Doc. 2034

~~5248~~

MASTER

COO-1592-36

IRRADIATION OF FRUITS AND VEGETABLES

Annual Report, April 16, 1968-July 15, 1970

July 1971

Department of Food Science
Michigan State University
East Lansing, Michigan

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22151.

Price: Paper Copy \$3.00
Microfiche \$0.95.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

IRRADIATION OF FRUITS AND VEGETABLES

Prepared By

P. Markakis and R. C. Nicholas

with collaborators

G. Blair and Noemi Diaz-Santiago

For The

**Division of Isotopes Development
United States Atomic Energy Commission**

Annual Report

For The Period April 16,

1968 to July 15, 1970

Contract AT(11-1)-1592

July 1971

**Department of Food Science
Michigan State University
East Lansing, Michigan**

A B S T R A C T

A total of 85 judges detected no differences in taste between white mushrooms treated with 0, 12.5, 25, 50 and 100 krad of gamma irradiation; one, two and seven days after irradiation.

Gamma irradiation was more effective than electron irradiation in inhibiting the cap opening of mushrooms at equal dose levels (12.5, 25, 50, 100 and 200 krad).

White mushrooms intentionally bruised by free fall or by shaking, either before or after exposure to 25 and 100 krad of gamma irradiation, remained lighter in color during 6 days of post-irradiation storage than non-irradiated controls. Inactivation of phenoloxidase, the enzyme responsible for the browning of fresh mushrooms, did not occur at irradiation levels prolonging the shelf life of this commodity.

White mushrooms stored at 0.5°C remained closed for 3 weeks, whether irradiated (25, 50 and 100 krad) or not. Non-irradiated mushrooms stored at 5°C opened at a rate 3 times greater than those irradiated at 50 or 100 krad.

Increasing the CO₂ concentration of the storage atmosphere of irradiated mushrooms did not extend their shelf life beyond that due to irradiation.

Mushrooms grown in Pennsylvania responded to irradiation treatment similarly to those grown in Michigan.

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	1
TASTE TESTING OF IRRADIATED MUSHROOMS	3
IRRADIATION OF PENNSYLVANIA-GROWN MUSHROOMS	5
COMPARATIVE EFFECT OF GAMMA AND ELECTRON IRRADIATION ON MUSHROOMS	10
IRRADIATION AND BRUISING OF MUSHROOMS	13
POST-IRRADIATION STORAGE TEMPERATURE AND SHELF-LIFE OF MUSHROOMS	18
EFFECTS OF IRRADIATION ON THE PHENOLOXIBASE OF MUSHROOMS	22
COMBINATION OF IRRADIATION AND CONTROLLED ATMOSPHERE STORAGE OF MUSHROOMS	24
DOSIMETRY	26
APPENDIX TABLE I	48
APPENDIX TABLE II	49
APPENDIX TABLE III	50
APPENDIX TABLE IV	52

SUMMARY

White mushrooms, which were treated to the average doses of 0, 12.5, 25, 50 and 100 Krad of gamma irradiation, were tasted by a total of 85 judges, one, two and seven days after irradiation. The mushrooms were sauteed in butter prior to serving. No statistically significant differences in taste were detected among the five groups of mushrooms.

The effect on shelf-life of white mushrooms after irradiation from Cobalt-60 and 1-Mev-accelerated electrons at the levels of 12.5, 25, 50, 100 and 200 Krad was determined. Gamma irradiation was more effective in inhibiting cap opening than electron irradiation at equal absorbed doses. It was also observed that if the electron beam was directed to the underside of the cap the inhibition of the opening was more pronounced than when the beam was directed to the top of the cap.

White mushrooms intentionally bruised by free fall or by shaking either before or after 0, 25 and 100 Krad of gamma irradiation were visually compared by a total of 37 judges for brown discoloration. The comparisons which were made three and six days after irradiation showed that the irradiated mushrooms remained lighter in color during storage than the nonirradiated controls.

White mushrooms were gamma-irradiated at 0, 25, 50 and 100 Krad and subsequently stored at 0.5°C and 5°C. All mushrooms held for 3 weeks at the lower temperature remained closed; however by the end of this period some mold growth was observed on the nonirradiated and the 25-Krad-treated mushrooms. This growth was absent on those exposed to 50 and 100 Krad. At the 5°C storage, the cap opening was 3 times faster in the nonirradiated than in the irradiated mushrooms.

A test on the phenoloxidase (the browning enzyme) activity of irradiated vs. nonirradiated mushrooms did not indicate that irradiation had an effect on the activity of this enzyme. Mushrooms treated at the 1000 Krad level had a 50% decrease in phenoloxidase activity; however this dose is far above the radiation levels considered necessary to control the cap opening of fresh mushrooms.

An experiment was conducted in which white mushrooms were irradiated at 0 and 50 Krad and subsequently stored at 11°C in common air vs. air containing 5% CO₂. The results indicated a decrease in cap opening as a result of irradiation, but no such decrease as a result of elevated CO₂ content in the air.

White mushrooms grown in Pennsylvania were flown to Michigan State University where they were irradiated at 0 to 200 Krad and then stored at 8°C. The results showed that after gamma exposure at levels ranging from 25-200 Krad the mushrooms opened considerably more slowly and remained lighter in color than the nonirradiated controls.

TASTE TESTING OF IRRADIATED MUSHROOMS

During June and July, 1968, six sessions were held on testing the taste of irradiated mushrooms. In four of these sessions the mushrooms were tasted on the day following irradiation; the fifth testing was done 2 days following irradiation and the sixth session was held seven days after irradiation. In all cases, the mushrooms were commercially harvested in the morning in Warren, Michigan and transported at ambient temperature (20-25°C), in 10 lb. baskets, by car, to the laboratory in East Lansing (approximately 80 miles away, or two hours by car). Upon arrival the mushrooms were sorted to ensure uniform and closed-cap mushrooms, placed in quart-size plastic tubs (described in Annual Report C00-1592-35) and on the same day exposed to gamma irradiation at 0, 12.5, 25, 50 and 100 Krad. Since the source at MSU is cylindrical and the irradiation is performed in air, it is possible to simultaneously irradiate samples to various dose levels using the same exposure time. This is done by using a precalculated source-to-sample distance. The samples for this test were irradiated to 0, 12.5, 50 and 100 Krad in one hour; they were rotated 180° at the end of the first 30 minutes to provide for maximum uniformity of dose distribution. The temperature during radiation was 20°C. Following irradiation the samples were stored in the tubs at approximately 2°C until just prior to tasting. For tasting the mushrooms were sliced, sauteed in butter, and presented immediately to the judges, who were asked to rank the samples (1-best, 5-worst). The data (rankings) were treated statistically according to Kendall (Principles of Sensory Evaluation of Food, Amerine

et. al., Acad. Press, 1965). Table 1 shows the statistical treatment of the pooled data of the five sessions in which the samples were tasted one or two days post-irradiation. A total of 70 judges (50 men, 20 women) were used in these sessions.

TABLE 1

Kendall's analysis of five samples of mushrooms corresponding to five irradiation levels, ranked for taste by 70 judges.

Dose (Krad)	0	12.5	25	50	100
Rank total	199	236.0	212.5	212.5	190.0(T 1050)
Avg. rank	2.84	3.37	3.04	3.04	2.71
Corr. term	3150				
Prod. S.S.	17				
Total S.S.	700				
W	0.024				
F	0.170				

The calculated F-value is lower than the Table value $F_{.95}=3.40$ indicating that the ranking differences between samples were not significant statistically. Irradiation under the conditions of this experiment did not affect the taste of the mushrooms.

A total of 15 judges (11 men, 4 women) tasted mushrooms seven days after radiation. The experimental value $F=1.04$ was below the Table value $F_{.95}=2.58$. This again indicates no significant differences in taste among the five groups of mushrooms.

IRRADIATION OF PENNSYLVANIA-GROWN MUSHROOMS

Twenty pounds of white mushrooms were shipped by air from Avondale, Pennsylvania, by the Penn-Eastern Mushroom Cooperative. The mushrooms had been picked at 3 a.m. and arrived at our Laboratory at 11:50 a.m. the same morning. They were then sorted for uniform size and closed caps, placed in pre-weighed 1-quart plastic tubs, weighed and at 3 p.m. they were radiated to 12.5, 25, 50, 100 and 200 Krad. Two tubs were irradiated per dose level. The irradiation was carried out at approximately 20°C , and lasted one hour. The tubs were rotated 180° after 30 minutes. Two tubs of mushrooms were held outside the irradiation room as controls.

