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GAMMA-RAY SPROUT INHIBITION OF POTATOES

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CONTRACT RESEARCH PROGRESS REPORT

QUARTERMASTER FOOD AND CONTAINER INSTITUTE
FOR THE ARMED FORCES, CHICAGO

Research and Development Division
Office of the Quartermaster General

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Title of Contract: Gamma-Ray Sprout Inhibition of Potatoes

SUMMARY

The data collected on Idaho seed potatoes from the 1954 crop which were treated with gamma radiation and stored at various temperatures and humidities were summarized by means of the following equation:

$$W_R\ T°K = e^{b}t[0.125 - 0.0008\ R.H. + 0.13e^{-0.15D}],$$

where

$W_R\ T°K$ = percentage weight loss at T°K,
t = storage time after irradiation, days,
T = absolute temperature, °K,
D = radiation dose, kilorep,
R.H. = relative humidity, %,
e = Naperian base, 2.3026, and
$b = -7.35 \times 10^{3} \left[\frac{1}{288} - \frac{1}{T}\right]$.

At present this "general" equation can be considered applicable only to the potatoes of the variety, size, source, and age used in the experiment and for storage for periods of from 0 to 4 months after irradiation. Additional data presently being collected on potatoes of different varieties, sizes, sources, and ages will be compared with this relationship.

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I. TECHNICAL OBJECTIVES

Low-dosage gamma irradiation of potatoes has been found to be very successful in preventing sprouting and spoilage of potatoes under storage without the development of undesirable changes. Northern-grown potatoes are available only 8 or 9 months of the year. Because of sprouting followed by rapid deterioration, it usually is not possible to keep potatoes under storage for longer periods. It is believed that desirable types of potatoes can, by irradiation, be made available the year around. This treatment might be particularly useful in increasing the storage life of any type of potato shipped overseas for the armed services.

More specifically, the general technical objective is described below:

A. A study will be made on the effect of low dosages of gamma radiation (approximately 5,000 to 25,000 rep) on at least one white-skinned and one russet-variety potato with the object of determining the dosage needed to inhibit sprouting when stored at 35°, 40°, 50°, 60°, and 80°F with 85% relative humidity.

B. An investigation will be made, using doses of gamma radiation as high as 200,000 rep on the same types of potatoes as studied in (A) above, to determine the effect of overdose.

C. A study will be made of the effect of three different relative humidities and at one storage temperature during storage on a white-skinned and a russet-variety potato.

D. An evaluation will be made at no less than four scheduled intervals during the storage of the irradiated potatoes that have been stored. The said evaluation shall include:

1. total starch, sucrose, and reducing-sugar content,
2. sprouting and its inhibition,
3. general appearance and texture,
4. interior fleshy region of peeled and sliced potatoes for decay, black heart, blackening, and other manifestations of enzyme and/or microbial action, and
5. loss in weight, to be determined and subdivided into combined respiration and transpiration loss and loss due to sprouts.

E. As time allows, a limited study will be made on the effects of wound healing, with special emphasis on formation of cork cambium, cellular organization, and structure.

F. A quantitative respiration study will be conducted on at least a white-skinned variety and a selected russet variety of potatoes.

G. The effect of gamma radiation on the activity of specific enzymes involved in potato respiration will be investigated. This will be aimed at understanding the inhibition of enzyme activity as reflected by changes in starch content, total and reducing-sugar content, and color change, allowing for extended storage life of the potato.

H. A study will be made of the growth hormone and inhibitors in and around the eyes of irradiated and control potatoes to determine whether or not gamma-ray-induced inhibition of potato sprouting is caused by an increase in the quantity of sprout inhibitors.

I. A study will be conducted to determine the incidence of common storage rot in irradiated potatoes. This will include inoculation and storage studies utilizing common potato-rotting bacteria and fungi.

J. Samples of potatoes described under (A) will be made available for acceptance testing by personnel of QMF and CI.

II. CORRELATION OF WEIGHT-LOSS DATA ON IDAHO-GROWN RUSSET SEED POTATOES

Figure 1 is a cross plot of weight loss vs radiation dosage for potatoes stored for 140 days at 90% relative humidity and 50°F. It clearly shows the general trend of the effect of increasing radiation dosage on the reduction of weight loss and an approach to an equilibrium value at about 20,000-rep dosage. Increases of radiation dosage above this level have little additional effect on the inhibition of weight loss. Figure 2 shows additional data plotted on semilogarithmic graph paper and further illustrates the phenomenon and demonstrates that the equilibrium value of "weight loss independent of radiation dose" varies with storage time and relative humidity. The potatoes lose weight for a number of reasons, but for simplicity the losses may be divided into two groups, (M) "physical" and (B) "biological."

Regardless of whether the potato tubers are living or dead, they will lose weight when stored in an atmosphere not saturated with water vapor. This is true because the skin of the potato tuber behaves as a membrane through which water, and also oxygen, carbon dioxide, etc., may diffuse. The "physical" weight loss is largely the result of the evaporation of water, which depends in part on the diffusivity of water through the skin, the partial pressure of water vapor in the storage air, and the velocity of air circulation around the stored tubers. These and other variables which influence the mass transfer coefficients will have some

