ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROPOSED NEW METHOD OF WHOLESALING FRESH MEAT BASED ON PASTEURIZATION BY GAMMA IRRADIATION

L. E. BROWNELL
J. V. NEHEMIAS
J. J. BULMER

Project 1943-7

U.S. ATOMIC ENERGY COMMISSION
CONTRACT NO. AT (11-1)-162
CHICAGO, ILLINOIS

December 1954

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I. INTRODUCTION

A new method of wholesaling fresh meat is proposed for consideration by some of the larger packing houses and some of the larger retailers of fresh meat. This proposed new method consists of preparing packaged standard cuts of fresh meat, packaged fresh ground meat, packaged cut-up chicken, etc. in retail-size portions at the packing house rather than at the retail meat market, and of pasteurizing the packaged meat at the packing house by means of a relatively small dose of gamma radiation prior to shipping to the retailer. Radiation pasteurization extends the refrigerator shelf-life of fresh meat, so that this method should be feasible. Recent trends in retailing meats and the economics of meat processing suggest the desirability of handling meats in this way.

A. Recent Trends in Retailing Meat

The meat departments of many supermarkets have found a consumer preference for purchasing weighed and packaged cuts of meat, cut-up chicken, ground meat, etc. This method of merchandising is popular with the majority of the customers, probably because it avoids the necessity of having the customer wait to be served by a butcher, and permits customer inspection of various cuts and selection of a purchase at leisure. This practice also permits the cutting and prepackaging of meat in advance of the busiest market hours and results in more efficient use of the meat cutter's time. This method of retailing meat is popular with both the retailer and the consumer and is becoming more or less standard practice in the larger meat markets.

One disadvantage of prepackaging fresh meat is the need for prompt sale of the cut-up meat to prevent loss by spoilage. This problem has limited the practice to the larger meat markets that have a rapid turnover.

Cut-up chicken and ground fresh meat can be kept for only a few days even under refrigeration, whereas the uncut carcasses can be kept under refrigeration much longer. The uncut flesh of an animal that was in good health at the time of slaughter is relatively sterile, but when the flesh is cut the surface becomes contaminated with a variety of microorganisms from the air and from the hands and implements of the butcher. This contamination can become quite extensive in the case of ground meat, since meat trimmings with a high surface contamination are frequently used for ground meat, and quite often the meat grinder itself is not free of contamination. This results in the introduction of a large number of microorganisms into an excellent growth medium and accounts for the short shelf-life of refrigerated ground fresh meats. Rapid spoilage practically prohibits the preparation of ground meat at the packing house unless it is to be frozen.

B. Advantages of Cutting and Prepackaging Fresh Meat at the Packing House

1. Advantages to the Retailer. If cut and prepackaged retail-size portions of fresh meats having a satisfactory refrigerator shelf-life were available to the retailer, a number of advantages would be realized.

a. Fewer butchers would be required at retail stores. (More would be needed at packing houses, where they could be used more efficiently.)

b. Some retailers might dispense entirely with meat cutting.

c. Handling of bones and meat scraps would be eliminated.

d. Shipping costs would be reduced.

e. Packaging of meat at the store would be avoided.

f. Less floor space would be required for meat processing.

g. Less refrigerator space would be required per pound of meat sold.

h. Total cost of packaged meat could be reduced by mass handling methods at packing houses.

i. Fresh pork would be free from danger of contamination by trichinae.[1]

j. Loss of meat by spoilage could be reduced.

k. Satisfying consumer preference for prepackaged meats, even in smaller stores, could increase trade.

2. Advantages to the Packing House. The packing house would also benefit in a number of ways.

a. Mass-handling methods of cutting could be used at packing houses for greater economy.

b. Mass-handling methods of prepackaging could be used at packing houses.

c. Packing houses could handle bones and meat scraps at a profit more easily than the retailer.

d. Demand for specialty items such as radiation-pasteurized prepackaged meat could increase the trade of packing houses using this method.

e. Total trade also could be increased by reduction of handling costs through mass-handling methods at packing houses.

f. The sale of pork could be increased by eliminating the danger of trichinae contamination.*

g. Since only salable meats would be shipped, both shipping cost and space, and handling would be reduced (70 lbs of cut meat is equivalent to 100 lbs of carcass meat).