Cap Opening

Immediately after irradiation, the tubs of mushrooms were placed in a 2°C room. On the fifth day of storage (first day being the harvest and irradiation day), the tubs or mushrooms were transferred to an 8°C room to accelerate the rate of cap opening. On the 7th day of storage, the degree of opening (D.O.) was measured on 20 randomly selected mushrooms, for each radiation level. The D.O. was again measured on the 12th day of storage on 12 mushrooms for each radiation level. Since all mushrooms were closed at the beginning of the experiment the initial D.O. was zero. The opening ratio (O.R.) was determined on 12 mushrooms

15 days after irradiation. This was done only when the experiment was terminated, since this is a destructive test and the number of mushrooms was limited. A summary of the results obtained appear in Tables 2 and 3. Details appear in Appendix Tables I and II.

TABLE 2

Degree of opening of Pennsylvania mushrooms 7 and 15 days after irradiation. (Average of 20 mushrooms at 7 days and 12 mushrooms at 15 days. Individual values in Appendix Tables I and II).

Dose, Krad	Days of Storage	
	7	15
0	0.3	1.0
12.5	0.1	0.7
25	0.1	0.4
50	0.2	0.6
100	0.1	0.4
200	0.0	0.1

TABLE 3

Opening ratio (O.R.) of Pennsylvania mushrooms stored 15 days after irradiation. (Average of 12 mushrooms. Individual values in Appendix Table II).

Dose, Krad	O.R. after 15 days
0	1.37
12.5	.61
25	.50
50	.64
100	.56
200	.50

Both the D.O. and O.R. data indicate that irradiation strongly retards the cap opening of Pennsylvania-grown mushrooms and agree with the observations previously made on Michigan-grown mushrooms.

Weight Loss

Two tubs of mushrooms were weighed on the 1st, 5th, 7th and 12th day. The results appear in Table 4.

TABLE 4

Percent decrease in weight of irradiated mushrooms 5, 7 and 12 days after irradiation. (Tub 1 contained 221 g of mushrooms and Tub 2 contained 236 g at start of storage).

Dose, Krad	Storage, Time, Days					
	5		7		12	
	<u>Tub 1</u>	<u>Tub 2</u>	<u>Tub 1</u>	<u>Tub 2</u>	<u>Tub 1</u>	<u>Tub 2</u>
0	1.4	1.9	2.5	3.0	5.7	6.0
12.5	1.5	2.4	3.4	2.3	6.9	5.8
25	2.0	4.2	2.8	5.5	5.4	9.9
50	2.4	3.1	4.0	3.1	7.3	5.7
100	2.2	3.4	2.7	4.1	6.1	6.9
200	1.9	2.2	2.6	2.9	5.5	5.8

The weight data indicate that there may be a slightly greater weight loss at intermediate (25 to 100 Krad) doses of irradiation, but the differences seem to have little, if any, importance.

Color Evaluation

After seven days of storage (5 days at 2°C and 2 days at 8°C), seven judges were asked to rank six samples (corresponding to the six doses of irradiation), each containing 10 mushrooms. (Rank 1 is for the lightest in color, 6 is for the darkest). The results appear in Table 5.

TABLE 5

Color ranking of six samples of irradiated Pennsylvania mushrooms by seven judges.

Krad	0	12.5	25	50	100	200
Judge 1	6	1	4	2	5	3
Judge 2	6	2	3	1	5	4
Judge 3	6	2	4	1	5	3
Judge 4	3	5	1	2	5	5
Judge 5	6	2	3	4	5	1
Judge 6	6	2	3	4	5	1
Judge 7	6	4	3	5	2	1
Average	5.57	2.57	3.00	2.71	4.57	2.57
Analysis of variance using Duncan's Multiple Range Test (5% significance) resulted in the following:						
Dose, Krad	12.5	200	50	25	100	0
Rank Average	<u>2.57</u>	<u>2.57</u>	<u>2.71</u>	<u>3.00</u>	4.57	5.57

This evaluation indicates that irradiation at any of the levels used, resulted in lighter color than the unirradiated mushrooms with no significant difference being noted between the samples irradiated at levels of 12.5, 25, 50 and 200 Krad . The samples irradiated at 100 Krads and the control were significantly different from the rest.

COMPARATIVE EFFECT OF GAMMA AND ELECTRON IRRADIATIONS ON MUSHROOMS

White mushrooms were obtained from Warren, Michigan, transported at 20-25°C to East Lansing, and sorted as in previous experiments. The mushrooms were placed in four groups. Group I - to receive gamma irradiation, Group II - to receive electron irradiation with the stem facing the beam (stem up), Group - III to receive electron irradiation with the cap facing the beam (stem down), Group IV - to receive no irradiation.

The gamma irradiation was performed at the M.S.U. Food Science Co-60 facility. The electron irradiation was performed with the electron accelerator of the Agricultural Engineering Department of this University. The irradiation doses used were 0, 12.5, 25, 50, 100, and 200 Krad. The energy of the electrons was 1 Mev and the different doses were obtained by varying the sample conveyor speed of the accelerator.

For gamma irradiation the mushrooms were placed in perforated plastic tubs (described in Annual Report, 1968). For electron irradiation the mushrooms were placed either in a stem up or in a stem down position using cardboard egg cartons.

After irradiation all samples were weighed, transferred into perforated plastic tubs, covered with polyethylene film, and placed in storage at 10°C, 90% R.H.

The mushrooms were stored 4 days and then tested for weight loss, degree of opening, and opening ratio. Table 6, 7, and 8 summarize the results of this experiment. Appendix, Table III shows the D.O. and O.R. readings taken on each of 12 mushrooms.

TABLE 6

Percent weight loss of mushrooms irradiated with gamma rays or electrons after 4 days storage at 10°C, 90% R.H. (Two tubs of mushrooms were used for the control and one tub for each of the 3 irradiation treatments.)

Dose, Krad	Damma	Electron/Stem down	Electron/Stem up	Control
0	---	----	----	---
12.5	8.3	11.6	6.7	---
25	8.3	6.2	14.9	---
50	10.1	7.3	5.0	---
100	5.7	7.6	8.4	---
200	7.7	9.9	1.4	---

No definite trend in weight loss among the different samples is apparent.

TABLE 7

Degree of opening of mushrooms irradiated with gamma rays or electrons after 4 days storage at 10°C, 90% R.H. (Each entry is the average of 12 mushrooms).

Dose, Krad	Gamma	Electron/Stem down	Electron/Stem up	Control
0	---	----	-----	.84
12.5	.25	.84	.69	---
25	.29	.97	.74	---
50	.11	.73	.66	---
100	.14	.64	.28	---
200	.09	.68	.36	---

TABLE 8

Opening ratio of mushrooms irradiated with gamma rays or electrons, after 40 days storage at 10°C, 90% R.H. (Each entry is the average of 12 mushrooms).

Dose, Krad	Gamma	Electron/Stem down	Electron/Stem up	Control
0	--	--	--	.80
12.5	.43	.63	.57	--
25	.41	.74	.57	--
50	.35	.64	.64	--
100	.42	.64	.43	--
200	.38	.66	.42	--

Tables 7 and 8 show that, at the same dose level, gamma irradiation is more effective in inhibiting cap opening than beta irradiation. This is most likely due to the greater penetration of gamma rays. It is also apparent from these tables that when the electron beam was directed to the under side of the cap the inhibition of the opening was more pronounced than when the beam was directed to the top of the cap. This again may be explained as a penetration effect, since the electrons entering from the top of the cap may not reach the area on the underside where the opening occurs.

IRRADIATION AND BRUISING OF MUSHROOMS

Mushrooms are very susceptible to bruising which results in darkening of the tissues. Two experiments were conducted to test if gamma irradiation has an effect on this bruise-induced discoloration.

Experiment I. White cultivated mushrooms harvested in the morning at Utica, Michigan, were transported unrefrigerated (20° - 25° C), by car, to East Lansing (approx. 80 miles from Utica), sorted to obtain medium-size mushrooms with closed caps. The mushrooms were divided into 8 groups, 12 mushrooms each. The groups corresponded to the following treatments:

0 Krad	to be	bruised
0 Krad	to be	non-bruised
25 Krad	to be	bruised before irradiation
25 Krad	to be	bruised after irradiation
25 Krad	to be	non-bruised
100 Krad	to be	bruised before irradiation
100 Krad	to be	bruised after irradiation
100 Krad	to be	non-bruised

The mushrooms were bruised by dropping them once, stem up, from a height of 50 cm onto a hardwood table top. Bruising and irradiation were applied on the day of harvesting. The following storage was at 10° C.

