964; and from cobalt-60 and cesium-137, 50-150 Gy on November 1, 1965.

Potatoes irradiated for sprout inhibition in the laboratory have consistently received excellent ratings by taste panelists and other consumers at Natick. The FDA approvals made it legally possible to attempt much more extensive processing, marketing, economic, and consumer evaluations of potatoes irradiated on a semi-commercial scale.

Two production tests of potatoes irradiated on a semi-commercial scale were conducted by the Armed Forces.[10] The potatoes for the first test were from the 1966 crop and for the second from the 1968 crop. The variety of potatoes in both instances was Idaho Russet Burbank.

The test on the 1966 crop comprised approximately 160,000 kg. The potatoes were sorted to meet U.S. No. 1 grade and packed in 22.7 kg cartons. Irradiation was carried out by the Nuclear Materials and Equipment Corporation using gamma rays from Coablt-60. The irradiation dose was in range of 50 to 150 Gy. Storage was carried out Rogers Bros. Co. Inc. in Idaho Falls, Idaho, in 22.7-kg cartons at 10°C and 90% RH.

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[9] See footnote 3.

[10] See footnote 4.

Shipments were made monthly, in some cases bimonthly to four widely separated military bases over the period January to October 1967.

Prior to shipment, samples were graded by a United States Department of Agriculture (USDA) inspector. The USDA inspector found that all except one shipment, which had to be resorted, met grade requirements. Rogers Brothers Co., Inc. also examined the potatoes after boiling, baking or french-frying. These examinations of boiled, baked and french-fried samples from 17 shipments over 9 months from January 1967 to October 1967 showed all samples to be good, very good, or excellent. Sugar content decreased gradually from about 5% in January to 1% to 2% during June to September 1967.

The potatoes were again examined on receipt at the military bases, and consumer preference ratings by the military personnel on a scale of 9 to 1 (9 = like extremely, 1 = dislike extremely) were obtained when the potatoes were served.

In March 1967 some slight sprouting was visible. These sprouts were not observed in later shipments. Mold growth was observed and attributed to storage at high humidity in cartons which prevented sufficient air circulation. This condition was corrected by reducing slightly the humidity in the storage area.

There were no particular problems with shipping, and all potatoes were received at the bases in good condition. Consumer preference test scores representing 4 to 7 shipments at each base and about 10,000 responses are summarized in Table 1. These scores are in the same zone as those obtained from military consumers in other tests with nonirradiated potatoes obtained from normal supply channels. It was concluded that irradiation of potatoes from the 1966 crop for sprout inhibition under the conditions of this experiment was successful.

The test with the 1968 crop involved approximately 60,000 kg of field run potatoes. These were rough sorted to 90 to 95 percent grade U.S. No. 1. One-half was irradiated and one-half was treated with the chemical sprout inhibitor, 3-chloroisopropylphenylcarbamate (CIPC), in a manner similar to that used in commercial practice. Harvesting, treating, and storing were conducted by the Idaho Agriculture Experiment Station at Aberdeen, Idaho. In January 1969 irradiation was done by the AEC using gamma rays from its mobile cobalt-60 source. The irradiation dose range was also 50 to 150 Gy. Storage was carried out in bulk by the Idaho Agriculture Experiment Station at 7.2°C, 95% RH and air flow of 0.0135 m^3/45 kg/minute.

After irradiation in January 1969, the potatoes were left in storage with only occasional product checks. On June 16, 1969, the potatoes were sent out to a nearby warehouse for commercial grading and packing and returned on June 18, 1969, to the experiment station. The U.S. No. 1 Grade potatoes were packed in 22.7-kg crates for shipment to the military bases. The U.S. No. 2 Grade potatoes and the culls were, for purpose of this test, considered as storage losses. Grading data are summarized in Table 2.

The chemically treated potatoes showed occasional small sprouts, the irradiated none. Cooking tests, as french fried, showed the irradiated potatoes to be slightly better (lighter in color) but both were quite satisfactory.

Shipment to the military bases had to be delayed until July 18, 1969. In preparation for shipment the U.S. No. 1 potatoes were re-sorted by hand. The results are shown in Table 3.

The total losses resulting from the two sortings of potatoes from the 1968 crop were 61 percent for the irradiated (5,909 kg shipped out of total 15,127 kg irradiated) and 49 percent for the chemically treated (8,386 kg shipped out of total 16,391 kg).

Shipments were made to Ft. Lewis, Washington, and Anderson Air Force Base, Guam. There were no shipping problems; all potatoes were received in good condition. The potatoes were eaten in late July and early August 1969. Consumer ratings showing a preference for the irradiated potatoes are shown in Table 4.

