Kempe, et al.[22] reported tests on the effects of gamma radiation on the spores of strain 62-A Clostridium botulinum. The sterility dosage for canned beef was found to increase from 2.5 to 4 megarep when the concentration of spores of this organism was increased from 0.4 to 40,000 per gram of meat. In tests using 40,000 spores per gram of meat of strain 213-B Clostridium botulinum (or an equal inoculation of putrefactive anaerobe No. 3679), 3.5 and 2.5 megarep, respectively, were required for sterilization.

f. Botulinum Toxin.—Botulinum toxin is more poisonous than any other toxin known. A small dose of 0.0084 mg[23] is lethal to an adult human. The toxin is unaffected by the digestive enzymes of the gastro-internal tract; hence it is effective when given by mouth.

(1) Heat Resistance.—The toxin can be completely destroyed by heating for 30 minutes at 80°C. Results of a study on different types of toxins were carried out by Meyer[10] and are summarized in Table III.

TABLE III

HEAT RESISTANCE OF TOXINS OF CLOSTRIDIUM BOTULINUM
(According to Meyer[10])

Temperature °C	Time of Destruction of Toxin Minutes	
80	1/2 - 6	Type A
72	2 - 18	
65	10 - 85	
80	15	Type B
80	30	Type C

(2) Radiation Resistance.—Dack and Wagenaar[21] reported that type-A toxin required a dose of 7.8 megarep for the reduction of toxin level from 1000 mld (minimal lethal dose) to 20 mld, while the toxin of type B required 4.3 to 5.3 megarep. Reduction of toxin level from 20 mld to the endpoint required 2.2 megarep.

2. Staphylococcus Food Poisoning.—The most common type of food poisoning is that produced by toxin from staphylococcal organisms. Unlike the toxin of botulinum, the toxin produced by staphylococci seldom produces fatal attacks of food poisoning. Almost every individual has had some experience with this type of food poisoning, as it is often encountered in foods prepared for banquets, public institutions, large-scale picnics and the armed services.

The symptoms usually appear about three hours after ingestion of the contaminated food and involve salivation, nausea, cramps in the abdominal region, and diarrhea. Recovery is usually quite rapid, with no aftereffects. Lethal cases are very rare.

Staphylococcal organisms are very widespread and exist in the throat and nasal passages of individuals and are particularly abundant in individuals suffering from colds. These organisms are the causative agents of local skin infections such as boils, pimples, and carbuncles. The wide distribution of these organisms in individuals and the fact that the food may be easily contaminated by the hands or from the air by sneezing account in part for the frequency of this type of food poisoning.

As in the case of Clostridium botulinum, the organism itself does not produce the illness, although it may under other circumstances produce infections in various parts of the body. This type of food poisoning is caused by the enterotoxin produced after sufficient growth of the organisms in the contaminated food. In addition to following good sanitary procedures in food preparation, refrigeration should be used to prevent growth of new organisms. Segalove and Dack[24] have shown that enterotoxin is not formed in foods stored for four weeks at normal refrigerator temperatures (4°-7°C).

Dack[25] summarizes three conditions necessary for the development of the staphylococcus enterotoxin: (1) there must be sufficient contamination of the food with an enterotoxin-producing strain of staphylococcus; (2) the food must be a good medium for the growth of the organisms and the production of enterotoxin; (3) the food must remain at about room temperature or above for several hours.

Common foods which have often produced this type of food poisoning are potato and macaroni salads for picnics, chocolate éclairs, cream puffs and other cream-type pastries, ham salad, egg-salad sandwiches, and other sandwiches with mayonnaise sold at drugstores.

The enterotoxin produced by staphylococcal organisms differs from the toxin produced by Clostridium botulinum with regard to its resistance to heat. Whereas a short cooking destroys the botulinum toxin, boiling for thirty minutes was reported by Dack[25] to be insufficient to reduce the toxicity of staphylococcal enterotoxin. On the other hand, Dack reports in a preliminary study that, when using a radiation dosage approximately ten times the dosage reported lethal for staphylococci (about 3.5 megarep), the enterotoxin was inactivated.

3. Salmonella Food Poisoning.—Salmonella is a generic name used to describe a group of bacteria previously known as "paratyphoid bacteria." The organisms were named for D. E. Salmon who was one of the early workers to describe it. The food poisoning caused by Salmonella organisms differs from that caused by organisms previously described in that this illness is

produced by an invection rather than by a toxin. Two types of infection are common. In one type, found only in man, the symptoms are similar to those of typhoid fever, but less severe. The second type produces a disease in either man or animals with symptoms similar to typhoid fever and accompanied by nausea, vomiting, cramps in the abdominal region, diarrhea, and sometimes fever and leucocytosis. The severity of the disease varies considerably but, like staphylococcus poisoning, it is seldom fatal.

Salmonella infections account for only a small portion of food-poisoning outbreaks. Although the symptoms are often similar to those produced by staphylococcal enterotoxin, the incubation period is usually about 24 hours after ingestion of the contaminated food, as compared to about 3 hours for the onset of symptoms of staphylococcal food poisoning.

Salmonella infection is often produced from eating raw or undercooked meats. The organism is common in the intestinal tract of animals and fish, and, as a result, it may be found in fresh meat. The organism also can be carried by the feces of rodents to types of food other than meat. Also, the common housefly may be a carrier. The organism has been reported by Dack[25] to grow in foods such as asparagus, string beans, peas, corn, salmon, shrimp, and tomato juice. Some large-scale outbreaks of Salmonella infection during World War II were traced to Salmonella organisms in dried eggs.

4. Alpha-Type Streptococci Food Poisoning.—Another type of organism which may cause food poisoning is the alpha-type streptococci. Cases of food poisoning from this organism are less common and usually less severe than those from either staphylococcus or Salmonella organisms and are usually associated with the ingestion of foods contaminated with extremely high populations of the organism Streptococcus faecalis. The symptoms are similar to those of staphylococcus food poisoning but milder and the onset of illness is usually later. Symptoms are nausea, colicky pains, and diarrhea. The illness is the result of an infection by the organism, as in the case of Salmonella, and is not the result of ingestion of toxin. The organism has been found in outbreaks of food poisoning from eating canned Vienna sausages, beef croquettes, turkey dressing, canned evaporated milk, dried eggs, and charlotte russe.

Streptococci grow fairly rapidly over a wide range of temperatures from 10° to 45°C. These organisms are relatively heat resistant, will survive thermal pasteurization, and can grow in salt concentrations of 6.5%. They are natural inhabitants of the intestinal tract of man and animals, and humans can tolerate a considerable number of them without becoming ill. Illnesses result when the population counts reach the range of from 1×10^6 to 1×10^7 organisms per gram of good. The organisms may be spread by the feces of rodents and may be found in fresh meat, fish, and fowl as a result of carelessness.

5. Summary.—A summary of these four principal types of food poisoning caused by microorganisms or their toxins is given in Table IV.

TABLE IV

SUMMARY OF CHARACTERISTICS OF FOOD POISONING
CAUSED BY BACTERIA OR THEIR PRODUCTS

Disease	Specific Agent	Intoxication	Infection	Symptoms	Onset of Symptoms After Eating
Botulism	*Clostridium botulinum* which produces toxin	+	-	Difficulty in swallowing, double vision (diplopia), difficulty in speech (aphonia), difficulty in respiration, followed by death from paralysis of muscles of respiration	2 hours to 8 days; average 1-2 days
Staphylococcus food poisoning	Staphylococci which produce enterotoxin	+	-	Nausea, vomiting, diarrhea, and acute prostration; abdominal cramps	1-6 hours; average 2-1/2-3 hours
Salmonella infection	*S. typhimurium* *S. enteritidis* *S. choleraesuis*	-	+	Abdominal pain, diarrhea, chills, fever, frequent vomiting, prostration	7-72 hours
Streptococcus food poisoning	A-type (*S. faecalis*)	-	+	Nausea, sometimes vomiting, colicky pains, and diarrhea	2-18 hours

6. Discussion.—At Michigan and elsewhere, radiation dosages of 1 megarep have been shown to destroy vegetative organisms. Thus, the vegetative cells of staphylococcal, Salmonella, and streptococcal organisms can be inactivated by dosages used in the proposed process of high radiopasteurization. This dosage of about 1 megarep also would destroy the vegetative cells but not the spores of Clostridium botulinum. Thus, the primary danger of food poisoning, using dosages in this range, would be that of botulism which, of course, is a serious consideration. Storage conditions should be maintained that would prevent the development of spores of this organism to the vegetative state with the accompanying production of toxin. As these spores do not develop at refrigerator temperatures, storage at 40-50°F should provide ample protection. In the case of mishandling or storage for some time at room temperature, additional safeguards can be used. As the vegetative cells of Clostridium botulinum are destroyed by high radiopasteurization, and as some time is required for spores to develop into vegetative cells, accidental storage for a few days at the high temperatures should be entirely safe. But as a further precaution, it is proposed that such food items to be processed in this manner be packaged aerobically in containers such as polyethylene, which readily transmits oxygen. Aerobic conditions are unfavorable to the development of the spores of Clostridium botulinum into vegetative cells. As a further precaution, it is suggested that the foods to be treated with high-radiopasteurization doses first be given a heat treatment such a cooking, in the case of seafoods and meat, or blanching, in the case of fresh vegetables. Although such a limited heat treatment would not destroy all the spores of anaerobes, when used in combination with the subsequent radiation treatment of 1 megarep it will provide an additional factor of safety to this process.