3. Advantages to the Consumer. The consumer also would benefit from this method.

a. Of even greater importance to the consumer than to the retailer and packing houses, pasteurization of pork would remove the causative agent of trichinosis and eliminate any danger from this disease.

b. Pasteurized meat has a longer refrigerator shelf-life than untreated fresh meat, which would be of advantage to housewives who shop at a supermarket only once or twice a week.

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*Certain types of meat products popular in Europe, such as some of the sausages made with uncooked pork, could be prepared from irradiated pork without the danger of trichinosis. Such variety products would increase meat consumption.

c. The cost of meat could be reduced by savings realized in mass-handling techniques.

d. Other less common parasites such as tapeworm and certain pathogenic microorganisms which are sometimes found in meat could be rendered harmless. (This idea should be investigated.)

II. EXPERIMENTS ON PASTEURIZATION OF RAW MEAT

A. Microbiological Studies

The personnel of Michigan Memorial-Phoenix project 41 have made a limited microbiological study of gamma-ray-pasteurized raw meat. The results of this study have been reported previously.[2]

In these experiments raw ground lean beef, obtained from the University Food Service, was innoculated with a psychrophillic organism isolated from raw meat. After innoculation the meat had an initial count of about 5×10^5 microorganisms per gram. The meat was divided into six portions. Two portions were used as controls and the other four were given irradiation dosages of 20,000, 40,000, 80,000, and 160,000 rep. After irradiation the meat was stored in a refrigerator at 4°C. The growth of microorganisms was measured by making four separate counts on each sample at regular intervals up to a total of 13 days of storage.

Growth of the organism in the irradiated samples showed a lag, whereas there was no lag in the growth observed in the controls. This lag increased with dosage. The count of the microorganisms in the controls increased as a logarithmic function of time from the start of the test. After the initial lag the count in the irradiated samples increased in a similar manner. The lag was 0 for the controls, approximately 1/2 day for the sample receiving 20,000 rep, 1-1/2 days for the sample receiving 40,000 rep, 3-1/2 days for the sample receiving 80,000 rep, and 5 days for the sample receiving 160,000 rep.

Spoilage as evidenced by an off-odor after 13 days of storage was detected only in the controls and in the 20,000-rep sample. No off-odor was detected after 13 days of storage in the samples receiving 40,000, 80,000, and 160,000 rep. The samples receiving 80,000 and 160,000 rep showed a brownish color after 2 days of storage.

There is no exact relationship between the microorganism count and "spoilage"; however, a large population of certain microorganisms results in certain types of spoilage. Taste-panel tests are required to evaluate properly the quality of the food.

A study of the microbiology of fresh beef stored at 2°C under aerobic conditions and high humidity was conducted at the American Meat Institute Foundation.[3] The results of this study indicate that the lethal dose of gamma rays for two representative cultures, P. geniculata and an unidentified species, is approximately 30,000 rep.

B. Taste-Panel Studies

Taste-panel studies on gamma-ray-pasteurized fresh meat have been reported previously.[2] In these studies two series of tests were made on irradiated raw ground lean pork, one series on raw ground beef (with 25-percent fat), and one series on chicken legs. The controls for the ground pork and the ground beef, stored at a refrigerator temperature of 40°F, spoiled after approximately 4 days of storage. For taste-panel tests after 4 days of storage, controls which had been stored in the frozen state were used for all three meats.

Taste-panel tests on ground pork and ground beef definitely showed an increase in refrigerator shelf-life as a result of radiation pasteurization. Doses of the order of 60,000 to 100,000 rep prevented spoilage of ground pork through 10 days of storage. (The supply of samples was exhausted at 10 days and the experiment therefore ceased.) Taste-panel studies on ground beef stored at 40°F for 7 days indicate no preference between the frozen control and the irradiated samples receiving radiation dosages from 50,000 to 110,000 rep. When the storage at 40°F was extended to 14 days, the frozen control was preferred to the irradiated samples; however, there was little preference between the samples receiving 50,000 rep and the frozen control.

These results are interesting in view of the fact that the unfrozen control of all ground meats tested spoiled after about 4 days of storage at 40°F, but the results are much too meager. Additional data on the meats tested and on other types of fresh meat, fish, etc. are necessary to establish the advantages and limitations of a gamma-ray pasteurization process. Such a study is being made by the American Meat Institute Foundation. The limited data available to this laboratory indicate that such a process may be quite promising.