It is concluded that irradiation of potatoes is an effective procedure for preventing sprouting during controlled temperature and humidity storage of potatoes. Under the conditions of bulk storage of the crop harvested in 1968 and tested in 1969, high losses were experienced during sorting and packing and subsequent in-carton storage, with irradiated potatoes showing higher losses than chemically treated potatoes.

Wheat and Wheat Flour

The QMF&CI and the Army Medical Department completed the technology and wholesomeness studies on wheat flour irradiated for disinfestation of insects before the Army moved the food irradiation program to Natick. The data derived from these studies were used by Brownell *et al.* in their petition to FDA in 1962 to approve "The use of gamma radiation to process wheat and wheat products for the control of insect infestation."[11] FDA issued regulations approving 200 to 500 Gy exposure of wheat and wheat products (a) to gamma radiation from cobalt-60 on August 21, 1963 and from cesium-137 on October 2, 1964 and (b) to electrons (5 to MeV maximum energy) on February 26, 1966. On March 4, 1966, FDA changed the approval from "wheat and wheat products" to "wheat and wheat flour." On July 19, 1967, FDA approved Natick's petition to use kraft paper as a contactant packaging material for flour subsequently exposed to 200 to 500 Gy ionizing radiation.

Exposure in the laboratory of wheat flour to irradiation has been a highly effective method for disinfestation of insects. Rolls, bread, cakes, and cookies made with this irradiated flour have consistently received excellent ratings by taste panelists and other consumers at Natick. The FDA approvals made it legally possible to attempt much more extensive evaluations of wheat flour irradiated on a semi-commercial scale. The objectives were to demonstrate the industrial capability to product the irradiated flour within the constraints of the regulation issued by FDA, to establish whether flour disinfested by ionizing radiation could be used *in lieu* of the regularly procured flour based on the quality of the baked items, and to determine the attitudes of consumers toward foods preserved by ionizing radiation.

Two lots, approximately 60,000 kg each, of bleached, enriched, hard-wheat flour were procured from three different industrial sources for evaluation by the Armed Forces.[12] One lot, which was procured in 1967, was

[11]Brownell, L. E., T. Horne and W. J. Kretlow. Petition for the use of Gamma irradiation to process wheat and wheat products for the control of insect infestation. Submitted to the Food and Drug Administration, Department of Health, Education and Welfare. The University of Michigan, Ann Arbor, Michigan. July 1962

[12]See footnote 5.

packed in 15.9-kg square-shaped metal cans (Production IA and IB), and the other procured in 1969, in 22.7 kg multiwall kraft paper bags (Production II) (Table 5). Both lots of the packaged flour were irradiated with a dose of 300 to 500 Gy for disinfestation of insects using three different cobalt-60 sources (Table 6). The dose range of 300 to 500 Gy instead of 200 to 500 Gy allowed by the FDA was used to see whether the highest dose range attainable in the irradiation facilities used would be detrimental to the quality of the baked products made from the flour.

After irradiation, the flour was shipped to various military installations for storage under conditions favorable for growth and reproduction of insects and for evaluation. The military installations of the Army, Air Force, Navy and Marine Corps and one USDA laboratory participated in the tests (Table 7).

After 4 to 12 months of storage, the flour was evaluated for the absence of insect infestation and for the quality of the bakery products made from the flour, mainly bread and hot and sweet rolls (Tables 8, 9).

The overall results showed that there were no live insects in the irradiated flour, (except in one instance when the integrity of the primary container was violated); that the overall quality of bread and other baked items was not adversely affected by using irradiated flour; and that there was a slight, but not a statistically significant, change in acceptance of bread and other baked products when the consumers were aware that irradiated flour was used. Based upon experience from other military consumer tests, the acceptance hedonic ratings of the items baked with irradiated flour were approximately the same as those of baked items made from good quality nonirradiated flour obtained from regular supply channels. It was concluded that the use of irradiated flour is feasible where insect infested flour is a problem.

Small amounts (1000 to 2000 kg) of the two lots of flour were shipped as experimental lots to Natick for a long-term storage study at 21°C.[13] The experimental lots represented both nonirradiated control flour and the flour irradiated (300 to 500 Gy) for disinfestation of insects. Packaging for the nonirradiated control flour from each of the two lots was similar to the irradiated flour. One difference did exist in the packaging of the flour in bags; both the irradiated and control flour for Natick were packaged in 4.54-kg kraft paper pockets with 5 of these pockets packed in a 22.7-kg multiwall paper bag.

The flour packed in cans was received at Natick 3 months after irradiation; the flour packed in bags, 1 month after irradiation. Upon arrival, the flour was inspected by military veterinarians, the cans and bags were assigned random numbers for sequence of evaluation.

