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IRRADIATION OF FRUITS AND VEGETABLES

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Department of Food Science
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East Lansing, Michigan

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Annual Report**IRRADIATION OF FRUITS AND VEGETABLES****Prepared By****P. Markakis and R. C. Nicholas****with collaborators****W. J. Gill and Noemi Diaz-Santiago****For The****Division of Isotopes Development
United States Atomic Energy Commission****Contract Number AT(11-1)-1592****Period Covered: April 16, 1967 to April 15, 1968****Department of Food Science
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INTRODUCTION

This report covers the second year's research conducted at the Food Science Department of Michigan State University under Contract No. AT (11-1)-1592 of the Atomic Energy Commission. The first year's results, as well as those obtained previously under Contract No. AT (11-1)-1283 of the A.E.C., have already been reported to the sponsoring agency.

During the second year most of the effort of this contractor was concentrated on the study of the irradiation effects on five commodities: asparagus, mushrooms, peaches, strawberries and sweet cherries. The 10,000 Curie Cobalt-60 gamma irradiator of the University of Michigan was used during the first 3 or 4 months of this contract year. Later the new 50,000 Curie Cobalt-60 gamma facility of this Department at Michigan State University was installed and used. Considerable time was devoted to the self-education of the principal investigators and the training of graduate assistants in the operation of the new facility, in the correction of technical difficulties encountered in this operation, and in dosimetry work.

SUMMARY

Asparagus

This year's results confirmed previous findings that irradiation of fresh asparagus retarded the lengthening of the spears. It was observed that 10 Krad inhibited this lengthening almost to the same extent as doses of 30 and 100 Krad. The irradiated spears contained slightly less water than the controls. No change in the fiber plus ash content of the spears during storage was detected as a result of irradiation. An undesirable odor was developed in the irradiated spears after 11 days of storage at 10 C.

Strawberries

A combination treatment of irradiation and soaking in 0.5% Ca^{++} did not yield consistent results in two different experiments, regarding the texture and spoilage rate of the fruit. In both cases, however, irradiation plus soaking resulted in less spoiled fruit than soaking alone.

Sweet Cherries

Sweet Cherries, variety Schmidt, dipped in water at 46 C and 50 C for 4 minutes and subsequently exposed to 100 and 200 Krad of gamma irradiation did not keep better than cherries heated only, or irradiated only, or not treated at all. Heating alone did not cause softening of the cherries but irradiation did, especially at the 200 Krad level. The softened cherries refirmed considerably during storage at 9 C.

Peaches

Dipping Red Haven peaches in water at 46 C or 55 C for 4 minutes and then exposing them to 50 or 100 Krad of gamma irradiation did not improve the keeping of this fruit. Heating alone caused some softening of the fruit during storage at 5 C.

The radiation-induced softening was more severe than that induced by heat.

Mushrooms

This year's results confirmed previous observations by this contractor that gamma irradiation retards the rate at which white cultured mushrooms (Agaricus bisporus, Sing.) open during storage at 5 to 15 C. Appreciable retardation in the rate at which the cap diameter increases and the veil breaks is observed with a dose of 10 Krad. Higher levels of radiation further decreased the rate of cap opening, but in a way less than proportional. The increase in height of the mushrooms was enhanced by 10-20 Krad, but retarded by 100 Krad. The texture and the weight loss of mushrooms was not affected by levels up to 100 Krad. Mushrooms exposed to 50 Krad or higher were judged to darken less than unirradiated controls. The shorter the delay between harvest and irradiation the longer the extension of shelf-life of mushrooms.

ASPARAGUSExperiment I

On May 25, 1967, asparagus was obtained from the Walter Neubauer farm, Romulus, Michigan. It was transported 20 miles, by car, at ambient temperature to Ann Arbor where it was sorted (small and deformed spears were removed), and exposed the same morning to 0, 10, 30, and 100 Krad of gamma radiation. On return without delay to East Lansing (approximately 60 miles) the spears were measured and cut to the length of eight inches. They were then placed into quart-size plastic tubs, butt end down, containing 100 milliliters of water. The samples were stored at 10 C.

At 0, 4, 6, and 11 days after irradiation, 40 spears of each treatment were removed from storage and measured for length. The average values of these measurements appear in Table 1. Seven days after irradiation two samples for each dose level, weighing approximately 30 grams and composed of random sections from 6 spears, were dried in vacuo at 70 C until constant weight. The moisture content appears in Table 2.

At 0, 2, 6, and 11 days after irradiation, an estimate of crude fiber was obtained for three portions of the asparagus spears irradiated at the levels of 0 and 30 Krad (Table 3). The method of analysis is appended to the asparagus report.

Table 1. Length (inches) of asparagus spears irradiated and stored at 10 C. (Average of 40 spears plus or minus one standard deviation).

Dose, Krad	Storage, days			
	0	4	6	11
0	8.00 $\pm$.05	9.05 $\pm$.20	9.05 $\pm$.20	9.10 $\pm$.25
10	8.00 $\pm$.05	8.70 $\pm$.05	8.75 $\pm$.10	8.85 $\pm$.10
30	8.00 $\pm$.05	8.65 $\pm$.10	8.75 $\pm$.10	8.80 $\pm$.15
100	8.00 $\pm$.05	8.65 $\pm$.10	8.70 $\pm$.10	8.85 $\pm$.10

Table 2. Percent water in asparagus spears seven days after irradiation and storage at 10 C.

<u>Dose, Krad</u>	<u>% Water (2 samples)</u>
0	94.2, 93.8
10	93.2, 92.8
30	93.3, 92.9
100	93.3, 93.1

Table 1 indicates that irradiation slightly retarded the lengthening of asparagus spears during storage. A t-test applied to the averages between 0 and 10 Krad indicated that the unirradiated spears were significantly ($t_{.05}$) longer at all three periods of storage. There was no significant difference in spear lengthening between 10, 30, and 100 Krad at any of the three storage periods.

From the figures of Table 2 it appears that the unirradiated spears contained slightly more water than the irradiated ones. This would agree with the observations on spear lengthening.

Table 3. Percent crude fiber-plus-ash in asparagus irradiated and stored at 10 C.
(Average of 2 samples, 75 g each).

Dose Krad	Portion, in. From cut-end	Storage Time (days)			
		0	2	6	11
0	4 - 6	.94	.94	.74	.72
	2 - 4	.78	.91	.76	.79
	0 - 2	1.38	1.84	1.36	1.44
30	4 - 6	.82	.90	.82	.80
	2 - 4	.90	.84	.74	.82
	0 - 2	1.33	1.06	.96	1.00

Analysis of variance

Source	DF	SS	MS	F
Total	47	4.6234	--	--
Dose (D)	1	.0173	.0173	.75
Storage (S)	3	.2272	.0757	3.26
Portion (P)	2	3.9546	1.9773	85.33**
D S	3	.0660	.0220	3.46*
D P	2	.0501	.0250	3.84*
S P	2	.0922	.0154	2.43
D S P	6	.0636	.0106	1.67
Error	24	.1524	.0063	--

F for dose, storage and portions was calculated from an average MS of DS + DP to reduce type error I.

The results of the crude fiber determinations are given in Table 3. The analysis of variance showed the fiber-plus-ash content to be independent of dose level and storage period, but highly dependent on the portion of spear. The lowest 2 inches of an 8-inch spear contained considerably more crude fiber than the higher portions. The two slightly significant interactions, dose-storage and dose-portion, are probably due to one extraordinarily high figure.

At the end of the storage period (11 days at 10 C), the following observations were made:

0 Krad samples -- The spears showed little or no decay and no objectional odors were present. The butt ends of the spears were cracked and split for a depth of about 1/8 inch. The color was acceptable.

10, 30, and 100 Krad samples -- Some of the spears showed a loss of rigidity and developed an undesirable (fishy) odor after 11 days of storage. As in the control samples, the butt ends of the spears were split.

Procedures for Crude Fiber Determination for Asparagus (based on FDA method for determining crude fiber of green beans)

1. Approximately 40 spears were randomly chosen from the samples to be analyzed.
2. Each spear was divided into two-inch portions, measured from the bottom, and these portions were sorted into three groups:
 - 0-2" from bottom
 - 2-4" from bottom
 - 4-6" from bottom
3. Each two-inch portion was cut into five or six smaller pieces, and all the pieces in each group were mixed together thoroughly. From this point, all steps were done in duplicate, for each of the three groups.
4. Seventy-five grams of asparagus pieces plus 100 ml of tap water were mixed in a Waring blender driven at slow speed for 45 seconds, and then transferred to a 500-ml Erlenmeyer flask. The blender jar was rinsed with 125 ml of water into the flask.

5. The water-asparagus mixture was boiled under reflux for 10 minutes, then stirred in a malted milk stirrer at low speed (one scalloped blade) for 60 seconds.
6. Twenty-five ml of 50% (by weight) sodium hydrozide were added, and the mixture was boiled under reflux for 5 minutes.
7. The digested mixture was poured through a tared, 30-mesh wire screens and washed with low-pressure distilled water until the filtrate was clear. The residue was assumed to be crude fiber plus ash.
8. The screen and contents were dried overnight at 100 C, cooled in a desiccator, and weighed.