II. DESIGN OF A RADIATION FACILITY FOR HIGH RADIOPASTEURIZATION

A radiation dose of from 0.8 to 1 megarep would be required for high radiopasteurization. As this is an appreciable radiation dose, radiation costs will be high and a radiation facility which makes efficient use of radiation should be used. For this reason, a multipass conveyor, similar to that considered for the irradiation of prepackaged raw meat or the irradiation of potatoes,[2,4] is proposed. If cesium-137 sources were purchased for such a facility, four passes, each containing 1/2-value thickness of food, are recommended. However, if cooling-reactor fuel elements were used as a source of radiation, the cost might be reduced from that of purchased cesium-137 sources. In using cooling-reactor fuel elements, two passes are recommended.

It has been shown previously that a number of cooling-reactor fuel elements properly arranged can be used to provide a uniform radiation field in one plane at selected distances from the source.[26,27] Such a scheme is proposed for the high-radiopasteurization facility.

A. DESIGN OF A RADIATION CHAMBER

The radiation chamber for a high-radiopasteurization gamma facility was considered, using the same basic design as the irradiation facility designed to pasteurize prepackaged meat.[2] However, a number of changes were made, such as increasing the tray width from 8 to 12 inches and the tray height from 18 to 30 inches. This will require an increase in the conveyor pitch of from 4-1/2 to 7-1/2 inches. Also, because of the increase in the width of the conveyor trays, the spacing between each pass will be increased from 15 to 24 inches.

The increase in width of conveyor trays and the increase in spacing between conveyor passes increase the distance of the absorber from the source. The radiation field is decreased with distance. Therefore, only two passes of the conveyer will be used on either side of the radiation source rather than four passes as used in the previous design.

Figure 5 shows a section of the elevation view of the modified radiation chamber designed to high radiopasteurized bulk prepackaged food items or cartons of such prepackaged foods. Kraft cardboard cartons filled with food in sealed plastic bags and having a size of 1 x 2 x 2-1/2 feet, or plastic bags of food in bulk, are brought by conveyor and transferred to the irradiation conveyor at point A. As the irradiation conveyor moves, the cartons or bulk packages of prepackaged food are carried down into the radiation chamber through openings, B and C, past concrete shields, D and E. Two vertical passes, F and G, are made on the left side of the row of source rods, H, and two passes, I and J, are made on the right side of the source. This arrangement permits irradiation of the food items from both sides so as to produce a more uniform dose of radiation.

The well, K, is filled with water as in previous designs and is used to hold the source when the radiation must be shut off to permit entry into the radiation chamber for maintenance, routine inspection, or addition of source rods. If the radiation chamber is located above grade as shown in Fig. 5, a concrete wall, L, which is 3 feet 10 inches thick, is used for shielding. If the radiation chamber is placed below grade, the wall thickness may be reduced to that required for structural strength alone, since the earth will act as a radiation shield. A labyrinthine entrance to the radiation chamber is provided at the lower left as shown in Fig. 5.

A plan view of the radiation chamber is presented in Fig. 6. This view shows the simple labyrinth used as an access passage for routine inspection and maintenance. The conveyor in the radiation chamber may be driven by sprockets on stub shafts. Some of the sprockets may be "idlers," with one or more sprockets to be used as a "driver."

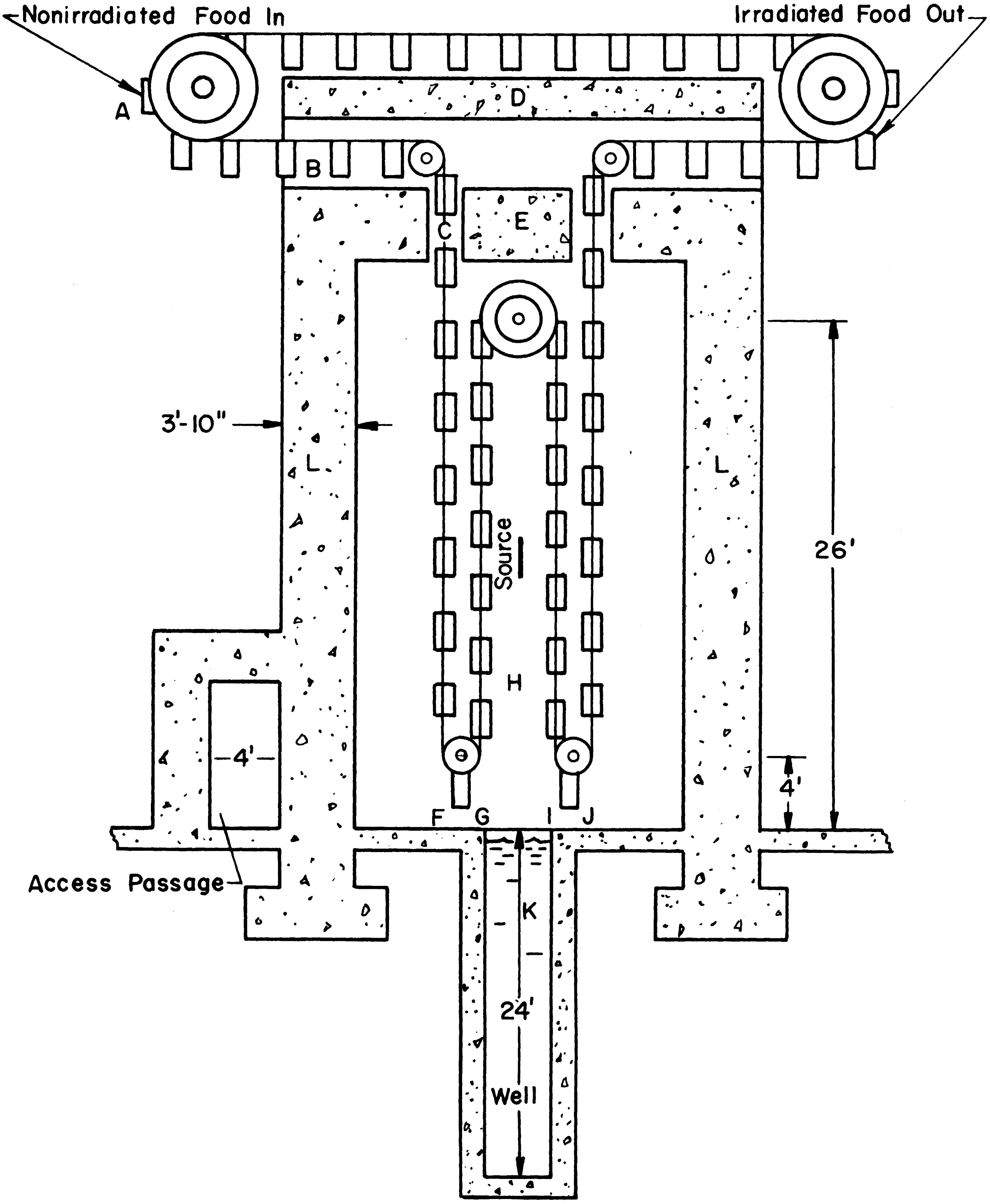

Fig. 5. Elevation view of high-radiopasteurization chamber.