Factors investigated included insect infestation, retention of vitamins (thiamine, riboflavin, pyridoxine and niacin), chemical characteristics (diastase activity, titratable acidity, pH, ash, protein, and moisture content), dough and baking characteristics (bread scores, rheological and alpha-amylase activity), and acceptance of bread and other baked products (hot rolls and pie crust) made from the flour.

The flour in cans was evaluated shortly after arrival at Natick and after 3-, 6-, 12-, 27- and 48-month storage. The flour packed in bags was evaluated shortly after arrival and after 4-, 9-, 16-, and 25-month storage.

No insects were found in any samples during the entire study. Neither the irradiation treatment nor storage had any significant effect on the vitamin content in the irradiated flour or in the bread made from the

[13] See footnote 5

flour (Tables 10,11). Farinographs, dough characteristics, and bread scores (Table 12) were similar for the products made from irradiated and control flour. The irradiation had no effect on the pH, although time in storage caused a slight decrease (Table 13). There appeared to be a change in the titratable acidity in the 27-month withdrawal in the flour packed in cans; however, this change was not noted in the 52-and 72-month withdrawals. Irradiation had no effect on the diastase activity of the flour; however, storage caused a reduction in diastase activity (Table 14). There were no differences in the acceptance scores of bread and other baked products made from irradiated and nonirradiated flour. Time in storage caused a slight decrease in the acceptance scores of bread, but not rolls, made from both the irradiated and control flour (Table 15).

It was concluded that irradiation of wheat flour is an effective process for disinfestation of insects. The process did not adversely affect the quality or acceptability of baked products made from this flour under the test conditions used.

Radicidized and Radurized Fresh Chicken

In the United States most broiler chickens are marketed as refrigerated, nonfrozen whole birds that have been slaughtered, eviscerated, washed, and chilled in ice-water to 2°to 4°C or as tray-packed, cut-up chicken parts. The giblets are cleaned separately and packed in the cavity of the chicken. The whole birds or the parts are shipped to the retail stores in crates packed with crushed ice, cartons held at -2° to 0°C, or insulated cartons chilled with carbon dioxide snow. Normal maximum shelf-life of the chicken depends mainly on the storage temperature, which influences the total microbial count, being about 6 days at 4°C, 8 days at +1°C and 10 days at -1°C.[14]

The use of ionizing radiation to control microbial spoilage and to increase the salable shelf-life of fresh chicken had been investigated widely in the United States and abroad prior to 1965. Commercial interests in the United States and Canada indicated an economic benefit, if an extension of the marketable shelf-life of fresh chicken could be achieved by reducing the total counts of the spoilage organisms. Health officials in both countries indicated the desirability of developing a suitable process to destroy organisms of public health significance from the chicken carcasses.

In 1965 the Atomic Energy of Canada, Ltd, (AECL), the United States Atomic Energy Commission (AEC), and Natick began a cooperative program for radicidation and radurization of fresh chicken. The objective was to develop, by using irradiation and proper post-irradiation storage temperature, a process for chilled, drained poultry carcasses assuring desired salable shelf-life (14 to 16 days) with freedom from contaminants of public health significance, such as coliform organisms, fecal streptococci and Salmonellae.

The Health Authorities pointed out three potential microbial problems that must be addressed in developing a satisfactory irradiation process: (a) increased radiation resistance of both the pathogenic and nonpathogenic microbial flora, (b) induction of more virulant mutants; (c) ecological changes in microflora resulting in eliminating nonpathogenic food spoilage competitors which warn the consumer by odor or sight to reject a "spoiled"

[14]Elliott, R. P. and H. D. Michener. Factors affecting the growth of psychrophilic microorganisms in food. Technical Bulletin No. 1320. U.S. Department of Agriculture, Washington, D.C. 1965.

chicken. In the absence of these competing microorganisms, pathogens not giving such warning could multiply and/or secrete toxic products to jeopardize the health and safety of the consumer. These three microbial aspects were studied by scientists at Natick and under contract at the Hazleton Laboratories, Alexandria, Virginia; the Massachusetts Institute of Technology, Cambridge, Massachusetts; and the Macdonald College of McGill University, Montreal, P.Q., Canada. The published data[15,16,17,18,19] show that there are no microbial hazards associated with increased resistance, increased virulence, or spoilage recognition.

The nonmicrobial aspects of proof of safety for consumption (wholesomeness) of radurized and radicidized chicken were studied by Bio-Research Laboratories, Ltd., Pointe Claire, Quebec, under contract with AECL. By 1965, the US Army Medical Department had completed a study on wholesomeness of radappertized vacuum packaged chicken given a mild heat treatment prior to irradiation to inactivate autolytic enzymes. The data from this study were made available to AECL.

