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Progress
~~FINAL~~ REPORT

IRRADIATION OF FRUITS AND VEGETABLES

MASTER

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INTRODUCTION

This report covers the first year's work on this contract. Previous studies on fruit and vegetable preservation performed at Michigan State University have been reported under Contract No. AT(11-1)-1283.

The work done is reported under two headings: commodity studies and yeast studies. The current status of the MSU Research Irradiator is also reported. All the irradiations reported herein were performed with CO-60 source at the Phoenix Memorial Laboratory, University of Michigan--source strength about 10,000 C. Storage and analysis of samples was performed at MSU.

1. COMMODITIES - Summary Statement and Status

The experiments on commodities fall into two general categories, those in which the objective of the radiation is reduction of microbial load with the expectation of increased shelf life of the commodity and those in which shelf life extension might be achieved through a retardation of maturation.

Radiation at 50 Krad retards the elongation of asparagus spears during storage without apparent deleterious effects; however, our analyses have not demonstrated a quality superiority, such as improved texture or less wastage. Experiments are continuing.

Irradiation of strawberries (at the fully ripe stage for Michigan marketing practices) continues to give mixed results. This season ('66) there was no increase in shelf life, in contrast to other years when 200 Krad had appreciably extended the shelf life. Experiments are continuing.

A dose of 300 Krad materially increases the rate at which blueberries can subsequently be freeze-dried. The market potential of this application is limited and no further tests are planned.

Sweet cherries, if not heavily contaminated, keep well for 4 weeks so that irradiation does not improve shelf life. Radiation softening can be overcome by soaking the cherries in a CaCl_2 solution, preferably before irradiation. Experiments are continuing.

Post-harvest sweet corn maturation (conversion of starch) was not inhibited by irradiation (30 Krad or 300 Krad). Additional experiments are planned.

Combinations of heat and irradiation treatment of apple juice did not give a synergistic effect on microbial destruction. However, total counts in reasonably clean juice did approach pasteurization and there is some promise of improved quality. No extensive experiments are planned.

Irradiation of mushrooms at doses above 10 Krad markedly retards the opening of the mushroom caps during storage. This effect is most promising as an application of radiation and further experiments are planned.

1.1. Asparagus

Irradiation of asparagus at doses of 30 and 100 Krads retarded post-harvest growth even when the spears were stored (38°F.) with the ends immersed in water. Bracts remained closed even on the unirradiated spears. Visual and colorimetric analyses (acetone extract at 440 and 660 mμ) revealed no color change during the first 16 days of the storage period. The spears (all treatments) toughened through the 8th day of storage but re-softened by the 16th day. Color and texture were measured on raw samples.

Table I. Length of asparagus spears (inches), harvested and irradiated on 6-17-66. (Average of 20 spears. Storage temperature $38 \pm 1^\circ$ F.)

Dose - Krad	Storage time - da					Ave.
	0	4	8	16	32 ^a	
0	8.34	8.82	8.75	8.77	8.91	8.72
30	8.35	8.55	8.55	8.60	8.56	8.52
100	8.32	8.61	8.62	8.68	8.68	8.58

^aAt 32 days, a full sample of 20 was not measured due to deterioration of 10 to 20% of the spear tips.

Table 2. Shear resistances^a (micro-amperes) of asparagus spears harvested and irradiated on 6-17-66 and stored at $38 \pm 1^\circ$ F.

Dose - Krad	Portion of Spear	Days after Irradiation				
		0	4	8	16	32
0	top	33.7	53.0	51.0	38.0	37.0
0	bottom	34.0	50.5	54.5	37.5	38.5
30	top	35.9	52.0	53.0	39.5	36.0
30	bottom	36.1	51.5	53.0	39.0	39.5
100	top	32.0	52.0	54.5	39.0	38.0
100	bottom	32.1	51.0	53.0	38.0	37.5

^aAllo-Kramer shear press with 250 lb. ring, range 100, Lo, on 75g samples, all blades used, blades perpendicular to the stalks.