Three and six days after treatment, 17 and 20 untrained judges, respectively, were asked to compare and rank the groups of mushrooms collectively for color (1=lightest, 8=darkest). Both the 3-day and 6-day color scores were treated statistically using Kendall's coefficient of concordance. The means of the rankings were compared using Duncan's Multiple Range Test and the results of these tests are presented in Table 9. Irradiation was able to reduce the discoloration associated with the bruising of mushrooms. The data presented for the 6-day-old samples are especially clear in the respect. They also show no apparent difference in the effect between the doses of 25 and 100 Krad, and between samples bruised before and after irradiation.

TABLE 9

The effect of irradiation on the color evaluation of bruised (by fall) mushrooms three and six days after storage at 10°C. (Duncan's presentation, $P = 0.99$).

<u>3 days</u>								
Treatment	100 Krad unbruised	25 Krad bruised after irr.	100 Krad bruised after irr.	0 Krad unbruised	25 Krad unbruised	100 Krad bruised before irr.	25 Krad bruised before irr.	0 Krad bruised
Average rank by 17 judges (9 men, 8 women)	1.88	2.41	3.62	3.85	4.35	5.38	<u>6.71</u>	<u>7.79</u>
<hr/>								
<u>6 days</u>								
Treatment	100 Krad bruised before irr.	25 Krad bruised after irr.	100 Krad unbruised	25 Krad unbruised	100 Krad bruised after irr.	25 Krad bruised before irr.	0 Krad bruised	0 Krad unbruised
Average rank by 20 judges (11 men, 9 women)	2.20	3.07	3.72	3.85	4.20	4.25	<u>7.05</u>	<u>7.65</u>
<hr/>								

Experiment II. In this experiment mushrooms of the same origin and history as in the previous experiment were used. The bruising, however, was accomplished in a different manner. Twenty mushrooms for each of the 8 groups (as previously described in Experiment I) were placed in two 6-oz. cardboard boxes, ten mushrooms per box. The boxes were then randomly stacked in an 11 gallon plastic bucket and the bucket was shaken for 3 minutes in a Tyler Ro-Tap Testing Sieve Shaker, using standard operating conditions and with the tapping arm in place. A ninth group was added representing control (non-irradiated) mushrooms shaken for 6 rather than 3 minutes (double bruised). The mushrooms boxes were randomly rearranged halfway through the shaking period to insure uniform bruising. The boxes of mushrooms were irradiated either before or after bruising and subsequently stored at 10°C.

The color evaluation by a panel was conducted on the third and seventh days of storage. Seventeen untrained judges were asked to rank the 9 samples, each containing 10 randomly selected mushrooms from each group, for color (1 = lightest, 9 = darkest). The results were corrected for continuity according to Kendall and the ranking averages were statistically analyzed by Duncan's Multiple Range Test. Table 10 summarizes these results, and shows that, even if bruised, mushrooms treated with 25 or 100 Krad gamma irradiation will remain lighter throughout in storage than unirradiated and unbruised mushrooms.

TABLE 10

Irradiation effect on the color evaluation of bruised (by shaking) mushrooms after 3 and 7 days storage at 10°C. (Duncan's presentation, $P = 0.99$)

3 days

Treatment	25 Krad unbruised	100 Krad bruised after irr.	25 Krad bruised after irr.	100 Krad unbruised	100 Krad bruised before irr.	25 Krad bruised before irr.	0 Krad unbruised	0 Krad double bruised	0 Krad bruised
Average rank by 17 judges (12 men, 5 women)	1.00	<u>3.79</u>	<u>3.82</u>	<u>3.88</u>	<u>4.06</u>	<u>5.03</u>	6.76	<u>8.21</u>	<u>8.44</u>

7 days

Treatment	100 Krad unbruised	25 Krad unbruised	25 Krad bruised before irr.	100 Krad bruised after irr.	25 Krad bruised after irr.	100 Krad bruised before irr.	0 Krad unbruised	0 Krad bruised	0 Krad double bruised
Average rank by 17 judges	<u>1.59</u>	<u>1.65</u>	<u>3.76</u>	<u>3.85</u>	<u>5.18</u>	<u>5.38</u>	<u>7.09</u>	<u>7.50</u>	9.00

POST-IRRADIATION STORAGE TEMPERATURE AND SHELF-LIFE OF MUSHROOMS

From previous experiments, in which nonirradiated mushrooms were stored at 5°C, 10°C, and 15°C, it could be deduced by extrapolation that little, if any, opening of the caps should be expected at 0°C. The intent of this experiment was to show whether irradiation had an effect on the dimensional characteristics and the transpiration rate (weight loss) of mushrooms stored after irradiation at or near 0°C as compared to 5°C.

Freshly picked mushrooms from the Detroit area were transported unrefrigerated (20°-25°C) to East Lansing, sorted, placed in the ventilated plastic tubs (described previously in C00-1592-35 Annual Report), and irradiated at 0, 25, 50 and 100 Krad. At noon of the same day three tubs of mushrooms for each temp-dose combination were placed in controlled environment cubicles set at 0.5°C (98% RH) and 5°C (95% RH). The 0.5°C temperature rather than 0.0°C was used for two reasons: (a) to avoid defrosting the refrigeration coils and (b) to prevent eventual freezing of the mushrooms since the temperature fluctuation in these cubicles may reach $\pm 0.5^{\circ}\text{C}$.

On the 7th, 14th and 21st day of storage at 0.5°C three determinations were made: transpiration rate by reweighing each of the 24 tubs of mushrooms, plus D.O. and O.R. on 10 randomly selected mushrooms for each dose-time combination. Similar determinations were applied to the samples stored at 5°C but on the 5th, 10th, 15th and 20th day. The results are summarized in Tables 11, 12 and 13.

The changes in dimensional characteristics of the mushrooms stored at 5°C are similar to those previously reported: irradiation at all doses from 25 Krad up depressed the opening rate of the caps as measured by O.R. and D.O. There was no significant differences in O.R. among the 25, 50 and 100 Krad mushrooms. Letting the value of 0.8 for O.R. to be arbitrarily chosen as the end of storage life, the non-irradiated mushrooms last only 6-7 days when stored at 5°C, whereas the irradiated mushrooms are still good after 20 days of storage.

Mushrooms stored at 0.5°C remained tightly closed for 3 weeks whether they were irradiated or not. On the 21st day, some mold growth was visible on the control samples, very little mold growth on the 25 Krad samples and no mold on those exposed to 50 and 100 Krad.

The transpiration rate differences between the control and irradiated mushrooms appeared to be small. It is difficult to attach any particular significance to these differences, especially since the containers had to be opened every time samples were removed for the O.R. and D.O. measurements. In no instance off-odors were detected.

TABLE 11

Opening Ratio of gamma irradiated mushrooms stored at 0.5° and 5°C.
(Ave. of 10 mushrooms. The initial O.R. was 0.4).

Dose Krad	Storage temperature, °C						
	0.5			5			
	Storage time, days			Storage time, days			
	<u>7</u>	<u>14</u>	<u>21</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>
0	0.4	0.5	0.5	0.7	1.1	1.9	2.9
25	0.4	0.5	0.5	0.5	0.5	0.7	0.6
50	0.4	0.6	0.5	0.5	0.7	0.5	0.5
100	0.4	0.5	0.5	0.4	0.5	0.6	0.6

TABLE 12

Degree of opening of gamma irradiated mushrooms stored at 0.5° and 5°C.
(Ave. of 10 mushrooms).

Dose Krad	Storage temperature, °C						
	0.5			5			
	Storage time, days			Storage time, days			
	<u>7</u>	<u>14</u>	<u>21</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>
0	0.0	0.0	0.0	0.3	1.0	1.0	1.0
25	0.0	0.0	0.0	0.1	0.1	0.4	0.4
50	0.0	0.0	0.0	0.0	0.4	0.2	0.2
100	0.0	0.0	0.0	0.0	0.1	0.2	0.2

TABLE 13

Transpiration rates of gamma irradiated mushrooms stored at 0.5°C and 5°C. (Each entry is the average percent weight loss per day for three containers).

