PNL-5373

UC-70

2F

Cherry Irradiation Studies
1984 Annual Report

April 1985

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830,
the U.S. Department of Agriculture,
and Washington State University

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5373

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

PNL-5373
UC-70

CHERRY IRRADIATION STUDIES

1984 ANNUAL REPORT

D. E. Eakin, F. P. Hungate, and G. L. Tingey
Pacific Northwest Laboratory

K. L. Olsen and J. B. Fountain
USDA/ARS, Wenatchee, Washington

A. K. Burditt, Jr., and H. R. Moffit
USDA/ARS, Yakima, Washington

D. A. Johnson and J. D. Lunden
Washington State University/IAREC
Prosser, Washington

April 1985

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830,
the U.S. Department of Agriculture,
and Washington State University

Pacific Northwest Laboratory
Richland, Washington 99352

CONTENTS

TABLES

INTRODUCTION

Export of Northwest agricultural products is currently limited because of foreign quarantine regulations to prevent the spread of harmful insects. For example, cherries must be fumigated with methyl bromide for export to Japan, and apples cannot be exported to Japan because an effective fumigation process does not exist. Therefore, the need for a reliable treatment that precludes the presence of live insects has increased interest in irradiation as a means for both disinfestation and preservation. Although there are several agricultural commodities that are being considered for irradiation treatment, cherries for export are one of the high-priority products.

The Cherry Irradiation Activity began in 1983, and work has continued in 1984. This activity is part of the Northwest Food and Agricultural Product Irradiation Task, which in turn is part of the U.S. Department of Energy (DOE) Defense Byproducts Production and Utilization Program managed by Pacific Northwest Laboratory (PNL).[a] Commodities to be evaluated in the Northwest Food and Agriculture Task are expected to include, but are not limited to, cherries, apples, hay, hides, asparagus, and spices. Additional commodities could be added as warranted by regional needs and desires.

An integral part of the Cherry Irradiation Activity has been the cooperative research of the U.S. Department of Agriculture/Agricultural Research Service (USDA/ARS) laboratories in Yakima and Wenatchee and the Washington State University/Irradiated Agriculture Research and Extension Center (WSU/IAREC) in Prosser. Their involvement in this activity has been funded by their respective organizations.

The Cherry Irradiation Activity has two specific goals: 1) to evaluate the effectiveness of irradiation as a method of insect control and 2) to evaluate the effect of irradiation on product quality. The work conducted during FY 1984 included continuing irradiation tests that were started in 1983. One goal was the exposure of cherries infested with fruit flies at lower doses and at different stages of insect development than previously

(a) Operated for DOE by Battelle Memorial Institute.

tested to determine the effective dose for prevention of adult emergence. Another FY 1984 goal was to obtain better control of the source of cherries to assure comparability and more even quality of the fruit. Standard methods to evaluate insect control were used. Appropriate quality index measurements and taste panel evaluations were used to determine shelf life and any change in quality with respect to treatment technique. The USDA/ARS laboratory in Yakima conducted the insect control evaluations, and the USDA/ARS laboratory in Wenatchee was responsible for the quality evaluations. Some of the cherries irradiated for quality evaluations were also sent to Oregon State University (OSU), Corvallis, Oregon, for sensory evaluations. Irradiated cherries were also evaluated for rot with regard to potential shelf life extension by WSU/IAREC at Prosser.