1.2 Strawberries

1.2.1. Texture and spoilage.

There was no significant quality preservation of berries irradiated at 20 Krads and 200 Krads; however, these berries were picked immediately after an early morning rain. They were still wet and bruised easily. In previous years, depending on the storage temperature and other factors, spoilage had been delayed from 2-8 days by a dose of 200 Krad.

Table 3. Keeping quality (% sound fruit by weight) of irradiated strawberries,^a Robinson variety, picked 6-27-66, stored at 38 ± 1° F.

Treatment		Storage time, days			
Dose, Krad	Wrapping	0	5	10	Ave.
0	Wrapped	93	37	11	47
0	Not Wrapped	94	66	14	58
20	Wrapped	93	42	21	52
20	Not Wrapped	99	73	16	63
200	Wrapped	95	29	26	50
200	Not Wrapped	94	75	13	61
Ave.		95	54	17	55

<u>Treatment</u>	<u>Ave.</u>
Wrapped	49.6
Not wrapped	60.6
0 Krad	52.5
20 Krad	57.5
200 Krad	58.0

^a10 pints (about 280 g/pint) each treatment
18-20 berries

Table 4. Shear resistance^a (ma/100 grams) of Robinson variety strawberries^b picked 6-27-66, stored at 38° F., average of five samples

Treatment		Storage time, days			
Dose Krad	Wrapping	0	5	10	Ave.
0	Wrapped	40	46	42 ^c	43
0	Not wrapped	40	48	49 ^c	46
20	Wrapped	48	45	41	45
20	Not wrapped	43	44	46 ^c	45
200	Wrapped	39	46	37	40
200	Not wrapped	38	36	47	40
Ave.		41	44	43	43

Treatment	Ave.
0 Krad	44.5
20 Krad	45.0
200 Krad	40.0

^aThe Allo-Kramer shear press was used with the 250 lb. ring, range 50, setting Lo - values given are peak values.

^bBerries tested were only remaining sound fruit.

^cAdequate samples were not available for five trials.

The unwrapped berries kept better probably because the moisture trapped in the wrapped (1.5 mil, unperforated polyethylene film) boxes provided ideal conditions for mold growth. The softening in the berries treated at 200 Krad, although only 10% less than unirradiated berries, is believed to be noticeable by tasting, although no flavor panel analysis was made.

1.2.2 Microbial analysis

Microbial analysis of single berries, or even a combined sample of a few berries, showed too much variation among samples. The technique finally used was to irradiate aliquots of a slurry (700-800 ml) at different doses.

The results show that, with a homogenous sample, ionizing radiation decreases the microbial contamination in Sparkle variety strawberries. Also, it seems that yeasts and molds were somewhat more resistant than were bacteria at low (0 to 200 Krad) levels of irradiation.

Table 5. Microorganisms per gram of fruit for Sparkle variety strawberries picked, irradiated, and plated on July 8, 1966.

Dose Krad	Sample ^a	Total count	Total yeast and mold	% Survival Total count	% Survival Yeast and mold
0	A	8.2×10^4	6.2×10^4	100	100
	B	10.1×10^4	6.1×10^4	100	100
100	A	3.7×10^4	3.7×10^4	39.	59.
	B	3.9×10^4	3.4×10^4	40.	56.
200	A	1.6×10^4	1.4×10^4	19.	23.
	B	1.7×10^4	1.4×10^4	17.	23.
400	A	6.7×10^2	4.2×10^2	0.81	0.69
	B	$12. \times 10^2$	3.9×10^2	1.2	0.64
800	A	2.7×10^2	0	0.33	0.10
	B	1.8×10^2	0	0.18	0

^aAll sample A's or B's are subsamples of the same master sample.