	Storage temperature, °C							
	0.5			5				
	<u>Storage time, days</u>			<u>Storage time, days</u>				
Dose								
Krad	<u>7</u>	<u>14</u>	<u>21</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	
0	1.2%	1.3%	1.5%	1.4%	1.4%	1.6%	1.8%	
25	1.0%	1.1%	1.1%	1.7%	1.9%	2.0%	2.2%	
50	0.8%	1.0%	1.1%	1.0%	1.2%	1.3%	1.5%	
100	0.9%	0.9%	1.0%	1.2%	1.2%	1.6%	2.1%	

EFFECT OF IRRADIATION ON THE PHENOLOXIDASE ACTIVITY OF MUSHROOMS

Radiation doses considered adequate for extending the shelf-life of fresh, white mushrooms (10 to 100 Krad) would not be expected to affect strongly the enzymes of mushrooms, in situ. In view, however, of the fact that irradiation decreases the darkening of irradiated mushrooms, the effect of irradiation on the activity of phenoloxidase, the enzyme responsible for the browning of fresh mushrooms, was measured.

Fresh mushrooms were obtained from the Great Lakes Mushroom Cooperative Warren, Michigan, and transported to East Lansing, where they were sorted and only the tightly closed, medium-size mushrooms were retained for study. The mushrooms were placed in 1-quart polyethylene tubs and the samples irradiated at 0, 10, 50, 100 and 1,000 Krad. The dose of 1000 Krad was added only for theoretical reasons. Radiation time was one hour, and the samples were turned 180° at half the radiation time.

Crude enzyme acetone powders were prepared in triplicate for each dose as follows: 25 g of mushrooms were covered with 200 ml of chilled (-15°C) acetone and macerated in a Waring blender for 60 seconds at top speed. The slurry was filtered through a Buchner funnel and washed with approximately 500 ml of chilled acetone. The powders were dried at room temperature under vacuum and stored in a desiccator at 4°C. Approximately 2 grams of dried acetone powders were obtained from each 25 gram sample of mushrooms.

Three days after the preparation of the powders, the enzymes were extracted by filtering a suspension of 300 mg of powder in 10 ml of 0.1M phosphate buffer, pH 7.0. A 1:25 dilution of the filtrate with the same buffer was made. The activity of the enzymes was tested spectrophotometrically. Catechol was added to a dilute solution of the enzyme (.2 ml of the 1:25 dilution, 2.3 ml of buffer, .5 ml of 5×10^{-3} M catechol, in a 1 cm light-path spectrophotometer cell), and the changes in light absorbance at 420 nm were recorded automatically by a Beckman DU spectrophotometer connected to a log-converter and a recorder. The rate of browning was determined by measuring the slope of the absorbance-time line. This line was straight for the first few minutes of the assay. The results are summarized in Table 14.

TABLE 14

Phenolase activity of mushrooms exposed to various doses of irradiation. The numbers express the activity in arbitrary units.

<u>Dose, Krad</u>	<u>Activity (arbitrary units)</u>
0	.94
10	.99
50	1.45
100	1.05
1000	.50

These data can not explain the diminished darkening of mushrooms exposed to irradiation up to 100 Krad, in terms of phenolase activity. It is known, however, that enzymatic reactions do not proceed at the same speed in intact tissues and cell-free extracts. The increased phenolase activity at 50 Krad may be due to a more efficient extraction of the enzyme from irradiated rather than nonirradiated tissues.

COMBINATION OF IRRADIATION AND CONTROLLED ATMOSPHERE STORAGE OF MUSHROOMS

White mushrooms were transported from a producer near Detroit to East Lansing (80 miles), at ambient temperature ($20-25^{\circ}\text{C}$), sorted and placed in plastic tubs. The tubs for this experiment had only two perforations, 0.5 cm in diameter each, and they were located on the lid. Through one perforation a 0.5 cm diameter latex rubber tube was inserted and coiled on the bottom of the tub. Six small holes were bored on the coiled part of the tube so as to insure uniform distribution of the gas which was to be used to sweep around the mushrooms. The second perforation would serve as the exit port for the gases.

Four individual gases, or gas combinations were originally used; air, air containing 0.5% CO_2 , air containing 5% CO_2 and air containing 15% CO_2 . Because of mishaps, the 0.5% and the 15% CO_2 systems were eliminated and the experiment was run with only the air, and the air with 5% CO_2 atmospheres, the latter being the most common CO_2 concentration in the controlled atmosphere storage of certain fruits and vegetables. The gases were bubbled through water before sweeping the mushrooms, in order to avoid desiccation of the latter. (The bubbling also enabled observation of the flow rate.)

Forty-two mushrooms were used as unirradiated controls (21 for each of the two gases) and another 42 (21 for each gas) were exposed to 50 Krad of gamma radiation. The mushrooms were irradiated at ambient temperature ($20-22^{\circ}\text{C}$) and subsequently stored at 11°C under the gas conditions described previously. Degree of opening (D.O.) and opening ratio (O.R.) measurements were made on the day of harvest and irradiation, as well as 5 days post-irradiation. The results are summarized in Table 15. The individual readings are given in Appendix Table IV.

TABLE 15

Degree of opening and opening ratio of control and irradiated (50 Krad) mushrooms stored at 11°C for 5 days in air and in air containing 5% CO₂, (Ave. of 21 mushrooms.)

Gas	Air		CO ₂	
<u>Dose</u>	<u>D.O.</u>	<u>O.R.</u>	<u>D.O.</u>	<u>O.R.</u>
0	.59	.53	.57	.54
50	.11	.31	.24	.42

These averages indicated a rather large reduction of both D.O. and O.R. as a result of irradiation. No such effect on D.O. and O.R. was apparent when the CO₂ concentration was raised to 5%.

Analysis of variance was applied on the O.R. data only (Table 16), because the D.O. values are not normally distributed (they cluster near 1.0 or 0.0, indicating that once the velum is broken the detachment of the pileus from the stipe proceeds to completion rapidly).

TABLE 16.

Analysis of variance of O.R. values (X100) from the irradiation-controlled atmosphere experiment.

Source	DF	SS	MS	F
Total	83	51,327	618	1.13
Dose	1	6,069	6,069	11.09 ^{xx}
Gas	1	933	933	1.71
Dose x Gas	1	544	544	0.99
Error	80	43,779	547	

Only the dose exerted a statistically significant effect on the O.R. of the mushrooms.

*O.R. values were multiplied by 100 to avoid decimals.

DOSIMETRY OF THE MSU FOOD SCIENCE IRRADIATOR

(50,000 Ci Cobalt-60 Installed Strength, June, 1967)

1. The Fricke Dosimeter

a. Preparation and standardization of ferric ion solutions

- i. Two stock solutions (A and B) of ferric sulfate in 0.8 N H_2SO_4 for calibration of the source were made up from weighed portions of ferric sulfate and held overnight in an oven at 90-95°F.
- ii. Each stock solution was standardized (duplicate aliquots) against 0.1111 N KMnO_4 ; the potassium permanganate was standardized against duplicate, accurately weighed portions of sodium oxalate.
- iii. Titrations of two 25 ml portions of stock solution A with 20.26 and 20.28 ml KMnO_4 reagent yielded an average concentration of 0.0901 M Fe^{-3+} ; for stock solution B, 23.15 and 23.10 ml of KMnO_4 reagent yielded an average of 0.1028 M Fe^{3+} .

Note: Standardization procedures were taken from Kolthoff, I.M., and R. Belcher, 1957, Volumetric Analysis Vol. III. Titration Methods: Oxidation-Reduction Reactions, Interscience Publishers, Inc., New York.

b. Establishing the calibration curve

- i. Dilutions: All glassware was cleaned first in dichromate cleaning solution, rinsed in distilled water, cleaned in concentrated nitric acid, and rinsed in distilled water. Two sets of dilutions, one set from each of the stock solutions A and B were prepared with 1-, 2-, 3-, 4-, and 5-ml.

volumetric pipettes and made up in 1-liter volumetric flasks with distilled, deionized water at 23°C. Note: All the water, except rinse water, used to prepare standard solutions, dilutions of standard solutions, and dosimetry solutions (described below) was distilled and then deionized by a mixed bed (Barnstead) resin.

- ii. The calibration curve: The calibration curve was derived by the method of least squares from a regression of absorbance on concentration. The thirty absorbance measurements are given in Table 17 and comprise triplicate readings (three separate aliquots) of each of the five dilutions from each stock solution. The equation of the calibration curve, where A is absorbance at 305 mμ (0.5 mm slit width, 0.8 N H₂SO₄ blank) and C is the concentration of ferric ion, is

$$A = 2.10 \times 10^{-3} \mu\text{MFe}^{3+} C + 0.01065$$

The standard error of estimate, s_{AC} , is .0081 and the 95% confidence limits on the extinction coefficient are $\pm 0.022 \times 10^{-3}$. The 95% confidence limits on a single absorbance reading at A = 0.7 are ± 0.018 , or $\pm 2.67\%$.