NOTE: The coefficient of variation of this method is 8% (for a crude fiber plus ash content of 1%).

STRAWBERRIES

Experiment I

On the morning of June 27, 1967, fresh strawberries of the Midway variety were obtained from the Makielski Berry Farm, Ypsilanti, Michigan. They were hand sorted, and all spoiled, immature, over-ripe, very large and very small berries were removed, by a student crew. The berries were then placed in pint-size wooden baskets and transported at ambient temperature to the Phoenix Memorial Laboratory (approximately 15 miles), where equal quantities of the sorted berries were given doses of 0, 200, and 400 Krad. In the afternoon the fruit was transported unre-
frigerated to the Laboratory at E. Lansing (approximately 70 miles from the irradiation site), where the berries of each dose were soaked in a solution of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, corresponding to 0.5% Ca^{++} , for 30 minutes, at room temperature. Following overnight cooling at 2 C, the berries were placed in storage at 15 C to simulate unrefrigerated display conditions.

At the end of three days of storage, the berries were tested for percent sound fruit (by weight) and shear resistance (Allo-Kramer shear press, 250 lb. ring, range 50 Lo). Shear resistance was measured on destemmed representative samples, before sorting for sound and unsound berries. Any berry showing decay or mold was considered to be unsound. Only the peak value of the shear curve is reported. A visual inspection of the berries was also made at the end of six days of storage.

Table 4. Percent sound fruit (by weight) of Midway strawberries three days after irradiation and a 30 minute soak in 0.5% Ca^{++} . Averages of 4 pint-samples stored at 15 C.

Dose, Krad	Ca^{++} Soak	No Soak
0	28	25
200	53	18
400	44	9

Analysis of variance

A. Two-way Classification

Source	DF	SS	MS	F
Total	23	9530	414.3	----
Dose (D)	2	455	222.5	.96
Soak (S)	1	3577	3577.0	15.38**
DXS	2	1314	657.0	2.82
Error	18	4184	232.4	----

B. Single Classification

Source	DF	SS	MS	F
<u>No Soak</u>				
Total	11	1938.7	176.2	---
Dose	2	488.7	244.3	1.52
Error	9	1450.0	161.1	---
<u>Soak</u>				
Total	11	4456.9	405.2	---
Dose	2	1933.2	966.9	3.45
Error	9	2523.7	280.4	---

Table 4 contains the percent sound fruit values at the end of three days of storage. Each entry is the average of four pints. The weight of sound and spoiled berries is given in Appendix Table I. The data show that irradiation did not affect the spoilage rate of the fruit under the conditions of this experiment. Irradiation plus soaking, however, significantly reduced the proportion of spoiled strawberries.

Table 5. Peak shear resistance (chart readings) of Midway strawberries three days after irradiation and a 30 minute soak in 0.5% Ca^{++} . Average of eight 100 g samples tested in an Allo-Kramer shear press (250 lb. ring, range 50, Lo). Storage at 15 C.

Dose, Krad	Ca^{++} Soak	No Soak
0	33.4	30.1
200	30.9	32.1
400	34.8	29.9

Analysis of variance

Source	DF	SS	MS	F
Total	47	1172.0	--	---
Dose (D)	2	5.6	2.8	0.11
Soak (S)	1	63.0	63.0	2.59
DXS	2	80.5	40.3	1.66
Error	42	1022.9	24.3	---

Table 5 contains the average peak shear values obtained with the Allo-Kramer press after three days of storage and indicate that neither irradiation nor soaking exerted any statistically significant effect on the shear resistance of the berries. The individual shear press readings are given in Appendix Table 2.

After six days of storage at 15 C, the berries from all treatments were .95 - 100% spoiled.

Experiment II

On July 10, 1967, strawberries of the Midway variety were obtained from the Fruit Haven Nursery, Kaleva, Michigan. Thirty quarts of the berries were soaked at Kaleva in a 0.5% Ca^{++} solution for one-half hour at room temperature. On return to East Lansing (approximately 200 miles, ambient temperature) the berries were found to be of low quality (many were over-ripe and spoiled).

The berries were sorted as in Experiment I, placed in wooden pint baskets and given doses of 0, 200, and 400 Krad in the MSU-Food Science Irradiator. After irradiation the berries were placed in storage at 3 C, later in the afternoon of the same day.

At the end of 4 days of storage the berries were examined for percent sound fruit and shear resistance. Percent sound fruit, weight basis, was determined by sorting out all berries showing decay or mold and weighing. Table 6 gives the percent sound fruit values calculated from these measurements. The weight of sound and spoiled fruit is given in Appendix Table 3.

Table 6. Percent sound fruit (by weight) of Midway variety strawberries 4 days after irradiation and 30 min. soak in 0.5% Ca^{++} . Averages of 8 pints stored at 3 C.

<u>Dose, Krad</u>	<u>Ca^{++} Soak</u>	<u>No Soaking</u>
0	12.2	21.5
200	23.0	27.2
400	20.3	28.3

Analysis of variance

A. Two-way Classification

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Total	47	3799.88	---	---
Dose (D)	2	721.02	360.51	6.23**
Soak (S)	1	589.02	589.02	10.2 **
DXS	2	60.74	30.4	0.53
Error	42	2429.10	57.84	---

B. Single Classification

1. Soak

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Total	23	1696.6	73.77	----
Dose (D)	2	552.9	276.4	5.08*
Error	21	1143.7	54.46	-----

2. Soak

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Total	23	1522.2	66.2	---
Dose (D)	2	236.9	118.4	1.94
Error	21	1285.3	61.2	---

An analysis of variance indicated that irradiation dose had no significant effect on the percent sound fruit when the berries were not soaked in the Ca^{++} solution. However, irradiation significantly increased the percent sound fruit when the berries were soaked. The Ca^{++} soak treatment caused a significant ($P=.99$) overall decrease in percent sound fruit. Perhaps this is due to the heavy microbial load of the berries which was spread by the soaking to the uncontaminated berries. Had the soaking been applied after sorting, the adverse effect might have been avoided as was the case in Experiment I.

Table 7 gives the average peak shear resistance chart readings in an Allo-Kramer shear press of the berries 4 days after treatment. The individual shear press chart readings are given in Appendix Table 4.

Table 7. Peak shear resistance of Midway strawberries 4 days after irradiation and a 30 min. soak in 0.5% Ca^{++} . Average of 8 readings of 100 gram samples in an Allo-Kramer shear press, 250 lb. ring, range 50 Lo. Storage at 3 C.

<u>Dose, Krad</u>	<u>Soak^a</u>	<u>Not Soaked</u>
0	30.0	25.4
200	28.8	21.2
400	25.5	22.4

Analysis of variance

A. Two-way Classification

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Total	47	901.9	19.2	---
Dose (D)	2	119.5	59.8	5.35**
Soak (S)	1	310.1	310.1	27.76**
DXS	2	472.3	236.2	21.14**
Error	42	469.2	11.17	---

B. Single Classification

1. Soak

<u>Source</u>	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Total	23	285.8	12.4	---
Dose	2	86.3	43.2	4.54*
Error	21	199.5	9.5	---

2. No Soak

Source	DF	SS	MS	F
Total	23	306.0	13.3	-
Dose	2	72.8	36.4	3.28
Error	21	233.2	11.1	-

A two-way classification analysis of variance indicated that irradiation significantly reduced the shear resistance of the berries, while soaking exerted a strong firming effect on the fruit. However, when the radiation effect was analyzed separately for the soaked and unsoaked berries (single classification), it was found that the radiation-induced softening was significant only for the soaked berries. The dissimilar response of the strawberries to a combination of Ca^{++} soaking and irradiation in the two experiments may be due to the different locations where the fruit was grown, the different degree of maturity, the different time of soak with respect to irradiation and the different temperature of post-irradiation temperature (Southeast Mich., less mature, post-irradiation soak, 3 C in Experiment II).

SWEET CHERRIES

On July 27, 1967, Schmidt variety sweet cherries harvested on that day were obtained from Cherry Growers, Inc., Traverse City, Michigan. They were transported by unrefrigerated truck to East Lansing, 175 miles away, where they were stored overnight at 3 C. A mechanical harvester had been used and considerable mechanical injury had occurred.

On the following day, bruised and immature cherries were taken out and any remaining stems were removed. The following treatments were then given:

- I. No contact with water was allowed
- II. The cherries were dipped in 26 C water for 4 minutes, then put into a 13 C water spray for 5 minutes

III. The cherries were dipped in 46 C water (4 min.), then sprayed as in II.

IV. The cherries were dipped in 50 C water (4 min.), then sprayed as in II.

After draining and packing the cherries into pint-size wooden baskets, each treatment was divided into three groups of 16 baskets which were exposed to 0, 100 and 200 Krad in the M.S.U. Food Science Gamma Facility, 1.5 days after harvesting. Following irradiation, the samples were placed in storage at 9 C. The weight of cherries in a basket varied from 255 to 360 grams.

At 4 and 11 days of storage, the samples were tested for percent sound fruit. At both times, 8 pints of each treatment were individually sorted and inspected for spoiled fruit. This allowed weighing of sound and unsound fruit and the calculation of percent sound fruit. Table 8 contains the average and ranges of values for these 8 pints for each treatment and time interval. Inspection of this Table makes it clear that no differences in per cent sound fruit were caused by irradiation and/or heat treatment.