1.3 Blueberries

1.3.1 Freeze-drying characteristics.

A dose of 300 Krads increased the freeze-drying rate of whole blueberries.

Table 6. Percent weight loss of Jersey blueberries during freeze-drying. Average of two samples irradiated August 16, 1966.

Dose-Krad	Drying time (hours)				
	0	3	8	18	30
0	0	10.3	33.7	61.8	71.8
300	0	14.1	41.8	73.8	83.1

Each tabular entry (Table 6) is the average of two boxes; that is, two different boxes at each drying time. The initial moisture content of these berries is not known. The berries were irradiated first, then frozen within 6 hours. Drying was begun 2-5 days after irradiation.

1.3.2. Refirming.

Gamma irradiation of blueberries at the level of 200 Krads caused a significant softening. However, when the berries were soaked, after irradiation, in a Ca^{++} solution for one hour, the softening effect of the gamma irradiation was nearly eliminated after only one day of storage. Then, after 13 days of storage, the soaked-irradiated samples appeared to be even more firm than the control samples. After 27 days of storage at $38 \pm 1^\circ \text{F}$, the 200 Krad-soaked samples were more firm than either the control or 0 Krad-soaked samples.

It can be concluded, then, that if softening of blueberries during irradiation proves to be detrimental to quality, the original firmness can be restored by a one hour soak in a Ca^{++} solution. Also, if firmness is shown to be directly related to quality, irradiated-soaked samples appear to show a better retention of this quality factor after prolonged storage.

Table 7. Peak shear resistance (micro-amperes) for Jersey variety blueberries irradiated August 16, 1966. Average of four to five samples stored at $38 \pm 1^\circ \text{F}$.

Dose - Krad	Treatment	Days after irradiation			% loss in 27 da
		1 ^a	13 ^b	27 ^a	
0	none	47.2	100.5	30.0	36
0	Ca^{++}	52.4	127.0	35.2	33
200	none	32.6	61.5	21.5	34
200	Ca^{++}	41.6	108.7	39.8	4

^a Allo-Kramer shear press -- 250 lb. ring, range 50, 10, on 100 g samples.

^b Allo-Kramer shear press -- 100 lb. ring, range 100, on 40 g samples.

1.4. Cherries

1.4.1. Spoilage

Irradiation gave no extension of shelf life of sweet cherries, whether the cherries were soaked (Ca^{++}), either before or after irradiation, or not. There was a difference in keeping quality between cherries with the stems on and those with the stems removed (stemmed), 20% less sound fruit at the end of 28 days storage.

Table 8. Percentage by weight, sound fruit of Schmidt variety sweet cherries harvested 7-20-66 and irradiated 7-21-66. Average of five samples, stored at $38 \pm 1^\circ \text{F}$.

Treatment		Days storage					Ave.
Krad - Soak		1	7	14	21	28	
0	None	99.4	99.1	93.9	92.2	80.7	93.1
0	Before	99.3	98.9	93.1	90.2	79.5	92.2
0	After	100.0	98.4	91.3	90.7	83.5	92.8
20	None	100.0	99.2	94.5	85.2	81.4	92.1
200	None	100.0	97.1	93.4	92.5	80.1	92.6
200	Before	99.3	97.5	93.9	88.0	82.3	92.2
200	After	99.2	98.8	89.9	90.1	83.3	92.3
0	Stemmed	-	-	-	-	60.9	-
200	Stemmed	-	-	-	-	50.7	-

1.4.2. Refirming

Irradiation (200 Krad) caused a softening of sweet cherries, but a one hour soak in calcium chloride ($0.5\% \text{Ca}^{++}$) induced refirming, perhaps more rapidly in cherries soaked after irradiation than in those soaked before irradiation.

Table 9. Shear resistance ^a (micro-amperes) of Schmidt variety cherries harvested 7-20-66 and irradiated 7-21-66. Average of five samples stored at 38 ± 1° F.