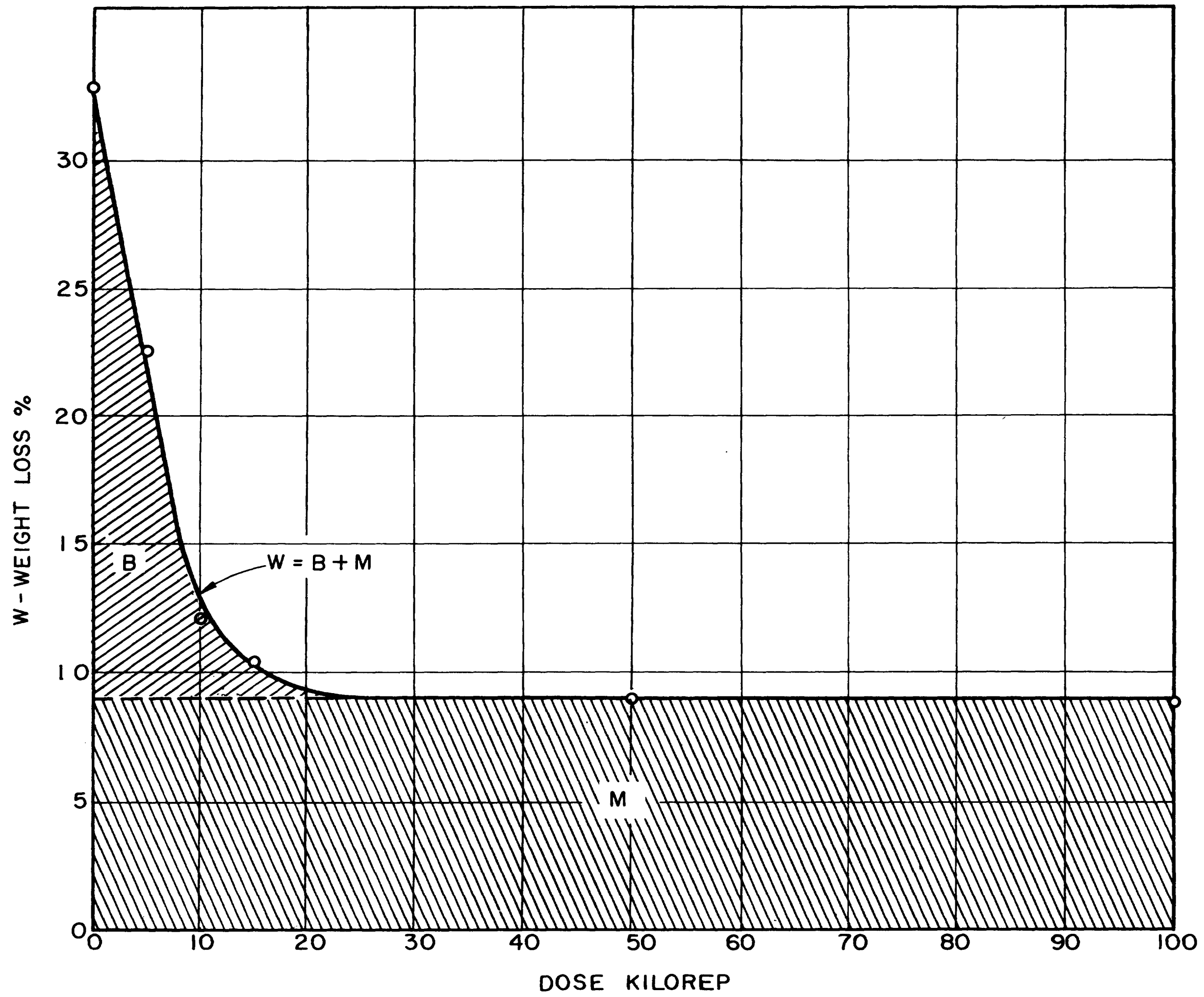

Fig. 1. The graphical relationship between the total percent weight loss, W, the biological weight loss, B, and the weight loss independent of radiation, M (potatoes stored 140 days at 50°F and 90% R.H.).

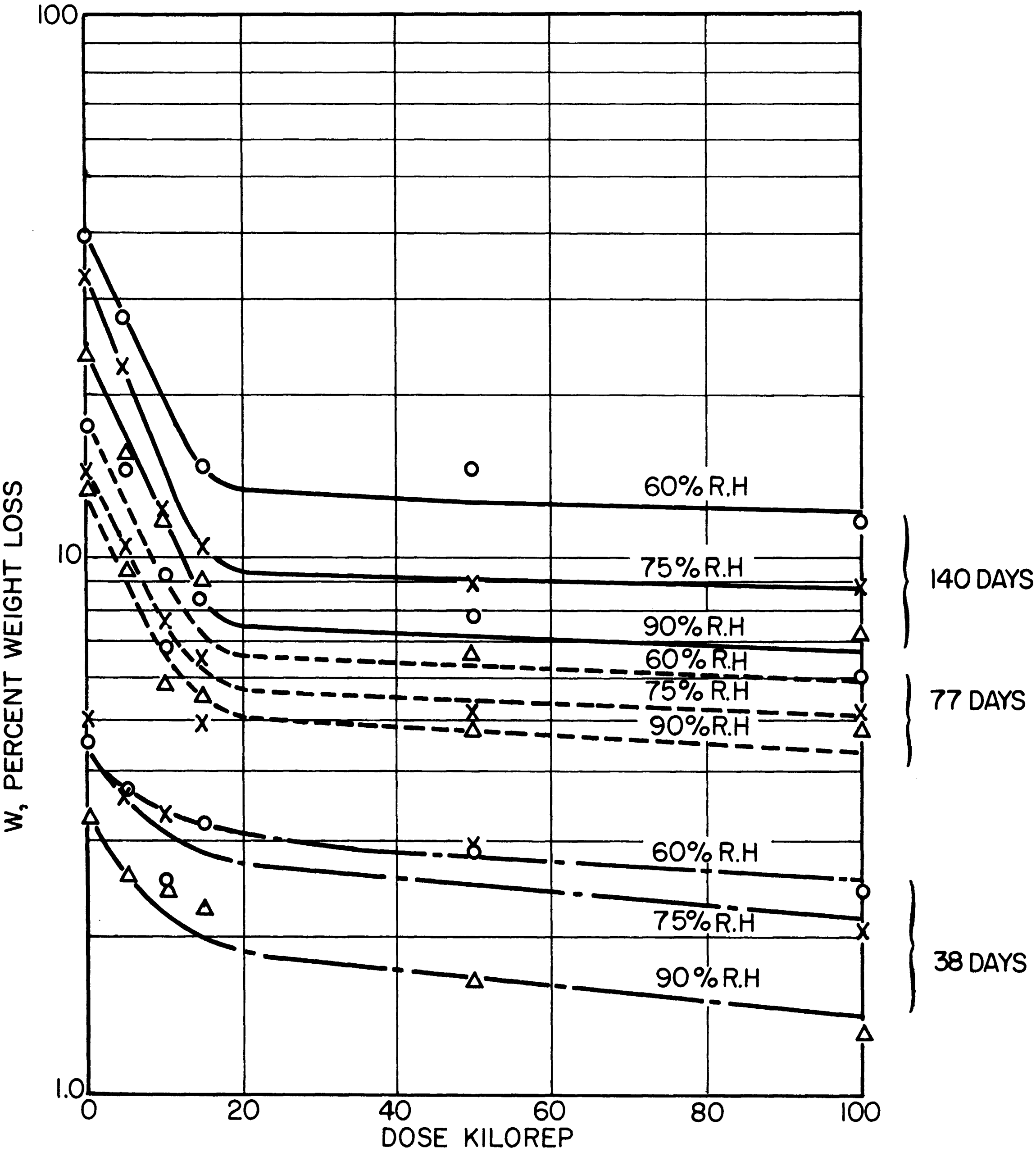

Fig. 2. Weight-loss data as a function of radiation dose, length of storage, and relative humidity.

effect on this "physical" or "radiation-independent weight loss." If this value of "radiation-independent weight loss," M, is subtracted from the curve for "total weight loss," W, the remaining "biological" weight loss, B, shown in Fig. 1 is shown to be radiation-dependent. For instance, one component of total weight loss might be expected to be proportional to the number of living cells in the potato. If radiation reduces the number of living cells, that component of the weight loss should be proportionally reduced.

Potato tubers with living cells and/or with active enzyme systems may lose weight as a result of biological processes such as sprouting and respiration. This loss will be in addition to the loss by evaporation and will be influenced by the biological activity of the tubers.

Some damage to the skin of the tubers was observed at the higher doses. This damage consisted of a weakening of the skin as indicated by cracking of the skin when stretched. The higher doses may introduce a modification of the skin of the tuber and, therefore, increase weight loss for another reason. For this reason, and because of the extreme sensitivity of the "radiation-dependent" weight loss when the total weight loss nearly equals the "radiation-dependent" weight loss, only the data from zero to 50,000-rep dose were used in the analysis of the relationships.

