ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

A PRELIMINARY STUDY OF THE EFFECT OF GAMMA RADIATION ON THE BAKING QUALITY OF FLOURS

L. E. BROWNELL
H. A. HARLIN

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I. INTRODUCTION

The infestation by insects of stored grain, flour, cereal meals, and other cereal products results in a great annual loss of these staple food items. Studies have indicated that a gamma radiation dose of 25,000 rep is sufficient to control such insect infestation in cereal products[1,2]. However, little information has been published on the effects of gamma radiation on the quality of cereal products. To explore this question a preliminary study has been made of the quality of bread, biscuits, and cake prepared from irradiated bread and all purpose flour.

II. RADIATION FACILITIES AT MICHIGAN

The first commercial facilities for gamma irradiation for reasons of economy will probably use cooling reactor fuel elements or the separated fission products as sources of radiation. Although large quantities of gamma emitters exist in the waste fission products, they exist in the form of dilute liquids and slurries which are stored in underground tanks for processing at some future date.

In June of 1951, Michigan, and later other universities, received "kilocurie" cobalt-60 gamma sources from Brookhaven National Laboratory.[3] These gamma sources serve as substitutes for the fission products and are quite expensive because they are made by neutron bombardment in a reactor. However, they are useful laboratory tools and as such are more convenient and probably as cheap as waste fission products processed on a small scale. More important, the kilocurie sources are available but processed gross fission products are not as yet.

Figure 1 is a sectional view of the container for the Michigan kilocurie source.[4] A pneumatic lift is used for charging and removing the aluminum tube in which the samples are placed for irradiation.

A larger source ten-times as powerful and of different design, has been installed in the Fission Products Laboratory,[5,6] and has greatly increased

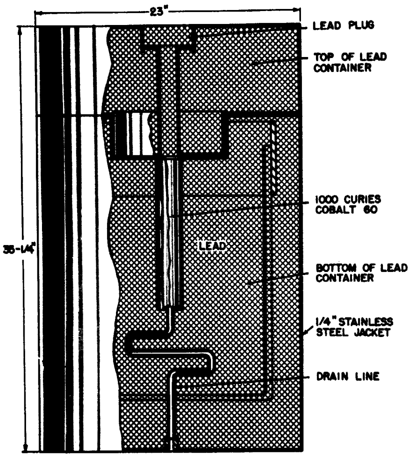


Fig. 1. Sectional View of the Container for the Michigan One-Kilocurie Source.

the range of experiments. For example, with the new source it is possible to sterilize whole hams and number 10-sized tin containers, and to irradiate sufficient volumes of food to conduct appropriate animal feeding experiments. Figure 2 is a cutaway drawing of the new cave. The essential features of the radiation cave are the four-foot thick concrete walls necessary to shield laboratory personnel and the surrounding area from gamma radiation and the 16-foot well used for shutting off the radiation in the cave. The four-foot barrier wall provides a simple labyrinthine entrance and prevents the source from "seeing" the door. The barrier wall serves to diminish the radiation flux in the labyrinthine entrance so that a heavily shielded door is not required. The door is provided with a safety interlock so that it is impossible to enter the radiation cave when the source is in the raised position.

Figure 3 shows a photograph of the source in the well of water. This photograph was taken by the light from the glow caused by the effect of gamma radiation on the water in the well.

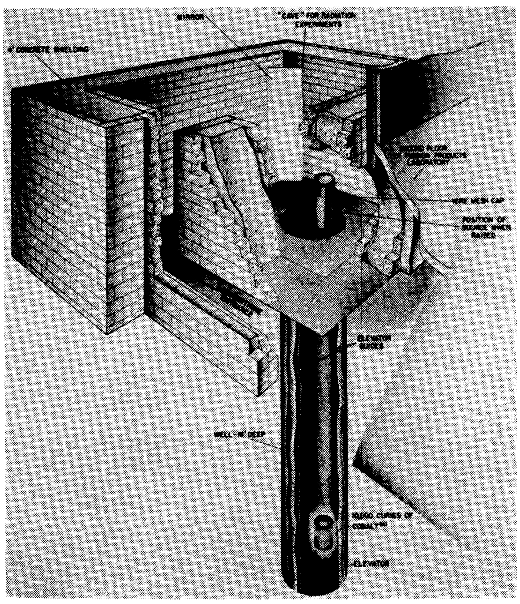


Fig. 2. View of Radiation "Cave" at the University of Michigan.