Treatment		Storage time (days)					
Krad	Soak	1	7	14	21	28	Ave.
0	None	52.2	52.6	63.8	62.2	60.4	58.2
0	Before	54.4	57.6	65.8	67.6	63.2	61.7
0	After	54.6	63.6	63.2	69.2	60.0	62.1
20	None	51.8	55.0	62.4	62.0	60.2	58.3
200	None	39.8	40.4	49.0	55.4	64.0	49.7
200	Before	45.8	52.2	56.4	63.2	71.8	57.9
200	After	48.2	55.4	64.6	64.0	65.6	59.6

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

1.4.3. Microbial analysis and color.

Increasing dose of irradiation of aliquots of a slurry generally reduced the microbial load in sweet cherries. An unusually dry season and absence of brown rot probably explain the light initial contamination and the good keeping quality.

Table 10. Microorganisms per gram ^a of Schmidt variety sweet cherries harvested July 20, 1966, irradiated July 26, 1966.

Dose - Krad	Total Count	Total Yeast and Mold
0	1200	580
200	720	0
300	240	100
400	480	80
800	40	30

^a Average of 3 plates.

The color changes caused by irradiation depend upon the condition of the fruit at the time of irradiation. Between the whole and pitted samples, the L value decreased (became darker), the a value increased (more red) the b value

decreased (became less yellow). Comparison of the whole and macerated samples showed a decrease in the a value (less red) and an increase in the b value (more yellow). Between the pitted and macerated samples, the L value increased, the a value decreased (less red), and the b value increased (more yellow).

Visual inspection agreed with the results of the Gardner in that with irradiation, the macerated samples showed a definite increase in the intensity of their yellow color. This was probably due to the increased oxidation of the anthocyanin pigment during irradiation. Maceration may release this pigment and thus make it more susceptible to oxidation.

Table 11. Gardner color difference values for Schmidt variety cherries harvested July 20, 1966, irradiated July 26, 1966. ^a

Krad	Treatment	L-value	a-value	b-value
0	Whole	19.9	12.7	4.6
0	Pitted	15.2	7.8	4.5
0	Macerated	17.5	3.4	4.7
300	Whole	18.8	12.0	5.7
300	Pitted	18.3	5.8	5.4
300	Macerated	19.0	5.0	6.0
600	Whole	22.2	9.9	8.2
600	Pitted	19.8	11.5	6.1
600	Macerated	27.2	6.6	10.7

^a +a = redness; -a = greenness; +b = yellowness; -b = blueness;
L = 0 to 100 (black to white); standard plate: L = 24.8;
a = +20.4; b = +6.0.

1.5. Sweet corn.

Irradiated sweet corn showed no better quality retention as measured by moisture content.

Table 12. Percent moisture (wet basis) for Northern Bell sweet corn harvested and irradiated 8-24-66. (3 ears at each dose).

Dose-Krad	<u>Days storage</u>		Difference	Average Difference
	1	14		
0	79.0	59.4	19.6	19.6
	78.2	58.6	19.6	
	73.3	53.7	19.6	
30	77.6	57.7	19.9	20.3
	76.1	54.2	21.9	
	73.9	54.9	19.0	
300	77.6	56.4	21.2	20.8
	75.1	56.9	18.2	
	78.5	55.5	23.0	

Moisture content was determined by a vacuum oven method. The ears were stored at 38° F. in plastic bags; kernels (for moisture determination) were stripped from the ears.

1.6. Apple juice.

1.6.1. Quality factors.

Fresh, unpasteurized, unfiltered apple juice was subjected to various heat, radiation, and heat-irradiation treatments. Post treatment analysis at 1 day and 9 days storage (38° F.) showed no change in soluble solids (range, all treatments, 12.0% to 12.5%) and no change in percentage acid (range, all treatments 0.402 - 0.409%, calculated as malic acid).