Table 8. Percent sound fruit, by weight, of Schmidt sweet cherries 4 and 11 days after exposure to heat and irradiation. Average and range of 8 pints of fruit stored at 9 C.

Dose, Krad	Water treatment	Days of Storage			
		4		11	
		Ave.	Range	Ave.	Range
0	None	83	74-94	37	15-59
100		80	64-89	33	17-47
200		79	67-90	32	17-51
0	26 C	83	76-92	28	23-37
100		78	70-89	33	18-53
200		82	74-87	32	13-57
0	46 C	85	82-91	38	24-52
100		78	71-89	44	28-75
200		84	78-94	33	15-42
0	50 C	81	66-95	48	31-69
100		78	69-96	38	27-46
200		84	70-95	37	24-52

At 0, 4, and 11 days of storage samples were pitted mechanically and five 100-gram aliquots for each dose-water temp. - storage time treatment were tested in an Allo-Kramer shear press. The average values and a complete factorial analysis of variance appear in Table 9.

Table 9. Peak shear values for Schmidt sweet cherries exposed to heat and irradiation. Average of 5 chart readings on 100 g samples in an Allo-Kramer shear press (250 lb. ring, range 50, Lo). Storage at 9 C.

Dose, Krad	Water treatment	Storage time, days		
		0	4	11
0	None	20.8	21.6	21.8
100		17.8	20.4	22.8
200		15.0	19.2	23.2
0	26 C	20.2	20.8	21.8
100		17.2	19.8	23.2
200		13.2	19.2	24.4
0	46 C	21.0	23.0	27.8
100		18.0	22.6	26.2
200		13.8	21.4	26.2
0	50 C	20.8	23.8	26.6
100		17.6	22.6	25.4
200		13.8	21.8	27.2

Analysis of variance

Source	DF	SS	MF	F
Total	179	3639	--	---
Dose (D)	2	208	104	12.38
Time (T)	2	1594	797	95 **
Heat (H)	3	194	65	7.75**
DXT	4	294	73.5	8.75**
DXH	6	12	2	.24
TXH	6	110	18	2.14
DXT	12	18	1.5	0.18
Error	144	1209	8.4	---

Irradiation generally softened the cherries. The softening, however, became insignificant after 11 days of storage. Time of storage had a very significant firming effect. It is not known, however, whether this was due to a biological recovery of the fruit or simple desiccation, since no moisture determinations were made. An apparent firming effect of the heat treatment was noticeable after 4 and 11 days of storage. Here again greater loss of moisture during storage from the heated than the unheated fruit is a possible explanation.

PEACHES

On August 15, 1967, twelve bushels of freshly harvested Red Haven peaches were purchased from Bardon Brothers, Inc., South Haven, Michigan. They were transported 110 miles to East Lansing by truck, without refrigeration, and placed the same afternoon in storage overnight at 5 C. The following morning, the peaches were removed from storage, sorted for uniformity of maturity, and given the following water treatment:

1. No treatment
2. 24 C water bath for 4 minutes
3. 46 C water bath for 4 minutes, then 14 C water spray for 3 minutes
4. 55 C water bath for 4 minutes, then 14 C water spray for 3 minutes

Following the water treatment, the peaches were drained for 30 minutes, placed in 10 lb. Kraft paper bags and irradiated. Approximately 4 bushels were used for the 4 water treatments (no water treatment, 24, 46, and 55 C water treatments) at 0 Krad and 3 bushels for each of the 50 and 100 Krad levels (corresponding to 24, 46, and 55 C water treatments). It was not deemed necessary to irradiate samples untreated with 24 C because no differential synergistic effect between heat and irradiation was expected among samples treated and untreated with 24 C water.

Table 10. Number of defects (mold growth, soft spots, discolored spots) per peach on fruit subjected to various combinations of irradiation and heating. Average of 30 randomly chosen peaches, stored at 5 C for 15 days and followed by 7 days at 20 C.

Dose, Krad	Water treatment (a)	Days of Storage			
		15		22	
		Ave.	Range	Ave.	Range
0	None	1.4	0-4	5.7	0-20
	24 C	1.4	0-5	3.9	0-15
	46 C	2.7	0-7	4.7	0-15
	55 C	9.7	3-20	5.7	2-20
50	24 C	2.7	0-12	4.5	1-18
	46 C	1.9	0-4	3.9	2-10
	55 C	10.2	6-16	8.0	4-15
100	24 C	3.4	0-7	5.0	2-10
	46 C	3.5	0-6	5.0	2-10
	55 C	8.7	3-15	6.7	3-15

(a) Placed in a water bath at the given temperature for 4 minutes then sprayed for 3 minutes with water at 14 C. The 24 C samples were not subjected to the spray.

On the 15th and 22nd days of storage the quality of the peaches was evaluated by counting soft, discolored and moldy surface spots and by measuring the resistance to puncture by the Magnus-Taylor tester on fruit, the skin of which had been removed. Tables 10 and 11 summarize the results. On the 22nd day the texture was too soft to be measured by this instrument.

Table 11. Magnus-Taylor puncture values (7/16 in. tip) for Red Haven peaches subjected to various combinations of irradiation and heating. Average of 8 measurements on the right cheek of 8 peaches stored at 5 C.

<u>Dose, Krad</u>	<u>Water treatment (b)</u>	<u>Days of storage</u>			
		0	15		
		Ave.	Range	Ave.	Range
0	None	21	18-27	19	11-30
	24 C	20	18-22	13	4-26
	46 C	19	12-24	13	4-21
	55 C	21	18-25	11	3-16
50	24 C	17	14-20	7	3-13
	46 C	16	12-20	9	5-16
	55 C	17	15-20	7	3-13
100	24 C	11	9-13	6	4-9
	46 C	10	7-14	8	4-13
	55 C	9	7-13	8	3-12

(b) Same as in Table 10.

The results of this experiment indicate that heating of Red Haven peaches in a water bath at 46 C or 55 C for 4 minutes and subsequently exposing them to 50 or 100 Krad of gamma radiation did not improve the keeping quality of this commodity. On the contrary, the water dip at 55 C resulted in a mottled appearance of the fruit, while the irradiation softened them. No effort was made to separate the fruit to sound and unsound, because in this experiment, more than in others, such a separation would be the result of an arbitrary and subjective judgment.

MUSHROOMS

A. Introductory Remarks

1. Objective: The over-all purpose of these experiments was to partially define the circumstances under which radiation will extend the storage life of fresh cultured mushrooms and to develop some quantitative measurements of storage life. There are no precisely described indices which allow an exact definition of the storage life of mushrooms. In the published recommended storage conditions (Wright et al., 1963^a) the term "prime condition" is used without further elaboration. It is our conviction that some of the factors that contribute to the impression of degradation are the presence of mold growth, slime, putrid odor, darkening of the fruiting body, opening of the cap exposing to view the gills (which become progressively darker), lengthening of the stem, and a withered or desiccated appearance. Any one of these quality attributes, depending no doubt on the degree of degradation, might signal the end of storage life in the eyes of a potential purchaser. Packaging practices vary widely even in our local markets: open climax baskets from which the customer may help himself, cardboard boxes with ventilation holes, closed cardboard boxes with see-through, moisture-proof film. There are marketing considerations and post-harvest physiological events which might make any one of these containers desirable. In our judgement, no matter what wholesale or retail package, and no matter what storage factor is considered, temperature is the most important factor which governs the length of storage life regardless of how storage life is measured. Therefore, temperatures of the storage (following treatment) is the experimental variable which we controlled. Commercial practices at the retail level in our locality probably are not the best. As a guess, mushrooms may be held at temperatures anywhere from 50 to 70 F.

^aWright, R.C., Rose, D.H., and Whiteman, T.M., 1963. Agr. Handbook No. 66, U.S. Dept. of Agr., Washington, D.C.

2. Quality factors: In the absence of standardized or recognized quality attributes or variables, the right-thinking researcher invents them. We have used one or more of the following variables in analyzing the results of the experiments reported herein.

a. Transpiration loss. This was a variable to be controlled at a level between too rapid a loss and no loss at all. The last of several preliminary experiments designed to determine a reasonable control level is described in detail below.

b. Cap opening. It appeared to us that the process of the opening of the cap could be described quantitatively. For this purpose we chose a parameter which we named the Opening Ratio, O.R. (See Figure 1). In the button stage, if the cap is curled inward until the tip of the gills touches the stem, the opening gap, e , less the diameter of the stem, d , will be 0 and O.R. will be 0. As the mushroom cap opens, O.R. becomes larger and, in principle, has no upper bound. As a practical matter, it is our judgment that mushrooms which have an O.R. between 0.8 and 1.0 are, unless some other quality factor over-rides, at the end of their storage life. The chief disadvantage of O.R. as a research tool is that the measurement is destructive: the mushroom must be cut in half to make the measurements. However, it is superior to the Degree of Opening, D.O. (discussed below), in that progressive opening can be followed during the storage period before the veil breaks and during the period after the veil is completely broken away from the stem and the gills are fully exposed.

c. Degree of Opening, D.O. Partly a concomitant of the phenomenon of cap opening is the breaking away of the veil from the ring (or parts of the ring and veil together breaking away from the stem). We judge this breaking away to be a loss of quality to the extent that a broken veil indicates that the desirable button stage has ended. The breaking way is progressive and can be measured by remarking the extent of separation along the circular line between veil and ring. The

measurement we used was the ratio of the arc of separation to the arc of a complete circle; we made the measurement with a transparent, circular gage graduated in tenths (36°) of a circle. The gage has a hole in the center into which the stem is inserted. This ratio is called the Degree of Opening, D.O., and ranges from 0 (veil unbroken) to 1.0 (veil completely separated).