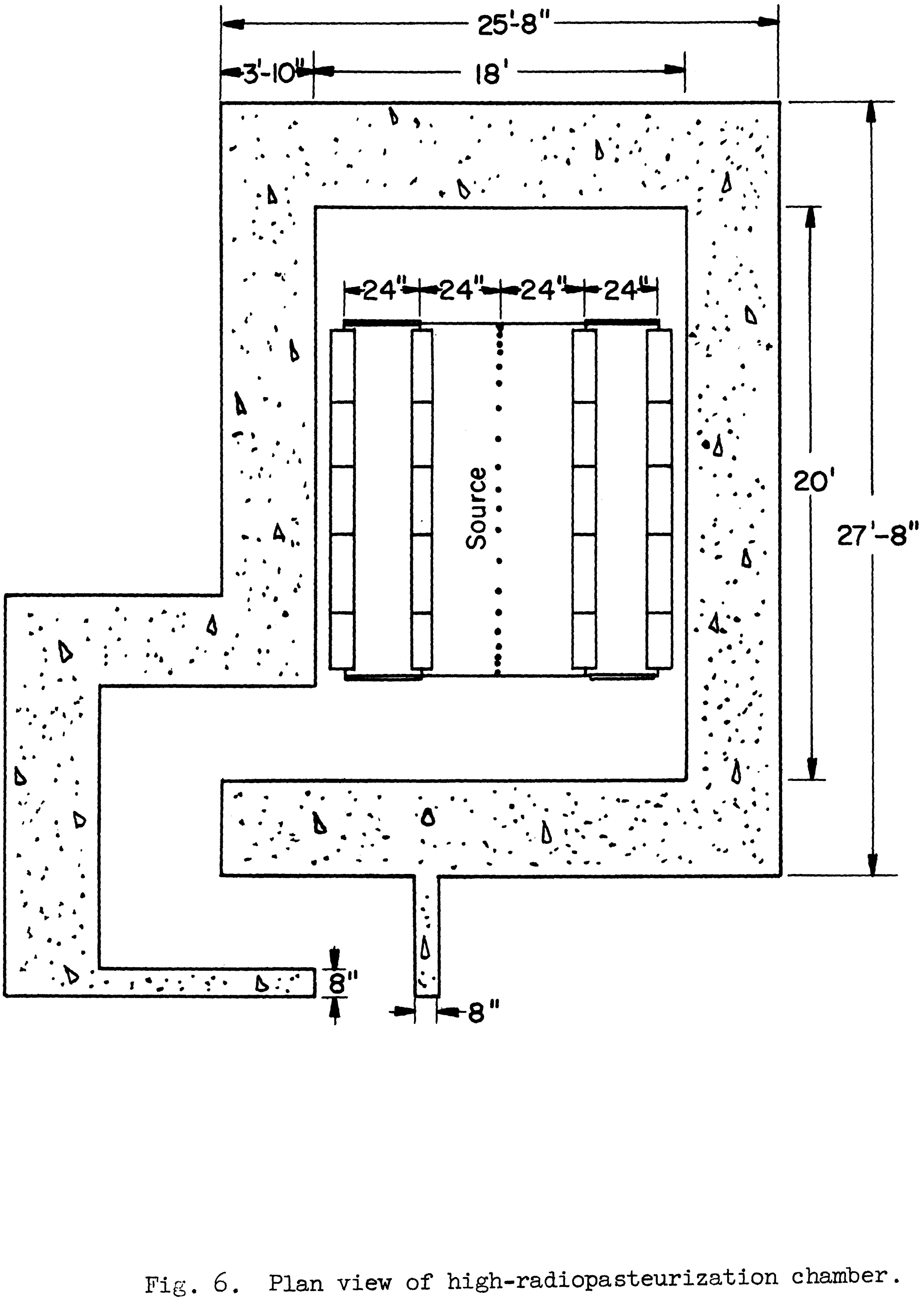

Fig. 6. Plan view of high-radiopasteurization chamber.

B. RADIATION SOURCE

Packaged mixed fission products or packaged cesium-137 separated from fission products might be used as the sources of radiation for a high-radiopasteurization gamma facility. However, such sources are not presently available and will not be available until suitable plants are put into operation to process fission-products wastes. On the other hand, cooling-reactor fuel elements are being removed constantly from reactors now operating, and the supply will increase as new reactors come into operation. The supply of such cooling-reactor fuel elements is limited, but it is believed that a sufficient number could be made available to establish a limited number of radiation facilities capable of processing foods on a commercial scale.

It is not proposed that cooling-reactor fuel elements be considered as the answer to the problem of suitable gamma sources for general use in industrial plants, but they might fill the need for radiation sources for the immediate future. Reactor fuel elements may be too expensive to use if the high inventory costs of fissionable materials were charged against the fuel elements when used as a source of radiation. However, for reasons relating to the processing techniques, it is the practice in present fuel-processing plants to store these elements under water for several weeks before they are processed. During this period, the intense radiation is dissipated in the water used to shield the cooling elements. Except when used in some research experiments, this radiation is being wasted at present. It is proposed that some of these elements be used as sources of radiation for a limited number of radiation facilities designed for high radiopasteurization of foods.

The reactor fuel elements proposed for use in this facility have a very high gamma activity but a very rapid decay rate. It is suggested that each fuel element be used for a period of about two months and then replaced with a new one. If the replacement schedules for different fuel elements are staggered, greater uniformity of radiation flux will be possible. However, it probably will be necessary to make adjustments in the material flow rate through the facility during the period of operation to compensate for the decay of the fuel elements. The irradiation of a large volume of foods necessitates continuous operation involving the use of a conveyor system to pass the foods into the chamber, past the radiation source, and out of the radiation chamber. Efficient operation requires that the total thickness of foods being conveyed through the chamber absorb most of the radiation.

The decision was made to specify 20 reactor fuel elements as the source of radiation after considering the radiation flux available from one fuel element and the amount of radiation required to affect radiopasteurization. A dose of 1 megarep was selected as being most suitable for high radiopasteurization. The productive capacity for the radiation chamber is a function of this required dose and also a function of the radiation field provided by the source.

The radiation field will, of course, vary with the geometry of the source. If the fuel elements were arranged side by side with no distance separating them, the radiation field would vary in all directions and would appear as if emanating from a plaque source of uniform concentration. This type of source previously was found too inefficient.[2] A more efficient design would be to distribute the activity of the source in such a way as to provide a uniform radiation field in one direction. In the case of fuel elements, the activity may be distributed by spacing the fuel elements. Since the foods will be transported through the chamber on a conveyor in a number of vertical passes, it was decided to establish a uniform radiation field in the horizontal direction. This would mean that although the food travels in a varying radiation field in the vertical direction, the uniform horizontal field would insure that the food on one end of the conveyor would receive the same dose as those foods located on the other end, at a fixed lateral distance.

The uniform horizontal field can be accomplished by aligning the long axis of the fuel elements in a direction parallel to the direction of the two passes. In addition, the elements would be arranged with horizontal spacings as shown in Fig. 7. The smaller pitch of the fuel elements near the ends is used to produce a more uniform radiation field at the extremities of the source.

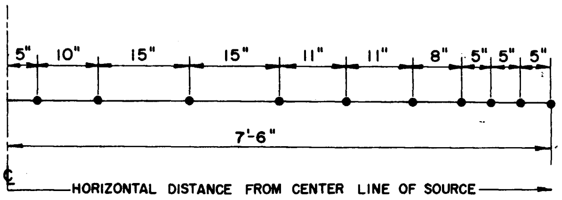

Fig. 7. Plan view showing spacing of one half of fuel elements for irradiation facility.

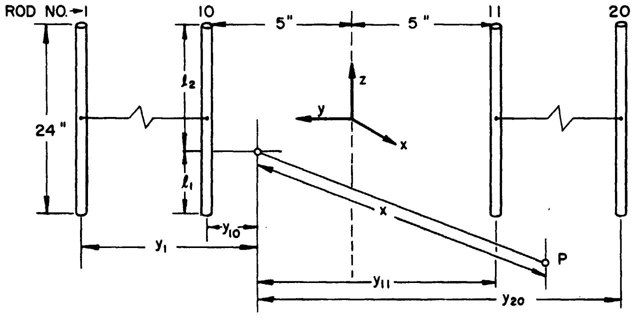

Fig. 8. Source elements, elevation view.

The optimum spacing of the fuel elements was determined by trial and error by calculating the dose rate in air at certain positions and then plotting the dose rate vs horizontal distances for a definite vertical distance from the source to ascertain the effect of a particular spacing scheme.

The procedure for calculation of the dose rate in air was quite extensive because of the irregular spacings of the 20 different components of the source contributing to the flux at any arbitrary point. The total flux at a point is a scalar sum of the contributions from each of the fuel elements. The calculations were simplified by assuming that at a sufficient distance from the fuel elements the source may be considered as being comprised of 20 line segments. The dose-rate contribution of one of the fuel elements is given by

$$I = \alpha(H_1 + H_2), \tag{1}$$

where

α = concentration coefficient for each fuel element.

The calculation of the radiation flux at any point in a given plane parallel to the face of the group of source rods will be demonstrated. The values of H_1 and H_2 for one fuel element are obtained at any point P from the general equations

$$H_1 = \int_0^{l_1} \frac{dz}{x^2 + y^2 + z^2} = \frac{1}{\sqrt{y^2 + x^2}} \tan^{-1} \frac{z}{\sqrt{y^2 + x^2}} \Bigg]_0^{l_1} \tag{2}$$

and

$$H_2 = \int_0^{l_2} \frac{dz}{x^2 + y^2 + z^2} = \frac{1}{\sqrt{y^2 + x^2}} \tan^{-1} \frac{z}{\sqrt{y^2 + x^2}} \Bigg]_0^{l_2} , \tag{3}$$

where P = the point where dose rate is to be calculated,

z = length along the vertical axis of element,

x = lateral distance between the vertical plane of source elements and the parallel plane containing point P,

y_n = horizontal distance between point P and the nth source element,

and

l_1 and l_2 = lengths along the axes of the fuel elements between the base of perpendicular from point P and the extremities of fuel element (see Fig. 8).