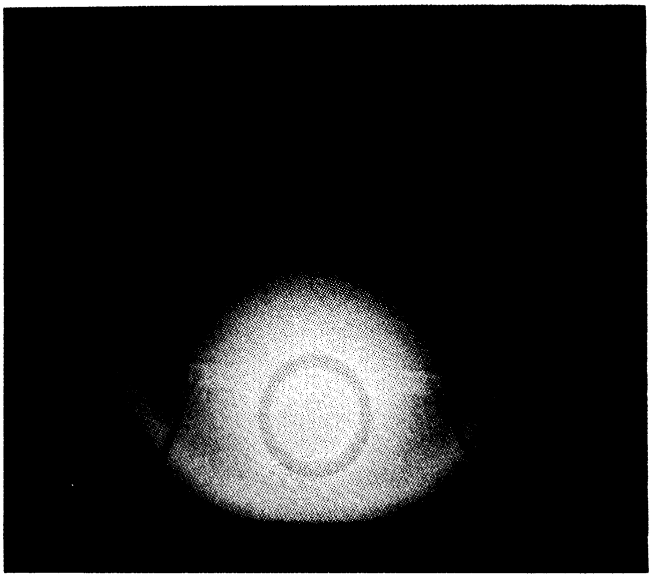


Fig. 3. Photograph of 10,000 Curie Cobalt-60 Gamma Source Glowing Under 10 Feet of Water.

III. EXPERIMENTAL TESTS

A. CAKES

In the first test with irradiated flour three types of flour; (1) bread flour, (2) all-purpose flour (General Mills), and (3) cake flour (Swansdown), were given 20,000 rep of gamma radiation.[7] Baking tests were made the day following irradiation. A quick-mix cake flour recipe was used to make cakes with the irradiated and nonirradiated cake flour, whereas a quick-mix all-purpose flour recipe was used for the irradiated and nonirradiated all-purpose and bread flour. Table A in the Appendix gives the formulas and method used.

One cake was baked with each flour, nonirradiated and irradiated, and used for two taste panels. The data were not analyzed statistically since there were too many variables. However, the general conclusion made was that a low dose of gamma radiation of 20,000 rep does not affect the baking, eating qualities, and flavor of the three flours. The volumes of the cakes made with the irradiated flours were equal to those made with nonirradiated flours. The cakes made with the irradiated and nonirradiated bread flour were extremely heavy and soggy with poor symmetry and volume.

A second test with irradiated flour was made to explore whether or not the gluten of bread flour could be modified by radiation in such a way as to make a softer crumb. A quick-mix recipe for making cake with bread flour was first developed. Then cakes were made with irradiated bread flour that had been exposed to gamma radiation doses of 20,000, 50,000, 100,000 and 150,000 rep. Table B in the Appendix gives the formulas and method used.

All the cakes browned evenly and had a golden brown crust. The cakes made with flour given 50,000, 100,000, and 150,000 rep were more flat topped (not as symmetrical) than the control and the cake made with 20,000 rep. There was no noticeable difference between the control cake and that made with 20,000 rep bread flour. The cakes made with 50,000 and 100,000 rep bread flour were considered to be of better quality than that made with 150,000 rep flour which had a wet soggy layer near the bottom of the cake. Taste panel results are shown in Table I (using rank analysis of incomplete blocks).[8,9]

Using a radiation dose of 50,000 rep some flavor change was observed, but cakes made from flour given 100,000 and 150,000 rep were considered to have a different flavor. It is difficult to describe this flavor change other than to say that the sweetness appeared to have been increased. These tests indicated that irradiating bread flour did not improve its qualities with regard to use in cakes.