III. PROPOSED METHOD OF PREPARING CUT-UP PREPACKAGED MEATS FOR IRRADIATION AT THE PACKING HOUSE

A. General Plan

The proposed method of handling cut-up, prepackaged, and pasteurized meat consists of the usual slaughtering procedures through chilling. Chilling prior to cutting is desirable so as to firm the meat for easier cutting and also because there is less growth of microorganisms if the meat is cut while chilled and kept at refrigerator temperature until used by the consumer. Instead of refrigerated quarter and half carcasses of beef, pork, and lamb being shipped from the packing house to the retailer, it is proposed that the chilled carcasses be cut, prepackaged, weighed, packed in cartons, and pasteurized by gamma radiation at the packing house and then shipped under refrigeration to the retailer. The pasteurization treatment with gamma radiation might be used to destroy about 99+percent of the microorganisms without developing off-flavors in the packaged meat, thereby increasing the refrigerator shelf-life of the meat.

B. Cutting, Prepackaging, and Weighing

In the method proposed, the meat cutting would be performed as a mass-handling operation with each cutter performing a special function such as the cutting of steaks, chops, roasts, trimming, etc. All cuts of meat on such a cutting floor would be of retail size and would be conveyed from the cutting tables to packaging machines. Here the meat would be packaged using plastic films such as polyethylene, saran, and plio film; cellophane; paper; perhaps aluminum foil or combinations of foil, paper, and plastic; etc.

Films of polyethylene have very good properties as water-vapor barriers, are odorless and strong, and can be heat-sealed. One of the disadvantages of polyethylene film is that it is not a very satisfactory oxygen barrier. Also, many of the aromatics, flavor substances such as the esters, and volatile oils pass through polyethylene film. Saran film is more satisfactory as a barrier to oxygen and flavor substances but cannot be heat-sealed easily. Cellophane is inexpensive and has good properties as a barrier to oxygen, but is a poor barrier to water vapor and loses its strength when wet. Aluminum foil has excellent properties as a barrier to all substances, providing that it is free from tiny holes, but has poor strength when used alone. Laminated packaging material can be used so as to take advantage of the properties of each of the components. Thus, a laminated material with an outer layer of heavy Kraft paper, a center layer of thin aluminum foil, and an inner layer of thin polyethylene has the strength and economy of the paper, the barrier effectiveness of aluminum foil, and the heat-sealing properties of polyethylene. A single transparent film may be preferred, however, to permit visual inspection of the contents. As a compromise a transparent plastic window might be placed in wrappings of meat packaged with a laminated material.

Immediately following the packaging by machine, it is proposed that the individual packages be weighed and the weight stamped on the package by machine. This would avoid the tiresome and expensive operation of weighing and recording the weight manually, which is usually necessary when the packaging is performed by the retailer. As retail prices vary, the final pricing would be done by the retailer. However, this operation is rather simple for weighed and packaged products and is necessary for nearly all grocery items. If it is desirable, the packaged and weighed cuts could be machine sorted according to weight in such a mass-handling operation. Thus, all roasts of a certain cut weighing 3 lbs, 0 oz could be separated by machine from those of all other weights and shipped to retailers asking for cuts of exact weights. Such a degree of specialization probably would not be desirable for most retailers, but might be of advantage in the largest supermarkets.

C. Cartons for Irradiation and Shipping

The packaged and weighed cuts of meat must be packed into cartons of suitable size for shipping. Such cartons probably would be made of Kraft paperboard, which is more or less standard material for cartons used to ship other packaged food products. The cartons should have sufficient thickness to handle the larger cuts of meat and yet be of economical and convenient size.

The maximum-size cut of fresh meat normally sold is a fresh ham of pork or a rib roast of beef; such cuts usually do not exceed 8 inches in thickness. An 8-inch carton therefore should be big enough to hold the larger cuts and would not be so thick as to give difficulty in providing a uniform irradiation dose. A carton weighing about 100 to 150 lbs is the maximum weight that any one man can lift safely (portland cement and chemicals are usually packaged in 100-lb bags, partly for this reason). For easy stacking in refrigerated carriers and cold rooms, a carton 2 feet by 1-1/2 feet by 8 inches thick will be considered and a 20-percent loss in effective thickness will be allowed for voids caused by irregularities in the shape of the cuts. Using a density of 70 lbs/ft^3 for the packaged cuts of meat, the cartons are estimated to have an approximate weight of $2 \cdot 1\text{-}1/2 \cdot 8/12 \cdot 0.8 \cdot 70 =$ 112 lbs/carton.