- iii. Glassware for dosimetry solutions: The dosimetry solutions were irradiated in either of the two sizes of borosilicate glass, glass stoppered test tubes described in Table 18. Both kinds of tube exceed in wall thickness the limit suggested by the ASTM method (ASTM, 1959, Tentative method ... Supplement to Book of ASTM Standards Par. 69, pp. 54-56, American Society for Testing Materials, Philadelphia, Pa.). Two separate experiments (data not shown) were made with dosimetry

solution in thin-walled (0.7 mm) glass vials, eight samples in each experiment. In one case the calculated average dose derived from the ferric ion concentrations in the irradiated vials was 1.1% higher than that derived from those in the thick-walled tubes. But in the second test the dose in the vials was 1.2% lower than in the tubes. An analysis of variance indicated no significant difference due to tube wall-thickness ($\alpha = .05$); therefore, no adjustment for tube thickness has been made to our dosimetry readings.

- iv. Fricke solution: Dosimetry solution was prepared according to the ASTM procedure, ASTM Designation D1671-59T (ASTM op. cit., 1959). Fresh dilutions were prepared from a stock solution each day; no stock solution was kept longer than 2 months. The diluted stock solution was oxygenated by bubbling O_2 through the solution for about 5 min shortly before irradiations were performed.
- v. Sample placement: All the tubes of dosimetry solution for measurements outside the center well were set and held in place by one of two methods; either the tube was fastened by its upper end to one end of a 3-foot long wooden dowel the other end of which was clamped to a steel ring stand (the ring stands were placed as far as possible away from the source) or the tube was fastened by rubber bands to the edge of a 2" wide piece of styrofoam and the styrofoam was fastened to a wooden stand. Placement error is estimated to be ± 2 mm. Inside the center well, a pair of styrofoam discs, one with holes cut through, one with holes cut half-

way through, were used to support the tubes. The holes were located 45° apart at radial distances of 0, 5, and 10 cm from the center. Height adjustment was achieved by styrofoam spacers of appropriate length, depending on the height above the cell floor at which dose measurements were desired. Typically, nine tubes were irradiated at the same time, 4 tubes each at 5 and 10 cm, and one in the center. The total mass (liquid, glass, and styrofoam) introduced into the center well was 430 g. The volume of the center well, up to a height equal to the active length of the source strips, is $15,800 \text{ cm}^3$.

- vi. Calculations: All exposures for dosimetry were automatically timed. Timing begins when the source is fully raised and the source does not start down until timing ends. The time equivalent of the transient dose is estimated to be 3 seconds in this installation. The total travel time of the elevator, up plus down, is 40 sec.; the total distance is 24.5 ft., of which, 3.5 ft. is in air. The three-second transient dose equivalent is assumed to be half of the travel time in air. Most of the set times for dosimetry runs have been in excess of 5 minutes. Exposure times were chosen so that the absorbance readings would fall between 0.4 and 0.9. Each absorbance reading was converted to concentration of ferric ion by the formula for the calibration curve (See Part 1. I. b. ii.) The dose rate, D/t , at the location in question, was calculated from the equation $D/t = C/Gt$, where C is the ferric ion concentration, G is the yield (15.6 molecules oxidized/

100 ev), and t is the set time plus three seconds. Other conversion factors used were Avogadro's number 6.025×10^{23} , 1.602×10^{-12} erg/ev, and a density of dosimetry solution of 1.02/g/ml. Each dose rate (expressed in Krad/hr) was adjusted to an arbitrary reference date of August 1, 1967, using the decay factors published for 15-day intervals and interpolated to the nearest day (U.S. Public Health Service, 1960. Radiological Health Handbook).

The final equation for dose rate measured by Fricke dosimetry, adjusted by the decay factor, f , is

$$\frac{D}{t} = \frac{28.86 (A - 0.01065)}{f \cdot t} \text{ Krad/hr.}$$

Note: In all dose rate calculations 4 or 5 digits were carried for all operations and rounded to 3 significant figures for the final dose rate.

II. The Ferrous-Cupric Dosimeter

a. Preparation and other procedures

References used for this dosimetry method were taken from Jarrett, R. D. and J. Halliday, undated, "Proposed tentative method of test for absorbed gamma and electron radiation dose in the ferrous sulfate-cupric sulfate dosimeter." (Mimeograph) NLABS - Natick, Mass., and Jarrett, R. D., Sr., 1967, "Radiation dosimetry in relation to high intensity sources," Radiation Preservation of Foods, American Chemical Society, Washington, D. C. Some modifications, changes, or options to the basic methods were as follows: solutions were aerated before irradiation, no correction was made for the extent of container

surface; no temperature correction was made; absorbance was read against distilled water, and all absorbances were reduced by the absorbance of a sample of unirradiated solution which was read after the irradiations were finished; glassware was not cleaned with irradiated solution. Glassware cleaning procedures, dosimetry tubes, and sample placement were the same as described under Fricke dosimetry.

b. Calculations

Each absorbance reading was converted to dose according to the same calibration curve used for Fricke dosimetry. Dosimetry is reported in terms of dose rate, adjusted as described to a reference date of August 1, 1967; the value used for yield was 0.66; the density of dosimetry solution was assumed to be 1.00 g/ml. The final equation for dose rate measured by Ferrous-Cupric dosimetry, adjusted for decay is

$$\frac{D}{t} = \frac{696.4 (A' - 0.01065)}{f \cdot t} \text{Krad/hr.}$$

where A' is the absorbance minus the absorbance of unirradiated dosimetry solution.

III. Comparison of Fricke and Ferrous-Cupric Methods

Table 19 shows the results of a comparison of the two dosimetric methods at two different distances from the source. In both cases ($\alpha = 5\%$) the methods gave significantly different results. The Fricke method gave the lower value in both instances, about 1% lower at the higher dose rate and 3.0% lower at the lower dose rate. Moreover, in two of the four tests the differences in means among replications of the same method are significantly different ($\alpha = 5\%$).

Figure 1 shows the comparisons of the two methods as well as the variation in dose rate as a function of angular position about the source. The error mean square was lower for the Ferrous-cupric method, hence the Ferrous-cupric method was slightly more sensitive in indicating the existing differences in dose rate with position. At 25 cm from the source center, the rate at 0° is 8% below the average value and at 90° it is 5.5% above the average. At 50 cm from the source, all the variations are within 2% of the average. The reason for the variation in dose rate with angular position is the range in the activity of the individual source strips, which is just over a factor of 2. When a sample is positioned for irradiation at some predetermined dose, the average value of all positions is used to decide how far from the source the sample should be placed. At distances beyond 50 cm from the source, no adjustment is made for the variation with position. But, at distances between 25 and 50 cm, we do not put samples at the 0° and 90° positions which are marked on the floor of the room.

IV. Dose Rates in the Center Well

Mapping of the radiation field was according to a cylindrical coordinate system with the origin $r = 0$, $h = 0$ defined by the geometric center of the source holder and the cell floor, which coincides with the bottom of the active portion of the source strips when the strips are in the raised position.

In the center well, the dose rate was measured at 27 locations defined by three planes: $h = 2.6$ cm (the center of the liquid height in a dosimetry tube), $h = 15.2$ cm, the mid-plane (a plane passing through the center of the active length of the source strips), and $h = 27.8$ cm (a plane a distance above the mid-plane equal to the

distance of the 2.6 cm-plane below the mid-plane); three distances from the center of the source: $r = 0, 5, \text{ and } 10 \text{ cm}$; and, at 5 and 10 cm, eight angular positions 45° apart. All measurements were with the Ferrous-cuprice method. The coefficient of variation between replicates averages about 2%. The results are given in Table 21.