Viscosity generally decreased upon storage. However, the heated-irradiated samples changed very little because most of the viscosity loss was caused by irradiation, and the heat treatment stabilized the system with respect to viscosity loss upon storage.

Table 13. Viscosity (time of flow through No. 100 Ostwald viscometer) values for apple juice treated October 26, 1966 at two and nine days after treatment.^a

Dose-Krad	Heat (min) at 120°F.	Time of Flow (sec)	
		1 da	9 da
0	0	121.8	105.6
0	30	119.4	115.8
150	0	109.8	97.8
150 ←	30 ^b	111.0	108.0
150 →	30 ^c	108.6	108.0

^aSamples stored at 38° ± 1° F.

^bHeated first

^cIrradiated first

The absorbance (480 μ) was reduced by all treatments; the greatest bleaching was caused by radiation. Moreover, neither heat nor irradiation completely stabilized the color. But the irradiated-heated samples changed least during storage. These color changes are easily detected by eye.

Table 14. Absorbance of filtered apple juice treated October 26, 1966 after two and nine days of storage at 38° ± 1° F.

Dose-Krad	Heat at 120° F. (min)	Absorbance at 480 μ	
		2 da	9 da
0	0	.713	.693
0	30	.650	.553
150	0	.405	.362
150 ←	30 ^a	.350	.272
150 →	30 ^b	.346	.330

^aHeated first

^bIrradiated first

1.6.2. Microbiological analysis.

Apple juice to which heat and irradiation was applied could be stored for 15 to 20 days at 38° F. before the microbial contamination would reach its original level. There was a marked reduction in the number of viable bacteria

and yeasts and molds when heat, gamma irradiation, or a combination of the two treatments was applied to apple juice. There was no evident synergistic effect on total count as the predicted number of survivors from radiation plus heat is 8 compared with 4 survivors for the combined treatment.

Table 15. Organisms per milliliter of apple juice treated on October 26, 1966, plated (in triplicate) at one and nine days following treatment.^a

Dose-Krad	Heat (min. at 120° F)	Total Count		Total Yeasts and Molds	
		1 da	9 da	1 da	9 da
0	0	2.38×10^4	1.3×10^7	3.0×10^5	2.7×10^5
0	30	1.80×10^3	3.7×10^5	8.7×10^3	4.2×10^5
150	0	1.06×10^2	5.7×10^3	2.1×10^4	4.8×10^4
150	← 30 ^b	4.0	2.2×10^2	6.8×10^1	5.3×10^2
150	→ 30 ^c	3.7	5.5×10^2	2.4×10^1	8.9×10^2

^aSamples stored at 38° ± 1° F.

^bHeated first

^cIrradiated first

1.7. Mushrooms

1.7.1. Extent of opening.

Radiation retards the extent to which mushroom caps expand during storage. The extent of opening during storage was less as the dose was increased, and generally greater at higher storage temperatures.

Table 16. Opening Ratio and Degree of Opening of mushrooms (*Agaricus bisporus*) irradiated 1-12-67, held at 5, 10 and 15° C for seven days. Average of 20 mushrooms at each temperature and gamma ray dose.

Storage Temp.	Dose, Krad	Fruiting body dimensions, in.			Opening Ratio ^b	Degree of Opening, ^c %
		Cap dia., D	e ^a	Stipe dia. d		
5° C (41° F)	0	1.59	1.20	.51	.76	57
	10	1.49	1.01	.50	.68	6
	20	1.52	1.01	.48	.54	6
	50	1.51	1.04	.50	.56	2
	100	1.55	1.02	.50	.51	1
10° C (50° F)	0	1.74	1.48	.53	1.21	98
	10	1.49	1.10	.48	.70	83
	20	1.46	1.02	.45	.64	67
	50	1.55	1.05	.44	.63	32
	100	1.49	0.99	.44	.59	11
15° C (59° F)	0	1.90	1.88	.53	2.49	100
	10	1.53	1.11	.50	.67	90
	20	1.48	1.11	.47	.76	86
	50	1.58	1.13	.43	.79	69
	100	1.52	0.97	.42	.57	11

^ae = distance between lamellae tips

^b(e-d) [D-(e-d)]

^cDegree to which the veil has broken free from the ring and exposed the gills.