In buying from a packing house a retailer would order by the carton in anticipation of market sales. For example, the retailer might place an order for 6 cartons of steaks, 10 cartons of beef roasts, 8 cartons of ground beef, etc. This would have a definite advantage in that some markets have a large demand for some cuts such as steaks, whereas other markets find a greater demand for roasts, ground beef, or some other cut. It is the present practice to supply the retailer with meat by the half or quarter carcass; he must therefore sell a rather fixed percentage of all cuts. If local demand is not in this exact proportion the retailer is forced to dispose of surplus cuts by grinding or by lowering the price on those cuts. With the new method proposed for wholesaling meat, the retailer could simply order fewer cartons of those cuts for which the demand happened to be low in his area. As the wholesaler would serve many retail markets, local differences would tend to be averaged out and the relative demand for the different cuts would fix the relative prices as it does today, but on an overall basis.

IV. DESIGN OF THE RADIATION CHAMBER

A. Selection of Number of Passes

The radiation chamber should be designed to irradiate packaged meat in cartons on a mass scale. This will involve the use of a conveyor to pass the cartons of meat into the radiation chamber, through the field of radiation, and out of the radiation chamber. For high efficiency in utilizing the radiation a sufficient total thickness of meat should be used to absorb most of the radiation.

The thickness of pork necessary to absorb half the gamma radiation (half-value thickness) has been measured for gamma radiation from cobalt-60 and from spent reactor fuel rods (essentially gamma radiation from cerium-144) and found to be about 10 inches.[1] Cobalt-60 emits gamma rays of 1.33 and 1.17 mev, while cesium-137 emits gamma rays of 0.67 mev. On the basis of the experimental measurements and the difference in energy the half-value thickness for cesium-137 radiation in meat is estimated to be 8 inches. For design purposes the prepackaged meat will be considered to be packed to a thickness of 8 inches in cartons conveyed so as to present an 8-inch-thick absorber over 80 percent of the area through which the conveyor passes. The cartons would have some voids because of the irregular shapes of meat cuts. However, for a given conveyor speed the minimum total dose per pound of meat will result when the cartons are packed to a full 8 inches with meat, which would be possible with ground meat.

One pass of the meat conveyor would theoretically result in the absorption of 50 percent of the incident radiation normal to the carton surface. The distribution of the meat within the cartons and the free space between cartons reduces this value. However, this is somewhat compensated for by the greater total thickness the meat offers to all the radiation not normal to its surface, such as that from the extremities of the source. On the basis of these considerations, the meat conveyed as shown in the following design was considered to be 85 percent efficient as an absorber. Therefore, each path of travel would absorb 50 percent (half-value thickness) times 85 percent (efficiency), or 42.5 percent of the radiation in the area through which the conveyor passes.

The first pass should be at least 1-1/2 to 2 feet from the source to provide a relatively uniform radiation dosage. Subsequent passes must be further away from the source, but the distances should be kept to a minimum to decrease the radiation loss as a result of space attenuation. If the first conveyor pass is located 21 inches from the source, the radiation absorbed by the meat at this position may be calculated. The radiation flux at the second pass will be decreased by absorption in the meat of the first pass and by distance from the source. As successively less radiation is available to each additional pass a practical limit to the number of passes will be reached. Figures 1, 2, and 3 show a design with four passes on either side of the source.

B. Description of Design

Figure 1 shows an elevation view of the radiation chamber and conveyor system. Prepackaged meat cuts packed into cartons 8 inches by 24 inches by 18 inches are brought by belt conveyor A from the meat cutting and packaging areas. The cartons move down slide B into tray 1 of the irradiation conveyor while this conveyor is in the stationary phase of its intermittent operation. As the irradiation conveyor moves, the cartons are carried down into the radiation chamber through opening C and past concrete shield D. Four vertical passes, E, F, G, and H, are made on the right side of the source and four passes, J, K, L, and M, are made on the left side of the source. This arrangement permits irradiation of the cartons from both sides so as to produce a more uniform radiation dose.