The "H" function was evaluated as defined above for different distances between the field point P and one of the fuel elements. The "H" curve, as a function of the distance between a given fuel element and point P, was drawn (Fig. 9). Since the activity of the fuel elements is not accurately de-

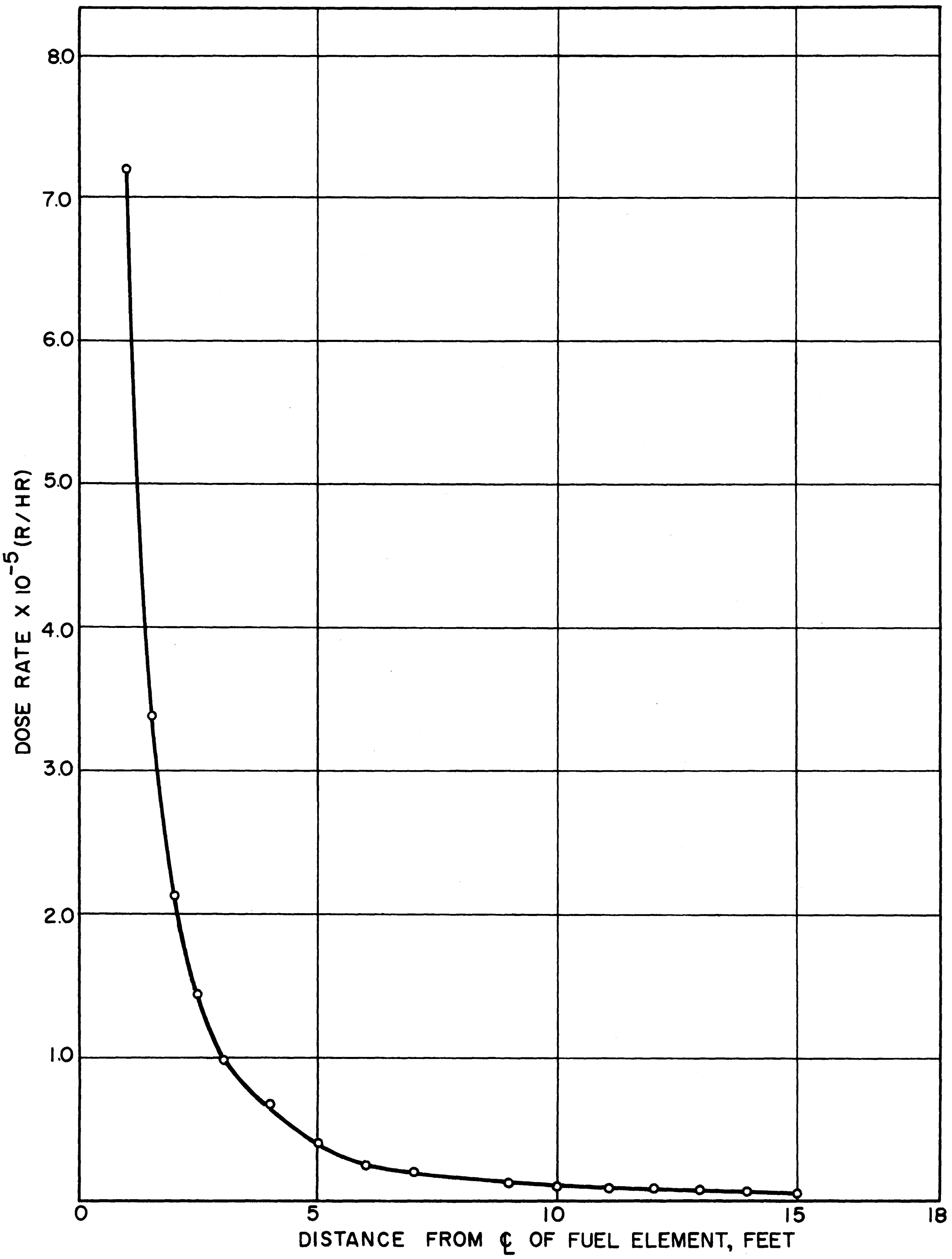

Fig. 9. H function vs distance from one fuel element (dose rate normalized to 10^5 r/hr at 3 feet from one fuel element).

terminable in terms of curies and α is not known accurately, the H-function curve was normalized to 10^5 rep/hr at a distance of 3 feet from one of the fuel elements. This radiation field was considered typical of cooling fuel elements from high-neutron-flux reactors cooled from 1 to 5 months and in use for 2 months.

In order to determine the total dose rate at a point, the distances from different elements were calculated and the corresponding dose rates were obtained from the curve in Fig. 9:

$$\text{total dose rate } I = I_1 + I_2 + \ldots I_{20}.$$

This procedure of calculation was adopted to obtain dose rates at any point in space surrounding the fuel elements.

C. ISODOSE CURVES

In order to obtain isodose curves in space, three sets of curves were obtained.

1. Dose Rate—vertical distance (z) for different lateral distances (x) (Fig. 10).
2. Dose Rate—lateral distance (x) for different vertical distances (z) (Fig. 11).
3. Dose Rate—horizontal distance (y) for different lateral distances (x) (Fig. 12).

The set of curves obtained in Fig. 12 demonstrates the uniformity of dose rate at the central lines of trays at 24- and 48-in. lateral distances (x) from the ℄ of source elements. Thus, the horizontal coordinate (y) may be eliminated in the determination of isodose curves.

Isodose curves in the plane (x,z) perpendicular to the face of the source have been obtained (Fig. 13) by cross-plotting data obtained from the curves given in Figs. 10 and 11. Since gamma rays must pass through the food, the isodose curves were corrected for the absorption due to the food in trays. A value of 12 inches for the half-value thickness was selected, based upon previously determined experimental values.[6] According to the well-known exponential law, and assuming that the radiation passes through 12 inches of meat with an average absorption efficiency of 85%, and neglecting build-up-factor correction,

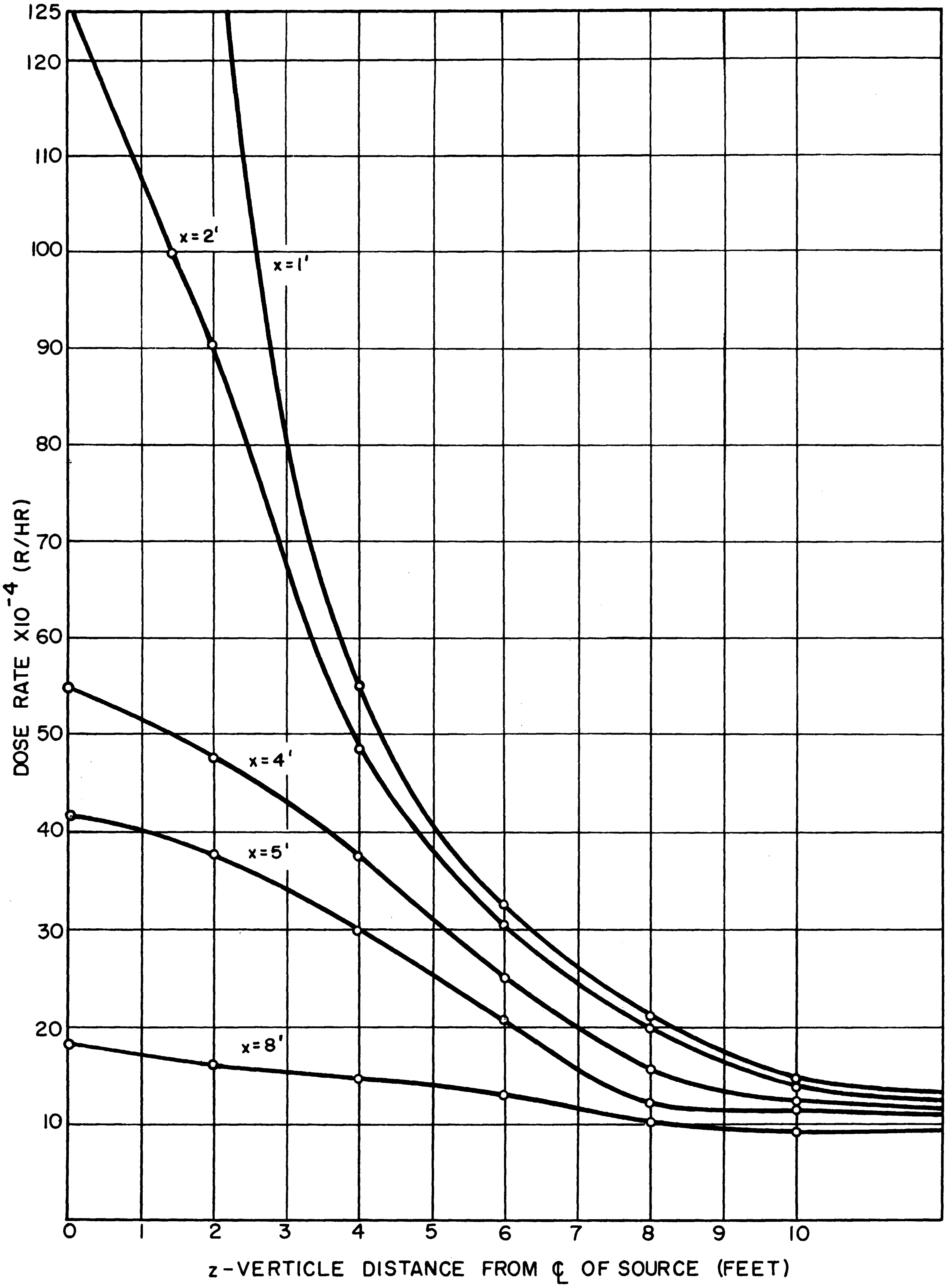

Fig. 10. Vertical distance vs dose rate for different values of x.