SUMMARY AND CONCLUSIONS

Fresh cherries, cherry fruit fly larvae, and codling moth larvae were irradiated using the PNL cobalt-60 facility to determine the efficacy of irradiation treatment for insect disinfestation and potential shelf life extension. Cherry fruit fly larvae and codling moth larvae were irradiated at doses up to 17.4 krad and 16 krad, respectively, to determine the effect on the insects. Quality evaluation measurements and sensory evaluations were conducted on cherries irradiated at doses up to 200 krad to determine the dose at which deterioration begins and to evaluate the potential for shelf life extension. In addition, the irradiated cherries were compared with cherries fumigated with methyl bromide at 7°C (45°F). Other cherries were irradiated at doses up to 500 krad to determine the impact of irradiation on cherry rot due to fungi growth. The results of these tests led to the following conclusions:

- Irradiation is an effective disinfestation treatment with no significant degradation of fruit at doses well above those required for quarantine treatment.
- Sufficient codling moth control was achieved at projected doses of less than 25 krad; cherry fruit fly control, at projected doses of less than 15 krad.
- Dose levels up to 60 krad did not adversely affect cherry quality factors tested.
- Irradiation above 60 krad reduced the firmness of cherries but had no significant impact on other quality factors tested.
- Irradiation of cherries below 80 krad did not result in any significant differences in sensory evaluations (appearance, flavor, and firmness) in tests conducted at OSU.
- Irradiation up to 200 krad at a temperature of about 25°C (77°F) did not measurably extend shelf life.
- Irradiation at 500 krad at 25°C (77°F) increased mold and rotting of cherries tested.

- There is no apparent advantage of irradiation over low-temperature fumigation. (However, no sensory tests were conducted on fumigated cherries.)

To further evaluate the potential for extending the shelf life of cherries, a test is planned for the 1985 crop that will use higher dose levels at lower temperature and/or in modified atmosphere. To provide a more thorough comparison with fumigation, a sensory evaluation test will be conducted on cherries fumigated at low temperature.

RESULTS AND DISCUSSION

The procedures, results, and discussions are included below for the following separate evaluation categories: quality evaluation, sensory evaluation, fungi rot, and effectiveness of disinfestation.

QUALITY EVALUATION

During the 1984 crop year, two batches of cherries were irradiated for quality evaluation. The first batch was obtained from a packing plant in Grandview, Washington; and the second batch, from a packing plant in Wenatchee, Washington. Each batch consisted of cherries from three orchards. The cherries were irradiated at total doses of 0, 20, 40, 60, 80, 100, and 200 krad. Samples of cherries from the same sources were also fumigated. The first batch was fumigated at a commercial plant in Wenatchee; and the second batch at the USDA laboratory in Yakima. The fumigation procedure was conducted at about 7°C (45°F); an earlier procedure had used temperatures of about 26°C (78°F).

Following irradiation, the cherries were transported to the USDA laboratory in Wenatchee and prepared for chemical and physical testing. Samples of the cherries were held in cold storage at -0.5°C (31°F) for 0, 7, 14, and 28 days following irradiation. The quality of the cherries was evaluated immediately after samples were removed from cold storage and also after they had been held in the ripening room at 20°C (68°F) for three days following cold storage. The following tests were conducted on each sample:

- percent decay - the percentage of cherries showing decay (such as mold)
- weight - the weight measured in grams
- condition - subjective visual evaluation on a scale of 1 (good) to 4 (poor)
- stem diameter - measured in one-thousandths of an inch with a micrometer
- stem color - subjective visual evaluation on a scale of 1 (good) to 4 (poor)

- size - a measure of cherry diameter by row number (9, 10, 11, 12, 13 row corresponding to 75/64, 67/64, 61/64, 56/64, and 52/64 of an inch, respectively)
- color - visual evaluation comparing cherries to standard industry color balls; scale of 1 (light) to 5 (dark)
- color measurement - three-filter reflectance method
- firmness - measured with pressure tester with readings in percent (100% = 8 oz)
- acid - following pitting and juicing, measured by titration and expressed as percent malic acid
- pH - the pH of the juice
- soluble solids - measured with a refractometer.

The results showed some statistically significant differences in color, condition, percent decay, pH, soluble solids, stem color, and stem diameter for individual test periods; but there was no correlation with treatment (dose level or fumigation). Generally, there were no significant differences in initial weights or weight losses during ripening or in fruit size with respect to treatment. The acid measurements showed significant differences in individual test periods but no correlation with dose level. The fumigated cherries generally had the highest acid content of any of the samples. Loss of acid occurs during ripening, and retention of acid is normally desirable. However, the fumigation process may produce other undesirable changes that would offset the beneficial acid retention.