Well N is filled with water and is used to hold the source when the radiation must be shut off to permit entry to the radiation chamber for maintenance, routine inspection, or replacement of a portion of the source. If the radiation chamber is located above grade as shown in Fig. 1, a concrete wall, P, which is 3 feet by 4 inches thick, would be used for shielding. If the radiation chamber is placed below grade, the wall thickness may be reduced to that required for structural strength alone, as 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. 1.

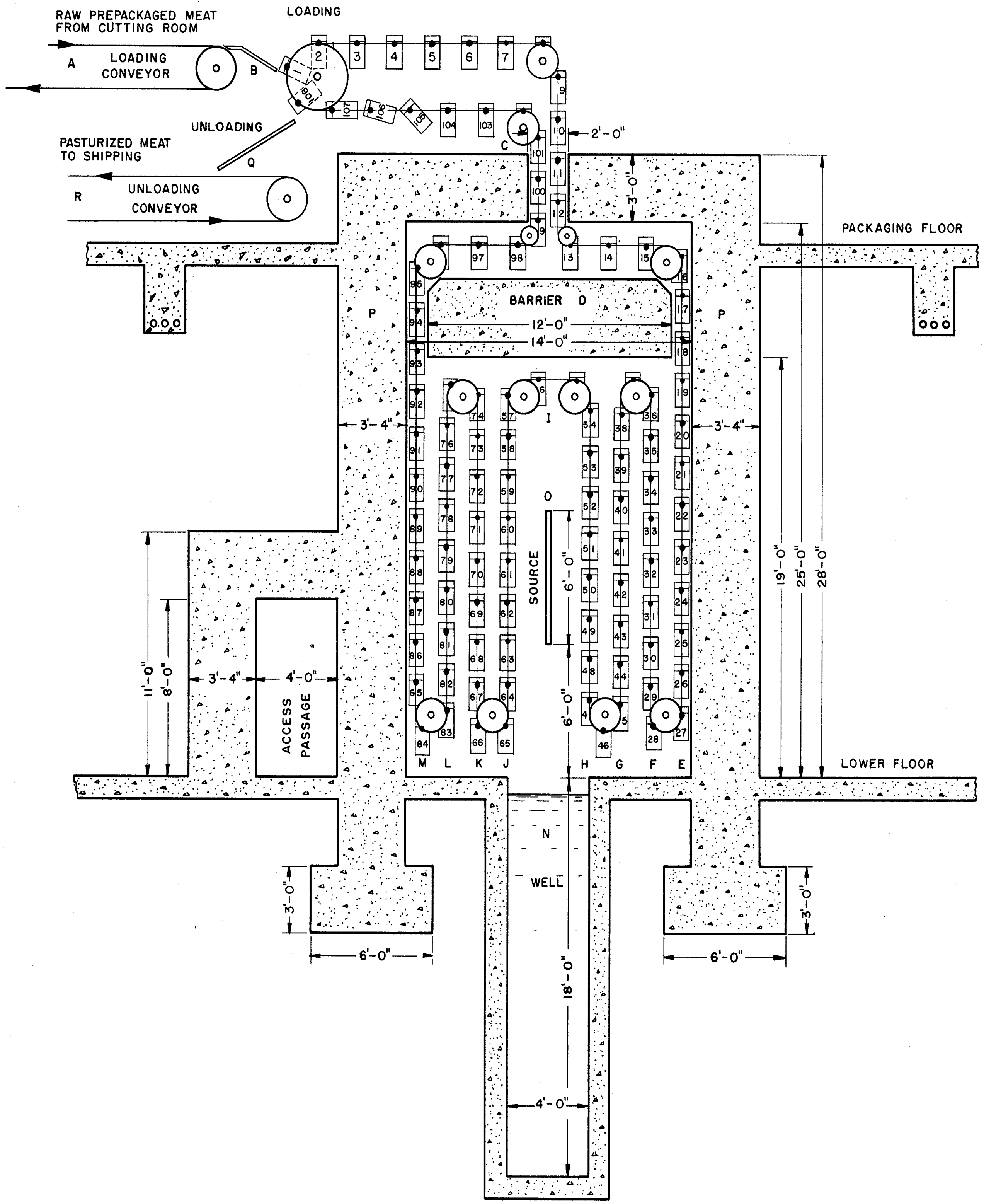

Fig. 1. Elevation View of Radiation Chamber for Prepackaged Meat.