Packaging materials such as medium density polyethylene were studied by Natick and by the Hazleton Laboratories under contract with the AEC. Data derived from these investigations led to FDA approval on August 14, 1964 of medium density polyethylene as a food contactant for radurization and radicidation (10k Gy maximum absorbed dose) and on June 10, 1967 for

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[15] See footnote 6.
[16] See footnote 7.

[17] See footnote 8.

[18] Idziak, E. S. and K. Incze 1968. Radiation treatments of foods. I. Radurization of fresh eviscerated poultry. Appl. Microbiol. 16: 1061.

[19] Epps, N. A. and E. S. Idziak, 1970. Radiation treatments of foods II. Public health significance of irradiation recycled Salmonella. Appl. Microbiol. 19: 338

radappertization (60 kGy maximum absorbed dose).

All data from the combined efforts of AECL, AEC, Natick and their contractors were provided to AECL. On June 20, 1973, the Canadian Health Authorities approved for test marketing eviscerated poultry in plastic bags radicidized (Salmonella eradication) by exposure to the gamma rays of cobalt-60 at absorbed doses not to exceed 7 kGy.

Some of the unpublished supporting data contributed by Natick to AECL are reported here. The microbiological aspects studied by Natick have been published by Previte et al.[20, 21, 22]

Fresh eviscerated chicken (0.9 to 1.4 kg) without giblets were transported in ice-packed insulated carriers from Boston area, USDA inspected poultry processers to Natick within four hours post-slaughter. The chickens were individually packaged in 2-mil medium-density polyethylene bags and cobalt-60 irradiated at 2^{o}C with 2.5 kGy (+9%), or 5 kGy (+5%), at a dose rate of 9.6 Gy per second, within 24 hours postslaughter. Post irradiation storage was at 1.6^{o}C. The carcasses were examined for odor, sliminess, color, total plate count (TPC), coliform and faecal streptococci, and sensory characteristics. Indications of preference were made on a hedonic scale of 1 to 9 with 1 being "disliked extremely" and 9 meaning "like extremely." A rating of 5 (neither like nor dislike) was considered the base line for product acceptability. Samples were also evaluated for intensity of irradiation flavor and mushiness. A score of 1 signified "None" and 9, "Extreme" intensity.

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[20] See footnote 6.

[21] See footnote 7.

[22] See footnote 8.

Table 16 shows the total plate count (TPC) of nonirradiated controls and chicken irradiated at doses of 2.5 and 5 kGy. The 2.5 kGy dose reduced the initial TPC by 2 log cycles. This irradiation level and storage at 1.6°C inhibited bacterial multiplication from 15 to 22 days; the irradiated TPC then equaled the initial nonirradiated count (10^4). This time period was of greater duration than that of normal enzymatic degration (mushiness) of chicken meat, which became noticeable after approximately 18 days storage. The 5 kGy dose eliminated or inhibited bacterial multiplication for over 31 days.

Tables 17 and 18 are coliform and faecal streptococci counts on nonirradiated and irradiated chicken carcasses. The tables indicate that the 2.5 kGy and 5 kGy gamma-ray doses were sufficient to eliminate almost all the coliform and faecal streptococci on chicken carcass skin; those surviving cannot proliferate at 1.6°C storage. Coliform and faecal streptococci are a hundred-fold more numerous than Salmonellae on chilled chicken and, therefore, can be more easily detected. A determination of coliform and/or faecal streptococci count would supply indirect information on Salmonellae contamination. It appears that the 2.5 kGy dose would destroy the majority of the organisms that are of public health significance.

The odor of the nonirradiated chicken carcasses when stored at 1.6°C deteriorated from a fresh chicken odor to no odor after eight days, a slight off-odor at eleven days, and an increasingly putrid odor after fifteen days (Table 19). The irradiated carcasses exhibited a slight irradiation odor that dissipated after four days storage. A chicken odor then predominated and prevailed until approximately 18 days when a stale "old chicken" odor, sometimes sour, replaced it.

The appearance of the nonirradiated chicken showed no discoloration up to about 8 days in storage, after which a dull grayish appearance was observed indicating the onset of decomposition (Table 20). This appearance correlated with the loss of characteristic chicken odor. Discoloration increased with storage time, indicating further decomposition. The irradiated chicken had a slight pink discoloration of the breast (white) meat that was more evident in the higher dose (5 kGy) carcasses. This discoloration was not discernible in the dark (thigh) meat. A dull, followed by brown, discoloration of the meat was noted after 18 to 22 days in storage. This observation correlated with the perception of the stale "old chicken" odor.

Due to the irradiation-induced bacterial reduction, the shelf-life increased from 8 days for the control samples to 15 to 18 days for the irradiated carcasses. The putrid odor present in the decomposing controls, usually characteristic of pseudomonas, was not noted in the irradiated carcasses. This indicates the effective elimination of the pseudomonas by the irradiation dose used in this study. The microbiological population altered by the irradiation treatment along with autolytic action caused apparent deterioration after 18 to 22 days storage.