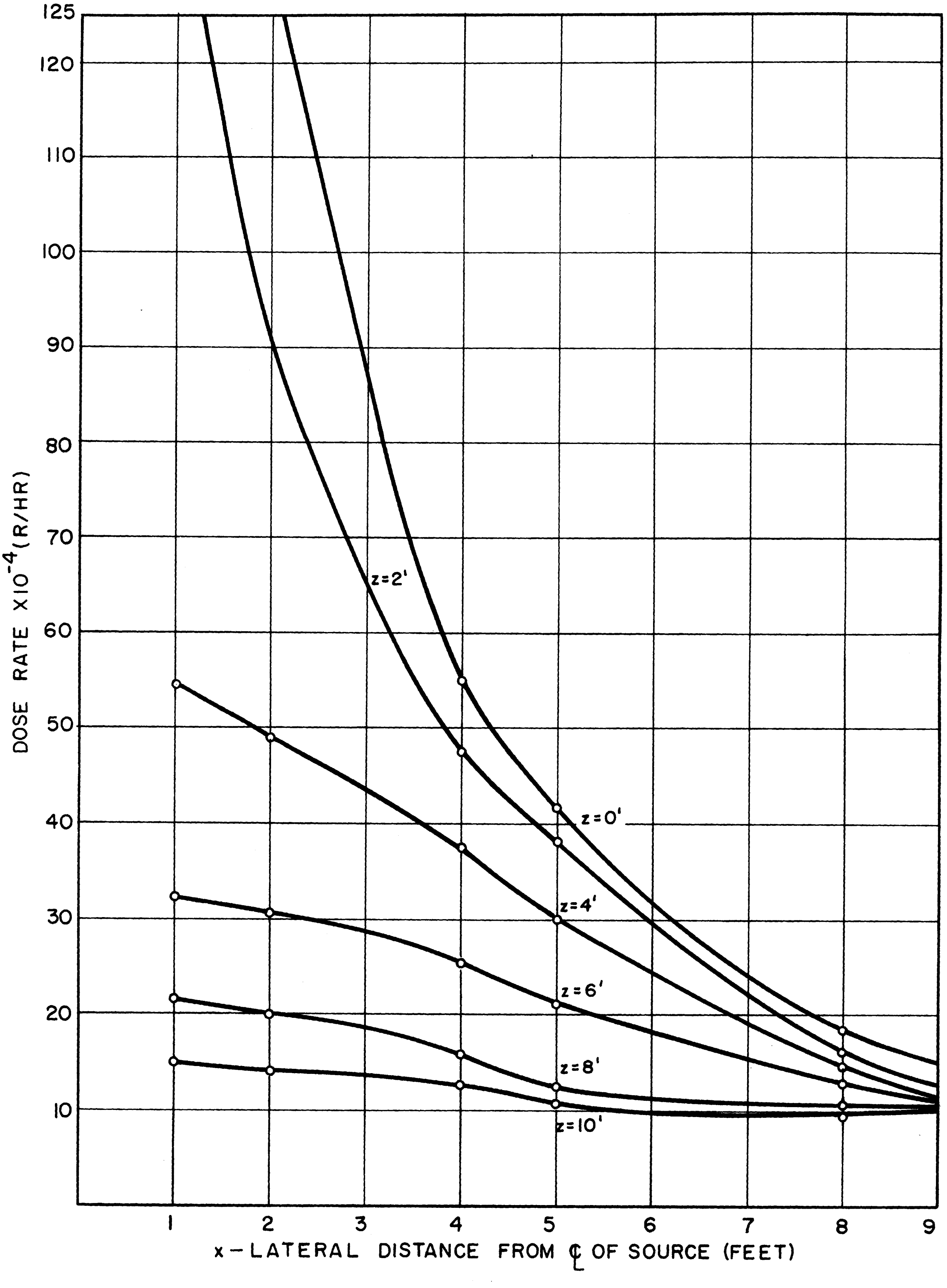

Fig. 11. Dose rate vs lateral distance from ℄ of source for different values of z.

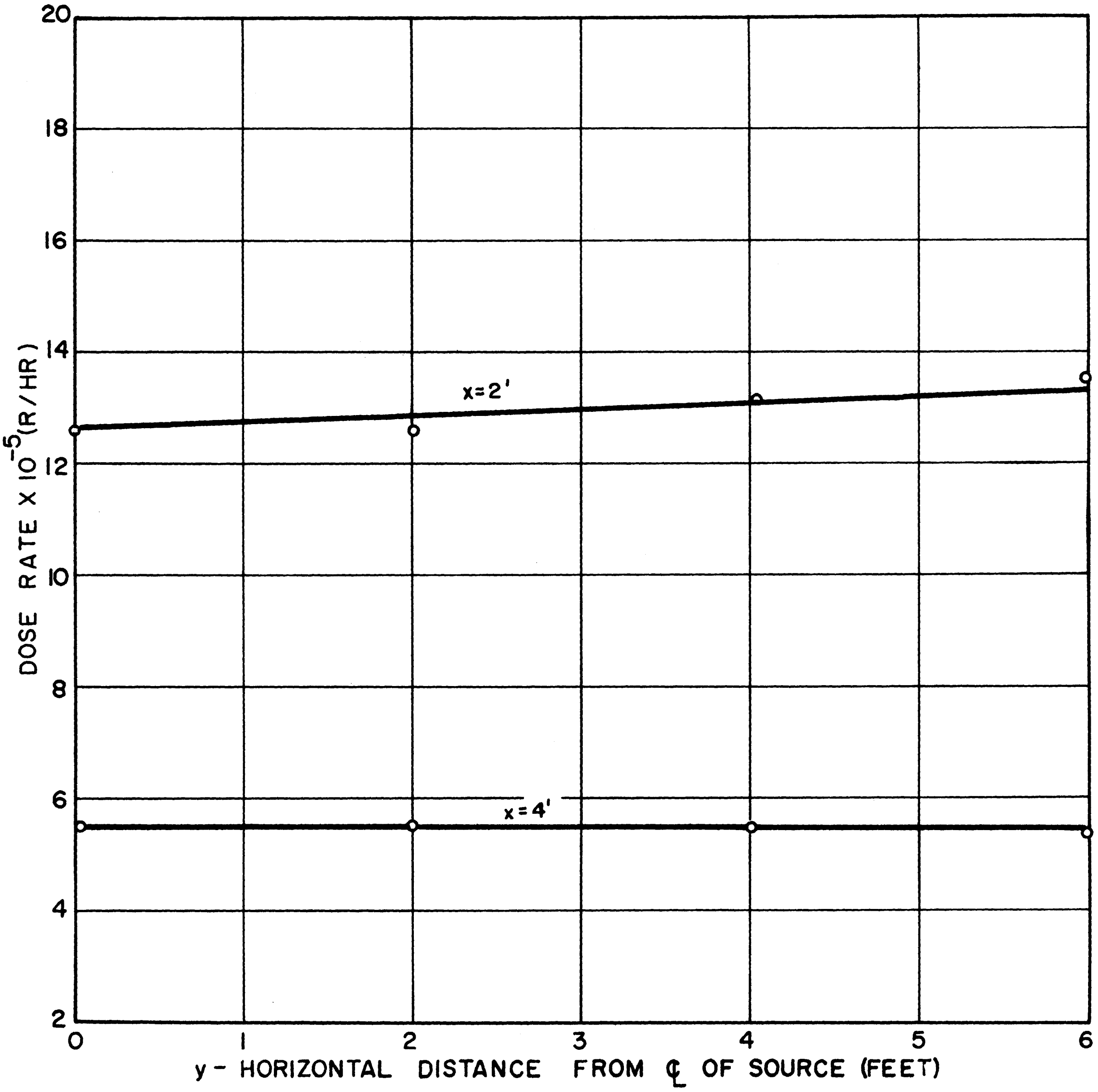

Fig. 12. Dose rate vs horizontal distance for different values of x.