The most notable effect of irradiation was on cherry firmness. Cherry firmness ratings for both batches of cherries immediately following cold storage and after three days of ripening following cold storage are presented in Table 1. Cherry firmness tended to decline with increasing dose levels. In nearly all cases, the cherries that received a total dose of 200 krad were rated as being the least firm. The differences between those cherries irradiated to 200 krad and the nonirradiated control were generally great enough to be considered statistically significant. The fumigated cherries

TABLE 1. Cherry Firmness Measured with Pressure Tester (10 = full scale = 8 oz)

Treatment, krad	Batch 1, Yakima District Storage Time, days				Batch 2, Wenatchee District Storage Time, days			
	0	7	14	28	0	7	14	28
0	6.80^{a}	7.04^{a}	7.08^{a}	6.73^{a}	6.49^{a}	6.58^{a}	6.53^{a}	6.83^{a}
20	6.73^{a}	6.92^{ab}	6.97^{a}	6.44^{ab}	6.49^{a}	6.49^{ab}	6.30^{ab}	6.83^{a}
40	6.37^{bc}	6.83^{bc}	6.99^{a}	6.51^{ab}	6.47^{a}	6.37^{ab}	6.53^{a}	6.70^{ab}
60	6.26^{cd}	6.66^{d}	6.90^{a}	6.59^{ab}	6.26^{ab}	6.36^{ab}	6.37^{ab}	6.60^{ab}
80	6.30^{bcd}	6.67^{d}	6.87^{a}	6.46^{ab}	6.23^{ab}	6.55^{a}	6.27^{ab}	6.50^{ab}
100	6.33^{bcd}	6.70^{cd}	7.00^{a}	6.20^{b}	6.32^{ab}	6.40^{ab}	6.30^{ab}	6.43^{b}
200	6.13^{d}	6.43^{e}	6.54^{b}	6.37^{ab}	6.04^{b}	6.08^{b}	6.10^{b}	6.37^{b}
Fumigated	6.47^{b}	6.79^{bcd}	7.10^{a}	6.67^{ab}	6.34^{a}	6.54^{a}	6.57^{a}	6.67^{ab}
LSD*	0.206	0.156	0.238	0.493	0.298	0.437	0.432	0.352
	Batch 1, After 3-Day Ripening Period				Batch 2, After 3-Day Ripening Period			
0	6.59^{a}	6.63^{ab}	6.79^{a}	6.77^{a}	6.45^{ab}	6.38^{a}	6.24^{a}	6.37^{a}
20	6.49^{ab}	6.67^{a}	6.55^{ab}	6.46^{ab}	6.20^{ab}	6.15^{a}	5.99^{ab}	6.22^{ab}
40	6.43^{ab}	6.50^{ab}	6.48^{b}	6.65^{a}	6.26^{ab}	6.11^{ab}	5.93^{ab}	6.07^{bc}
60	6.42^{ab}	6.50^{ab}	6.41^{b}	6.48^{ab}	6.22^{ab}	6.15^{a}	5.88^{ab}	6.07^{bc}
80	6.35^{b}	6.50^{ab}	6.49^{b}	6.50^{ab}	6.00^{b}	5.81^{c}	5.83^{ab}	5.87^{cde}
100	6.30^{b}	6.47^{ab}	6.58^{ab}	6.42^{abc}	6.15^{b}	5.76^{c}	5.67^{b}	5.97^{cd}
200	6.09^{c}	6.27^{b}	6.00^{c}	6.08^{c}	5.91^{b}	5.84^{bc}	5.57^{b}	5.67^{e}
Fumigated	6.60^{a}	6.53^{ab}	6.50^{b}	6.25^{bc}	6.80^{a}	6.14^{a}	5.93^{ab}	5.83^{de}
LSD	0.201	0.384	0.273	0.368	0.620	0.281	0.517	0.224

abcde - Any score within each column with a common superscript is not significantly different.
* LSD - least significant difference at the 95% confidence level.