Several events can cause the veil to break away: normal opening of the cap during which time the veil stretches and finally breaks at some point; desiccation, which causes a loss of elasticity in the veil; and shrinkage in the diameter of the stem - in this case the stem and ring break away from the veil. Whereas changes in O.R. are slow and nearly linear with time in storage, D.O. progresses relatively faster and follows in an S-form curve.

d. Mushroom height. As the mushroom, in storage, continues to respire and the cap opens, the stem elongates and shrinks in diameter. We judge this elongation-shrinkage to be undesirable because the smaller stem diameter enhances the exposed view of the gills and because the stem, as it elongates, often bends and lends what can be described as a debilitated air to the fruiting body.

e. Texture. Texture is a somewhat elusive quality to discuss for fresh mushrooms inasmuch as mushrooms are usually sauteed before they are eaten and, as might be expected, there are no well-defined quality standards for mushroom texture. Moreover, different parts of the mushroom, partly because of structural differences among the various parts, have quite different responses to stress. Nevertheless, since radiation is known to soften some food products, even at modest doses, it seemed advisable to make some measurements of texture of the fresh mushrooms just for the record. All texture measurements were made on an Allo-Kramer shear press with 75-g samples.

B. Experimental Conditions.

1. Procurement, initial quality, and transportation. All mushrooms used in the 6 experiments described below came from the Great Lakes Mushroom Cooperative, Warren, Michigan. In all cases we selected the mushrooms ourselves, in Warren, from stocks on hand at the Cooperative. Selection was based on the relative appearance of the baskets in the cooler at the Coop, and there was no effort made to get a pre-history on the mushrooms selected. The initial quality varied in respect to color, average size, amount of adhering dirt, and other impressionistic factors. It was our practice to buy an amount of mushrooms far in excess of requirements and sort ruthlessly, primarily on the basis of tightness of cap, uniformity of shape, absence of bruises, and uniformity of size. Except for the first mushroom experiment, all irradiations were done with the MSU Food Science Research Irradiator. In Experiment 1 the mushrooms were brought to MSU, sorted into the various containers used in that experiment, and taken to Ann Arbor the next day for irradiation. While a reasonable effort was made to keep all delays and adverse handling to a minimum, no record was made of times, temperatures, and relative humidities, prior to irradiation. All the handling and sorting was done at ambient; transportation was at ambient; the mushrooms were carried in open peck baskets. Zero time in the experiments described below was measured from the time of irradiation. Warren is about 80 miles from East Lansing; Ann Arbor is about 60 miles from East Lansing. The dates on which we got mushrooms and irradiated them are, with the exception of Experiment 1 noted above, Exp. No. 1 - 4/6/67, No. 2 - 10/24/67, No. 3 - 11/30/67, No. 4 - 12/18/67, No. 5 - 1/9/68, and No. 6 - 3/5/68.

After irradiation, the care of the samples was less cavalier: only a few samples at a time were brought out of storage for examination and were returned as quickly as possible, depending on the particular test.

2. Control of storage variables. The refrigerated cubicles in which the mushrooms were stored are especially designed for close temperature control, about ± 1 F maximum variation throughout the cubicle and throughout the storage period. The relative humidity in these cubicles varies somewhat with the storage temperature and with the temperature differential between coil and set temperature. Although the relative humidity in the cubicle puts a lower limit on the humidity in the mushroom container (which limit is in the neighborhood of 90%), the actual humidity inside any one container is governed by the rate of exchange between cubicle atmosphere inside the container, as well as the rate of respiration and transpiration. Except for a few tests for which the mushroom containers were entirely closed (and the relative humidity was 100%), the relative humidity in the containers is not known. The air circulation in these cubicles is continuous.

3. Radiation. All irradiation referred to in this report was done with Co-60. During irradiation the exposures were interrupted at half-time and the samples turned 180 F, so as to minimize the variation in dose within the container. Dosimetry of the MSU Research Irradiator (with which all irradiations after July, 1967 were performed) is described in another report.

C. Experiments

1. Type of Container, Dose, Transpiration Loss, Texture. This experiment is, in part, an extension of a previous experiment (reported in Co-1592-25 Irradiation of Fruits and Vegetables Annual Report April 16, 1966 - April 15, 1967) which demonstrated the interdependence of transpiration losses, dimensional changes, and other undesirable effects, particularly microbial growth leading to off-odors and slime development. It had been determined that, independent of irradiation, there were at least two ways to prevent or retard opening of the cap: first, sealed containers, in which, we presume, the high carbon dioxide content and low oxygen content

created by respiration prevented further maturation as manifested by opening of the cap; and, second, rapid drying, that is, an average rate of weight loss of 5%/day or more. However, in the sealed containers, because the humidity is 100%, microbial growth is prolific. While there is no microbial growth if the mushrooms are rapidly dried, there is, unfortunately, extreme withering and darkening. At the time of the present experiment we were looking for a container which in our storage cubicles (where the air circulation is continuous and at fairly high velocities, and where the humidity is above 90%) would permit enough moisture loss to prevent accumulation of free water in the container, but which was not so high as to cause extreme shriveling of the mushrooms.

The containers used in the test are described in Table 12. Two containers of each type, except closed tubs and commercial boxes, in which one container was used, were irradiated at 0, 10, and 100 Krad, stored at 10 C, and examined at the end of a week for weight loss and Degree of Opening. Table 13 shows the results. Only one set each of closed containers and commercial boxes were tested because we already knew these containers were unsatisfactory, and the results would provide a check against the previous container experiment referred to above. Table 14 shows the analyses of variance of the transpiration losses.

Table 12. Partial description of containers used in mushroom experiments.

<u>Container</u>	<u>Shape</u>	<u>Inside dimensions</u>	<u>Internal volume, cm³</u>	<u>Surface area, cm²</u>	<u>Surface-to-volume, cm⁻¹</u>	<u>Material</u>
Tub	Frustum of a right cone	$r_1=5.32$ cm ^a $r_2=4.09$ cm $h=13.7$ cm ^a	960	550	0.57	0.015-in. thick polyethylene
Box, commercial	Rectangular Parallelepiped	$l=16.8$ cm $w=12.0$ cm $h=6.0$ cm	1200	750	0.62	0.02-in. thick wax-coated (one side) cardboard, weight 180 lb/ream (b)

<u>Container designation as used or modified</u>	<u>Description of use or modification</u>	<u>Open area as percentage of total</u>
Tub, open	Top left uncovered	0
Tub, closed	Top covered with any one of several water vapor-proof materials held in place with a rubber band	16
Tub, perforated	Six 3/8-in. diameter holes punched in the side with a heated glass rod: total hole area 4.3 cm ² ; top covered with any of several water-vapor proof materials.	0.8
Box, commercial	Used as received with 8 7/16-in. diameter holes, 4 in the top, 4 in the bottom: total hole area 7.8 cm ²	1.0
Box, commercial modified	The 8 holes referred to immediately above were reduced in size to 1/4-in. in diameter: total hole area 2.5 cm ²	0.3

^aTo the fill line which is about 3/8" below the rim of the tub

^b300,000 in.²

Table 13. Effect of irradiation and container on transpiration and extent of opening of mushrooms after 7 days' storage at 10 C.

<u>Container^a</u>	<u>Dose, Krad</u>	<u>Initial weight,g</u>	<u>Weight loss after 7 days, %^b</u>		<u>Degree of opening, D.O.^c</u>
			<u>Each container</u>	<u>Average, all 3 doses</u>	
Tub, open	0	272.8	33		1.00
		257.1	25		
	10	260.1	22		.50
		287.5	26		
	100	259.5	26		.10
		286.0	27	26	
Tub, closed	0	288.6	0.7		.50
	10	293.1	0.8		.30
	100	264.7	0.5	0.7	.34
Tub, perforated	0	273.8	6.3		1.00
		272.6	7.8		
	10	258.2	5.7		.66
		288.7	7.5		
	100	247.5	5.5		.54
		268.4	4.2	6.2	
Box, commercial	0	429.8	21		1.00
	10	415.6	22		1.00
	100	373.7	19	21	.36
Box, commercial modified	0	403.2	17		1.00
		417.0	19		
	10	413.5	17		.95
		379.9	18		
	100	397.3	18		.47
		414.3	17	18	

(a) See Table 12 for description of containers. (b) The analysis of variance, of the results for a given container and for which there were duplicate containers, showed no significant difference in transpiration loss due to radiation. (See Table 14).

(c) The contents of both containers at a given dose, for those treatments for which there are duplicate containers, was analyzed as a single combined lot. There was about 25 mushrooms in each tub and about 38 mushrooms in each box. D.O.'s of each mushroom are not available.