Opening ratio, O.R., and degree of opening, D.O., are indicators of the opening process which were invented for this study. Both increased as the mushroom cap opens. A freshly picked mushroom would be tightly closed. D.O. = 0%, and would have an O.R. of 0.35 - 0.50. When the O.R. reaches 0.7 the D.O. is generally over 50% and the gills will soon be completely exposed. Figure 1 shows the parts of the mushroom which were measured and from which the O.R. was calculated. The D.O. was measured by a graduated circular scale with a hole cut in the center to fit over the stipe; measurements on an individual mushroom were estimated to the nearest 10%. The D.O. is the extent to which the vellum has broken away from the annulus; total separation would be 100%.

Fig. 1. Mushroom showing measurements d , e , and D from which the opening ratio was calculated.

1.7.2. Color (Reflectance)

The reflectance (Gardner color difference meter) did not vary with dose, but did decrease some with storage time. The method of measurement is not completely satisfactory because of the difference in curvature of individual caps, because only the larger caps can be measured, and because of the irregular distribution of blemishes due to handling injury.

Table 17. L_D values (determined by a Gardner color difference meter) for mushrooms irradiated 11-16-65. Average of from 7 to 10 mushrooms stored at $38 \pm 1^\circ$ F.

Dose-Krad	Storage time (da)			
	2	7	15	21
0	81.2	78.9	70.9	66.5
10	76.5	80.1	68.5	62.1
15	81.8	69.8	69.2	61.0
20	78.8	74.7	69.5	64.9
50	<u>80.2</u>	<u>71.9</u>	<u>66.6</u>	<u>65.0</u>
Ave.	79.7	75.1	68.9	63.9

1.7.3. Respiration

Irradiation at dose levels from 10 Krad to 100 Krad reduced the respiration rate of mushrooms stored at 15° C (Fig. 2). The effect was small or non-existent on mushrooms stored at 5° C. At 15° C the effect was more pronounced at the longer storage times. Samples stored at 10° C (data not shown) showed effects intermediate to those at 5° C and 15° C.

Fig. 2. CO₂ gas exchanged (cc/100 gm-hr) vs. storage time (days) for mushrooms irradiated 1-27-67. Average of three replicate samples.

Table 18. Percent weight loss of Mushrooms during storage, irradiated 3/7/67.
(Each item is the average of 3 replicates; air flow over the container
0.6 ft/sec.)

	Temp.	Dose, Krad	Storage Time (days)						
			1	2	4	6	7	8	10
1. Open Tub (1 qt. polyethylene, no cover)	5° C. ^a (41°F)	0	6.45	11.59	24.10	32.36	-----	43.58	49.74
		10	6.06	11.07	20.50	29.57	-----	37.97	45.31
		100	5.56	11.15	25.48	31.65	-----	39.92	46.61
2. Tub with 4 1/4" Perforations in 1 1/2 mil poly- ethylene top.		0	0.63	0.81	2.58	3.84	-----	6.92	7.71
		10	0.86	1.76	3.32	4.34	-----	5.93	7.30
		100	0.76	1.38	3.12	4.32	-----	5.71	7.05
3. Tub Closed With 1 1/2 mil polyethylene		0	0.06	0.12	0.16	0.31	-----	0.50	0.65
		10	0.07	0.15	0.31	0.42	-----	0.54	0.88
		100	0.05	0.11	0.28	0.35	-----	0.43	0.57
4. Commercial Box, 1 lb. cap., waxed inside, 10 7/16 "" perforations.		0	6.80	12.43	27.02	37.34	-----	47.26	55.63
		10	6.60	12.26	27.19	35.94	-----	45.59	55.18
		100	6.82	13.73	25.39	33.92	-----	43.77	53.37
1. Open Tub	15° C. ^a (59°F)	0	6.60	15.45	38.54	52.50	55.80	-----	-----
		10	8.25	17.92	38.87	48.91	54.01	-----	-----
		100	12.44	20.20	37.38	47.00	52.15	-----	-----
2. Tub with Perforations		0	0.91	1.95	4.73	6.15	7.06	-----	-----
		10	0.97	2.10	4.20	5.44	6.49	-----	-----
		100	0.87	1.78	3.85	5.19	6.22	-----	-----
3. Tub without Perforations		0	0.09	0.23	0.54	0.75	0.90	-----	-----
		10	0.11	0.23	0.53	0.63	0.82	-----	-----
		100	0.13	0.25	0.50	0.64	0.72	-----	-----
4. Comm. Pack		0	8.38	16.76	36.80	49.23	55.32	-----	-----
		10	8.25	17.00	35.05	47.86	54.13	-----	-----
		100	9.52	17.72	37.09	50.31	56.59	-----	-----