generally ranked between the lower-dose and the higher-dose irradiated cherries. Although the cherries that were irradiated up to 60 krad received lower firmness ratings, the ratings were not seen as being significantly different from those for nonirradiated cherries. In the table, a rating of 6 or less would probably represent an unacceptable cherry. Therefore, when starting with cherries softer than normal (as was the case for Batch 2), irradiation at the 200-krad level could reduce firmness to less than acceptable levels. By comparing firmness measurements between Batches 1 and 2, a great variation in ratings, depending on the source of the cherries, is apparent. This variation was often greater than the differences caused by irradiation.

SENSORY EVALUATION

A portion of the cherry samples irradiated at 0, 40, 80, and 200 krad from Batch 2 was sent to the Sensory Science Laboratory, Department of Food Science and Technology, OSU. These cherries were evaluated by a 20-member panel on the basis of appearance, firmness, and flavor after refrigerated storage intervals of approximately 1, 2, 3, and 4 weeks following irradiation. The mean scores for each testing period are presented in Table 2. One week after irradiation, there was no statistical difference in appearance ratings. The panel rated the flavor of the 200-krad irradiated sample somewhat less desirable than the others and observed a statistically significant decrease in firmness with dose.

After two weeks of storage, a difference in appearance was noted between the samples. The appearances of the control and 40-krad samples were significantly preferred over the other samples. For firmness, the 80- and 200-krad samples were judged significantly less firm. The flavor rating declined, with the 200-krad sample being rated significantly lower than the control and 40-krad samples. The flavor of the 40-krad sample was the only one to be rated not significantly lower than the control after two weeks of storage.

TABLE 2. Cherry Sensory Evaluation

Time After Irradiation, wk	Treatments, krad	Mean Score Appearance*	Flavor*	Firmness**
1	0	7.10^{a}	7.30^{b}	6.35^{c}
	40	6.35^{a}	6.75^{b}	5.85^{bc}
	80	6.95^{a}	6.75^{b}	5.10^{b}
	200	6.35^{a}	5.45^{a}	4.10^{a}
		(LSD = 0.80)	(LSD = 0.98)	(LSD = 0.91)
2	0	7.30^{b}	6.50^{bc}	6.10^{b}
	40	7.30^{b}	6.85^{c}	5.85^{b}
	80	5.65^{a}	5.75^{ab}	4.75^{a}
	200	5.95^{a}	5.25^{a}	4.10^{a}
		(LSD = 0.84)	(LSD = 1.07)	(LSD = 0.93)
3	0	7.10^{b}	7.20^{b}	6.10^{b}
	40	7.25^{b}	7.25^{b}	5.80^{b}
	80	5.35^{a}	5.50^{a}	3.95^{a}
	200	5.05^{a}	5.50^{a}	3.90^{a}
		(LSD = 0.73)	(LSD = 0.80)	(LSD = 0.79)
4	0	7.35^{b}	6.30^{a}	5.85^{b}
	40	5.90^{a}	6.25^{a}	5.00^{ab}
	80	5.55^{a}	5.75^{a}	4.50^{a}
	200	5.50^{a}	6.15^{a}	4.55^{a}
		(LSD = 0.89)	(LSD = 0.98)	(LSD = 0.97)

abc - Any score within each column (by week) with a common superscript is not significantly different (95% confidence level).

* Scored by use of nine-point Hedonic scale (9 = like extremely; 1 = dislike extremely).

** Scored by a seven-point firmness scale (7 = just right; 1 = too soft).

After three weeks of storage, the panel rated the 80- to 200-krad samples lower than the 40-krad sample in all three properties. The 40-krad sample continued to be rated as not significantly different from the control, and there was no significant decrease in rating with storage time.