Table 14. Analyses of variance of percentages of transpiration loss in irradiated mushrooms stored for 7 days at 10 C. (Data of Table 13)

Container ^a	Source of variation	Degrees of freedom	Mean square	F ^b
Tub, open	Between doses	2	12.5	0.93
	Within a dose	3	13.5	
Tub, perforated	Between doses	2	2.70	2.3
	Within a dose	3	1.20	
Box, commercial, modified	Between doses	2	0.17	0.17
	Within a dose	3	1.00	

^aSee Table 12 for description of containers.

^bF_{.95} (2,3) = 9.55.

The texture was measured on mushrooms from this same lot irradiated at doses of 0, 10, 50, 100, and 500 Krad. All these mushrooms were stored in perforated tubs at 10 C. Texture measurements after both 1 and 7 days' storage are given in Table 15. With two trips to Ann Arbor and weighing the samples for the transpiration test, day zero was over before there was enough time left to get zero-day texture readings. The analyses of variance of the texture (shear resistance) measurements are given in Table 16.

Discussion: It was on the basis of the results of this experiment that perforated tubs were selected for many subsequent mushroom experiments. The transpiration losses in open tubs and in commercial boxes was excessive; closed tubs were unsatisfactory, as mentioned, because of the high humidity and concomitant microbial growth. Radiation had no demonstrable effect on transpiration loss (Table 14). Radiation does retard opening, as inferred from the Degree of Opening. In all the containers open to some extent, the D.O. was 1.0 by the end of 7 days for unirradiated mushrooms; in the closed tub, unirradiated mushrooms failed to open completely probably because of the high CO_2 and low O_2 atmosphere.

The analyses of variance of the shear resistance (Table 16) suggests that there is a softening with dose; however, this softening is only evident at 500 Krad; at doses of 100 Krad and below there was no change in shear resistance as storage time increases from 1 to 7 days. It may be remarked that, since the sample weight for shear tests was always 75 g, after 7 days' storage there was a higher proportion of solids in the portions tested.

Table 15. Shear resistance^a, chart units,, of whole irradiated mushrooms stored in perforated tubs^b at 10 C (50 F). The entries are the averages of several^c 75-g lots.

<u>Dose,</u> <u>Krad</u>	<u>Length of storage period</u> <u>After irradiation, days</u>	
	<u>1</u>	<u>7</u>
0	50	51
10	51	54
50	54	49
100	53	50
500	46	42

^aAllo-Kramer shear press, 250-lb ring, range 50, Lo.

^bSee Table 12 for description of containers.

^cSix lots for each dose after 1 day's storage; 5 lots for each dose at 7 days' storage except 50 Krad for which there were 4 lots.

Table 16. Analysis of variance of shear resistance exhibited by 75-g lots of whole, irradiated mushrooms stored at 10 C (50 F) in perforated tubs (data of Table 15).

<u>Length of storage</u> <u>after irradiation, days</u>	<u>Source of</u> <u>variation</u>	<u>Degrees of</u> <u>freedom</u>	<u>Mean</u> <u>square</u>	<u>F</u>
1	Among doses	4	62.2	6.6**
	Within a dose	25	9.38	
7	Among doses	4	92.8	6.4**
	Within a dose	19	14.5	

** P= 0.01

2. Opening Ratio and Degree of Opening vs. Dose (Storage at 10 C). Having settled the question of a container suitable for these studies, one which would minimize the effects of desiccation on the one hand and microbial spoilage on the other (COO-1592-25, Report, 1966-67) a second test was designed to determine in more detail the progress of Opening Ratio and Degree of Opening as function of dose and storage time. Table 17 gives the average value of these two opening characteristics. Figure 2 shows the change in Opening Ratio as a function of time and dose.

Since the Opening Ratio is a destructive measurement, it follows that each entry and plotted point (Table 17, Figure 2) is an average for a different group of mushrooms. The variation in O.R. among mushrooms similarly treated is fairly large: for the 30 mushrooms irradiated at 50 Krad and stored for a week the coefficient of variation in O.R. was 35% (a standard deviation of 0.2). If this standard deviation is representative of the 30 mushroom groups, then a difference of about 0.1 between means in Table 17 would be required for significance at the 95% level of confidence. The difference in the rate of opening (O.R./day) between irradiated and unirradiated mushrooms is clearly demonstrated, but no difference in O.R., or, at best, a small one, is evident among mushrooms irradiated at various doses between 10 and 100 Krad.

Degree of Opening as an index of quality has some interesting features (Table 18). First, there is a tendency for the mushrooms subjected to a given treatment to be clustered at one or both ends of the D.O. range; this fact is attributed to the rapidity of the process of separation of veil, once it begins. Second, the data suggest the need for either very large samples or, if possible, for following the same mushrooms throughout the storage period; compare the two 20-Krad groups at 2 vs. 7 days. Third, it is clear that these data cannot be handled, as is, by analysis of variance; chi-square could be used if the urge arises.

Table 17. Opening Ratio (O.R.) and Degree of Opening (D.O.) of mushrooms irradiated and stored in perforated tubs at 10 C (50 F)^a.

Opening characteristic	Storage time after irradiation, days ^b							
	1		2		4		7	
	O.R.	D.O.	O.R.	D.O.	O.R.	D.O.	O.R.	D.O.
Dose, Krad								
0	0.42	0.2	0.50	0.4	0.76	0.9	1.32	1.0
10	.38	0.1	.35	.1	.41	.5	.52	.8
20	.31	0.0	.43	.3	.50	.6	.50	.5
50	.29	0.0	.36	.2	.45	.2	.56	.6
100	<u>.38</u>	0.0	<u>.38</u>	.0	<u>.50</u>	.4	<u>.56</u>	.4
Mean, All irradiated	0.34		0.38		0.46		0.53	

^a Average of measurements on 30 mushrooms for each dose and time interval.

^b Original Degree of Opening of all mushrooms was 0; the average original O.R. taken on 60 mushrooms was 0.30, range 0.10 - 0.57, std. dev. = 0.11.

Table 18. Distribution (percentage in the given range) of Degree of Opening (D.O.) among irradiated mushrooms stored at 10 C (50 F).^a

D.O., range	Storage time after irradiation, days					
	2			7		
	0.0 - <u>0.33</u>	0.34- <u>0.67</u>	0.68- <u>1.00</u>	0.0 - <u>0.33</u>	0.34- <u>0.67</u>	0.68- <u>1.00</u>
Dose, Krad						
0	50	10	40	0	0	100
10	80	20	0	10	20	70
20	60	10	30	30	20	50
50	80	10	10	30	20	50
100	100	0	0	60	10	30

^a 30 different mushrooms for each dose and storage time.

The results of this test may be summarized as follows:

- a. Radiation in the range of 10 - 100 Krad reduces the rate at which mushrooms open, as measured by O.R./day;
- b. There is little, if any, difference in this reduced rate of opening, O.R./day, among the several doses tested;
- c. There may be a difference in the Degree of Opening, D.O., among the various irradiated groups in that at the higher doses, 50 and 100 Krad, the average D.O. of these two groups taken together is higher at all storage times than is the average D.O. of the 10 and 20 Krad groups.

At the end of a week's storage at 10 C (50 F), the mushrooms irradiated at 20, 50, and 100 Krad had an acceptable appearance. Although the veils in just over half of the mushrooms treated at the three highest dose levels had begun to separate, we believe a good deal of this effect can be attributed to desiccation during storage. The caps of the control mushrooms, which were fully opened, appeared to have darkened more than any of the irradiated samples, particularly those at 50 and 100 Krad.

3. Dimensional Changes vs. Dose (One storage temperature) and Texture. The previous experiment revealed no difference in the rate of opening O.R./day, among the groups of mushrooms irradiated in the range 10 to 100 Krad; there was a strong hint, however, that some additional benefit, such as reduced Degree of Opening or reduced darkening, might accrue from doses higher than 10 Krad. The rather large variation within groups of mushrooms similarly treated suggested an experiment in which individual mushrooms are followed throughout the storage period. The technique chosen consisted of putting the mushrooms, cap down, in numbered depressions in chip board egg filler flats. This practice proved excellent as a means of identifying the individual mushrooms and keeping handling and inspection time to a minimum, but, as we feared, probably because the chip board absorbed some moisture from the mushrooms, the weight loss during the storage period was about twice that experienced in the perforated tubs. This loss occurred despite the fact that the

filler flats were put in unperforated plastic bags. As mentioned previously, the interaction between the figures of merit, such as $\Delta D.O.$, and transpiration loss becomes confounded with the technical effect of the radiation. In this particular experiment the weight loss averaged 1.5%/day; previous experience with the perforated tubs showed an average weight loss of 0.8%/day; by comparison, the commercial box permitted an average loss of 3%/day. Nevertheless, the results proved interesting, with two reservations: the moisture loss was high, twice that expected in perforated tubs; and, since the filler flats were stored inside unperforated polyethylene bags, the gas content of the surrounding atmosphere was likely different from that found in perforated tubs.

Table 19. Changes in dimensions, weight and D.O. of irradiated mushrooms stored at 10 C (50 F)^a.