TABLE 17

Absorbance measurements of Fe^{3+} for calibration. (Beckman DU, 305 mu, 0.5 mm slit width. 0.8 N H_2SO_4 blank)

<u>Dilution</u>	<u>Stock solution A, 0.0901 M Fe^{3+}</u>	<u>Stock solution B, 0.1028 M Fe^{3+}</u>
1:1000	0.196 .196 .200	0.222 .214 .224
2:1000	.386 .402 .395	.442 .448 .440
3:1000	.576 .578 .578	.654 .660 .662
4:1000	.768 .778 .788	.875 .870 .880
5:1000	.946 .965 .965	1.07 1.08 1.09

TABLE 18

Some characteristics of the test tubes used for dosimetry work.
(Both kinds of tubes - Pyrex glass, glass stoppered)

Characteristics	<u>Tube</u>	
	Large	Small
Volume of solution, ml	10	7.5
O.D., cm	1.9	1.7
I.D., cm	1.34	1.28
Liquid height, cm	5.2	5.3
Wall thickness, mm	2.8	2.6
Glass-to-liquid, volume ration ^a	3.0	3.6
Weight, empty, with stopper, g	35	29

^aonly the glass in contact with liquid

TABLE 19

Dose rates measured by two dosimetric methods, Krad/hr, adjusted to Aug. 1, 1967, at two distances from the center of the source. (The height above cell floor was 2.6 cm. Each item is the average of 8 readings at angular positions 45° apart. See Fig. 1).

Distance from source center, cm		Methods	
		Fricke	Ferrous-cuprice
25	Set exposure time	105 sec.	40 min.
		785.9	788.0
		769.8	785.0
		782.0	
	Mean, Krad/hr	779.2	786.5
	Actual dose, Krad	22	490
50	Set exposure time	5 min.	110 min.
		211.1	215.0
		209.6	217.4
		208.4	
	Mean, Krad/hr	209.7	216.4
	Actual dose, Krad	16	370

TABLE 20

Analysis of variance of dose measurements made by two dosimetric methods. (Data of Table 3a.)

Method		Fricke			Ferrous-cupric		
		Mean			Mean		
Distance from source, cm	Source of variation	D.F.	square	F	D.F.	square	F
25	Positions	7	2757	32.2***	7	2458	46.4***
	Replications	2	567	6.63*	1	36	0.68
	Error	14	85.6	-----	7	53.1	-----
50	Positions	7	6.61	1.5	7	14.56	6.39
	Replications	2	15.15	3.4	1	22.56	9.91*
	Error	14	4.45	---	7	2.28	----

TABLE 21

Dose rates ^a at various locations in the center well, Krad/hr, adjusted to August 1, 1967, Ferrous-cupric dosimetry.

<u>Height, h, above cell floor, cm</u>	<u>Distance, r, from the center of the source, cm</u>		
	<u>0</u>	<u>5</u>	<u>10</u>
27.8	1660	1770	2080
15.2	2120	2250	2730
2.6	1720	1800	2140

^a Entries for $r = 0$ are the averages of 4 measurements; entries for $r = 5$ and 10 cm are the averages of 16 measurements, duplicate runs at 8 angular positions.

Except at $h = 2.6$ cm, at a given value of h and r no significant difference with angular position was discovered. At the lower plane position there is a hot spot at 270° and a cold spot at 135° , above 3% above the below the average respectively.

Fig. 1a. Variation in dose rate with angular position at 25 cm from the source center, 2.6 cm above the cell floor. (Average of 3 measurements at each position with the Fricke method, 2 with the ferrous-cupric method. Rates adjusted to Aug. 1, 1967.)

Fig. 1b. Variation in dose rate with angular position at 50 cm from the source center, 2.6 cm above the cell floor. (Average of 3 measurements at each position with the Fricke method, 2 with the ferrous-cupric method. Rates adjusted to Aug. 1, 1967.)

V. Perspex-HX Dosimeter (proposed ASTM Recommended Practice)

A. This report comprises the results and supplementary information requested in the course of a performance test of Perspex-HX dosimeters. These tests were done in June and July, 1969, on dosimeters received in February, 1969.

B. Supplementary information:

1. Spectrophotometer - Beckman DU, Model 2400;
2. Single beam;
3. Compartment temperature - 72°F ;
4. Irradiator - described in attached Monthly Status Letter No. 28, Edited and revised copy, dated October, 1968:
5. Irradiation temperature - 62°F ;
6. Method of calibration of irradiator - described in the status letter referred to in B. 4. above;
7. Dose rate - 1,730 Krad/hr/
8. Drift checked between each reading;
9. Molar extinction coefficient with ferric ion solution - 2100 ± 22 , 95% confidence limits on the slope of the standard curve;
10. Method of Sample placement is described in Section D below.

C. Results:

1. Linearity - The individual measurements, five dosimeters for each dose and measurement time, are given in Table 22 for 305 μm and in Table 23 for 300 μm , in terms of the calculated calibration constant corrected for dosimeter thickness. The absorbencies, vs. air, of the "unirradiated" dosimeters varied some about a mean near 0.1 OD. The corresponding analyses of variance are

given in Tables 24 and 25. Figures 1 and 2 show, respectively, the dose dependence and bleaching effect. The irradiation dates were 6/18 for 0.5 Mrad, 6/23 for 1 and 3 Mrad, 6/24 for 2 and 4 Mrad, and 6/25 for 5 Mrad. The five dosimeters at each treatment were irradiated at the same time at five different locations. Moreover, the first entry at each dose corresponds to the same location; that is, in Table 22 the entries under 2 hours of 0.240, 0.257, 0.236, 0.228, 0.195, and 0.172 belong to 6 different dosimeters, all irradiated at different doses, but all placed at the same location in the radiation field. The same statement

Table 22. Calibration constant, C(305), OD/Mrad, adjusted for dosimeter thickness.

Dose Mrad	Time of measurement, hr				Total	Mean
	2	4	24	48		
0.5	0.240	0.232	0.232	0.222	0.926	0.232
	.240	.256	.232	.248	.976	.244
	.242	.242	.231	.231	.946	.236
	.228	.238	.215	.210	.891	.223
	.246	.244	.236	.238	.964	.241
	<u>.246</u>	<u>.244</u>	<u>.236</u>	<u>.238</u>	<u>.964</u>	<u>.241</u>
Total	1.196	1.212	1.146	1.149	4.703	
Mean	0.239	0.242	0.229	0.230	0.235	
1.0	0.257	0.253	0.253	0.250	1.013	0.253
	.250	.258	.250	.247	1.005	.251
	.237	.242	.243	.245	.967	.242
	.246	.246	.254	.246	.992	.248
	.252	.254	.259	.254	1.019	.255
	<u>.252</u>	<u>.254</u>	<u>.259</u>	<u>.254</u>	<u>1.019</u>	<u>.255</u>
Total	1.242	1.253	1.259	1.242	4.996	
Mean	0.248	0.251	0.252	0.248	0.250	
2.0	0.236	0.237	0.242	0.232	0.947	0.237
	.236	.241	.236	.232	.945	.236
	.242	.244	.235	.228	.949	.237
	.237	.236	.233	.231	.937	.234
	.238	.232	.232	.236	.938	.234
	<u>.238</u>	<u>.232</u>	<u>.232</u>	<u>.236</u>	<u>.938</u>	<u>.234</u>
Total	1.189	1.190	1.178	1.159	4.716	
Mean	0.238	0.238	0.236	0.232	0.236	
3.0	0.228	0.228	0.220	0.215	0.891	0.223
	.225	.223	.221	.221	.890	.222
	.222	.222	.218	.213	.875	.219
	.225	.222	.228	.221	.896	.224
	.227	.229	.224	.218	.898	.224
	<u>.227</u>	<u>.229</u>	<u>.224</u>	<u>.218</u>	<u>.898</u>	<u>.224</u>
Total	1.127	1.124	1.111	1.088	4.450	
Mean	0.225	0.225	0.222	0.218	0.222	
4.0	0.195	0.200	0.188	0.191	0.774	0.194
	.195	.191	.195	.180	.761	.190
	.201	.200	.198	.191	.790	.198
	.202	.197	.190	.184	.773	.193
	.202	.197	.192	.186	.777	.194
	<u>.202</u>	<u>.197</u>	<u>.192</u>	<u>.186</u>	<u>.777</u>	<u>.194</u>
Total	0.995	0.985	0.963	0.932	3.875	
Mean	0.199	0.197	0.193	0.186	0.194	
5.0	0.172	0.172	0.166	0.162	0.672	0.168
	.173	.175	.165	.163	.676	.169
	.164	.166	.159	.157	.646	.162
	.176	.174	.165	.160	.675	.169
	.172	.172	.167	.160	.671	.168
	<u>.172</u>	<u>.172</u>	<u>.167</u>	<u>.160</u>	<u>.671</u>	<u>.168</u>
Total	0.857	0.859	0.822	0.802	3.340	
Mean	0.171	0.172	0.164	0.160	0.167	
Grand Total	6.606	6.623	6.479	6.372	26.080	
Mean	0.220	0.221	0.216	0.212	0.217	

Table 23. Calibration constant, C(300), OD/Mrad, adjusted for dosimeter thickness.