After four weeks of storage, the appearance rating for the 40-krad sample dropped and was significantly lower than for the control sample. The control sample was rated significantly more firm than all three irradiated samples. The flavor scores for the control and 40-krad samples dropped considerably after the third week to a point where they were judged to be essentially the same as the other samples. However, it should be noted that in all cases, the cherries were judged to be desirable and, thus, acceptable for market.

EFFECT OF IRRADIATION ON CONTROL OF FUNGI ROT

Cherry fruit was obtained from a commercial packing house before hydro cooling and fungicide applications, separated into 450-g samples in 1-qt plastic bags, taken to the PNL cobalt-60 facility, and irradiated to 0, 60, 200, and 500 krad. The design was a randomized complete block with six replicates. The fruit was then returned to the WSU/IAREC facility in Prosser for storage and evaluation.

The cherries were placed in an 18°C (65°F) temperature chamber for 13 days in unsealed plastic bags. Following storage, the surface area of each cherry in a sample was visually inspected for rot and placed into one of the following categories: no rot, trace to 25%, 26% to 75%, and 76% to 100%. A rot index for each sample was determined by assigning a value from 1 to 4 to cherries in the four rot categories (4 - most severe) and calculating an average for the proportion of fruit in the four categories.

The effect of irradiaton on control of cherry rot is shown in Table 3. Irradiation did not reduce rot; the fruit treated with 500 krad rotted more severely than the other fruit. Irradiation apparently altered the physiology of the cherry, making it softer and more susceptible to fungi growth. Therefore, techniques (such as low-temperature irradiation) to reduce cherry damage need to be tested in relation to effect on fruit rot. The plastic bags were open, allowing recontamination by fungal spores. Therefore, these results may not be indicative of fungi control by irradiation.

In a previous experiment, it was demonstrated that cherries sealed in plastic bags and irradiated at 60 and 200 krad rotted more rapidly than irradiated cherries in unsealed plastic bags. Increased humidity in the sealed bags and fungal spores that survived the irradiation treatments appear to be the cause. No difference in rot was observed between the 60- and 200-krad treatments.

TABLE 3. Severity of Rot of Irradiated Sweet Cherry Fruit

Irradiation, krad	Rot Index
0	1.5[a]
60	2.0[a]
200	1.8[a]
500	3.3[b]

ab Numbers within a column followed by the same letter are not significantly different (95% confidence level).

EFFECTIVENESS OF DISINFESTATION

During the 1983 cherry irradiation studies, a batch of cherries was purposely infested with cherry fruit fly larvae by the USDA laboratory in Yakima. The infested cherries were irradiated to nominal doses of 0, 4, 6, 8, 12, and 20 krad in the PNL cobalt-60 facility. The results of these tests after the normal time required for adult emergence are summarized in Table 4. A substantial reduction in survival rate of pupae and emergence of adults was observed as a result of the irradiation. The table shows the survival rate as a function of gamma dose.

These data show a decrease in the ability of irradiated fruit fly larvae to mature and pupate even at the lowest dose tested (3.5 krad). The only adult emergence from treated larvae was a single fly at 10.5 krad. The lack

TABLE 4. Survival Rate of Cherry Fruit Flies as a Function of Irradiation Dose

Dose Received, krad	Number of Surviving Pupae/200 Cherries	Number of Emerged Adults/200 Cherries
0	218	156
3.5	92	0
5.3	72	0
7.0	53	0
10.5	37	1
17.4	15	0

of any adult emergence at lower dose levels leads us to believe that this single fly was due to post-treatment contamination of the fruit. The lack of adult emergence prevents an estimate of a dosage-mortality curve and prediction of a minimum value for the irradiation dose required to prevent adult emergence. However, the doses required to prevent 50% and 95% pupation of larvae were 2.7 and 26.4 krad, respectively.