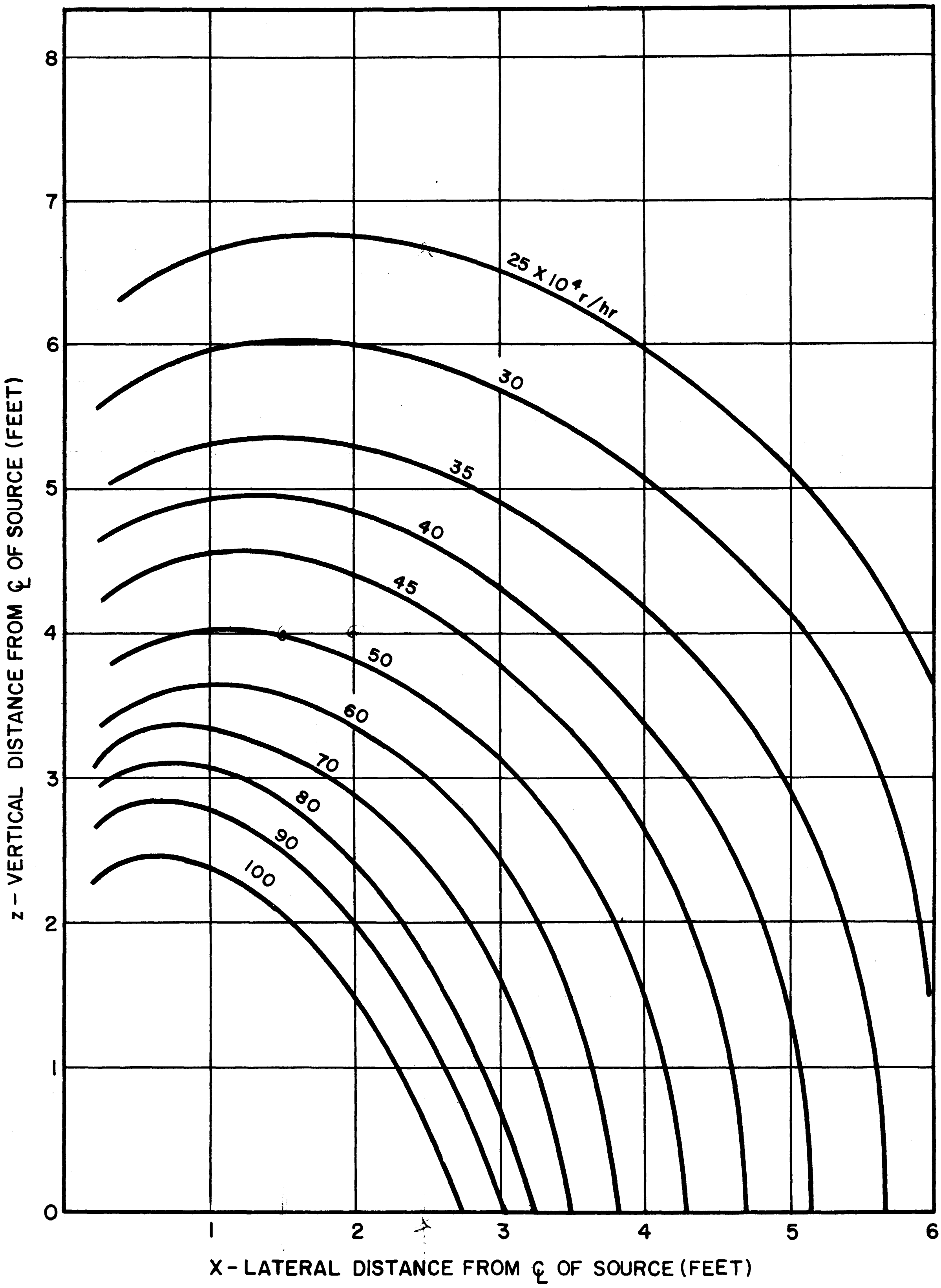

Fig. 13. Isodose curves in vertical plane perpendicular to source at center line for one quadrant of radiation chamber.

$$I = I_0 e^{-\lambda x},$$

$$\lambda = \text{decay constant}$$

$$\text{or } \lambda = \frac{0.693}{x_{1/2}},$$

$$x_{1/2} = \text{half-value thickness (taken as 1 foot)}, \qquad (4)$$

$$\therefore \lambda = 0.693 \text{ feet},$$

$$\text{and } \frac{I}{I_0} = 0.425.$$

Isodose curves corrected for absorption, and assuming 85% absorption efficiency, are shown in Fig. 14. These curves are utilized to give data for the variation of dose in the vertical direction at lateral distances (24 and 48 inches). The latter relationship is plotted in Fig. 15 for x = 2 feet and x = 4 feet. Figure 15 facilitated the preparation of the integral dose curve needed for the capacity calculation.

D. INTEGRAL DOSE CURVE

With the use of the curves of Fig. 15, the integral dose curve (dose vs distance of travel by the tray in the radiation chamber) shown in Fig. 16 was prepared. From Fig. 16 the total dose accumulated along the central line of the tray during the travel of 88 feet was calculated, using Simpson's Numerical Integration Rule:

$$I = \int_a^b f(x)\,dx = \frac{h}{3}\,[y_0 + 4(y_1 + y_3 + \ldots y_{n-1}) + 2(y_2 + \ldots y_{n-2}) + y_n]. \qquad (5)$$

For a travel of 88 feet, an accumulated dose at the central line of the tray was calculated and found to be 21.17×10^6 rep for a tray speed of 1 foot per hour.

E. CAPACITY CALCULATION

Distance of travel per cycle = 88 feet

Radiation dose = 10^6 rep

Radiation time per cycle $= \dfrac{10^6 \text{ (rep)} \qquad 88 \text{ (feet)}}{21.17 \times 10^6 \left(\frac{\text{rep-feet}}{\text{hr}}\right) \text{ cycle}}$

$= 4.15$ hour/cycle.

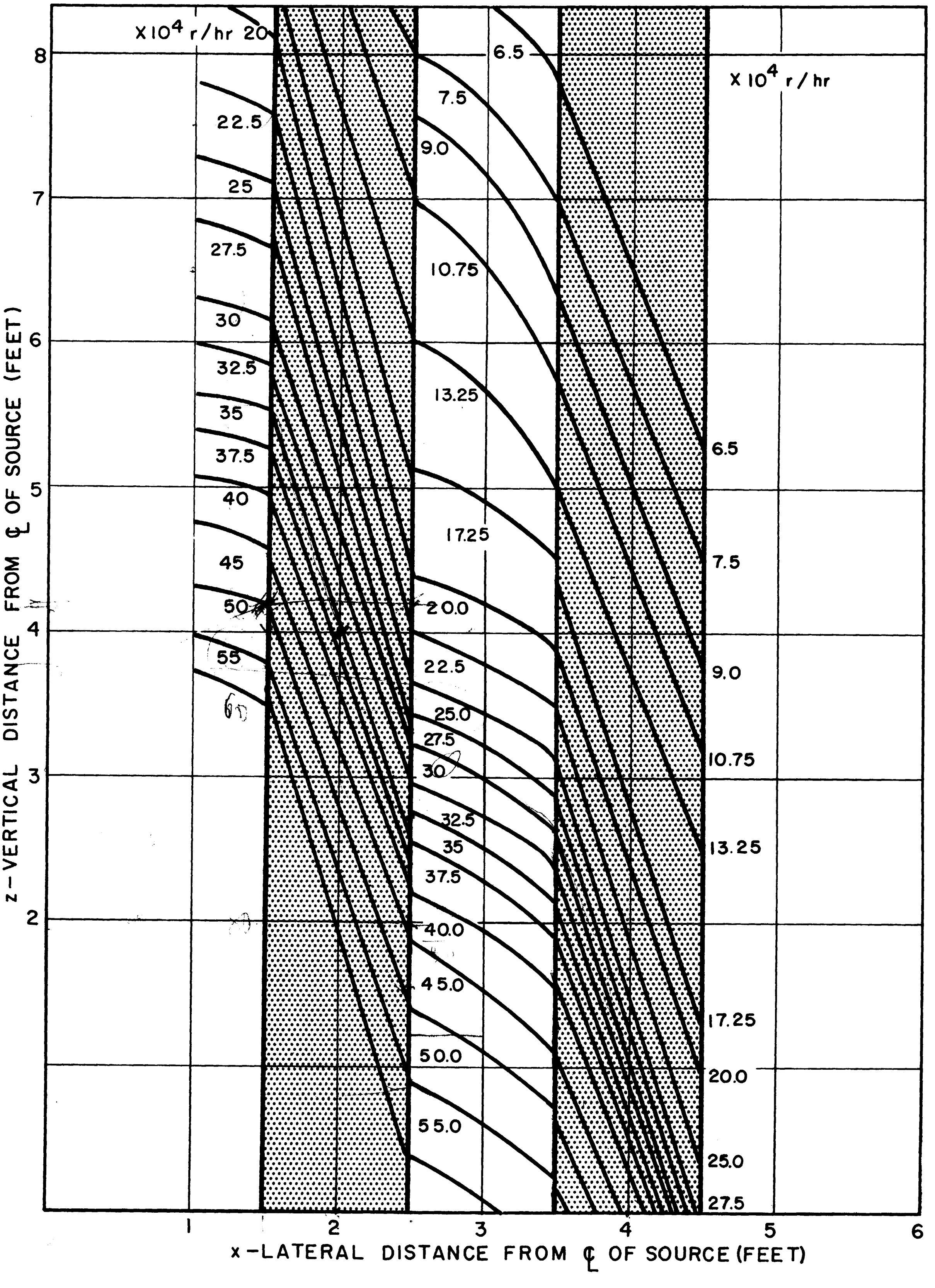

Fig. 14. Absorption-corrected isodose curves.

[illegible] 8.5 [illegible] X 0.5 [illegible] 4 [illegible]
49 [illegible]