Dose Krad	Storage time, days	Cap dia.,	Stem dia.,	Height,	Weight,	D.O.
		% increase	% decrease	% increase	% decrease	
0	2	3	7	4	6	0.0
	4	8	19	16	9	1.0
	7	16	27	32	11	1.0
	11	25	31	36	15	1.0
10	2	3	4	6	7	0.0
	4	3	11	21	12	.3
	7	6	21	40	16	.8
	11	7	27	43	20	.8
20	2	4	6	8	6	0.0
	4	5	12	32	8	.5
	7	7	17	47	14	.7
	11	8	23	50	17	.8
50	2	3	5	7	5	0.0
	4	5	12	23	7	.2
	7	5	15	34	11	.4
	11	5	21	36	15	.4
100	2	2	5	4	7	0.0
	4	3	12	12	10	.0
	7	3	16	18	13	.0
	11	3	21	19	15	.0
Original dimension, mean of all groups ...		1.37 in.	0.64 in.	1.29 in.	12.2 g	0.0

^aAt each dose, the same 15-mushroom group was measured throughout the storage period.

The results are shown in Table 19. The mushrooms were first irradiated in perforated tubs, then measured and transferred to the filler flats, all on the same day we picked up the mushrooms. The changes are reported as percentage change, because experience with phenomena of this kind leads one to expect changes proportional to the original value. The changes, in all the parameters measured, between 0 and 7 days for the 15 mushrooms irradiated at 10 Krad were examined for evidence of dependence of the magnitude of change on the original value. There was dependence of weight loss, stem shrinkage, and height increase on the original value, but there did not seem to be any dependence of diameter increase on the original diameter. Decreases in weight and stem diameter were approximately exponential during the 11 days storage period; the increases in cap diameter were approximately linear; increases in height were sigmoidal (See Figure 3).

The effects of radiation were by no means the same on the several dimensions measured. The diameter of the caps of all irradiated mushrooms increased very little by comparison with unirradiated mushrooms, but since even the lowest dose of 10 Krad permits only a small increase in diameter, there was not much room for improvement at the higher doses. By way of illustration consider the four irradiated groups after seven day's storage: an analysis of variance of the percentages shows that the increases for 10 Krad and 50 Krad were the same, 20 Krad was higher than any, and 100 Krad was lower than any. The standard deviation was 2.8%. The decrease in stem diameter was greater at doses of 0 and 10 Krad than at the higher doses. The changes in mushroom height were of special interest on several counts: (1) the form of the change with time was sigmoid; (2) at 20 Krad and perhaps to some extent at 10 Krad the increase was enhanced above that of the 0, and 50 Krad samples, but at 100 Krad the increase was less than controls; (4) of the dimensions measured the height of the irradiated mushrooms changed proportionally more than any other dimension. The analysis of the height increases is troublesome for several reasons:

(1) the height of any one mushroom, apart from some natural physiological height, is governed by the whim of the picker's knife; the combination of these two variables seems to make height variation larger than the other dimensional variations; (2) at any given storage time the variation in the percentages of change in height are not the same for each dose treatment; for example, among mushrooms treated at 100 Krad and stored for 7 days, the range in percentage change in height was from 12 to 20% and among those treated at 20 Krad, the range in increase at 7 days was from 36 to 60%. Weight loss was about the same at all doses. Degree of Opening, one of the most striking changes, is the most difficult to analyze statistically for reasons mentioned previously. As an example of the difficulty consider that the D.O.'s at 7 days storage for 10, 20, and 50 Krad samples ranged from 0 to 1.0, all the unirradiated mushrooms were open, all the 100 Krad mushrooms were still closed.

Mushrooms from this same lot were tested for texture to verify the results of the previous experiment. Since it was very late in the day by the time all the mushrooms for the dimension experiments had been measured, the mushrooms intended for texture measurements were kept over night in the perforated tubs in a refrigerated storage (5 C) and tested the next day. The results are given in Table 20. An analysis of variance showed no differences among samples from 0 to 100 Krad, but both the 500 and 1000 Krad samples were measurably softened. The softening, at least as measured this way by the shearpress, was linear up to 1000 Krad at which dose the readings were 12% lower.

Table 20. Peak shear resistance (chart reading)^a of mushrooms one day after irradiation.

Sample No.	0	10	50	100	500	1000
1	49	52	52	52	50	44
2	51	51	53	55	47	43
3	53	53	54	53	47	45
4	49	50	52	49	46	45
Ave.	50.5	51.5	52.8	52.2	47.5	44.2

^aAllo-Kramer shear press - 250-16 ring, range 50, Lo, 75-g samples.

An analysis of variance showed no difference among the shear resistance of the 0, 10, 50, and 100 Krad samples. However,,the 500 Krad samples had significantly lower values than the lower doses ($P = 0.99$) and the 1,000 Krad samples had significantly lower shear resistances than the 500 Krad samples ($P = 0.95$) or the lower doses ($P = 0.99$).

Experiment IV: Dose vs. Storage Temperature

The mushrooms were irradiated in perforated tubs. Following irradiation, all mushrooms were individually weighed and placed into numbered chipboard egg filler flats (15 mushrooms per treatment), covered with unperforated polyethylene bags, and placed in temperature controlled cubicles at 5° (41 F), 10° (50 F), and 15°C (59 F). An initial measurement of opening ratio (O.R.) was made at 0.0 time on 20 mushrooms. The periods of examination were chosen so as to minimize handling and still cover the expected range of storage life. The results were reported in Tables 21 through 24.

Table 21. Percent increase in cap diameter, D, of irradiated mushrooms stored at 5°, 10°, and 15°C in egg filler flats. Average of the same 15 mushrooms at each dose and temperature.

Dose, Krad	Storage Temp. °C	Storage time (days)							
		1.0	2.0	3.0	4.0	8.0	11.0	15.0	21.0
0	5	---	---	---	3.9	5.6	---	8.4	9.5
	10	---	4.2	---	9.1	18.0	21.0	24.0	---
	15	5.0	14.2	22.0	26.0	---	---	---	---
50	5	---	---	---	2.1	4.6	---	5.1	4.7
	10	---	2.9	---	5.0	6.5	5.9	5.0	---
	15	1.8	3.8	5.4	5.9	---	---	---	---
100	5	---	---	---	2.2	4.6	---	4.7	4.6
	10	---	3.2	---	5.9	7.0	6.6	5.1	---
	15	2.2	4.7	6.0	6.6	---	---	---	---
200	5	---	---	---	1.9	3.9	---	3.4	2.8
	10	---	1.9	---	4.9	6.4	6.1	3.6	---
	15	1.4	4.2	5.0	5.2	---	---	---	---

Table 22. Degree of opening, D.O., of irradiated mushrooms stored at 5°, 10°, and 15°C. in egg filler flats. Average of the same 15 mushrooms at each dose and storage temperature.

Dose, Krad	Storage Temp. °C	1.0	2.0	3.0	4.0	8.0	11.0	15.0	21.0
		1.0	2.0	3.0	4.0	8.0	11.0	15.0	21.0
0	5	---	---	---	.05	.26	---	.43	.57
	10	---	.13	---	.30	.67	.79	.85	---
	15	.19	.46	.93	1.00	---	---	---	---
50	5	---	---	---	.00	.09	---	.18	.19
	10	---	.00	---	.09	.27	.29	.29	---
	15	.00	.04	.29	.47	---	---	---	---
100	5	---	---	---	.00	.03	---	.12	.15
	10	---	.00	---	.00	.05	.06	.05	---
	15	.00	.11	.13	.19	---	---	---	---
200	5	---	---	---	.01	.06	---	.09	.11
	10	---	.00	---	.00	.00	.02	.02	---
	15	.00	.05	.13	.15	---	---	---	---

Table 23. Opening Ratio, O.R.^a and O.R. per day of irradiated mushrooms stored at 5°, 10°, and 15°C in egg filler flats. Average of 15 mushrooms at each dose.

Dose, Krad	15°C for 4 days		10°C for 15 days		5°C for 21 days	
	O.R.	O.R. per day	O.R.	O.R. per day	O.R.	O.R. per day
0	1.21	.22	1.94	.11	1.02	.032
50	.56	.052	.58	.015	.56	.010
100	.52	.042	.42	.0047	.60	.012
200	.48	.032	.42	.0047	.49	.0067

^a O.R. at 0 days was 0.35, average of 20 mushrooms

Table 24. Percent weight loss of irradiated mushrooms. Average of the same 15 mushrooms at each dose and storage temperature.

Dose Krad	Storage Temp., °C	Storage time (days)							
		1.0	2.0	3.0	4.0	8.0	11.0	15.0	21.0
0	5	---	---	---	5.5	3.9	---	12.0	16.0
	10	---	4.1	---	6.9	12.0	12.0	22.0	---
	15	4.0	7.7	9.9	14.0	---	22.0	---	---
50	5	---	---	---	5.7	9.0	---	13.0	16.0
	10	---	4.7	---	8.4	14.0	16.0	19.0	---
	15	6.0	13.0	16.0	22.0	---	---	---	---
100	5	---	---	---	5.3	8.2	---	14.0	16.0
	10	---	4.9	---	7.0	9.0	13.0	14.0	---
	15	5.7	8.8	11.0	15.0	---	---	---	---
200	5	---	---	---	5.3	7.9	---	18.0	22.0
	10	---	6.3	---	9.3	12.0	14.0	20.0	---
	15	4.4	7.5	10.0	15.0	---	---	---	---

The following can be deduced from Table 21 regarding the effects of irradiation dose and storage temperature on the increase in cap diameter. The Q_{10}^* for $\bar{D}$ for the control (0 Krad) samples was calculated to be 6.7 at 4 days of storage. The increase in the cap diameter was greater with increased storage temperature at all dose levels, but the temperature effect was not as great in irradiated samples, (Q_{10} about 3). The cap diameters of the control samples increased more than any of the irradiated samples at all storage temperatures and testing times. By the end of the storage times, the cap diameter of the 0 Krad samples had, in general, increased 4 to 5 times as much as those of the irradiated samples. Doses of 50 and 100 Krad retarded the increase in cap diameter to about the same extent while 200 Krad appears to have retarded the increase a little more effectively, especially at lower temperatures (5° and 10°C).