During 1984, two batches of cherries infested with fruit fly larvae were irradiated at nominal doses of 0, 0.375, 0.75, 1.5, 3.0, 4.5, 6, and 9 krad. The first batch was irradiated on July 5; the second, on July 11, 1984. The preliminary results from these tests are given in Table 5. There was a greater decline in total pupae and percent normal pupae for Batch 1 than for Batch 2 as a function of dose. The larvae in the Batch 2 test were further developed, and irradiation was not as effective in preventing pupation. However, the more important result will be the emergence of normal and abnormal adults, which will occur in the spring of 1985 (to be reported later).

Tests conducted in 1983 to examine control of the codling moth have been evaluated and indicate that the irradiation dose required to prevent emergence of adult codling moths was 20.7 krad for nondiapausing larvae (in fruit) and 22.5 krad for diapausing larvae (in fiberboard strips) (Burditt and Moffit 1983). The doses required to prevent emergence of apparently normal adults were 13.7 and 14.5 krad, respectively.

During 1984, irradiation tests were conducted on codling moths to determine the control achieved as a function of:

- length of time larvae were in diapause prior to irradiation
- dose rate
- state of larvae development at the time of irradiation.

The stage of development completed by codling moth larvae following irradiation as a function of time the larvae were in diapause is shown in Table 6. Results show that larvae that had been in diapause for over a year had a higher mortality than those in diapause for a shorter period. Over 90% of the adults emerging from irradiated larvae were males, compared

TABLE 5. Pupation of Irradiated Cherry Fruit Fly Larvae

Sample	Dose, krad	Cherry Fruit Fly Pupae Normal	Abnormal	Total	Percent Normal	Total/ Treatment
		Batch 1, Irradiated July 5, 1984				
A	0.000	56	50	106	52.83	
	0.375	20	32	52	38.46	
	0.750	17	74	91	18.68	
	1.500	11	57	68	16.18	
	3.000	5	60	65	7.69	
	4.500	3	98	101	2.97	
	6.000	1	84	85	1.18	
	9.000	1	16	17	5.88	
B	0.000	78	68	146	53.42	252
	0.375	37	31	68	54.41	120
	0.750	22	43	65	33.85	156
	1.500	1	41	42	2.38	110
	3.000	8	45	53	15.09	118
	4.500	2	62	64	3.13	165
	6.000	3	53	56	5.36	141
	9.000	0	36	36	0	53
		Batch 2, Irradiated July 11, 1984				
A	0.000	71	106	177	40.11	
	0.375	96	93	189	50.79	
	0.750	96	147	243	39.51	
	1.500	101	107	208	48.56	
	3.000	95	112	207	45.89	
	4.500	45	114	159	28.30	
	6.000	38	98	136	27.94	
	9.000	65	121	186	34.95	
B	0.000	86	199	285	30.18	462
	0.375	155	167	322	48.14	511
	0.750	76	139	215	35.35	458
	1.500	62	108	170	36.47	378
	3.000	86	107	193	44.56	400
	4.500	23	181	204	11.27	363
	6.000	28	147	175	16.00	311
	9.000	44	150	194	22.68	380

TABLE 6. Development Completed by Codling Moth Larvae Following Irradiation

Dose, krad	Type of Larvae Treated	Age in Diapause, months	Stage of Development Completed: Larvae, %	Pupae, %	Adults, %	Number Tested
0	Nondiapause	0	9	2.5	97.0	1,613
	Diapause	4.6	10.4	5.7	84.0	511
		7.0	10.3	6.4	83.3	329
		15.3	66.6	22.6	10.8	332
9.3	Nondiapause	0	9.1	63.4	27.5	11,151
	Diapause	4.6	23.4	64.3	12.3	3,641
		7.0	42.1	52.8	5.1	2,425
		15.3	85.4	13.9	0.7	3,340

with 54% for untreated larvae. Generally, females succumbed as pupae and failed to emerge as adults. The female adults that did develop from irradiated larvae did not lay any eggs. Normal females mated to males from irradiated larvae laid eggs that did not hatch.