1.7.4. Transpiration and storage container.

Irradiation had little or no affect on the rate of transpiration of mushrooms, but the container in which the mushrooms were stored and the storage temperature had a marked effect on the rate of weight loss, water loss by transpiration. Nevertheless, radiation did improve the quality as measured by general appearance and degree of opening.

Table 19. Quality of Mushrooms Irradiated 3-7-67, Seven and Ten days after Treatment.

Container ^a	Storage Temp. C	Dose, Krad		
		0	10	100
1	15 ^b	Degree of Opening (D.O.) = 100% Top mushrooms very shriveled Mold mycelia visible Much browning	D.O. = 100% Top mushrooms very shriveled Mold mycelia visible Moderate browning	D.O. = 5% Top mushrooms shriveled Slight browning No apparent mold
2	15 ^b	D.O. = 100% Free water within container Slime mold on surface Pronounced browning Obnoxious odor	D.O. = 95% Some free moisture Slime mold on surface Moderate browning Moderate off-odor	D.O. = 7-10% Some free moisture Some mold mycelia Very slight browning No off-odor
3	15 ^b	D.O. = 1-2% Some extreme browning Very moldy Extreme free moisture Musty (mold) odor	D.O. = 1-2% Moderate to slight browning Very moldy Some free moisture Musty odor	D.O. = 1-2% Slight browning Very little mold Slight free moisture Very little odor
4	15 ^b	D.O. = 100% (extremely open) Mushrooms very withered Extreme browning Stipes very small and dry	D.O. = 98% Much withering Moderate browning Stipes very small and dry Some mold	D.O. = 2% Some withering Slight browning No apparent mold Stipes small and dry

Table 19. continued

Container ^a	Storage Temp. C	0	Dose, Krad 10	100
1	5 ^c	D.O. = 15% Top mushrooms very shriveled Some very brown, others only slightly	D.O. = 0% Top mushrooms very shriveled Some very brown, others only slightly	D.O. = 0% Top mushrooms very shriveled Some very brown, others only slightly
2	5 ^c	D.O. = 15% Moderate browning Unpleasant odor Free moisture	D.O. = 5-8% Slight browning Some unpleasant odor Some free moisture	D.O. = 0% Very slight browning No unpleasant odor No free moisture on mushrooms Excellent quality
3	5 ^c	D.O. = 0% Moderate browning Evident decay of flesh Unpleasant odor	D.O. = 0% Slight to moderate browning No evident decay Slight odor	D.O. = 0% Slight odor No evident decay Little or no odor
4	5 ^c	D.O. = 0% (too dry to open) Extremely brown Extensively shriveled	D.O. = 0% (too dry to open) Extremely brown Extensively shriveled	D.O. = 0% (too dry to open) Extremely brown Extensively shriveled