A preliminary analysis was prepared for potatoes stored for 77 days at 50°F and 90% relative humidity by estimating "M" to be 3.69% weight loss. Subtracting this weight loss from the total weight loss gives the radiation-dependent weight loss, "B."

This radiation-dependent component of weight loss demonstrates a logarithmic reduction with radiation dosage, as illustrated in Fig. 3 (previously reported as Fig. 8, Progress Report No. 2). This phenomenon tends to confirm a hypothesis of weight loss proportional to the number of living cells, if the cells are inactivated by a random, statistical process. Extensive data on a wide variety of unicellular organisms from laboratories all over the world indicate similar exponential radiation inactivation phenomena.

The following discussion is an attempt to express B, M, and W as functions of the independent variables: temperature, T, relative humidity, R.H., storage time, t, and radiation dosage, D.

A. WEIGHT LOSS "M" INDEPENDENT OF RADIATION DOSAGE

Based on the method of analysis described and illustrated in Fig. 3, other data reported in Table I (previously reported as Table VI,

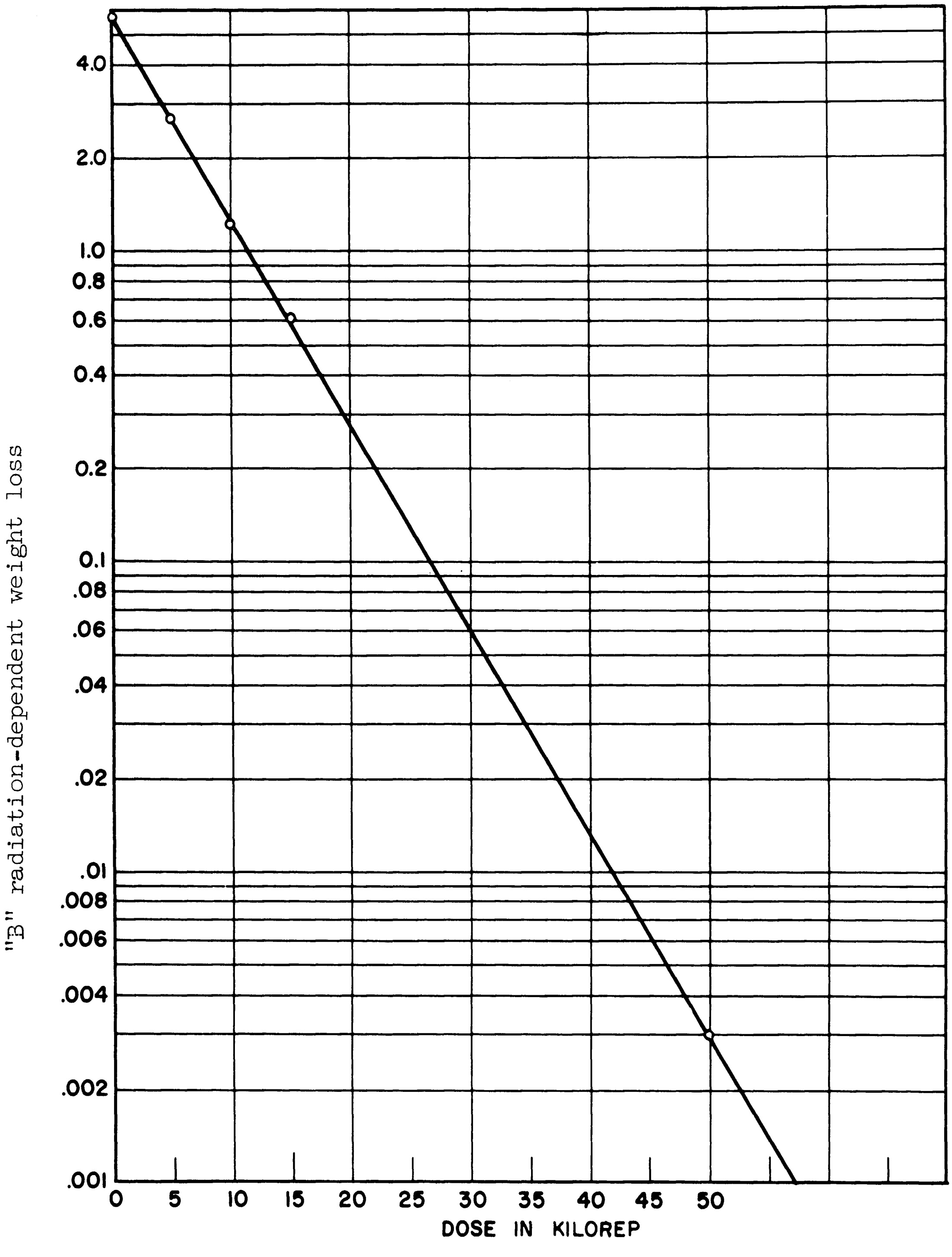

Fig. 3. Plot of "B" - Rate of weight loss dependent on radiation dosage.

Progress Report No. 3) were analyzed, using the assumption that the weight loss at 50 kilorep was in the equilibrium range and that the weight loss at the 50-kilorep dose was equal to "M," the radiation-independent weight loss.

TABLE I

PERCENT WEIGHT LOSS IN PERCENT OF ORIGINAL WEIGHT

Relative Humidity, percent	Dosage, kilorep	Initial	Date of Observation					
		6-14	7-1	7-22	8-11	8-30	10-5	11-1
60 (avg)	0	0	2.3	3.7	12.5	18.5	29.2	38.9
	5	0	2.2	4.5	10.4	14.6	21.1	27.3
	*(10	0	1.1	2.5	4.7	6.8	8.7	9.1)
	15	0	1.4	3.2	5.6	8.8	13.0	14.4
	50	0	1.2	2.8	5.1	7.8	12.8	14.3
	100	0	1.1	2.4	4.3	6.0	10.1	11.5
	200	0	1.3	2.9	5.2	8.0	10.7	11.1
75 (avg)	0	0	1.9	5.0	10.3	14.6	23.3	32.8
	5	0	1.4	3.7	3.9	10.5	16.6	22.5
	10	0	1.3	3.3	5.9	7.6	10.2	12.1
	15	0	1.2	2.6	3.3	6.5	8.8	10.4
	50	0	1.8	2.9	4.9	5.1	6.8	8.9
	100	0	0.8	2.0	3.6	5.1	7.3	8.8
	200	0	0.9	2.1	4.2	6.1	9.0	11.1
90 (avg)	0	0	1.2	3.3	9.4	13.4	20.0	23.8
	5	0	0.8	2.6	6.4	9.1	12.0	15.4
	10	0	0.7	2.4	4.9	5.8	7.9	8.8
	15	0	0.8	2.2	4.3	5.5	6.9	11.4
	50	0	0.4	1.6	3.7	4.8	5.8	6.6
	100	0	0.5	1.3	3.6	4.9	7.0	7.1
	200	0	0.5	1.4	3.0	3.7	4.8	5.5

*Data obviously inconsistent.