The nonirradiated and radurized chickens were oven-roasted at 177°C. White and dark meat were separately evaluated. The scores in Table 21 indicate all samples were in the acceptable range and the 2.5 kGy samples were slightly superior to the 5 kGy samples. Although the scores of the radurized, roasted chicken were "acceptable" in the 22 to 31 day storage period, the gross appearance of the unroasted carcass was borderline for acceptance. All meat samples were evaluated for intensity of irradiation flavor and mushiness (Table 22). No irradiation flavor, or at most only a trace, was perceived. A trace to slight intensity for "mushiness" was noted in the 5 kGy irradiated "dark" meat.

Based on these observations, it was suggested that a 2.5 kGy irradiation dose and storage at 1.6°C are sufficient for a radurized chicken process. The resulting chicken carcasses are free from microbial spoilage and are of excellent quality for at least 15 days. The 2.5 kGy irradiation dose has the following advantages: sufficient total plate count reduction; death or growth inhibition of coliform and faecal streptococci; less irradiation carcass odor and discoloration; high preference scores; and lower costs.

Summary and Conclusions

Although Natick's primary effort since 1962 has been devoted to radappertization, Natick has also been involved in applying submegarad doses of ionizing radiation to white potatoes, wheat flour, and fresh chilled chicken.

After FDA approved Natick's petition to use ionizing radiation to inhibit sprouting of white potatoes, two semi-commercial production tests were conducted using gamma rays from cobalt-60 in the dose range of 50 to 150 Gy. Evaluations were made by military personnel at bases both in the United States and abroad. It was concluded that irradiation of potatoes had commercial potential which was subsequently borne out by the establishment of a commercial potato irradiation plant in Hokkaido, Japan.[23]

[23] Matsui, T. 1975. Japan, Radiation sources and dosimetry. Food Irradiation Information. 4:23

Two semi-commercial production tests were performed using ionizing radiation (300 to 500 Gy gamma radiation from cobalt-60) to disinfest wheat flour of insects. Evaluations of the flour and items baked with this flour were made by the Armed Forces at widely dispersed military bases and at sea. It was concluded that ionizing radiation is very effective for disinfesting wheat flour of insects without adversely affecting the B-vitamin content. baking characteristics, and acceptance of items baked with this flour.

Processing methods were developed for radurized and radicidized fresh chilled chicken in cooperation with the United States Atomic Energy Commission and Atomic Energy of Canada, Ltd. (AECL). The Natick data were part of AECL's petition to the Canadian Health Authorities to approve radicidation of chicken. In June, 1973, the Health Authorities of Canada gave permission for test marketing of radicidized chicken.

This document reports research undertaken at the US Army Natick Research and Development Command and has been assigned No. NATICK/TR-78/003 in the series of reports approved for publication.

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TABLE 1. Consumer preference scores* for potatoes irradiated to prevent sprouting

Base	Irradiated
Ft. Lewis, Washington (Army)	6.8
Anderson Air Force Base, Guam	6.9
Eilsen Air Force Base, Alaska	6.2
Camp Pendleton, California (Marine Corps)	6.2

*9 point hedonic scale. 9 = like extremely; 1 = dislike extremely; 5 = neither like nor dislike.

TABLE 2. Grading data for potatoes stored* 5 months after treatment to prevent sprouting

	Irradiated		Chemically Treated (CIPC)	
	kg	%	kg	%
US No. 1	8,386	55.4	10,545	64.3
US No. 2	1,909	12.6	2,091	12.8
Culls	4,832	31.9	3,755	22.9
Totals	15,127	99.9	16,391	100

* At 7.2°C, 95% RH and air flow of 0.0135m 3/45 kg/minute.

Table 3: Losses in irradiated and chemically treated U.S. No. 1 potatoes re-sorted and stored during June-July 1969.

	Kilograms Irradiated	Kilograms Chemically Treated (CIPC)
Re-sorted	8,386	10,545
Shipped	5,909	8,386

Table 4. Consumer preference scores* for potatoes treated to inhibit sprouting

Base	Irradiated	Chemically Treated (CIPC)
Fort Lewis (Army)	5.3	4.8
Anderson Air Force Base	6.6	6.4

* 9 point hedonic scale. 9 = like extremely; 1 = dislike extremely; 5 = neither like nor dislike.