TABLE I. RANKING OF BREAD FLOUR USED FOR CAKES BY MEANS OF PAIRED COMPARISONS

Sitting No.	Dose and Total Score for Each Dose*				P	Significant Difference ?
	0	$5x10^4$	$1x10^5$	$1.5x10^5$		
Second Test						
1	26	26	28	28	.91	No
2	21	30	29	28	.04	Yes
	.62	.10	.12	.15		
	0	$1.5x10^5$	$2.0x10^5$	$5.0x10^5$		
Third Test						
1	18	23	22	27	.04	Yes
	.56	.17	.21	.06		
2	19	22	21	28	.02	Yes
	.45	.22	.28	.05		

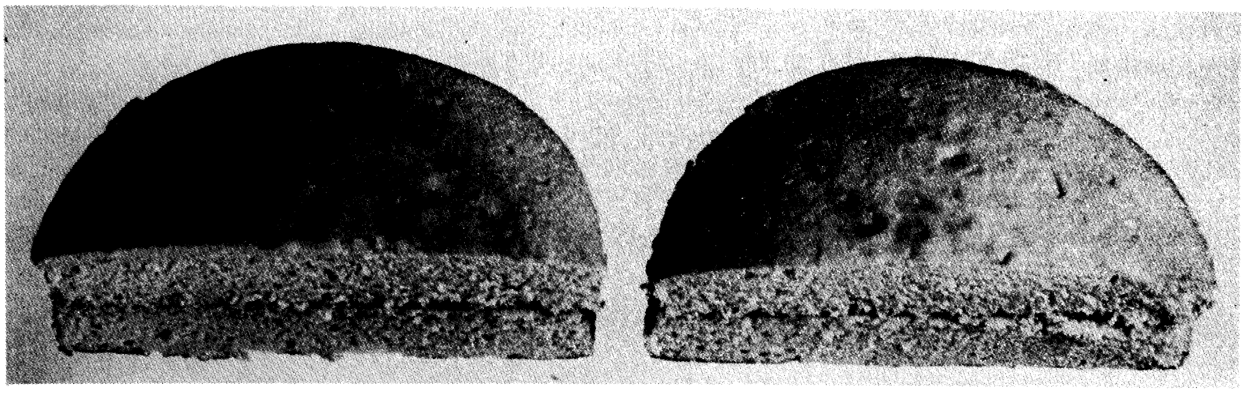
*Where significant differences exist estimates of the preference ratings are displayed below the total scores.

In a third test more bread flour was exposed to doses of 100,000, 150,000, 200,000, 500,000, and 1,000,000 rep. Cakes were made with all the irradiated flours and a nonirradiated control. For the taste panel tests cakes made with flours exposed to 150,000, 200,000, and 500,000 rep were used. Figure 4 shows the six cakes made with irradiated and nonirradiated bread flour. Table II gives the cake volumes and characteristics.

It was noticed that when mixing cakes with flour given 500,000 and 1,000,000 rep the batters tended to be drier and had a consistency like putty during the first 2 minutes of mixing. Taste panel results are shown in Table I. The judges showed a slight preference for the control over the cakes made with flour given 150,000 and 200,000 rep. However, there was a decided preference for the control cake when paired with cake made with flour given 500,000 rep. Cakes made with irradiated flour tend to be sweeter, particularly the crust. Flour given 5.10^5 and 10^6 rep had an odor resembling extreme mustiness.

B. BAKING POWDER BISCUITS

Baking powder biscuits were baked with bread flour that had been exposed to 20,000, 50,000, 100,000, and 150,000 rep of gamma radiation. Table C in the Appendix gives the formula and method used. It was decided to bake biscuits because color changes, if any, in irradiated flour would show up better in biscuits. Two bakings were made with each sample of treated flour