The effect of dose rate on codling moth control was to be determined by exposing two different batches of larvae to the same total dose at different dose rates. However, due to an error in the exposure time, the total doses ended up being different. Codling moth larvae were exposed to 9.7 krad at the rate of 32.5 krad/min or to 5.5 krad at the rate of 0.15 krad/min. Results from these treatments are summarized in Table 7. Comparing these data with data by Burditt and Moffit (1983) indicate that there is no major impact of dose rate (over the range tested) on the degree of codling moth control. The degree of control is more a function of total dose.

On May 24, 1984, codling moth eggs were placed on thinning apples to determine the effect of irradiation on codling moth larvae of different age groups. The infested apples that were irradiated on May 31 contained 54.6%, 40.5%, and 4.9% first, second, and third instar larvae, respectively. Those treated on June 8 contained 17.6%, 17.6%, and 64.8% third, fourth, and fifth instar larvae. Strips containing 88% mature larvae and 12% pupae were treated on June 2. Larvae were treated at doses of 0, 1, 2, 4, 6, 8, 10, 12, 14, or 16 krad. Adult emergence and the number and stage of development of those

TABLE 7. Development of Codling Moths Irradiated as Mature Larvae

Dose, krad	Type of Larvae Treated	Time in Diapause, months	Stage of Development Completed: Larvae, %	Pupae, %	Adults: Abnormal, %	Adults: Normal, %	Number Tested
0	Nondiapause	0	4.6	3.4	2.4	89.7	503
	Diapause	2.0	8.3	3.6	4.7	83.4	193
		6.5	4.8	12.4	0.5	82.4	210
		12.0	30.5	22.8	2.5	44.2	197
5.5	Nondiapause	0	4.3	2.4	23.2	70.1	1,690
	Diapause	2.0	54.2	5.9	24.3	25.7	526
		6.5	15.5	27.0	34.7	22.8	562
		12.0	38.7	41.5	12.1	7.7	556
9.7	Nondiapause	0	16.5	55.2	26.0	2.3	1,273
	Diapause	2.0	28.1	54.5	14.2	3.2	527
		6.5	37.2	56.1	6.5	0.1	675
		12.0	55.0	45.0	0	0	576

that did not develop to adults were recorded. Results of this experiment are shown in Table 8. Those older larvae irradiated on June 8, 1984, were more resistant to irradiation than younger larvae that had been treated on May 31; the mature larvae treated in strips on June 12 were the most resistant.

Analyses of the dosage-mortality data for larvae irradiated on May 31 showed that quarantine security mortality could be achieved by an exposure to 13.3 krad based on adult emergence. Exposure to 44.2 krad would be required to prevent any first, second, or third instar larvae from reaching maturity and spinning cocoons. However, the 13.3-krad dose would eliminate 95% of the mature larvae.

Analyses of the dosage-mortality data for older or mature larvae irradiated on June 8 or 12 showed that the doses required to prevent adult emergence were 17.7 and 23.0 krad, respectively. Since many of the former larvae were in the fifth instar, it was not possible to prevent larvae from reaching maturity.

TABLE 8. Development of Codling Moth Larvae Following Irradiation

Date Irradiated	Dose, krad	Stage of Development Completed: Mature Larvae	Pupae	Adults: Abnormal	Adults: Normal	Total
May 31, 1984	0	11	50	23	713	797
	1	24	26	13	634	697
	2	8	44	20	661	733
	4	9	59	67	528	663
	6	26	90	95	171	382
	8	45	122	33	4	204
	10	31	71	2	0	104
	12	22	46	0	0	68
June 8, 1984	0	6	24	15	760	805
	2	11	12	16	642	681
	4	20	37	59	643	759
	6	21	140	157	361	679
	8	83	311	194	26	614
	10	214	302	53	2	571
	12	433	286	6	0	725
	14	484	107	1	0	592
June 12, 1984	0	9	45	19	546	619
	4	7	41	78	414	540
	6	11	164	279	160	614
	8	9	366	117	14	506
	10	11	436	58	4	509
	12	78	389	13	1	481
	14	99	384	2	4	489
	16	106	338	2	0	446