Table 5. Industrial productions of irradiated flour

	Production IA	Production IB	Production II
Vendor	Hawaiian Flour Mills, Inc. Honolulu, Hawaii	Helix Milling Co. Helix, Oregon	Crowther Bros. Milling Co. Malad City, Idaho
Dates Packaged	26-28 July 1967	1-4 August 1967	21-23 May 1969
Quantity	36,082 kg	23,705 kg	59,977 kg
Packaging	15.9 kg/can	15.9 kg/can	22.7 kg/bag

Table 6. Irradiation of the industrial production of flour

	Production IA	Production IB	Production II
Radiation Source	Hawaii Devl. Irradiator Honolulu, Hawaii	Lockheed Georgia Co. Dawsonville, Georgia	Neutron Products, Inc. Dickerson, Maryland
Dates Irradiated	27 July-7 August 1967	15-17 August 1967	4-11 June 1969
Dose Range	300-500 Gy	300-500 Gy	300-500 Gy
Quantity	34,608 kg	22,722 kg	56,160 kg

Table 7. Evaluation of irradiated flour

Test Site	Packaging	kg	Storage Months
U.S. Army:			
Fort Leonard Wood, Missouri	Can	22,750	8
Canal Zone, Panama	Bag	23,400	7
Fort Lee, Virginia	Bag	454	11
Natick, Massachusetts	Can	955	1-48
Natick, Massachusetts	Bag	2,000	1-25
U.S. Marine Corps:			
Camp Lejeune, North Carolina	Can	11,391	9
Camp Lejeune, North Carolina	Bag	10,500	5
U.S. Navy:			
USS Guadalcanal	Can	11,391	12
Naval Training Center, Great Lake, Illinois	Bag	4,773	4
Naval Training Center, San Diego,CA	Bag	4,545	4
U.S. Air Force:			
Lajes, Azores	Can	5,505	12
Moron, Spain	Can	5,505	12
Lajes, Azores	Bag	11,455	8
U.S. Department of Agriculture:			
Savannah, Georgia	Can	2,273	1-12
Savannah, Georgia	Bag	2,841	1-12

Table 8. Military evaluation of irradiated flour bread scores

Test Site	Packaging	Average Score[1] Internal	External
U.S. Army:			
Fort Leonard Wood, Missouri	Can	27	94
Canal Zone, Panama	Bag	26	93
Fort Lee, Virginia	Bag	--	88
U.S. Marine Corps:			
Camp Lejeune, North Carolina	Can	28	86
Camp Lejeune, North Carolina	Bag	25	88
U.S. Navy:			
USS Guadalcanal	Can	23	83[2]
U.S. Air Force:			
Lajes, Azores	Can	28	97
Moron Spain	Can	27	93
Lajes, Azores	Bag	30	98

[1] Internal, 30 = perfect; External, 100 = perfect.

[2] Baker's comments: Low score due to uneven oven temperature distribution.

Table 9. Military evaluation of irradiated flour
Consumer acceptance of baked products

Test Site	Pack-aging	Baked Product	Acceptance Scores[1] Identified No.	Score	Not Identif. No.	Score
U.S. Army:						
Fort Leonard Wood, Missouri	Can	Bread	766	6.4	1,230	6.9
Canal Zone, Panama	Bag	Bread	100	7.6	93	7.6
U.S. Marine Corps:						
Camp Lejeune, No. Carolina	Can	Bread	1,000	6.6	1000	7.0
Camp Lejeune, No. Carolina	Bag	Bread	1,500	6.4	1500	6.7
U.S. Navy:						
USS Guadalcanal	Can	Bread	--	6.8	--	7.1
Naval Trng Ctr[2] Great Lake, IL	Bag	Rolls	--	7.0	--	7.5
Naval Trng Ctr[2] Great Lake, IL	Bag	Pie Crust	--	6.3	--	6.9
Naval Trng Ctr[2] San Diego, CA	Bag	Sweet Rolls	323	5.7	263	5.8
U.S. Air Force:						
Lajes, Azores	Can	Bread and Rolls	"...acceptable in lieu of regular issue flour, wheat, hard, because of its acceptability with regard to flavor, color, texture, aroma and freshness of the finished product.[3]			
Moron, Spain	Can					
Lajes, Azores	Bag					

[1] 9 point hedonic scale. 9 = like extremely; 1 = dislike extremely.

[2] Training Center

[3] Air Force Evaluation of Flour, Wheat, Irradiated, Hard, dated 29 Nov.1968 Department of the Air Force, Air Froce Services Office (AFLC), Philadelphia, PA, 19101, U.S.A.