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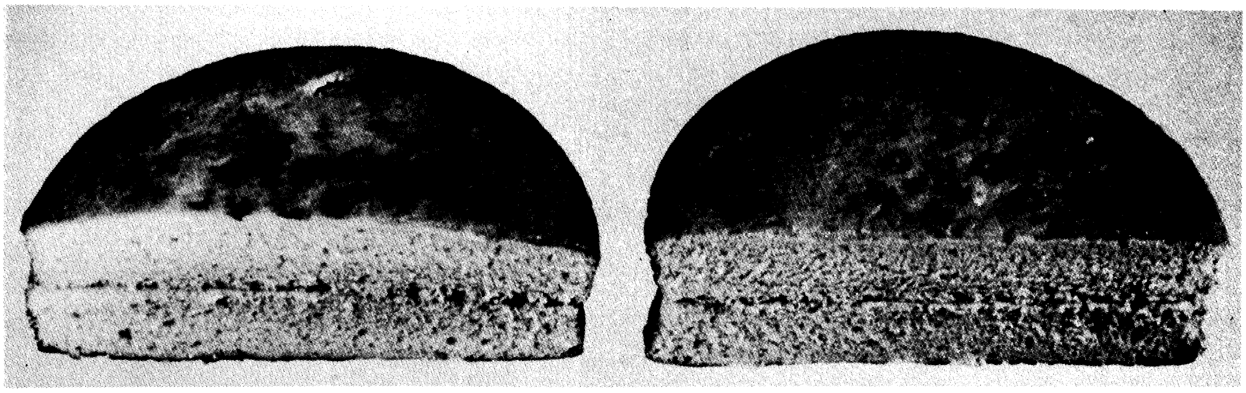

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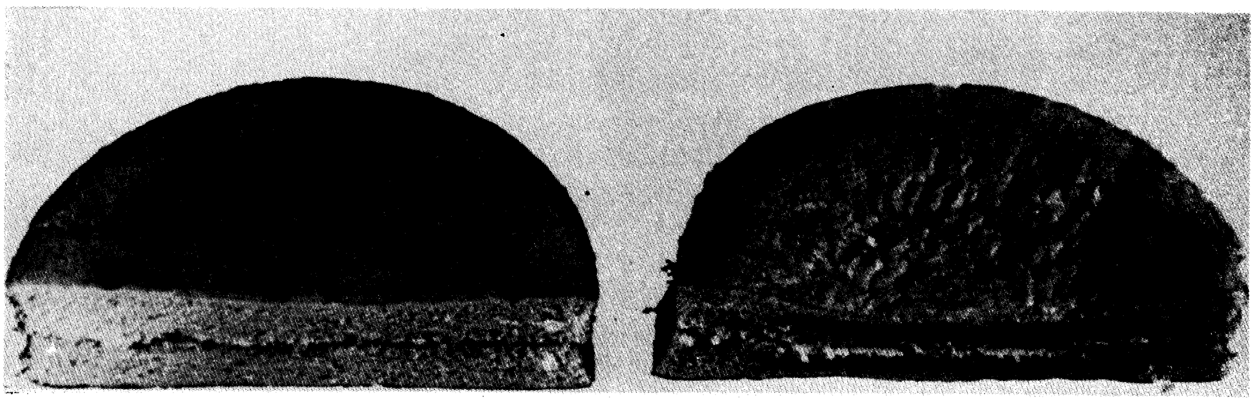

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Fig. 4. Six Cakes Made with Nonirradiated and Irradiated Bread Flour.