The data in Table 22 show the effects of irradiation dose and storage temperature on the degree of opening, D.O. The opening was greatly affected by storage temperature for all doses. The control samples, for instance, had D.O.'s of .05, .30, and 1.00 after 4 days at 5°, 10°, and 15°C, respectively. The effect of irradiation dose was also quite evident at all storage temperatures. A dose of 50 Krad reduced the D.O. by a factor of 2 to 4 as compared to control samples. Doses of 100 and 200 Krad showed a more substantial reduction than did 50 Krad, especially when stored at 10° or 15°C. These doses (100 and 200 Krad) gave about twice the reduction as did 50 Krad at these temperatures.

The measurements of $\bar{D}$, $\bar{d}$, and $\bar{e}$, (Figure 1) made immediately after irradiation on a separate group of 20 mushrooms and on the stored mushrooms at the end of the storage periods were used to calculate the O.R. values appearing in Table 23.

* Ratio of reaction rates measured at temperatures 10 C apart. Here, the ratio of the rates at which cap diameter changes when the storage temperatures differ by 10 C.

The initial O.R. of 0.35 was subtracted from the measured O.R.'s and this quantity was then divided by the number of days the mushrooms were stored to get the O.R. per day, an expression of opening rate. Here again, the storage temperature had a pronounced effect on the rate of cap opening as measured by O.R. per day. The Q_{10} as measured by this value, was about 7 for the control (0 Krad) mushrooms. Irradiated samples were again appreciably affected by storage temperature, but not to the same extent as the controls, (Q_{10} about 3.5 to 5). As has been shown in past experiments, the opening ratio was greatly affected by irradiation. A 50 Krad dose reduced the O.R. per day by a factor of 4.2 at 15 C, 7.3 at 10 C, and 3.2 at 5 C. Doses of 100 and 200 Krad were somewhat more effective than 50 Krad when the mushrooms were stored at 10 C, but the retardation of the opening rate was very similar for all three doses at storage temperatures of 5° and 15°C.

The effects of irradiation dose and storage temperature on the rate of weight loss (Table 24) were as follows. The rate of weight loss, as expected, increased with an increase in temperature; about 4% per day at 15°C, 1.3% per day at 10°C, and 0.8% per day at 5°C. The effect of irradiation dose on weight loss was not clear.

Experiment VI: Effect of delay between harvest and irradiation.

The radiation treatments were given in perforated tubs at 0.3, 1.3, and 3.3 days after storage began. All mushrooms were tightly closed at zero time* and stored at 10°C before and after irradiation.

Dimensional changes:

Measurements were made on separate groups of 20 non-irradiated mushrooms after 0.3, 1.3, and 3.3 days of storage at 10°C. These measurements were used to estimate the opening ratio (O.R.) reached by the lot at each time of irradiation. O.R.

* Zero time is the time the mushrooms were placed in storage rather than the time of harvest since the latter is not known exactly.

Days	0	0.3	1.3	3.3	7.3
	Storage Begins	Irradiations			Examination

measurements were also made at the end of the storage period (7.3 days) on all treatments. Measurements of cap diameter, mushroom height, and degree of opening (D.O.) were made immediately following irradiation and 7.3 days after storage began. These data were used to calculate the values presented in Table 25 through 28.

Table 25. Degree of opening of irradiated mushrooms after 7.3 days of storage at 10°C. Average of 20 mushrooms irradiated 0.3, 1.3, and 3.3 days after storage began.

Dose Krad	Delay, days		
	0.3	1.3	3.3
0	0.98	0.99	1.00
50	0.60	0.44	0.86
100	0.30	0.51	0.78
D.O. at time of irradiation	0.00	0.00	0.40

Table 26. Opening ratio, O.R., and O.R. per day^a of irradiated mushrooms after 7.3 days of storage at 10°C. Average for 20 mushrooms irradiated at 0.3, 1.3, and 3.3 days after storage began.

Dose, Krad	Delay, days					
	0.3		1.3		3.3	
	O.R.	O.R. per day	O.R.	O.R. per day	O.R.	O.R. per day
0	2.11	0.25	2.12	0.28	1.88	0.31
50	0.70	0.046	0.80	0.062	1.00	0.086
100	0.64	0.037	0.74	0.052	1.09	0.11
O.R. at time 0.38 of irradiation			0.43		0.65	

^aCalculated between time of irradiation and 7.3 days.

Table 27. Percent increase in height of irradiated mushrooms after 7.3 days of storage at 10 C. Average of 20 mushrooms irradiated at 0.3, 1.3 and 3.3 days after storage began.

Dose, Krad	Delay, days		
	0.3	1.3	3.3
0 ^a	22	13	11
50	39	28	12
100	31	26	9

^aThe control (0 Krad) mushrooms had very desiccated stems, probably to the extent that elongation was greatly retarded.

Table 28. Percent increase in cap diameter of irradiated mushroom after 7.3 days of storage at 10°C. Average of 20 mushrooms irradiated at 0.3, 1.3 and 3.3 days after storage began.

Dose Krad	Time between harvest and irradiation, days		
	0.3	1.3	3.3
0	17.0	15.0	10.0
50	12.0	3.6	2.8
100	6.8	5.7	1.1

The effect of delayed irradiation on the degree of opening is shown in Table 25. A delay between the time of harvest and the time of irradiation generally resulted in mushrooms with higher D.O.'s: the longer the delay, the less the benefit of irradiation for a given storage period.

The effects of delay and irradiation dose can be measured by O.R. and O.R. per day (Table 26). In every instance, irradiation doses of 50 and 100 Krad significantly retarded opening of the cap, as measured by O.R. and O.R. per day. The O.R. per day of control samples (0 Krad) was 6 times the O.R. per day of the samples irradiated (average of 50 to 100 Krad) at 0.3 days, 5 times the O.R. per day of those irradiated at 1.3 days, and 3 times the O.R. per day of the samples irradiated at 3.3 days from zero time. The magnitude of these factors emphasizes the great effect of irradiation on the opening rates of mushrooms. The 100 Krad dose proved to be more effective than the 50 Krad dose when the samples were irradiated at 0.3 and 1.3 days, but perhaps less effective when there was a delay of 3.3 days between harvest and irradiation. The variance in O.R. (about 25% at O.R. = 0.8) probably negates the apparent differences between the O.R.'s of the 50 and 100 Krad samples, i.e.

The decrease in the ratio,

O.R. per day of controls

O.R. per day of irradiated samples

as the delay between harvest and irradiation is increased (6, 5, and 3 for 0.3, 1.3, and 3.3 days respectively) also suggests that a delay before irradiation renders the treatment less effective. Without a doubt, an irradiation treatment at any of the times tested greatly retarded the rate of cap opening, but in order to obtain the greatest benefit from an irradiation treatment, it should be administered as soon as possible after harvest.

The increase in mushroom height is reported in Table 27. At the end of 7.3 days of storage, regardless of when irradiation occurred, the irradiated samples displayed a greater increase in mushroom height than the controls. The 50 Krad samples had increased more than those given 100 Krad. These results differ from those observed in Experiment II, in which the 0 Krad samples had increased at approximately the same rate as the 50 Krad samples and much more than the 100 Krad. This discrepancy is probably due to the difference in desiccation of the stems of the control samples compared to those given 50 or 100 Krad. It was noted that the stem of the control samples were very desiccated, probably to the extent that elongation was inhibited. It can also be concluded that elongation occurs most rapidly during the early part of the storage period. Again, this could be connected with desiccation.

The percent increase in cap diameter, D, for the mushrooms tested in this experiment is reported in Table 28. Regardless of the time at which the irradiation treatment was given, mushrooms given 50 or 100 Krad had opened significantly less than the control mushrooms. The rate of increase was more rapid during the early part of storage for the irradiated samples. There was no significant difference between the 50 and 100 Krad treatments when irradiation occurred at 1.3 or 3.3 days, but 100 Krad seemed to be somewhat more effective when the mushrooms were irradiated soon after harvest (0.3 days).

Color:

At the end of 8 days of storage, 9 mushrooms for each dose from those irradiated 0.3 days from zero time and controls were placed cap up on egg filler flats and presented in duplicate to 11 judges. They were asked to rate the lots of mushrooms on the basis of darkness, ranking the darkest as 1 and the lightest as 3. The totals for the 22 judgments were 22 for the control samples, 45 for the 50 Krad samples, and 65 for the 100 Krad samples. Therefore, the control samples were significantly ($P=0.99$) darker than the 50 or 100 Krad samples, and the 50 Krad samples were significantly darker ($P=0.99$) than the 100 Krad samples. The judges commented, moreover, that there was a substantially greater difference in darkness between the control and irradiated samples than between the two lots of irradiated samples.