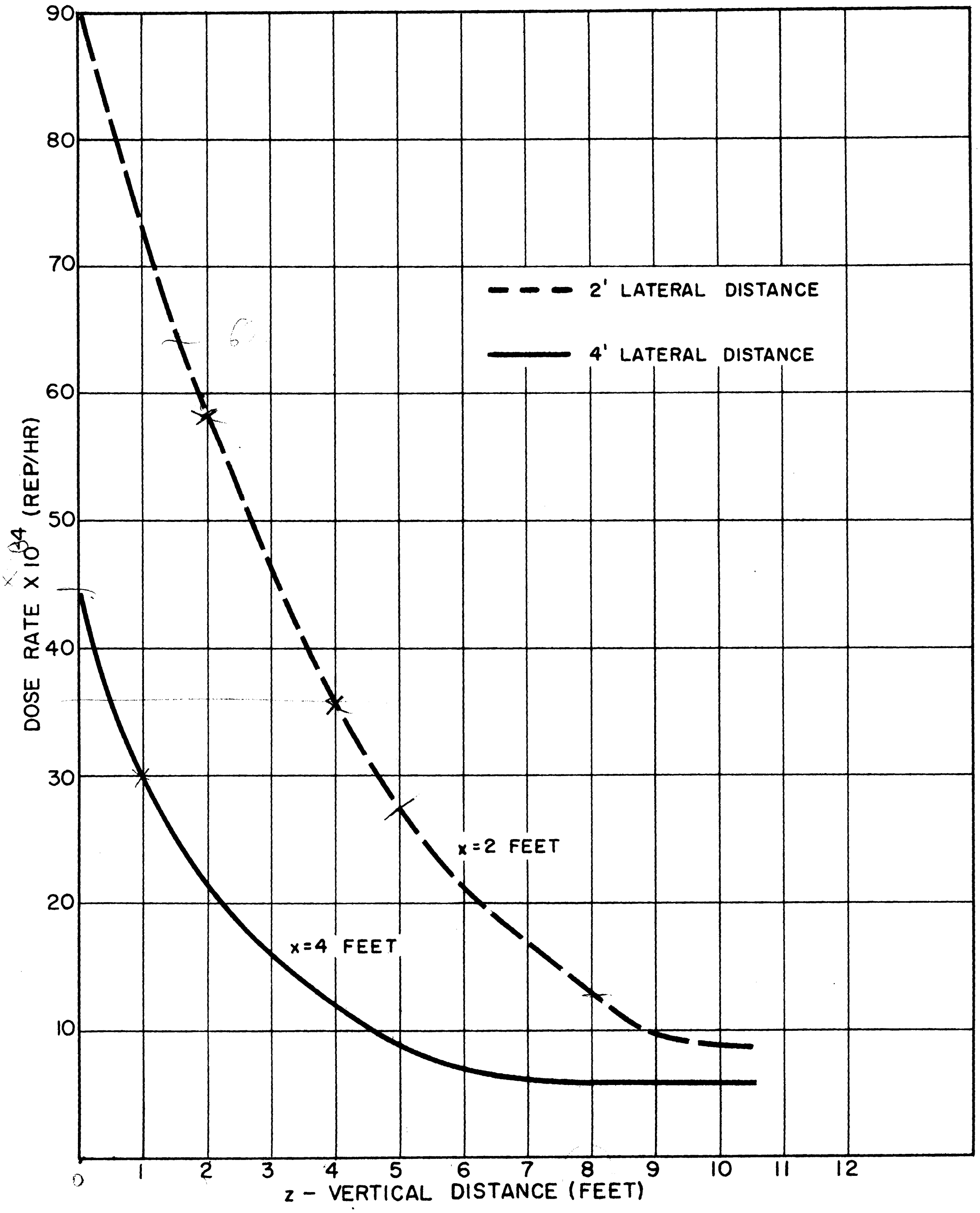

Fig. 15. Absorption-corrected dose vs vertical distance.

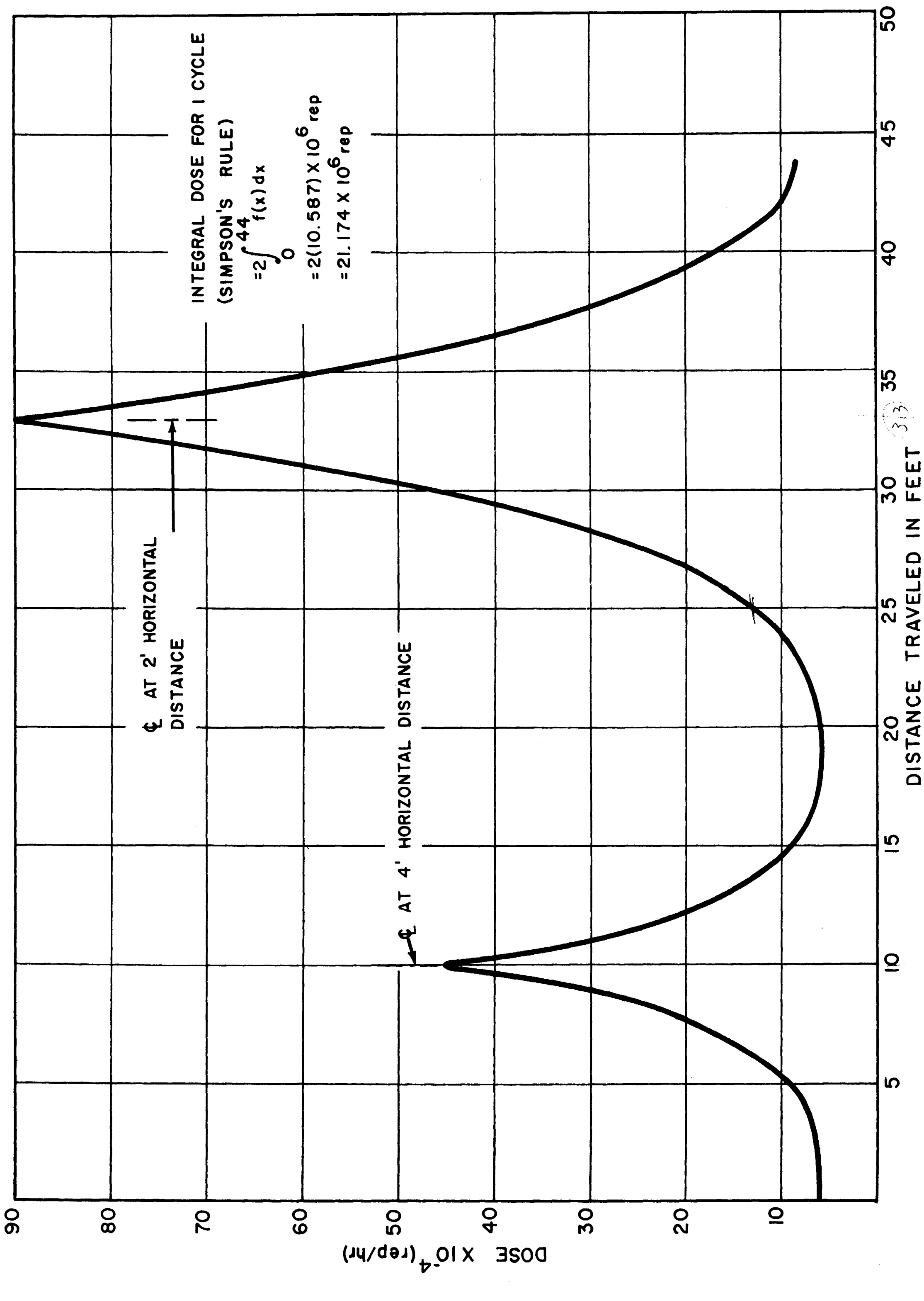

Fig. 16. Integral dose curve for half cycle (44').

The total number of trays in the radiation chamber equals 29. Each tray (2-1/2 x 1 x 12 feet) has six compartments, each considered to contain 100 lb of food packed in polyethylene bags.

$$
\begin{aligned}
\text{Capacity per cycle} &= 600 \times 29 \text{ lb/cycle} \\
&= 1.74 \times 10^4 \text{ lb/cycle} \\
\text{Capacity per hour} &= \frac{1.74 \times 10^4 \text{ lb/cycle}}{4.15} \text{(cycle/hr)} \\
&= 4.2 \times 10^3 \text{ lb/hr} \\
&= 4.2 \times 10^3 \text{ lb/hr} \left(\frac{1}{2000 \text{ lb/ton}} \right) \\
&= 2.1 \text{ tons/hr} \\
\therefore \text{Capacity per hour} &= 2.1 \text{ tons.}
\end{aligned}
$$

F. CAPACITY COMPARISONS

The capacity per hour can be increased by decreasing the radiation dose and also by increasing source strength. In Table V the radiation dose was varied from 10^4 rep to 4×10^6 rep while the normalized-radiation-field strength was varied from 10^5 r/hr (r = roentgen unit) to 10^6 r/hr and the corresponding capacities calculated. However, it should be pointed out that continued increase in source strength would increase the absorption of radiation by the source, which would result in the increase in temperature, possibly requiring a cooling system for the source.

TABLE V

CAPACITY COMPARISONS

N = radiation field at a distance of 3 feet from midpoint of one fuel element in r/hr

No.	Dose (rep)	Capacity (tons/hr) $N=10^5$	Capacity (tons/hr) $N=2.5\times10^5$	Capacity (tons/hr) $N=5.0\times10^5$	Capacity (tons/hr) $N=7.5\times10^5$	Capacity (tons/hr) $N=10^6$
1.	10,000	210	525.0	1,050.0	1,575.0	2,100.
2.	50,000	42.0	105.0	210.0	315.0	420.0
3.	75,000	28.0	70.0	140.0	210.0	280.0
4.	100,000	21.0	52.5	105.0	157.5	210.0
5.	150,000	14.0	35.0	70.0	105.0	140.0
6.	200,000	11.5	28.8	57.6	86.4	115.0
7.	500,000	4.2	10.5	21.0	31.5	42.0
8.	1,000,000	2.1	5.25	11.5	15.75	21.0
9.	2,000,000	1.05	2.62	5.24	7.86	10.5
10.	4,000,000	0.53	1.31	2.62	3.93	5.25