TABLE II. DIMENSIONS AND CHARACTERISTICS OF CAKES MADE WITH IRRADIATED BREAD FLOUR

	Dose Megarep	Layer	LE	M	RE	Characteristics
1.	Control	1st 2nd	2-4/16* 2-5/16	2-13/16 2-13/16	2-6/16 2-5/16	This cake had the best symmetry, volume, texture, tenderness, and crumb color.
2.	0.1	1st 2nd	2-3/16 2-3/16	2-9/16 2-10/16	2-4/16 2-2/16	A good cake, but not quite as good as the control. Texture was slightly coarse and compact. Cake was not quite as tender as control. There was no difference in crumb color; symmetry was good.
3.	0.15	1st 2nd	2-5/16 2-4/16	2-10/16 2-11/16	2 2-2/16	This cake was slightly poorer than the 100,000 rep cake. It had a heavy compact layer near the bottom and the crumb color was slightly darker than the control cake. The symmetry was good.
4.	0.20	1st 2nd	2-2/16 2-2/16	2-4/16 2-8/16	2-5/16 2-4/16	This cake had more of a heavy, compact layer near bottom. The texture was bready and coarse and the crumb was wet and sticky. Symmetry was poor; layers very flat topped.
5.	0.50	1st 2nd	2-2/16 2-1/16	2 1-14/16	2-1/16 1-15/16	The crust browned evenly but the cake had very poor symmetry; dipped in center. The texture was heavy, compact, bready, and coarse and was tough and gummy with a dark yellow crumb color.
6.	1.00	1st 2nd	1-11/16 1-14/16	1-4/16 1-6/16	1-14/16 2	This cake fell badly; had a very brown crust and dark crumb color. A wet, soggy, compact failure.

*Measurements were made in 16th's of an inch at the points marked on this diagram. A layer has been cut in half and the two bottoms placed together at the middle.

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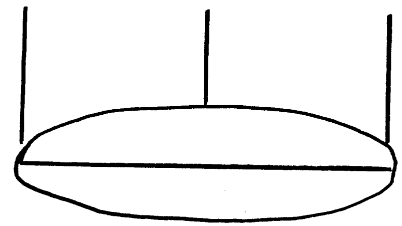

and the nonirradiated control. Two taste panels were held with these biscuits; results are shown in Table III.

TABLE III. RANKING OF BISCUITS BY MEANS OF PAIRED COMPARISONS

Sitting No.	Dose and Total Scores for Each Dose				P	Significant Difference ?
	0	$5x10^4$	$1x10^5$	$1.5x10^5$		
1	25	29	28	26	.70	No
2	19	18	17	18	.96	No

Dose	Characteristics
1. Control	These biscuits were even-grained and tender with light cell walls. They had the most tender outer crust.
2. 20,000 rep	These were slightly coarser and closer textured than the control and were not considered to be as "light" as the control biscuits. There was no difference in crumb color between these biscuits and control biscuits.
3. 50,000 rep	These were lighter and more tender than 20,000 rep biscuits, not as close in texture, but still not quite equal to the control. Differences in crumb color between these biscuits and the controls were very slight.
4 100,000 rep	These seemed to be the most tender of the irradiated biscuits, but not quite equal to the control. Also, they were more like the control in lightness and cell wall structure. They had a slightly grayer crumb color than the control biscuits.
5. 150,000 rep	These biscuits had a coarser texture, were more compact, and were not as tender as 100,000 rep biscuits and the control biscuits. The crumb color was slightly darker than 100,000 rep biscuits.

The control biscuits were observed to have the greatest volume. There was no apparent difference in volume in the biscuits made with irradiated flour. All the biscuits browned an equal amount and there were no differences in outer appearances.

Although there were no marked changes in the baking qualities of bread flour exposed to gamma radiation between 20,000 and 150,000 rep, there were some noticeable flavor changes. It seemed to some of the judges that the off-flavor of irradiated flour was accentuated by the presence of double-action baking powder. Not enough taste panel data were available to make any definite conclusions, but some of the panel members did not care for the flavor and eating qualities of the biscuits made with irradiated flour.

C. BREAD

While studying the baking characteristics of irradiated bread flour, it was decided to make some tests with bread. The formula and method used are shown in Table D in the Appendix. Bread was baked with flour that had been exposed to 200,000, 500,000, and 1,000,000 rep gamma radiation and a nonirradiated control. Figure 5 shows sections of loaves of bread made with these flours.

Fig. 5. Sections of Four Loaves of Bread Made with Nonirradiated and Irradiated Bread Flour.

Taste panel results are shown in Table IV. The judges had a slight preference for the nonirradiated loaf and those made from flour given 200,000 and 500,000 rep. However, the flavor of the control was definitely preferred to the loaf made with flour given a dose of 1,000,000 rep. Bread from the latter loaf was considered to have a definite off-flavor.