It was desirable to express M in terms of a rate so as to compare data collected at different storage intervals. Therefore, the values of accumulative weight loss independent of dosage were divided by the storage time to give M in terms of weight loss per day. This is considered permissible because observations indicated that weight loss varied nearly directly with time if storage conditions remained constant (see Fig. 2 of Progress Report No. 2). Table II gives the average values of M so determined as a function of humidity.

TABLE II

VALUES OF M: WEIGHT LOSS INDEPENDENT OF RADIATION DOSAGE

Relative Humidity, percent	"M" Weight Loss/Day Independent of Dose, lb/day per 100 lb of tubers
60	.0761
75	.0640
90	.0531

The values of M in Table II show a dependence on relative humidity during storage, as might be expected. As anticipated, the rate of weight loss decreases as the humidity increases. To correlate these data, the mass transfer relationships for "drying" were considered.

Water removed in any "drying" process involves the phenomenon known as mass transfer. This phenomenon, when limited to drying, consists of the transfer of mass of substance "x" from point 1 to point 2 as a result of a driving force. This driving force is often expressed as the difference in partial pressure of substance x between points 1 and 2. In the case of weight loss in potatoes by "drying," the substance x is water and the driving force is the difference between the partial pressure of water at the existing humidity and the vapor pressure of water at the existing temperature.

The water must pass through the skins of the potatoes; therefore, the greater the area of the potatoes, the greater will be the rate of weight loss. It is generally true that the mass transfer depends on the area of the mass transfer surface.

The water vapor must pass through a film of stagnant air that surrounds each tuber. The mass transfer characteristic by this film is termed the mass transfer coefficient, k', and is comparable to heat transfer coefficients in heat transfer relationships.

The relationships discussed above can be summarized by the following equation:

$$W = k'a\,(p_1 - p_2), \qquad (1)$$

where

W_1 = rate of weight loss by "drying," lb/day per 100 lb of tubers,
k' = mass transfer coefficient,
a = area of tubers, sq in. per 100 lb,
p_1 = vapor pressure of water at storage temperature, mm Hg, and
p_2 = partial pressure of water in bulk of air surrounding tubers, mm Hg.

The mass transfer coefficient may be correlated in terms of air velocity, diffusivity of water, temperature, and other properties of the system that affect the resistance of the stagnant-air film to mass transfer. However, as these are seldom major variables for conditions used in potato storage, k' will be considered to be a constant. Potatoes are of fairly uniform size and shape; therefore, the area per 100 lb "a" may be considered constant. It is more convenient to express partial-pressure difference of water vapor in terms of relative humidity. Combining these constants, Equation 1 may be rewritten as

$$W_1 = k\,(100 - \text{R.H.}), \qquad (2)$$

where

k = a constant and
R.H. = percent relative humidity.

Analysis of the data of Table II indicated that k has a value of 0.0008. Using this value of k in Equation 2 did not account for all the weight loss independent of radiation dosage. There was a constant rate of weight loss, W_2, which is independent of both radiation dosage and humidity of storage and which is equal to 0.045 lb per day per 100 lb of potatoes or

$$\begin{aligned} \text{"M"} &= W_1 + W_2 \\ &= 0.0008\,(100 - \text{R.H.}) + 0.045 \\ &= 0.125 - 0.0008\ \text{R.H.}, \end{aligned}$$

where

M = total rate of weight loss independent of radiation dosage, lb/day per 100 lb of tubers, and
W_2 = weight loss independent of both dosage and humidity of storage
= 0.045 lb/day per 100 lb of tubers.

It is not surprising that some of the weight loss independent of radiation dosage is also independent of humidity of storage, as some of this weight loss occurs by methods other than drying. Certain chemical reactions involved in respiration and which result in weight loss may be independent of radiation dosage and, of course, would be independent of humidity of storage.

B. WEIGHT LOSS "B" DEPENDENT ON RADIATION DOSAGE

To calculate values of "B," the value of M (the rate of weight loss at 50 kilorep) was subtracted from the total rate of weight loss obtained from Table I. These calculations are summarized in Table III and are plotted in Fig. 4.

TABLE III

VALUES OF "B" - RATE OF WEIGHT LOSS DEPENDENT ON RADIATION DOSAGE

Relative Humidity, percent	Dose, kilorep	"B" Rate of Weight Loss, lb/day per 100 lb of tubers				
		38 days	58 days	77 days	113 days	140 days
	0	.024	.127	.139	.136	.174
60	5	.045	.091	.088	.073	.093
	15	.0105	.0086	.0130	.0018	.0007
		3.4×10^{-5}	6.0×10^{-5}	23.4×10^{-5}	22.1×10^{-5}	27.1×10^{-5}
	0	.0632	.121	.105	.128	.160
75	5	.0290	.0396	.0519	.0690	.0865
	10	.0184	.0104	.0141	.0124	.0122
	50	9.21×10^{-5}	15.5×10^{-5}	19.2×10^{-5}	22.1×10^{-5}	28.6×10^{-5}
	0	.0447	.0983	.1121	.126	.123
90	5	.0264	.0465	.0559	.0549	.0629
	10	.0211	.0207	.0130	.0186	.0344
	15	.0158	.0104	.00910	.0097	.0157
	50	2.64×10^{-5}	5.18×10^{-5}	6.50×10^{-5}	6.29×10^{-5}	7.85×10^{-5}

There is a considerable scattering of the data, as might be expected in such measurements, and the greatest deviation occurs for 38 days, the shortest storage period analyzed. The percentage error is higher for this short period when the total weight loss was small, as was shown in Fig. 2.

Figures 3 and 4 show that (except for the scattering of the data in the latter figure) the logarithm of percent weight loss for a given storage period or the logarithm of the weight loss per day per 100 lb of tubers is a linear function of the radiation dosage. The equation of this line is