Dose Mrad	Time of measurement, hr				Total	Mean
	2	4	24	48		
0.5	0.260	0.260	0.256	0.246	1.022	0.256
	.264	.284	.254	.264	1.066	.266
	.271	.269	.256	.236	1.032	.258
	.265	.274	.249	.254	1.042	.260
	.269	.267	.265	.259	1.060	.265
Total	1.329	1.354	1.280	1.259	5.222	
Mean	0.266	0.271	0.256	0.252	0.261	
1.0	0.275	0.280	0.282	0.283	1.120	0.280
	.275	.284	.279	.283	1.121	.280
	.269	.273	.275	.279	1.096	.274
	.270	.271	.279	.271	1.091	.273
	.280	.269	.283	.281	1.113	.278
Total	1.369	1.377	1.398	1.397	5.541	
Mean	0.274	0.275	0.280	0.279	0.277	
2.0	0.265	0.266	0.273	0.264	1.068	0.267
	.265	.271	.266	.266	1.068	.267
	.271	.280	.266	.260	1.077	.269
	.266	.268	.261	.262	1.057	.264
	.270	.266	.260	.266	1.062	.266
Total	1.337	1.351	1.326	1.318	5.332	
Mean	0.267	0.270	0.265	0.264	0.267	
3.0	0.266	0.260	0.256	0.249	1.031	0.258
	.262	.259	.252	.255	1.028	.257
	.257	.257	.254	.250	1.018	.254
	.257	.257	.258	.252	1.024	.256
	.262	.261	.261	.262	1.046	.262
Total	1.304	1.294	1.281	1.268	5.147	
Mean	0.261	0.259	0.256	0.254	0.257	
4.0	0.237	0.232	0.225	0.227	0.921	0.230
	.230	.230	.223	.214	.897	.224
	.240	.215	.232	.227	.914	.228
	.236	.236	.224	.217	.913	.228
	.242	.234	.226	.221	.923	.231
Total	1.185	1.147	1.130	1.106	4.568	
Mean	0.237	0.229	0.226	0.221	0.228	
5.0	0.204	0.204	0.196	0.192	0.796	0.199
	.298	.208	.198	.190	.796	.199
	.221	.217	.206	.208	.852	.213
	.206	.206	.200	.193	.805	.201
	.201	.206	.201	.191	.799	.200
Total	1.040	1.041	1.001	0.974	4.048	
Mean	0.208	0.208	0.200	0.195	0.202	
Grand Total	7.564	7.564	7.416	7.322	29.866	
Mean	0.252	0.252	0.247	0.244	0.249	

Table 24. Analysis of variance of calibration constant results, C(305), data of Table 1.

<u>Source</u>	<u>D.F.</u>	<u>Mean square</u>	<u>F</u>
Dose	5	0.01932	520***
Time	3	.000462	12.5***
Interaction	15	.000037 ^a	8.5***
Error	96	.00000438	--

^aInteraction variance used to test the main effects.

Table 25. Analysis of variance of calibration constant results, C(300), data of Table 2.

<u>Source</u>	<u>D.F.</u>	<u>Mean square</u>	<u>F</u>
Dose	5	0.01563	420***
Time	3	.001798	48***
Interaction	15	.0000455	1.22
Error	96	.0000373	--

C. Results:

1. Linearity (continued)

applies to the second, third, etc. set of entries. Therefore, the error variance is not a strict measure of error, but has location and all its interactions in it. The significance of this explanation has to do with the fact that all 5 locations were considered to have the same radiation flux. It would seem, according to the size of the error variances, that this assumption was reasonable. The results of previous mapping tests of this part of the radiation field, with Ferrous-cupric dosimetry, indicated that among these same locations the dose rates were the same within 2% of each other.

The following conclusions, applicable to both 305 and 300 μ m, force themselves to one's attention.

a. Dosimeters similarly treated at the same time at the same dose, and read at the same time show good agreement, a coefficient of variation of 2-3%. This variation includes location variance as well and is about the same as the variance got with Ferrous-cupric dosimetry.

b. There is dose dependence in the range 0.5 to 5 Mrad; it is non-linear, exhibiting a peak at 1.0 Mrad; the extremes for C(305) were 0.250 and 0.167 OD/Mrad, a spread of $\pm 20\%$. This finding was upsetting, to say the least. Even adjusting the absorption for the 250 krad pre-test dose did not make C constant, although it did reduce the degree of dependence. Either the dosimeters are not especially suitable, or something about the study is defective.

c. The bleaching effect averaged about 3%/day between 2 hr and 24 hr for both C(300) and C(305). For C(305) the loss rates were 0.3%/hr (2 - 4 hr), 0.2%/hr (2 - 24 hr), and 0.1%/hr (24 - 48 hr); for C(300) the loss rate was 0.0% between 2 and 4 hr and the same as those for C(305) in the other two intervals.

d. The ratio, C(300)/C(305), increased with dose.

2. Additional dosimeters at 1 Mrad - Five dosimeters were irradiated on 7/7 under the same conditions as specified in Part 1 above, all at 1 Mrad. The results are given in Table 26. The ratio of C(300) to C(305) is the same as it was for 1 Mrad in Part 1, but the C's are lower by 6%.

Table 26. Calibration constants, for dosimeters given 1 Mrad OD/Mrad, adjusted for dosimeter thickness.

C(305)				C(300)			
Time of measurement, hr				Time of measurement, hr			
2	4	24	48	2	4	24	48
0.241	0.241	0.240	0.230	0.266	0.266	0.264	0.259
.234	.238	.235	.229	.258	.262	.258	.256
.231	.236	.224	.224	.258	.266	.251	.255
.236	.226	.236	.230	.258	.255	.258	.256
.240	.246	.240	.246	.266	.272	.268	.272
0.236	0.237	0.235	0.232	0.261	0.264	0.260	0.259

3. Additional tests - a. Five dosimeters were irradiated at 4 Mrad on 7/7 under the same conditions as in Part 1 above. The average calibration constant read at 1 hour was about 5% below the average value determined for 4 Mrad in Part 1, a confirmation of the results of the additional 5 dosimeters at 1 Mrad. These two sets of additional dosimeters confirm the non-linearity observed and reported in Part 1 and raise a new doubt because the C's were significantly lower than in the previous set of tests.
- b. Five dosimeters were irradiated on 7/7 at 1 Mrad at a rate of 1730 Krad/hr, but, instead of being enclosed between Acrylite sheets (described in Part D below), the dosimeters were put in 3.5 ml of distilled, deionized water in glass vials about 1 cm I.D. The readings 1 hour after irradiation were 0.99, 0.985, 0.873, 0.96, and 0.97 Mrad, based on the C(305) of 0.250 OD/Mrad determined from Part 1. Analyzed another way, if it is assumed that the dose was in fact 1 Mrad, the calibration coefficients C(305) were 0.248, 0.246, 0.218, 0.240, and 0.242 OD/Mrad (mean 0.239 OD/Mrad). The objective of this test was to compare water

Fig. 1. Dose dependence of the calibration constant for Perspex-HX

Fig. 2. Bleaching effect and dose dependence of Perspex-HX dosimeters at 300 μm

D. Sample placement:

The individual Perspex dosimeters were cleaned in alcohol, placed inside a small, folded piece of lens tissue, then centered between two 0.25"x2"x1.5" Acrylite sheets. The Perspex-Acrylite sandwich was held together with two rubber bands. All dosimeters were placed in the center well of our source at a distance of 5 cm from the source center and in the mid-plane of the active length of the source strips. The source strips are arranged in a cylindrical configuration at 14.5 cm from the geometric center of the source. Figure 3 shows the general arrangement for supporting the dosimeters, which were irradiated 5 at a time, one each N, E, S, W. and NW of the geometric center of the source.

Figure 3. Placement of Perspex-HX dosimeter for irradiation in center well of Cobalt-60 source. Perspex is 5 cm from the geometric center of the cylindrical source; source strips are 14.5 cm from the geometric center.

as the medium for providing electronic equilibrium with Acrylite. Since we were unable to confirm C from one test to another, no firm conclusion is justified from this test with water.