G. COST ESTIMATES

1. Total Investment—
Estimated cost of radiation chamber, $66,000

2. Operation Cost—			
a. Wages and salaries:			
(1) Two operators with limited Health-Physics training		$10,000	
(2) Supervision and clerical labor		2,000	
(3) Salaries and wages not associated with operation of radiation chamber		6,000	
	Total		$ 18,000
b. Other operation costs:			
(1) Shipping cost for 20 reactor fuel elements (every two months)		$12,000	
(2) Handling cost for fuel elements during transfer and installation		10,000	
(3) Rental of 20 fuel elements for 12 months ($5,000 per month)		60,000	
(4) Repairs and maintenance on chamber (5% of chamber and conveyor costs)		3,300	
(5) Miscellaneous		1,000	
	Total		$ 86,300
3. Overhead—			
a. Payroll overhead (15% of wages and salaries)		$ 2,700	
b. General plant overhead (50% of wages, salaries, and operation)		52,150	
c. General administration (10% of cost of labor and operation)		10,430	
	Total		$ 65,280
4. Taxes, Insurance, and Interest— 10% of total investment			$ 6,600
5. Depreciation and Obsolescence of Radiation Chamber— $66,000 x 0.08			$ 5,280
	TOTAL		$181,460

H. UNIT COSTS

$$\text{Capacity} = \frac{2.1 \text{ tons}}{\text{hr}} \quad (\text{for } 10^6\text{-rep dose})$$

1. 260 days/yr (16 hr/day)—

$$\text{Capacity per year} = 2.1 \times 16 \times 260 \text{ tons}$$

$$= 8.74 \times 10^3 \text{ tons}$$

$$\therefore \text{Unit cost} = 20.6 \frac{\text{dollars}}{\text{ton}}$$

$$= 1.03 \frac{\text{cents}}{\text{lb}}$$

2. 100 days/yr (24 hr/day)—

$$\text{Capacity per year} = 2.1 \times 24 \times 100 \text{ tons}$$

$$= 5.04 \times 10^3 \text{ tons}$$

$$\therefore \text{Unit cost} = 35.8 \frac{\text{dollars}}{\text{ton}}$$

$$= 1.79 \frac{\text{cents}}{\text{lb}}$$

TABLE VI

No.	Dose (rep)	I (260 Days)		II (100 Days)	
		Cost $\frac{\text{Dollars}}{\text{ton}}$	Cost $\frac{\text{Cents}}{\text{lb}}$	Cost $\frac{\text{Dollars}}{\text{ton}}$	Cost $\frac{\text{Cents}}{\text{lb}}$
1.	10^5	2.06	0.1	3.06	0.18
2.	2.5×10^5	5.15	0.25	7.65	0.45
3.	5.0×10^5	10.30	0.51	15.30	0.90
4.	7.5×10^5	15.45	0.76	22.95	1.35
5.	10^6	20.60	1.03	30.6	1.79

I. SHIELDING CALCULATIONS

Using broad-beam attenuation data,[28] it has been found that reduction of intensity by a factor of 4.66×10^{-8} from 15×10^4 r/hr at 9 feet from the source to a tolerance dose of 7 mr/hr (permitted for operators) would require 3 feet 10 inches of concrete (see Fig. 17). For the general public, a tolerance dose of 1 mr/hr would require 4 feet 3 inches of concrete.

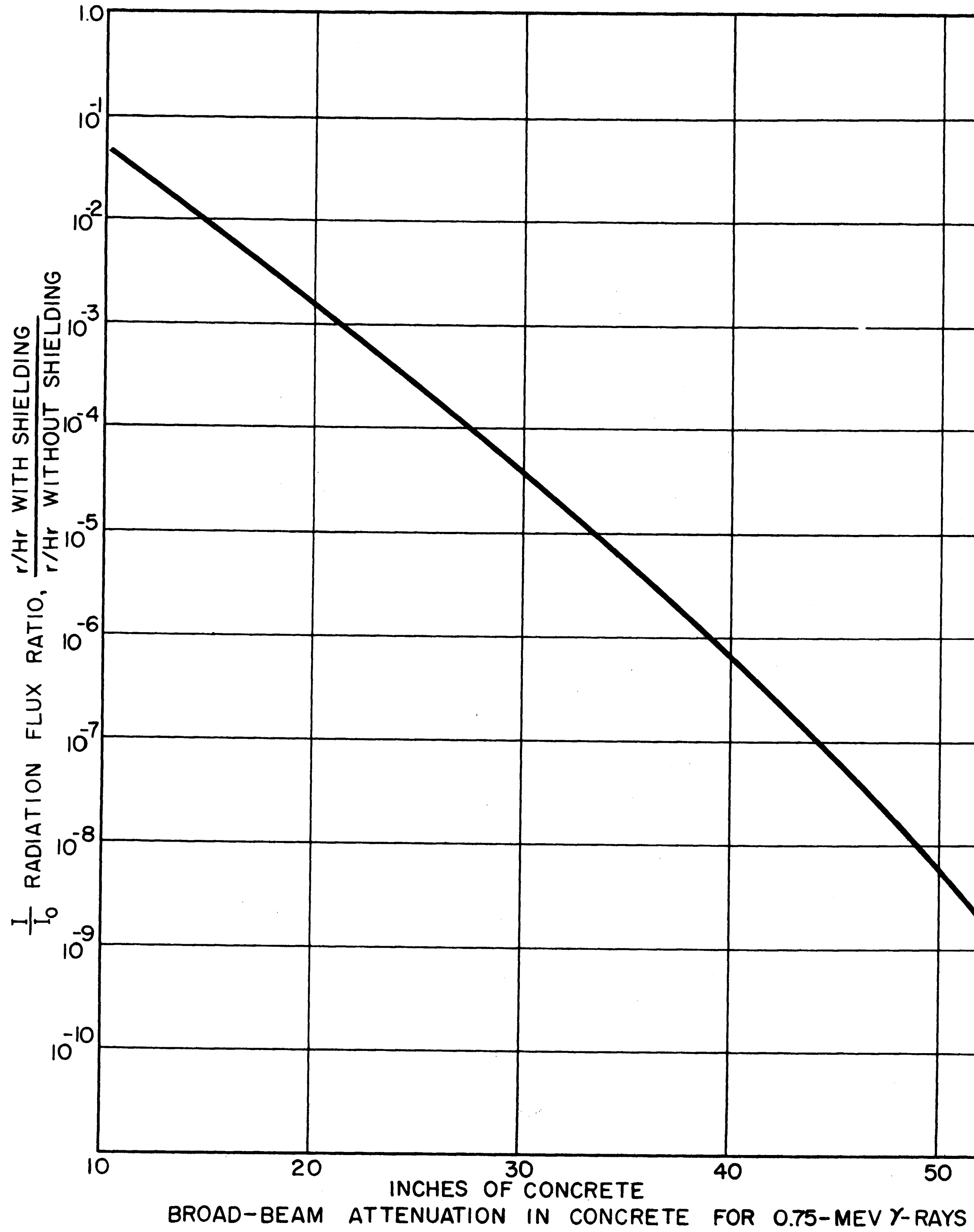

Fig. 17. Extrapolated curve for shielding calculations.

J. DISCUSSION AND SUMMARY

A "new" process in which high gamma radiation is combined with refrigeration has been proposed to increase the storage life of cooked meats, blanched vegetables, and perhaps other food items packaged in plastic bags. A review has been made of the various types of food poisoning caused by microorganisms and their toxins. Storage at refrigerator temperatures of around 40°F is considered to offer protection against the growth of the microorganisms that might possibly cause food poisoning. The use of plastic films that transmit oxygen readily, such as polyethylene, so as to maintain aerobic conditions within the package offers additional protection against the growth of the anaerobic spores of Clostridium botulinum. When spoilage does occur in packaged foods treated in this manner, the evidence has been visible, usually as a mold growth. Such samples of food are not toxic, but would be considered nonedible, and, in the commercial use of the process, any packages with spoiled foods of course would not be offered for sale. In regard to spoilage, the problem would be similar to that of handling fresh meats and produce, except that the loss due to spoilage could be reduced to almost zero percentage, if retail sales were made within a few weeks.

The commercial development of the process of high gamma radiopasteurization probably would increase greatly the use of refrigeration both in the commercial handling of food and in the storage of foods in the home. If foods could be kept for two or three months or longer by such a process, the housewife might use an additional refrigerator solely for storage. In this regard, the process would be competing with the use of a deepfreezer, but it would be used for food stored for shorter periods. Foods can be stored at 40° more cheaply than at deepfreezer temperatures, and the waiting period required for thawing would be eliminated. It is believed that the added convenience to the housewife of such a process and the savings in prevention of food spoilage would justify its use.

Cost estimates given in Table VI indicate that a large-sized plant capable of processing about two tons per hour with two eight-hour shifts per day for 260 days per year could irradiate foods with a high-radiopasteurization dose of 1 megarep at an estimated cost of about one cent per pound. This cost is considered to be in the range of commercial feasibility.

The design was based on the use of 20 cooling-reactor fuel elements rented at an estimated rental charge of $5,000 per month, plus handling and shipping charges. It is believed that such a rental charge might be helpful in making nuclear-power reactors more profitable and thereby hasten the day when electric power from nuclear reactors will be able to compete with electric power from fossil fuels.

Limited academic tests have demonstrated that a number of foods which were considered to have a satisfactory flavor would keep at refrigerator temperatures for an extended period of time. Additional tests along these lines should be made. Also, the process cannot be used commercially until approval has been obtained from the Food and Drug Administration. In addition to the long-term feeding and breeding studies presently being conducted with irradiated food at the Fission Products Laboratory and elsewhere, additional feeding experiments should be made with high-radiopasteurized foods that have been stored for selected periods of time.

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