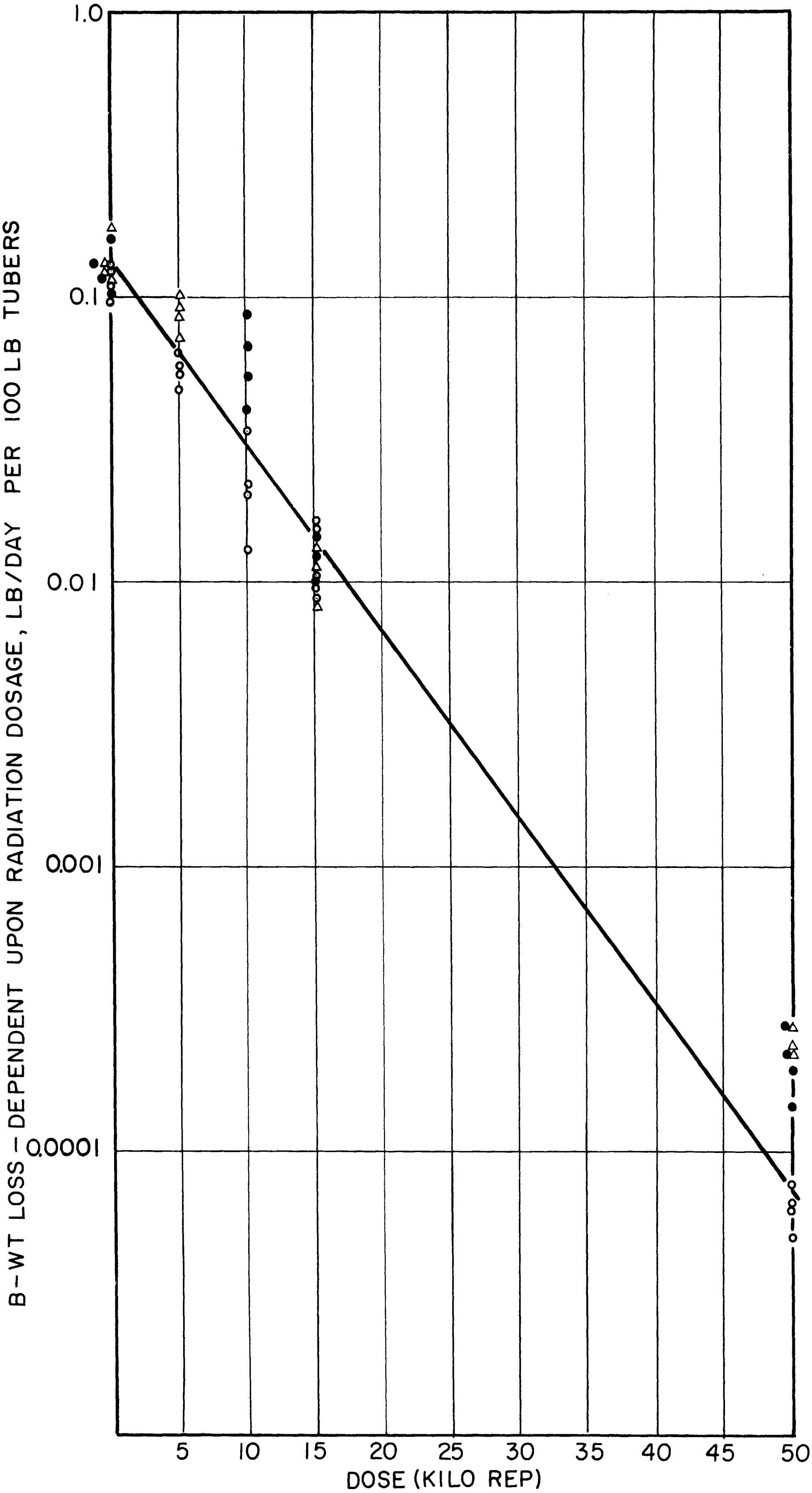

Fig. 4. "B" rate of weight loss dependent on radiation dosage.

$$\ell nB = \ell nc + mD$$

or, taking antilogs,

$$B = ce^{mD}, \qquad (4)$$

where

B = rate of weight loss dependent on radiation dosage, lb/day per 100 lb of tubers,
e = Naperian base, = 2.3026,
m = slope of line in Fig. 4 = 0.15,
D = radiation dose, kilorep, and
c = antilog of intercept of line in Fig. 4 = 0.13.

To solve for c and m, two points are selected on the curve at B = 0.0001 and B = 0.1:

$$2.3026\ (-4) = n(48) + \ell nc \qquad (5)$$

$$2.3026\ (-1) = n(2) + \ell nc, \qquad (6)$$

Subtracting Equation 6 from Equation 5,

$$m = \frac{2.3026(-3)}{46} = -\ 0.15$$

$$c = \text{intercept Fig. 4}$$

$$= 0.13$$

$$\therefore \ell n\ B = -\ 0.15\ D + \ell n\ 0.13$$

or

$$B = 0.13\ e^{-0.15D}. \qquad (7)$$

The semilogarithmic relationship given by Equation 7 indicates that the weight loss "B" dependent on radiation may be proportional to the number of living cells, if the cells are inactivated by a random statistical process. This phenomenon has been termed the "target theory" and has been given appreciable consideration with regard to the effects of radiation on the killing of microorganisms. The possible similarity between the effect of radiation on microorganisms and on potato tubers may warrant a brief review of the "target theory."

C. BRIEF DISCUSSION OF "TARGET THEORY" AS APPLIED TO THE KILLING OF MICROORGANISMS

Many investigators have reported that, for ionizing radiation, the dose required to kill microorganisms is independent of the duration and of whether the radiation is continuous or interrupted. These observations serve to substantiate the "target" or "direct-hit" theory. This theory is that death, when it does occur, is caused by only one particle, although many ionizing particles may pass through the bacterium before it is killed. This fatal particle happens to pass through a specially sensitive region or target in the organism. Such one-shot killing would be independent of the length of time during which the shots were made. Further, if the effect were the cumulative effect of many ionizations, one could expect some recovery to be exhibited by the bacterium in time, necessitating higher dosages for the lower intensities: this is contrary to many experimental observations. However, other investigators have reported such an effect. Continuous irradiation at 10,000 rep per hour has been observed to produce no effect on growth rate or culture size.

The target theory is supported by the exponential characteristic of the survival curve for microorganisms exposed to radiation. Many observers have noted that, within limits, the percentage of the microorganisms killed by any dose is independent of the initial concentration of organisms. If the chance of hitting a target were 1 in 1000 for a given dose, then 1/1000 of the bacteria exposed would be destroyed by that dose, independent of the number of bacteria exposed. However, some investigators have reported a protective effect at high concentrations. Above the freezing point, wide variations in temperature seem to have little effect on the lethality of gamma radiation.

The distance between successive ionization events in the absorption of ionizing radiation appears to have a significant influence. More damage may be produced per ionization when the distance is sufficient to prevent overlap of effects between events.

These phenomena can be explained by the target theory, in which each cell is considered to have one or more sensitive zones or targets. If an ionization occurs at or near a sensitive zone, the organism is inactivated. For a given radiation dosage, the probability of an ionization occurring within a target would be independent of temperature and rate of irradiation. Similarly, the fraction of the targets hit by a given dosage would be independent of the number of targets present.

With many ionizations close together, as in the absorption of alpha particles, more than one ionization may occur in the region of the given target, thereby decreasing the damage per ionization. The efficiency of each ionization event in destroying an organism can be used to estimate the target size. Estimated by this procedure, the target size of small viruses in a dry state is of the same magnitude as its nucleoprotein molecule. Study of larger viruses and bacteria indicates that more than one target is involved. The vegetative organism E. coli contains an estimated 250 targets having an average diameter of 12 millimicrons. It is of interest to note that this dimension is of the same order of size as a gene. This might indicate that the lethal effects of radiation are caused by ionizations near the nuclear material of a cell, which may contain the target.

An interesting extension of the target theory can be made with reference to the effect of radiation on haploid, diploid, and polyploid yeast cells. The haploids have one complete set of genes, whereas the diploids have two complete sets, and the polyploids multiple sets. For an organism with more than one set of genes, it would appear that at least one hit would be required in each set of genes to produce death. It can be shown mathematically that if only one hit is required to make a kill, the characteristic exponential curve is obtained, but if two hits are required, the curve will be shifted to the right and when plotted on semilog paper will give a sigmoidal curve rather than the straight line characteristic of the exponential curve. Similarly, organisms with multiple sets of genes such as the polyploids, would give still greater sigmoidal distortion in the experimental curve.