APPENDIX

Table I

Degree of opening of Pennsylvania mushrooms stored 5 days at 2°C and 2 days at 8°C.

Dose Krad	0	12.5	25	50	100	200
1.0	0	0	0	0	0	0
0	0	0	.4	.9	0	0
.3	.4	0	0	0	0	0
.2	.3	0	0	.7	0	0
.1	0	0	0	0	.2	0
.7	0	0	0	.2	0	0
0	0	0	0	.5	0	0
.9	0	0	0	.2	.1	0
.4	0	0	0	0	.1	0
.1	0	0	0	0	0	0
0	1	0	0	0	0	.4
.3	0	0	0	.1	0	0
0	0	.5	0	0	0	0
.4	.2	.2	0	0	.2	0
0	0	0	0	0	.6	0
0	.1	.1	0	0	.1	0
.9	.5	0	0	.1	.2	.1
.5	0	0	0	.8	0	0
.8	0	0	0	0	0	0
.3	0	0	0	0	.1	0
Ave. D.O.	0.33	0.12	0.06	0.18	0.08	0.02

APPENDIX

Table II

Degree of opening (D.O.) and opening ratio (O.R.) of Pennsylvania mushrooms stored 5 days at 2°C and 10 days at 8°C after irradiation.

Krad	0		12.5		25		50		100		200	
	DO	OR	DO	OR	DO	OR	DO	OR	DO	OR	DO	OR
	1.0	1.16	0.2	0.54	0.1	0.50	0.0	0.41	0.1	0.40	0.0	0.52
	1.0	0.99	0.9	0.91	0.5	0.56	0.3	0.64	0.4	0.66	0.0	0.52
	1.0	0.89	1.0	0.57	1.0	0.51	0.0	0.63	1.0	0.41	0.0	0.42
	1.0	2.38	1.0	0.87	0.0	0.45	1.0	0.74	0.1	0.63	0.0	0.61
	1.0	2.01	0.9	0.60	1.0	0.88	0.0	0.56	0.4	0.66	0.0	0.33
	1.0	1.83	0.4	0.74	0.5	0.50	0.4	0.71	0.0	0.59	0.0	0.32
	1.0	0.99	0.0	0.34	0.0	0.45	0.8	0.60	0.0	0.44	0.3	0.75
	1.0	2.00	0.7	0.52	0.2	0.57	1.0	0.88	0.9	0.78	0.0	0.45
	1.0	1.21	1.0	0.62	0.3	0.05	1.0	0.51	0.2	0.54	0.0	0.48
	1.0	0.77	0.0	0.48	0.0	0.70	1.0	0.75	0.0	0.45	0.1	0.55
	0.9	0.68	0.9	0.58	1.0	0.54	1.0	0.66	0.0	0.45	0.2	0.45
	1.0	1.51	1.0	0.56	0.2	0.35	1.0	0.60	0.3	0.69	0.8	0.63
Ave.	1.0	1.37	0.7	0.61	0.4	0.50	0.6	0.64	0.3	0.56	0.1	0.50

APPENDIX

TABLE III

Degree of opening (D.O.) and opening ratio (O.R.) of 12 mushrooms from lots irradiated with electrons, stem up or down, and gamma rays after days of storage at 10°C, 90% R. H.

Electron irradiation - Stem up

Krad	12.5		25		50		100		200	
	DO	OR	DO	OR	DO	OR	DO	OR	DO	OR
.90		.63	.50	.63	1.00	.48	0	.33	0	.36
.90		.46	.95	.55	.30	.95	.50	.57	.70	.57
.17		.40	.45	.75	.95	.54	0	.44	.70	.50
.50		.75	1.00	.77	.80	.41	0	.38	0	.35
1.00		.51	.40	.40	.50	.76	.15	.49	.65	.40
.50		.71	.70	.54	1.00	1.19	.90	.46	0	.28
1.00		.59	.70	.51	1.00	1.00	0	.53	.40	.43
.80		.58	1.00	.62	.10	.38	0	.34	1.00	.64
.30		.49	1.00	.59	.15	.43	.25	.28	.40	.41
.90		.64	1.00	.58	1.00	.49	.20	.49	.50	.43
1.00		.50	.95	.38	.70	.55	.50	.38	0	.26
.30		.60	.20	.47	.40	.57	.80	.49	0	.48

Electron irradiation - Stem down

Krad	12.5		25		50		100		200	
	DO	OR	DO	OR	DO	OR	DO	OR	DO	OR
.25		.55	.90	.64	1.00	.64	.80	.70	1.00	.62
1.00		.78	1.00	.60	.15	.62	1.00	.84	.90	.57
.70		.69	1.00	.67	.85	.61	0	.57	.80	.71
.80		.58	1.00	.63	.10	.56	.40	.56	.30	.59
1.00		.70	1.00	.95	.60	.52	.20	.54	.70	.72
1.00		.61	1.00	.91	.80	.55	1.00	.92	.40	.67
1.00		.62	1.00	.79	.50	.90	1.00	.81	1.00	1.03
.60		.62	1.00	.84	.80	.66	1.00	.80	.25	.53
1.00		.53	1.00	1.08	1.00	.67	.60	.56	1.00	.71
.85		.62	.70	1.58	1.00	.57	.80	.48	.25	.60
1.00		.76	1.00	.64	1.00	.89	.90	.52	.80	.54
.90		.51	1.00	.54	1.00	.54	0	.46	.75	.64

APPENDIX

Table III (cont.)

Gamma Irradiation

Krad	12.5		25		50		100		200	
	DO	OR	DO	OR	DO	OR	DO	OR	DO	OR
0		.35	.60	.47	.25	.41	0	.45	0	.28
.90		.55	.40	.36	1.00	.34	0	.23	0	.37
.35		.47	0	.23	0	.48	0	.37	0	.36
0		.39	.30	.51	0	.30	.60	.48	0	.41
1.00		.86	.05	.40	.10	.48	0	.32	.10	.49
.05		.39	.25	.62	0	.39	.50	.48	0	.26
.35		.40	.40	.43	0	.46	.10	.63	0	.23
0		.39	0	.20	0	.28	0	.45	0	.33
.40		.35	.40	.47	0	.36	0	.27	0	.35
0		.28	.40	.46	0	.27	.20	.56	1.00	.81
0		.44	.20	.32	0	.30	.25	.53	0	.40
0		.29	.50	.45	0	.28	0	.32	0	.27

Control, 0 Krad

<u>DO</u>	<u>OR</u>
1.00	.66
1.00	1.39
0	.56
1.00	.65
.90	.69
.95	.93
.40	.65
1.00	.73
.80	.71
1.00	.96
1.00	.91
1.00	.78

APPENDIX

Table IV

D.O. and O.R. of Control and Irradiated (50 krad) Mushrooms stored in the Air and 5% CO₂, at 11°C for 5 days.

<u>0 Krad - Air</u>		<u>50 Krad - Air</u>		<u>0 Krad - 5% CO₂</u>		<u>50 Krad - 5% CO₂</u>	
<u>D.O.</u>	<u>O.R.</u>	<u>D.O.</u>	<u>O.R.</u>	<u>D.O.</u>	<u>O.R.</u>	<u>D.O.</u>	<u>O.R.</u>
.9	.61	.0	.41	.0	.48	.0	.61
.0	.22	.4	.50	1.0	.95	1.0	.77
.0	.50	.2	.42	.9	.90	.5	.65
1.0	1.24	.6	.71	.0	.27	.5	.62
.0	.23	.0	.45	1.0	.57	.0	.62
.2	.51	.2	.64	1.0	1.10	.0	.37
.1	.36	.0	.34	.4	.47	.0	.33
1.0	.82	.0	.04	.1	.21	.0	.13
.1	.58	.0	.13	.0	.41	1.0	.38
.5	.41	.0	.21	1.0	.98	.5	.06
.0	.31	.0	.24	.8	.44	.0	.47
.5	.45	1.0	.36	.8	.57	.0	.59
1.0	.79	.0	.05	1.0	.22	.0	.28
.8	.64	.0	.31	.8	.76	.0	.39
1.0	.35	.0	.28	.0	.31	.0	.30
.9	.56	.0	.06	.0	.14	.3	.32
1.0	.59	.0	.34	.5	.75	.3	.35
1.0	.75	.0	.15	.9	.71	.0	.31
.7	.08	.0	.04	.1	.33	1.0	.54
1.0	.38	.0	.35	.0	.13	.5	.47
.6	.68	.0	.39	.5	.69	.1	.33