IV. CONCLUSIONS

Cake flour, all-purpose flour, and bread flour are not changed when given a dose of 20,000 rep gamma radiation. At 20,000 rep flour insects and weevils would be destroyed and insect eggs would be made sterile. Cakes made with these different flours given this radiation dosage were similar to the controls in all respects.

Bread flour given a dose higher than 50,000 rep is not improved. Cakes made with irradiated bread flour were progressively of poorer quality with increasing doses of gamma radiation. Cakes made with irradiated flour had low total volume, were heavier, more compact, gummier, and had a darker yellow crumb color. The gluten appears to lose its binding power and the flour has a drier or more starch-like texture in mixing. Flavor changes were noticeable in cakes made with bread flour given a dose of 100,000 rep. The cakes, particularly the crusts, have a sweeter flavor. Off-flavors were noticed with higher doses of irradiation.

When making biscuits with irradiated flour receiving 20,000 to 150,000 rep, it was necessary to add 10 cc more milk to obtain a workable dough. This dryness of irradiated flour was also noticed when mixing cakes. Biscuits made with irradiated flour had a satisfactory appearance but the eating qualities and flavor were not equal to those of the controls. The biscuits made with irradiated flour were gummier and off-flavors were present in samples made with flour given dosages greater than 20,000 rep.

Aside from total volume, which was slightly smaller in the bread made with 20,000 rep bread flour, the loaves made with flour given this dosage were equal in all respects to those made with the nonirradiated flour. Loaves made with flour given $5x10^5$ and 10^6 rep had a smaller volume and crumb color was comparable to honey bread.

TABLE IV. RANKING OF BREAD FLOUR USED FOR BREAD BY MEANS OF PAIRED COMPARISONS

Sitting No.	Dose and Total Scores for Each Dose*				P**	Significant Difference ?
	0	2x10^5	5x10^5	1x10^6		
1	24	25	28	31	.19	No
2	19 .44	20 .34	22 .20	29 .02	-	Yes

*Where significant differences exist estimates of the preference ratings are displayed below the total scores.
**-indicates less than 0.01.

Dose	Characteristics
1. Control	This was the best loaf, had tender cell walls, even grain, and had the largest volume.
2. 200,000 rep	This bread was still of good quality, but the volume was not quite as great as the control loaf. There was not much difference in texture, tenderness, crumb color, and crust color between this loaf and control loaf.
3. 500,000 rep	The volume of this loaf was appreciably smaller. There were more large gas holes and the texture was quite coarse near the bottom of the loaf. The crumb was not as tender as the loaf made with 200,000 rep flour and crumb color was darker than loaf containing 200,000 rep flour.
4. 1,000,000 rep	The volume of this loaf was equal to that made with flour given 500,000 rep. There were many more gas holes than in 500,000 rep loaf and the crumb was not as tender. Some small hard lumps were noticed in the crumb and the color was a medium tan. Both the 500,000 and the 1,000,000 rep loaves did not have very thick crusts nor were the cursts as brown as the other loaves, even though all were baked for the same period of time.

APPENDIX

A. DISCUSSION OF TASTE PANEL TESTS

The initial taste panel experiments conducted in this laboratory were based on a modification of the "triangle" test.[8] In some instances where the judges were successful in identifying the odd sample, some of the panel members expressed a preference for the flavor of the irradiated sample. Thus, the employment of a statistical design which permits not only detection of flavor differences but also assignment of ranking in terms of preference seemed in order. The rank analysis of incomplete blocks developed by Bradley and Terry[9] provides tests of various hypotheses pertinent to the problems of flavor-preference testing. This method permits tests of hypotheses of a general class and the estimation of treatment ratings or preferences. The mathematical model developed is relatively simple and easy to interpret and apply (statistically speaking). Ranks are used in incomplete blocks of size 2, which permits later generalization to blocks of larger size (such extension of theory is now under consideration). The method of maximum likelihood is employed, and tests depend on the likelihood ratio statistics. Two special tests are featured by Bradley and Terry with the null hypothesis (1) makes no assumpations of equality of treatment ratings and (2) makes the assumption that there are only two groups of treatments, within which treatments do not differ in ratings, but the two groups themselves may have different ratings. Attention is called to the fact that in application to this problem, the control food is considered as a treatment, as far as the nomenclature of this design is concerned. These procedures are particularly applicable here, since qualitative measurements alone are reliable. The method of combining data permits an overall test of significance without the usual assumption that members of a panel agree on the nature of the differences to be detected.