Although the target theory is essentially based on considerations involving physical effects, the mechanism may be chemical. Thus, the formation of OH or H radicals near nuclear material in a cell may result in chemical reaction with this material. If this is true, the target area must be considered sufficiently large to cover the effective range of mobile free radicals. As the effective range of free radicals can be varied, this would indicate a change in target size with conditions. There is evidence of variation of effective target size. Thus, the simple target theory probably requires considerable qualification to explain fully all the effects of radiation on cells.

D. COMBINATION OF EQUATIONS FOR WEIGHT LOSS FOR STORAGE AT 55°F

The data analyzed in the previous section were obtained from tubers stored at controlled humidities and at 55°F at Michigan State University. Equations 3 and 5 may be combined to give the total weight loss for irradiated Idaho seed potatoes stored at 55°F:

$$W_{55} = (.125 - .0008\ \mathrm{R.H.} + 0.13e^{-.15D})t, \qquad (8)$$

where

W_{55} = total weight loss at 55°F, lb/100 lb,
R.H. = relative humidity, %,
D = radiation dose, kilorep, and
t = time, days.

E. WEIGHT LOSS AS A FUNCTION OF TEMPERATURE

Total weight loss as a function of the temperature of storage was measured with tubers stored in different constant-temperature rooms in the Food Service Building at The University of Michigan. Some of these data were shown plotted on plain coordinate paper in Fig. 5 . Weight loss was shown to increase with temperature of storage, as might be expected from a consideration of the effect of temperature on chemical reactions. The Arrhenius equation for reaction rate as a function of temperature and other variables may be stated as follows:

$$k_1 = Ae^{-E/RT}, \qquad (9)$$

where

k_1 = specific reaction velocity constant,
A = frequency factor for reaction,
E = energy of activation, and
T = absolute temperature.

If storage humidities are high, the weight loss by "drying" will be proportionately small and an appreciable portion of the weight loss will result from respiration losses.

Thus, based on the concept that a major portion of the weight loss results from the chemical reactions involved in respiration, Equation 9 may be applied. As all the variables in Equation 9 may be considered constant except temperature, it is of interest to plot the data previously shown in Fig. 3, Progress Report No. 3, vs absolute temperature. Equation 9 is an exponential relation and, considering the form of the variables, the logarithm of the rate of weight loss (rate of reaction) should be plotted vs the reciprocal of the absolute temperature. Table IV summarizes the data on percentage weight loss vs storage temperature for control and 10-kilorep irradiated potatoes stored for 134 days.

TABLE IV

PERCENTAGE LOSS IN WEIGHT VS STORAGE TEMPERATURE
FOR CONTROL AND 10-KILOREP IRRADIATED POTATOES
STORED FOR 134 DAYS

Storage Temp. °F	Temp.°C	Absolute Temp. °K	1/T x 1000	(Control) W_O, % Wt Loss	Irradiated (10 Kilorep) W_R, % Wt Loss
35	1.66	274.66	3.64	5.2	3.2
41	5.0	278.0	3.597	7.6	4.4
42	5.55	278.55	3.589	-	4.8
50	10.0	283	3.534	21.6	7.3
52	11.11	284.11	3.521	23.2	7.2
63	17.22	290.22	3.446	48.8	15.6
80	26.66	299.66	3.340	-	29.6

The logarithm of the total percent weight loss (W) for 134 days was plotted against the reciprocal of Absolute Temperature (1/T) as shown in Fig. 5. Straight-line curves were obtained for the data on the control and the irradiated tubers. Equations for the straight lines are given as follows:

CONTROL Tubers

Equation of the straight line

$$\ell n \; W_o = \frac{m_o}{T} + C_o, \qquad (10)$$

where

ℓn = Naperian logarithm,
W_o = percentage weight loss for control tubers,
m_o = slope of line for control tubers, and
C_o = intercept on y-axis.

In order to determine m_o, two points are selected on the line for the control tubers:

$$\ell n \; 50 = m_o \times 3.44 \times 10^{-3} + C_o \qquad (11)$$

$$\ell n \; 8.5 = m_o \times 3.6 \times 10^{-3} + C_o . \qquad (12)$$

Subtracting Equation 12 from Equation 11,

$$3.91202 - 2.14007 = - 0.16 \times 10^{-3} \times m_o$$

or

$$m_o = - \frac{1.77195}{0.16 \times 10^{-3}}$$

$$m_o = -11.075 \times 10^3$$

$$W_o = A_o e^{\frac{-11.075 \times 10^3}{T}}, \qquad (13)$$

where $A_o = e^{C_o}$.

IRRADIATED Tubers

$$\ell n \; W_R = \frac{m_R}{T} + C_R, \qquad (14)$$

where

W_R = weight loss for irradiated tubers,
m_R = slope of line for irradiated tubers, and
C_R = intercept on y-axis.