^a See Table 18

^b Seven days after treatment

^c Ten days after treatment

2. YEAST STUDIES

In view of the importance of yeasts as fruit spoilage and fermentation microorganisms it was deemed desirable to study the effect of irradiation on their ability to propagate. In the course of this investigation an interest was also generated in the growth of yeasts in pre-irradiated media. A detailed account of the entire study is presented in the attached M.S. thesis submitted by Miss Noemi Diaz-Santiago and performed under this contract. A summary of this work follows:

2.1. Irradiation of yeast

Saccharomyces cerevisiae var. ellipsoideus ATCC 560, Candida krusei ATCC 2159 and Rhodotorula glutinis ATCC 2527 were exposed to gamma irradiation in demineralized water, in Difco yeast nitrogen base synthetic medium and in apple juice. The D values, in kilorad, for S. cerevisiae var. ellipsoideus, C. krusei and R. glutinis in demineralized water were 65, 43 and 50, respectively; in synthetic medium they were 95, 60 and 50, respectively; and in apple juice they were 125, 68 and 73, respectively. When these yeasts were irradiated in the same synthetic medium, but at the pH levels of 3.0, 4.5 and 6.0 it was found that lowering the pH increased the resistance of the yeasts. Repeated exposure of C. krusei to doses of 50 to 200 kilorad resulted in lowering the radiation resistance of this organism, while repeated exposure to 300 kilorad increased its resistance.

2.2 Growth of yeast in pre-irradiated media

Synthetic growth media containing either glucose or sucrose and sterilized by either heat or filtration were exposed to 1, 2, 3 and 4 megarad of gamma radiation and subsequently inoculated with the afore-mentioned yeasts as well as Candida tropicalis and S. cerevisiae. A significant reduction in the

outgrowth of these organisms was observed when the medium was pre-irradiated at 4 Megarad. Sucrose in the pre-irradiated medium inhibited the outgrowth of the yeasts more than glucose. S. cerevisiae var. ellipsoideus ATCC 560 did not grow in sucrose containing medium exposed to 1 Megarad or higher dose.

3. COBALT-60 RESEARCH IRRADIATOR

3.1 General Description:

The Cobalt-60 Research Irradiator Facility is located in the Food Science building on the Michigan State University campus in East Lansing, Michigan. The Cobalt-60 for this irradiator is provided under this contract. Four rooms comprise the facility itself; a preparation laboratory, Cobalt-60 cell, mechanical equipment room, and pump room. The Research Irradiator source, planned strength 50,000 C, consists of 24 BNL standard source strips arranged in a vertical cylindrical configuration, diameter about 1 foot. Irradiations will normally be performed in air.

The central controls for the irradiator will be in the preparation laboratory; the main entrance to the cell is from this laboratory. The cell is entirely below grade, with the top of the cell roof at grade level; three walls of the cell are surrounded by earth and the fourth wall is part of the maze entrance from the preparation laboratory. A 15'-deep water pool (tank capacity 2,800 gal) at one end of the cell has the dual function of providing shielding for the source when it is not in use and as the transfer area of source strips from shipping cask to source holder during assembly and replacement. Shipping casks may be lowered directly through the roof of the cell to the bottom of the tank; a removable 3-stepped cover (weight about 21 tons) is centered over one end of the tank. The mechanical

equipment room contains refrigeration equipment with capacity to cool the cell to 34° F. The pump room contains pumping, filtering, and deionizing equipment for the water in the tank.

3.2 Current Status

The Research Irradiator, was to have been installed in November, 1966. Construction delays of the new building necessitated changing the installation date to February, 1967. The irradiator (raising and lowering mechanism and control console) have not yet (May 10) been shipped by the irradiator contractor. The most recent shipping date given is May 12. Installation is expected to require at least two weeks. Final action on the license application, now through its second revision, is pending; however, it is expected that it will be approved as amended.