B. FORMULAE USED IN CAKES, BISCUITS, AND BREAD

TABLE A. QUICK-MIX CAKE FORMULA DEVELOPED FOR USE WITH CAKE FLOUR AND ALL-PURPOSE FLOUR

Quick-Mix Cake Flour Recipe		Quick-Mix All-Purpose Flour Recipe	
Ingredients		Ingredients	
Flour	2-1/4 c	Flour	2 c
Sugar	1-1/4 c	Sugar	1-1/4 c
Salt	1 tsp	Salt	1 tsp
Baking powder	3 tsp	Baking powder	3 tsp
Shortening	1/2 c	Shortening	1/2 c
Milk	7/8 c	Milk	1 c
Eggs	2	Eggs	2
Vanilla	1 tsp	Vanilla	1 tsp

Method. Sift together flour, sugar, salt, and baking powder. Place in mixing bowl with the shortening and approximately 3/4's of the milk. Beat for 2 minutes (150 strokes per minute). Scrape bowl often. Add eggs, vanilla, and remaining milk. Beat for 2 more minutes, scraping bowl often. Divide batter into two 8-inch layer pans. Bake at 350°F for 30 to 35 minutes. Let cool on racks for 10 minutes before removing from pans.

TABLE B. QUICK-MIX CAKE FORMULA DEVELOPED FOR USE WITH BREAD FLOUR

Ingredients	
Flour	2 c
Sugar	1-1/3 c
Baking powder	3-1/2 tsp
Salt	1 tsp
Shortening	1/2 c
Milk	1 c
Eggs	2
Vanilla	1 tsp

Method. Sift together flour, sugar, salt, and baking powder. Place in mixing bowl with the shortening and approximately 3/4's of the milk. Beat for 2 minutes (150 strokes per minute). Scrape bowl often. Add eggs, vanilla, and remaining milk. Beat 2 more minutes, scraping bowl often. Divide batter into 2 8-inch layer pans. Bake at 350°F for 30 to 35 minutes. Let cool on racks for 10 minutes before removing cakes from pans.

TABLE C. FORMULA DEVELOPED FOR USE IN MAKING BISCUITS WITH IRRADIATED BREAD FLOUR

Ingredients	
Flour	2 c
Baking powder	3 tsp
Salt	1/2 tsp
Shortening	1/4 c
Milk	180-190 cc

Method. Sift into mixing bowl the flour, baking powder, and salt. Cut in shortening. Add milk and mix until dry ingredients are wet. Knead on pastry board 30 times before rolling out to 1/2 inch thickness. Cut biscuits with a 2-inch cutter. Bake at 450°F for 8 to 10 minutes on an ungreased baking sheet.

TABLE D. FORMULA DEVELOPED FOR USE IN MAKING BREAD WITH IRRADIATED FLOUR

Ingredients	
Milk, scalded	1 c
Water	1/3 c
Shortening	2 T
Yeast	1/2 oz
Sugar	1 T
Salt	2 tsp
Flour, sifted	4 c, approximately

Method. Dissolve yeast in water (110°F). Pour scalded milk over shortening, sugar, and salt. When the milk mixture is lukewarm (80-85°F), add the yeast mixture. Add flour gradually. Knead dough 5 or 6 minutes until smooth, then place in a well-greased bowl and allow to rise from 1 hour 15 minutes to 1 hour 30 minutes. Knead dough again for 3 or 4 minutes; then allow to rise again for 45 to 60 minutes. Knead dough again for 1 minute; then shape it to fit the bread pan which is well greased. Allow dough to rise in the pan until slightly more than double in size. Bake for 30 minutes at 400°F and 20 minutes at 350°F. Yield: one (9x5x3) loaf.

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