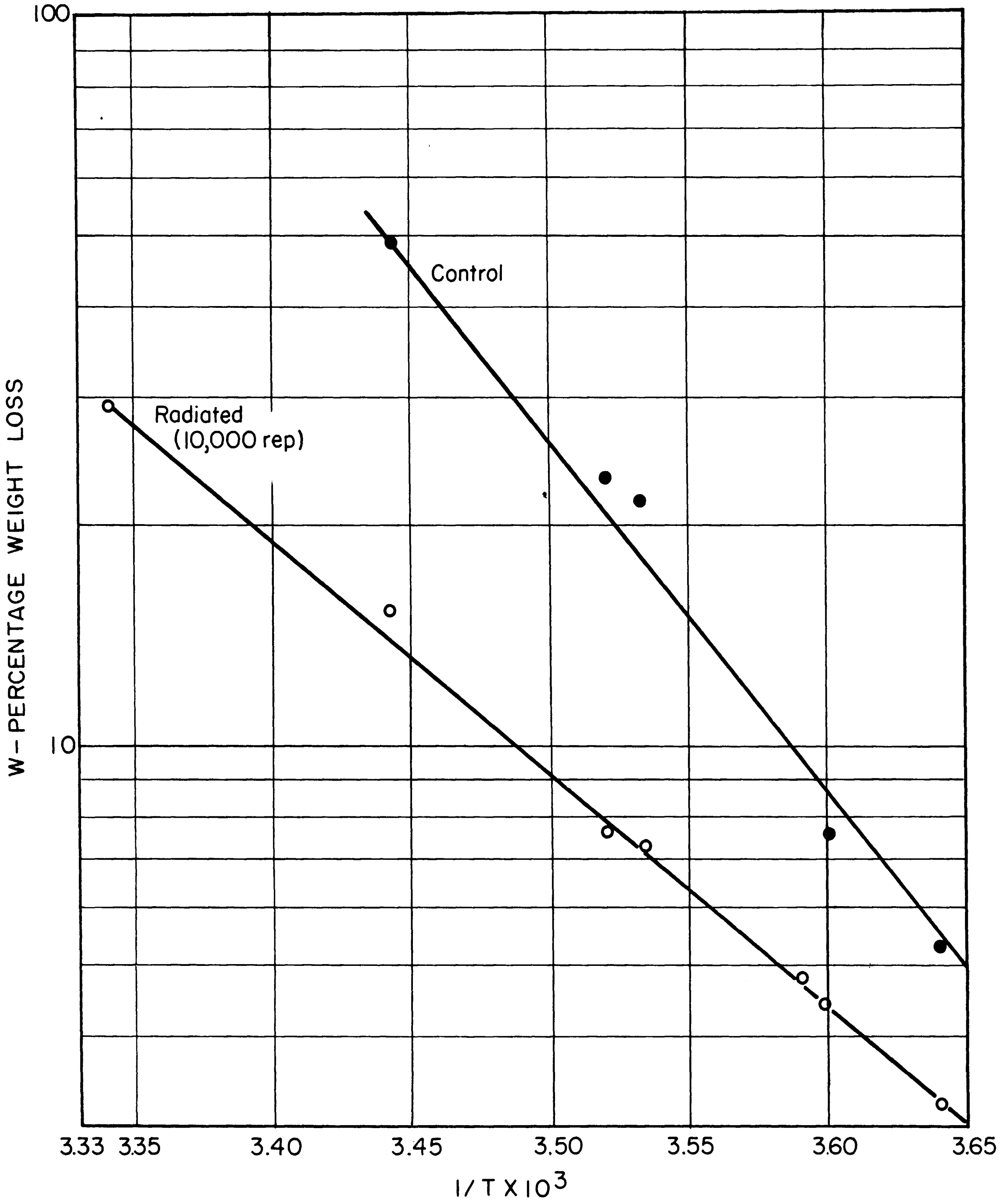

Fig. 5. Weight loss vs reciprocal of the absolute temperature of storage.

To determine m_R, two points are selected on the line for irradiated tubers:

$$\ell n\ 27.3 = m_R \times 3.35 \times 10^{-3} + C_R \qquad (15)$$

$$\ell n\ 4.35 = m_R \times 3.60 \times 10^{-3} + C_R. \qquad (16)$$

Subtracting Equation 16 from Equation 15,

$$3.30689 - 1.47018 = 0.25\ m_R \times 10^{-3}$$

$$\therefore m_R = -\ 7.3468 \times 10^3$$

$$W_R = A_R\ e^{\frac{-7.35 \times 10^3}{T}}, \qquad (17)$$

where $A_R = e^{C_R}$.

F. DEVELOPMENT OF GENERAL EQUATION INCLUDING TEMPERATURE

Rewriting Equation 17:

$$W_R = A_R\ e^{\frac{-7.35 \times 10^3}{T}}$$

To evaluate A_R, the value of W_R at 55°F may be calculated and equated to W_{55} obtained by Equation 8 or:

$$W_R \text{ at } 55°\text{F} = A_R\ e^{\frac{-7.35 \times 10^3}{288}} \qquad (18)$$

$$W_{55°\text{F}} = \left[0.125 - 0.0008\ \text{R.H.} + 0.13\ e^{-0.15D}\right] t. \qquad (19)$$

Equating $W_{55°\text{F}} = W_R$ at 55°F

or

$$A_R = \left[0.125 - 0.0008\ \text{R.H.} + 0.13\ e^{-0.15D}\ te^{\frac{7.35 \times 10^3}{288}}\right] \qquad (20)$$

∴ General Equation

$$W_{RT°K} = \left[0.125 - 0.0008\ \text{R.H.} + 0.13\ e^{-0.15D}\right] te^{7.35 \times 10^3 \left(\frac{1}{288} - \frac{1}{T}\right)} \qquad (21)$$

G. TESTING OF THE GENERAL EQUATION FOR WEIGHT LOSS

The general equation (Equation 21) obtained is applied to a number of data not used in the derivation to check the prediction of weight loss. Data were taken for different temperatures for 10-kilorep dose and for a total time of 61 days.

Dose = 10 kilorep
Time = 61 days

(1) <u>35°F</u>

$T = 274.6°K$
R.H. = 88%.

$$W_R = \left[0.125 - 0.0008\,\text{R.H.} + 0.13e^{-0.15D}\right] t\, e^{7.35\text{x}10^3}\left(\frac{1}{288} - \frac{1}{T}\right)$$

$$W_R = \left[0.125 - 0.0008 \text{ x } 88 + 0.13e^{-1.5}\right] 61\, e^{7.35 \text{ x } 10^3}\left[3.472 - 3.643\right] \text{x } 10^{-3}$$

$$W_R = 0.0833 \text{ x } 61\, e^{-1.26}$$

$$W_R = 0.0833 \text{ x } 61 \text{ x } 0.284$$

$$W_R = 1.44$$

W_R = 1.44 (Calculated)

W_R = 1.60 (Experimental)

(2) <u>40°F</u>

$T = 277.4°K$

R.H. = 80%

$$W_R = \left[0.125 - 0.0008 \text{ x } 80 + 0.13e^{-1.5}\right] 61e^{7.35 \text{ x } 10^3}\left[3.472 - 3.605\right] \text{x } 10^{-3}$$

$$W_R = 0.090 \text{ x } 61 \text{ x } e^{-0.978}$$

$$W_R = 0.090 \text{ x } 61 \text{ x } 0.376$$

$$W_R = 2.062$$

W_R = 2.062 (Calculated)

W_R = 2.04 (Experimental)

(3) 45°F

$$T = 280°K$$

$$R.H. = 95\%$$

$$W_R = \left[0.125 - 0.0008 \times 95 + 0.13e^{-1.5}\right] 61\, e^{7.35 \times 10^3 \left[3.472 - 3.571\right] \times 10^{-3}}$$

$$W_R = 0.078 \times 61 \times e^{-0.727}$$

$$W_R = 0.078 \times 61 \times 0.483$$

$$W_R = 2.3$$

$$W_R = 2.3 \text{ (Calculated)}$$

$$W_R = 2.1 \text{ (Experimental)}$$

(4) 50°F

$$T = 283°K$$

$$R.H. = 88\%$$

$$W_R = \left[0.125 - 0.0008 \times 88 + 0.13\, e^{-1.5}\right] 61e^{7.35 \times 10^3 \left[3.472 - 3.534\right] \times 10^{-3}}$$

$$W_R = 0.0833 \times 61 \times e^{-0.455}$$

$$W_R = 0.0833 \times 61 \times 0.634$$

$$W_R = 3.25$$

$$W_R = 3.25 \text{ (Calculated)}$$

$$W_R = 3.0 \text{ (Experimental)}$$

(5) 63°F

$$T = 290°K$$

$$R.H. = 53\%$$

$$W_R = \left[0.125 - 0.0008 \times 53 + 0.13\, e^{-1.5}\right] 61\, e^{7.35 \times 10^3 \left[3.472 - 3.448\right] \times 10^{-3}}$$

$$W_R = 0.11143 \times 61 \times e^{0.176}$$

$$W_R = 0.11143 \times 61 \times 1.19$$

$W_R = 8.0$

$$W_R = 8.0 \text{ (Calculated)}$$

$$W_R = 7.2 \text{ (Experimental)}$$

(6) Summary of Calculations

The calculations on the comparison of predicted and measured weight loss are summarized in Table V. The percent difference of the calculated value from the experimental value varies from +11% to -10%.