Transpiration:

Twenty mushrooms were weighed at 0.3 days, another 20 at 1.3 days, and another 20 at 3.3 days, from zero time, immediately after irradiation for the treated samples, (height and cap diameter was also measured at that time), placed back in the tubs, and re-weighed at 7.3 days. These data were used to calculate the percent weight loss for the three storage intervals. The results are reported in Table 29 and are inconclusive.

Table 29. Percent weight loss between the time of irradiation, 0.3, 1.3, or 3.3 days after harvest and 7.3 days after. Average of 20 mushrooms stored in covered perforated tubs at 10°C.

Dose Krad	Time of irradiation, days		
	0.3	1.3	3.3
0	19	16	11
50	9	18	13
100	10	12	17

There is no consistency within the data as related to irradiation dose or the delay before irradiation. A number of factors could have contributed to this variability including positioning within the storage cubicle, arrangements within the tubs, temperature fluctuations, and sampling errors.

Experiment VI: The effect of irradiation on transpiration rate and lengthening of the stem.

The mushroom were irradiated in perforated tubs, they were then resorted and placed stem up on four egg filler flats (20 mushrooms per dose, five mushrooms of each dose per flat) in a random pattern. Two flats were placed in each of two aluminum trays with controlled and equal openings for ventilation. The tops of the trays were covered with an unperforated polyethylene film. After three days of storage at 10°C some of the holes were covered in order to decrease the rapid rate of transpiration. The samples were then returned to 10°C storage. Measurements of weight, total mushroom height, and degree of opening were made at 0, 3, and 6 days after irradiation. Desiccation (nearly 7%/day) under these circumstances was far too high to make any useful analysis of the results.

MICHIGAN STATE UNIVERSITY-FOOD SCIENCE IRRADIATOR

Twenty four BNL MK-1 Cobalt-60 strips were received and placed in the water pool of the gamma facility by the Food Science Building of this University on June 29, 1967.

The strip strengths varied from 1410 to 2847 Ci, with an average of 2145 Ci and total activity of 51,500 Ci, measured on 5-8-67. The strips were transferred into the slots of a hollow cylindrical holder, 34 cm in outside diameter, on 6-30-67, and arranged so as to minimize variation in dose rate at a given distance from the source. A survey of the facility performed by the Radiation Safety Service of this University showed that radiation levels in the environment meet the CFR-10 requirements.

The entire gamma facility is under ground and comprises the cell, the refrigeration room, the preparation laboratory, and the pumproom, arranged as shown in the diagram.

The cell is a 13 x 23 ft. room surrounded by concrete walls, varying in thickness from 3 to 5.0 ft. Eccentrically located on the floor there is a 15 ft. deep stainless steel tank containing 2500 gallons of demineralized water for storage of the Cobalt-60. The tank is closed with a steel cover supporting a hollow steel cylinder which protects the Cobalt-60 holder when it emerges from the pool. The ceiling is made of 6 ft. thick concrete and has an opening directly above the tank to facilitate the transfer of radioactive material from outside the building into the pool. The opening is closed with a removable concrete plug weighing 20 tons. The cell is continually ventilated.

The refrigeration room contains equipment capable to cooling the cell down to 34°F. The preparation laboratory provides facilities for simple chemical work

V

and accomodates the control console for the operation of the source. The console allows push-button lifting and lowering of the source as well as automatically timed operation of it. The pump room contains filters, ion exchange tanks and a pump for the purification and circulation of the water of the pool. A number of safety features are connected with the operation of the facility.

During the first year of the use of this facility it has been necessary to discontinue its operation several times because of mechanical and electrical imperfections. No accidents involving humans or experimental materials occurred.

Pump room has 40 GPM centrifugal pump, filter, deionizing beds.

Source strength 51,000 Curies of Cobalt-60 on 7/1/67. Stored in 15' water pool, capacity 2500 gallons, when not in use.

Source strips arranged in a cylindrical configuration: dose rate in the center well 2000 Krad/hr; at 50 cm from the source 200 Krad/hr.

Refrigeration Equipment Room

The cell can be cooled to 34°F.

RESEARCH IRRADIATOR
Department of Food Science
Michigan State University

Scale: 1/8" = 1'

<u>Symbol</u>	<u>Name</u>
D	Cap diameter
d	Stem diameter
e	Total opening gap
h	Height

Definition of Opening Ratio, O.R.

$$O.R. = \frac{e - d}{D - (e - d)}$$

Figure 1. Mushroom section showing dimensions measured and formula for the computation of Opening Ratio.

Figure 2. The effect of irradiation on the rate at which fresh mushrooms open. Each point is the average of 30 mushrooms, except: 0 Krad, 0.2 days, 60 mushrooms; and, 10 Krad, 1.2 days, 51 mushrooms. (After 7.2 days the $\bar{O.R.}$ of the unirradiated mushrooms was 1.32.)

Figure 3. Stimulation and repression of height of irradiated mushrooms stored at 10°C (50°F). Each plotted point is the average of 15 mushrooms, the same 15-mushroom group at each dose.

Appendix - Table I

Weight (g) of sound and spoiled strawberries in Experiment I

<u>No Soak</u>			
<u>Dose, Krad</u>	<u>Pint</u>	<u>Sound</u>	<u>Spoiled</u>
0	1	97.8	97.3
	2	60.2	167.9
	3	6.4	197.8
	4	43.0	185.2
200	1	16.4	197.3
	2	68.5	190.5
	3	52.3	213.2
	4	47.6	192.9
400	1	25.0	167.9
	2	0	211.5
	3	21.0	234.3
	4	37.1	219.3
<u>Soak</u>			
0	1	0	202.3
	2	83.5	179.2
	3	43.1	196.2
	4	148.9	91.7
200	1	144.5	94.9
	2	123.8	91.9
	3	147.5	96.4
	4	82.6	158.0
400	1	96.5	102.2
	2	119.4	120.6
	3	60.9	132.4
	4	102.4	116.4

Appendix - Table 2

Shear press readings of strawberries in Experiment I

<u>Dose, Krad</u>	<u>Pint</u>	<u>Soak</u>	<u>No Soak</u>
0	1	36	26
	2	31	38
	3	34	27
	4	32	26
	5	33	29
	6	29	30
	7	35	28
	8	37	35
200	1	28	31
	2	31	25
	3	43	30
	4	22	40
	5	26	41
	6	30	31
	7	28	28
	8	39	31
400	1	39	35
	2	37	26
	3	40	33
	4	30	29
	5	35	28
	6	41	30
	7	24	27
	8	32	31

Appendix - Table 3

Weight (g) of sound and spoiled strawberries in Experiment II

No Soak			
<u>Dose, Krad</u>	<u>Pint</u>	<u>* Sound</u>	<u>Spoiled</u>
0	1	26.8	181.9
	2	44.6	196.4
	3	44.0	190.8
	4	25.7	188.0
	5	65.7	163.7
	6	104.6	125.1
	7	48.4	188.9
	8	31.7	197.6
200	1	67.7	168.8
	2	49.7	177.4
	3	48.6	179.8
	4	82.3	145.1
	5	64.5	139.0
	6	55.8	176.7
	7	54.3	146.0
	8	62.0	165.0
400	1	73.5	134.6
	2	74.9	143.7
	3	76.2	159.0
	4	55.5	163.3
	5	72.0	153.0
	6	52.8	161.1
	7	60.5	181.8
	8	46.3	200.8

Appendix - Table 3 (Cont.)

Weight (g) of sound and spoiled strawberries in Experiment II

<u>Soak</u>			
<u>Dose, Krad</u>	<u>Pint</u>	<u>Sound</u>	<u>Spoiled</u>
0	1	19.6	169.3
	2	36.0	193.3
	3	10.9	210.2
	4	23.6	187.1
	5	41.9	144.7
	6	55.5	164.5
	7	12.0	182.7
	8	3.4	212.7
200	1	47.4	158.2
	2	46.6	151.2
	3	31.7	192.4
	4	62.6	163.0
	5	20.7	176.6
	6	77.2	155.5
	7	41.5	182.7
	8	47.5	76.0
400	1	35.0	136.6
	2	53.3	172.7
	3	36.4	169.9
	4	46.1	163.2
	5	39.3	179.0
	6	46.3	164.8
	7	44.3	182.4
	8	40.6	171.3

Appendix - Table 4

Shear press readings of strawberries in Experiment II

<u>Dose, Krad</u>	<u>Pint</u>	<u>Soak</u>	<u>No Soak</u>
0	1	28	27
	2	32	30
	3	29	28
	4	27	23
	5	26	23
	6	38	24
	7	30	23
	8	30	25
200	1	26	22
	2	28	21
	3	34	17
	4	24	24
	5	30	17
	6	26	24
	7	31	23
	8	31	22
400	1	28	19
	2	24	24
	3	26	30
	4	25	19
	5	24	19
	6	23	22
	7	26	27
	8	28	19