Table 10. Effects of irradiation[1] and storage on vitamins[2] in flour

	Packed in Cans (Ave. - 48 Month Study at 21°C)		Packed in Bags (Ave.- 25 Mo Study at 21°C)	
	Irradiated	Control	Irradiated	Control
Thiamine	0.47	0.47	0.65	0.67
Riboflavin	0.30	0.30	0.32	0.32
Pyridoxine	0.05	0.04	0.04	0.04
Niacin	0.35	0.39	0.48	0.47

1 300 to 500 Gy

2 mg/100 gm

Table 11. Effect of irradiation[1] and storage of flour on vitamins[2] in bread

	Packed in Cans (Ave. - 48 Mos at 21°C)		Packed in Bags Ave. - 25 Mo. Study at 21°C)	
	Irradiated	Control	Irradiated	Control
Thiamine	0.30	0.29	0.48	0.46
Riboflavin	0.22	0.22	0.24	0.24
Pyridoxine	0.04	0.04	0.04	0.04
Niacin	0.27	0.23	0.32	0.31

1 300 to 500 Gy

2 mg/100 gm

Table 12. Effect of irradiation[1] and storage of flour on bread scores

	Months at 21°C	Bread Scores[2] Irradiated	Control
Flour in Cans	27	89	93
	48	91	94
Flour in Bags	1	93	93
	4	93	94
	9	99	99
	16	94	94
	25	93	93

[1] 300 to 500 Gy

[2] External, 100 = perfect

TABLE 13. EFFECTS OF IRRADIATION[1] AND STORAGE ON pH AND ACIDITY OF FLOUR

	Months at 21° C	% H_2O Irrad.	% H_2O Cont.	pH Irrad.	pH Cont.	Titratable Acidity[2] Irrad.	Titratable Acidity[2] Cont.
Flour in Cans	3	13.08	13.12	6.06	6.08	2.08	2.04
	6	13.12	13.06	5.90	5.90	1.74	1.65
	12	13.34	13.31	5.90	5.99	1.82	1.89
	27	13.90	13.34	5.00	5.60	3.64[3]	1.94
	48	—	—	5.30	5.50	—	—
	52	13.34	12.64	5.30	5.50	2.69	2.08
	72	13.25	13.14	5.60	5.60	1.68	1.93
Flour in Bags	1	13.50	12.81	6.23	6.19	1.80	2.40
	4	12.90	12.61	—	—	1.70	1.70
	16	—	—	5.90	5.90	—	—
	25	12.80	12.74	5.95	5.95	2.00	1.90
	50	12.60	12.40	5.70[4]	5.70[4]	1.84	1.90

1 300 to 500 Gy

2 meq NaOH/100 gm flour sample.

3 Significant increase probably due to higher moisture content.

4 Significant decrease due to time in storage.

Table 14. Effects of irradiation[1] and storage on diastase activity in flour

Months at 21°C	Packaging	Diastase Activity[2] Irradiated	Control
3	Can	303	290
6	Can	323	344
12	Can	322	300
48	Can	226[3]	238[3]
1	Bag	310	295
4	Bag	306	305
16	Bag	341	302
25	Bag	285[3]	278[3]

[1] 300 to 500 Gy

[2] mg. maltose/10 gm sample

[3] Significant (95%) decrease due to storage

Table 15. Effects of irradiation[1] and storage of flour on acceptance[2] of baked product.

	Months at 21°C	Bread Irradiated	Bread Control	Rolls Irrad.	Rolls Control
Flour in Cans	1	7.1	7.2	7.5	7.5
	6	7.7	7.6	7.4	7.4
	12	7.5	7.4	7.8	7.8
	14	6.6[3]	6.8[3]	7.4	7.4
Flour in Bags	1	7.0	6.8	7.7	7.7
	4	6.9	6.6	7.7	7.8
	9	6.9	7.0	7.9	7.9
	16	6.9	6.8	7.5	7.2
	25	6.5[3]	6.5[3]	7.2	7.4

[1] 300 to 500 Gy

[2] 9 point hedonic scale: 9 = like extremely; 5 = neither like nor dislike; 1 = dislike extremely

[3] Significant (95% decrease due to time in storage)

Table 16. Total plate counts* of nonirradiated and radurized chicken stored at 1.6°C

Days Storage	Nonirradiated	2.5 kGy	5 kGy
0	4.1×10^4	2.3×10^2	< 100
4	6.8×10^4	1.0×10^2	< 100
8	1.0×10^6	3.0×10^2	< 100
11	5.3×10^7	1.0×10^2	< 100
15	5.0×10^8	2.2×10^4	< 100
18	5.5×10^8	9.0×10^2	< 100
22	1.0×10^9	5.5×10^4	< 100
31	1.9×10^9	5.0×10^5	< 100

* Bacteria per 6.25 cm^2 of chicken surface, means of 6 carcasses, after incubation at 21°C for 5 to 7 days.

Table 17. Coliform count* of nonirradiated and radurized chicken stored at 1.6°C

Days Storage	Nonirradiated	2.5 kGy	5 kGy
0	10	<1	<1
4	21	<1	<1
8	3	<1	<1
11	5	<1	<1
15	8	<1	<1
18	24	<1	<1
22	2	<1	<1
31	11	<1	<1

*Coliforms per 6.25 cm^2 of chicken surface,means of 6 carcasses, using method of Powers (9).