REFERENCES

Burditt, A. K., and H. R. Moffitt. 1983. "Irradiation as a Quarantine Treatment for Fruit Subject to Infestation by Codling Moth Larvae." Presented at the International Conference on Radiation Disinfestation of Food and Agricultural Products, November 14-18, 1983, Honolulu, Hawaii.

DISTRIBUTION

No. of Copies

OFFSITE

J. A. Coleman
Nuclear Energy
U.S. Department of Energy
Washington, DC 20545

J. J. Jicha, Jr.
R&D and Byproducts
U.S. Department of Energy
Washington, DC 20545

J. N. Maddox
U.S. Department of Energy
Washington, DC 20545

W. H. McMullen
U.S. Department of Energy
P.O. Box 5400
Albuquerque, NM 87115

30 DOE Technical Information Center

S. B. Ahlstrom
CH_2M Hill
Albuquerque, NM 87185

J. S. Sivinski
CH_2M Hill
Albuquerque, NM 87185

L. Fife
Idaho Agriculture Department
P.O. Box 790
Boise, ID 83701

S. Miller
3311 West Clearwater
Suite 105
Kennewick, WA 99336

The Honorable Sid Morrison
U.S. House of Representatives
208 Cannon House Office Bldg.
Washington, DC 20515

No. of Copies

A. E. Tesdal
Oregon Agriculture Department
635 Capitol Street N.E.
Salem, OR 97310

M. R. McDaniel
Oregon State University
Department of Food Science and Technology
Corvallis, OR 97331

P. L. Vick
Port of Pasco
P.O. Box 769
Pasco, WA 99301

A. K. Burditt, Jr.
USDA/ARS
3706 W. Nob Hill
Yakima, WA 98902

J. B. Fountain
USDA/ARS
1104 N. Western
Wenatchee, WA 98801

K. L. Olsen
USDA/ARS
1104 N. Western
Wenatchee, WA 98801

H. R. Moffitt
USDA/ARS
3706 W. Nob Hill
Yakima, WA 98902

D. A. Johnson
WSU/IAREC
P.O. Box 30
Prosser, WA 99350

J. D. Lunden
WSU/IAREC
P.O. Box 30
Prosser, WA 99350

No. of
Copies

J. Wommack
Washington State Agriculture
Department
406 General Administration Bldg.
Olympia, WA 98504

M. L. Smith
Department of Commerce and
Economic Development
State of Washington
312 First Avenue N.
Seattle, WA 98109

T. Hale
Washington State Apple
Commission
P.O. Box 18
Wenatchee, WA 98801

K. Severn
Washington State Fruit
Commission
1005 Tieton Drive
Yakima, WA 98902

FOREIGN

R. A. Bush
Department of Commerce and
Economics Development
State of Washington
#205 Kowa Building No. 2W
11-39 1-Chome, Akasaka
Minatu-Ku, Tokyo 107, Japan

No. of
Copies

ONSITE

3 DOE Richland Operations Office

M. Dayani
H. E. Ransom
J. D. White

2 Rockwell Hanford Operations

K. A. Gasper
I. E. Reep

45 Pacific Northwest Laboratory

T. D. Chikalla
D. E. Eakin (25)
S. K. Edler
C. R. Hann
P. E. Hart
R. F. Hazelton
F. P. Hungate
J. H. Jarrett
G. A. Jensen
J. L. McElroy
P. M. Molton
A. M. Platt
G. L. Tingey
P. C. Walkup
Publishing Coordination (2)
Technical Information (5)