TABLE V

COMPARISON OF PREDICTED AND EXPERIMENTAL VALUES OF WEIGHT LOSS FOR CONTROL AND 10-KILOREP IRRADIATED POTATOES STORED FOR 61 DAYS AT VARIOUS TEMPERATURES AND HUMIDITIES

No.	Temp °F	Temp °K	Relative Humidity percent	Calculated (W_R)	Experimental (W_R)	Percentage Diff. from Exper. Value
1	35	274.6	88	1.44	1.60	-10
2	40	277.4	80	2.062	2.04	+ 1.08
3	45	280.0	95	2.3	2.1	+ 9.5
4	50	283.0	88	3.25	3.0	+ 8.3
5	63	290.0	53	8.0	7.2	+11

III. INITIATION OF STORAGE EXPERIMENT WITH NEWLY HARVESTED POTATOES

A total of 1000 lb each of Michigan-grown field-run Sebago and Russet Rural varieties of potatoes have been irradiated and put into storage according to the plan shown in Table XVI of Progress Report No. 3. The plan calls for five different storage temperatures from 35° to 85°F and for nine different doses of gamma radiation from 0 to 200,000 rep. There are seventeen combinations of treatments. Forty-five pounds of potatoes have been assigned to each treatment and are stored in specially constructed boxes (see Fig. 6) to allow for adequate inspection with the minimum of disturbance. The mesh bag holds potatoes at exactly the same conditions which are used from time to time for chemical analyses.

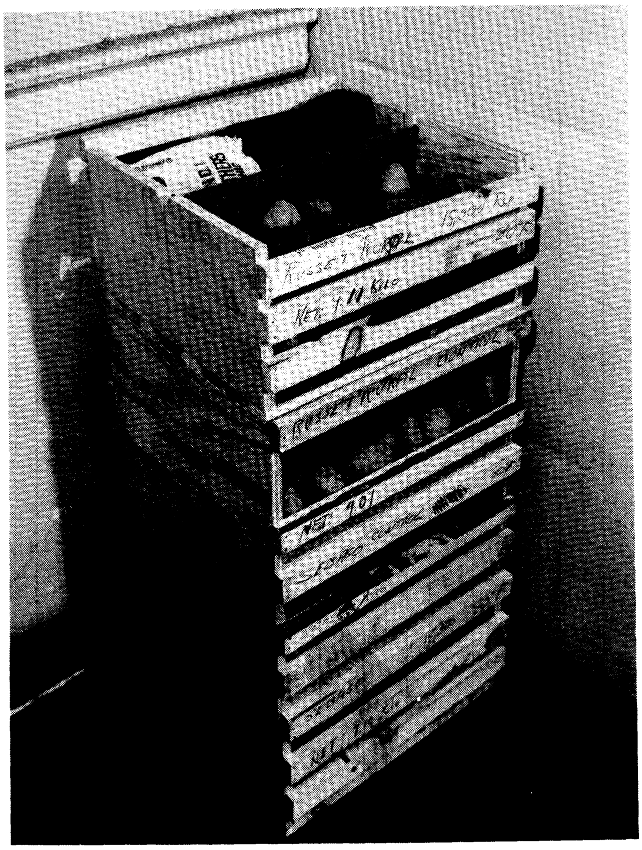

Fig. 6. View of tier of specially constructed wooden crates for storages studies on current potatoes.

At present, only zero-time data are available on these potatoes. This will be presented in the next report and will consist of reducing-sugar and sucrose levels on all 34 treatments, plus values for starch content on some of the potatoes. Some of the Sebago variety potatoes stored at the higher temperatures started to sprout before values for reducing sugar could be obtained.

Data describing the Sebago and Russet Rural potatoes are given in Tables VI and VII, respectively.

TABLE VI

DATA ON 1955 CROP SEBAGO POTATOES SUPPLIED BY MICHIGAN STATE UNIVERSITY

Seed Type: Field run, B size whole and larger ones cut.
Seed was one year from certification, grown on Station farm.
Seed came from storage in good condition.

Planting Date: May 27.

Fertilizer: 15 tons barnyard manure on clover, June, 1954.
300 lb 3-12-12 with rye on August 15, 1954.
200 lb 12-12-12 on rye on April 6, 1955.
550 lb 5-20-20 at time of planting, May 27, 1955.
All the above applications are for each acre.

Soil Type: Most of the soil is Iosco sandy loam, with a trace of Selkirk silt loam.

Rainfall: May, after the 27th, 0.29 inch; June, 4.11 inches; July, 4.34 inches; August, 2.49 inches; September, 0.71 inch; October (to the 6th), 0.40 inch.

Irrigation: Four applications of 2 inches each.

Spray Schedule: Started June 21, DDT. Sprayed every ten days with Dithane and DDT until first week in August. Sprayed every week with Manzate and every other week with DDT during August. Sprayed once with Manzate and once with Dithane in September.

Beating Date: September 19, and covered with disk cultivator.

Digging: October 5-6.

Temperature at Digging: October 5, 74 degrees high and 55 low.
October 6, 71 degrees high and 61 low.
October 3, had a low of 25, the lowest to that date.

Approximate Temperature Potatoes Held Since Digging: 45 to 55 degrees.

Shipped to East Lansing by Closed Truck on November 4: High temperature, 33
Low temperature, 28

This field was sprayed with Dow's Premerge (Dinitro) on June 14.

TABLE VII

DATA ON 1955 CROP OF RUSSET RURAL POTATOES SUPPLIED BY MICHIGAN STATE UNIVERSITY

Seed Type: B size potatoes planted whole. Certified Seed Growers' samples sent in for inspection.

Planting Date: May 10.

Fertilizer: 15 tons barnyard manure on clover, June, 1954.
300 lb 3-12-12 with Balbo rye on August 15, 1954.
200 lb 12-12-12 on rye on April 6, 1955.
550 lb 5-20-20 at time of planting, May 10, 1955.
All of above applications are for each acre.

Soil Type: Most of the off-type potatoes came from Selkirk silt loam, the rest from Iosco sandy loam.

Rainfall: May, after the 10th, 1.70 inches; June, 4.11 inches; July, 4.34 inches; August, 2.49 inches; September, to the 28th, 0.69 inch.

Irrigation: Four applications of 2 inches each.

Spray Schedule: Started on June 8 with DDT. Sprayed every ten days with Dithane and DDT until the first week in August. Sprayed every week with Manzate and every other week with DDT during August. Sprayed once with Manzate and once with Dithane in September.

Beating Date: September 13 and 14, covered at once with disk cultivator.

Digging Date: September 26-28.

Temperatures at Digging: High and low on 26th, 58 and 28; on 27th, 60 and 28; 67 and 61 on the 28th; 27 on the night of September 12 was the lowest previous temperature.

Approximate Temperature Potatoes Held Since Digging: 45 to 55 degrees.

Shipped to East Lansing in Closed Truck on November 4: High temperature was 33 degrees and the low 28.

This field was sprayed with Dow's Premerge (Dinitro) on May 31.