Table 18. Faecal streptococci count* of nonirradiated and radurized chicken stored at 1.6°C

Days Storage	Nonirradiated	2.5 kGy	5 kGy
0	10	<1	<1
4	4	<1	<1
8	12	<1	<1
11	3	<1	<1
15	20	<1	<1
18	10	<1	<1
22	14	<1	<1
31	7	<1	<1

*Faecal streptococci per 6.25 cm^2 of chicken surface, means of 6 carcasses, using method of Powers (9).

Table 19. Odor profile of nonirradiated and radurized chicken* stored at 1.6°C

Days Storage	Nonirradiated	2.5 kGy	5 kGy
0	Fresh Chicken	Slight irradiation odor	Irradiation odor
4	Fresh Chicken	Fresh chicken odor	Slight irrad. odor
8	No odor	Fresh chicken odor	Fresh chicken odor
11	Slight off odor	Chicken odor	Chicken odor
15	Putrid	Slight chicken odor	Slight chicken odor
18	Putrid	Stale chicken odor	Stale chicken odor
22	Putrid	Stale chicken odor	Stale chicken odor
31	Putrid	Stale chicken odor (sour)	Stale chicken odor

* Examination of 6 carcasses

Table 20. Appearance of nonirradiated and radurized chicken* stored at 1.6°C

Days Storage	Nonirradiated	2.5 kGy	5 kGy
0	No discoloration	Breast meat slight pink	Meat salmon pink
4	No discoloration	Breast meat slight pink	Meat salmon pink
8	Breast meat dull	Breast meat slight pink	Meat salmon pink
11	Carcass dull	None	Pink wings
15	Flesh decomposed	Breast meat slight pink	Carcass pink
18	Flesh decomposed	Breast meat slight pink	Carcass pink
22	Flesh decomposed	Meat dull	Viscera brown
31	Flesh decomposed	Flesh decomposed	Slight decomposition

* Examination of 6 carcasses

Table 21. Preference scores[1] of nonirradiated and radurized chicken stored at 1.6°C

Days Storage	Nonirradiated[2]		2.5 kGy[2]		5 kGy[2]	
	White Meat	Dark Meat	White Meat	Dark Meat	White Meat	D.Meat
0	7.2	7.2	--	--	--	--
4	7.0	6.6	6.6	6.4	6.4	6.6
8	6.2	5.9	7.0	6.2	6.6	5.1
11	6.9	6.4	6.9	6.2	6.1	5.9
15	spoiled		6.9	6.7	7.1	6.2
18	spoiled		6.5	6.4	6.7	6.3
22	spoiled		6.7	6.1	6.3	6.1
31	spoiled		6.4	6.5	6.0	6.0

[1]9 point hedonic scale: 9 = like extremely; 5 = neither like nor dislike; 1 = dislike extremely

[2]Means of two tests, eight panelists

Table 22. Intensity scores for irradiation flavor and mushiness[1] of nonirradiated and radurized chicken stored at 1.6°C

Days Storage	Nonirradiated[2]				2.5 kGy[2]				5 kGy[2]			
	White Meat		Dark Meat		White Meat		Dark Meat		White Meat		Dark Meat	
	Rad Flav	Mush	Rad Flav	Mush	Rad Flav	Mush	Rad Flav	Mush	Rad Flav	Mush	Rad Flav	Mush
0	1.0	1.9	1.0	1.6	--	--	--	--	--	--	--	--
4	1.1	1.5	1.2	1.8	1.3	1.3	1.5	1.6	1.2	1.3	1.1	1.6
8	1.6	1.3	1.3	2.1	1.3	1.4	1.1	1.8	1.4	1.1	1.9	2.1
11	1.2	1.3	1.2	1.6	1.5	1.1	1.2	1.6	1.5	1.3	1.5	1.9
15		Spoiled			1.1	1.4	1.1	1.6	1.1	1.1	1.2	2.7
18		Spoiled			1.2	1.5	1.2	2.1	1.1	1.4	1.2	1.7
22		Spoiled			1.2	1.1	1.5	1.7	1.4	1.4	1.6	1.8
31		Spoiled			1.3	1.3	1.1	1.5	1.0	1.8	1.1	2.2

[1] 9 point intensity scale: 1 = none, 2 = trace, 3 = slight, 4 = below moderate, 5 = moderate, 6 = above moderate, 7 = strong, 8 = very strong, 9 = extreme.

[2] Means of two tests, eight panelists per test: Rad Flav = Irradiation Flavor, Mush = Mushiness.