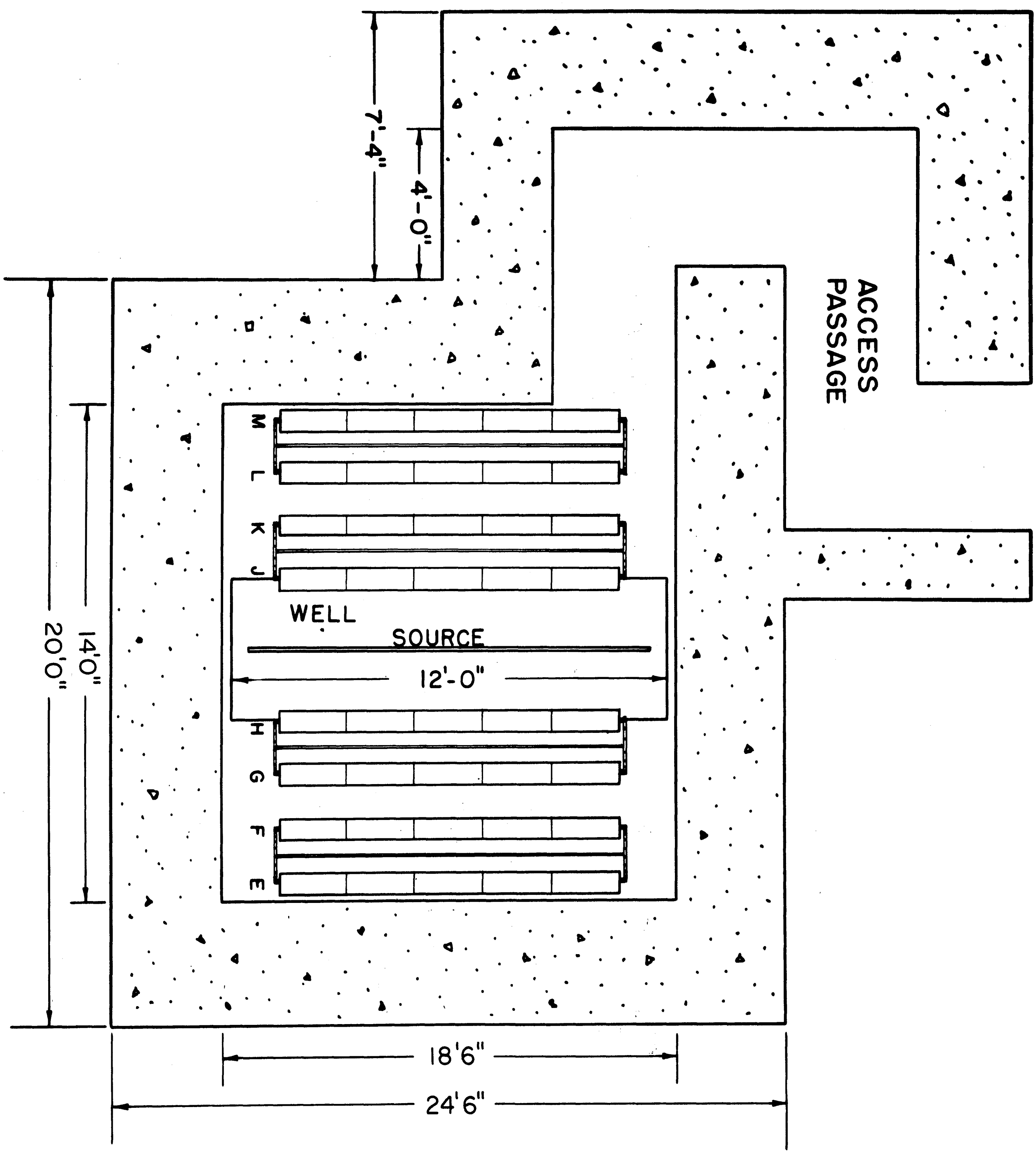

Fig. 2. Plan View of Radiation Chamber for Prepackaged Meat.

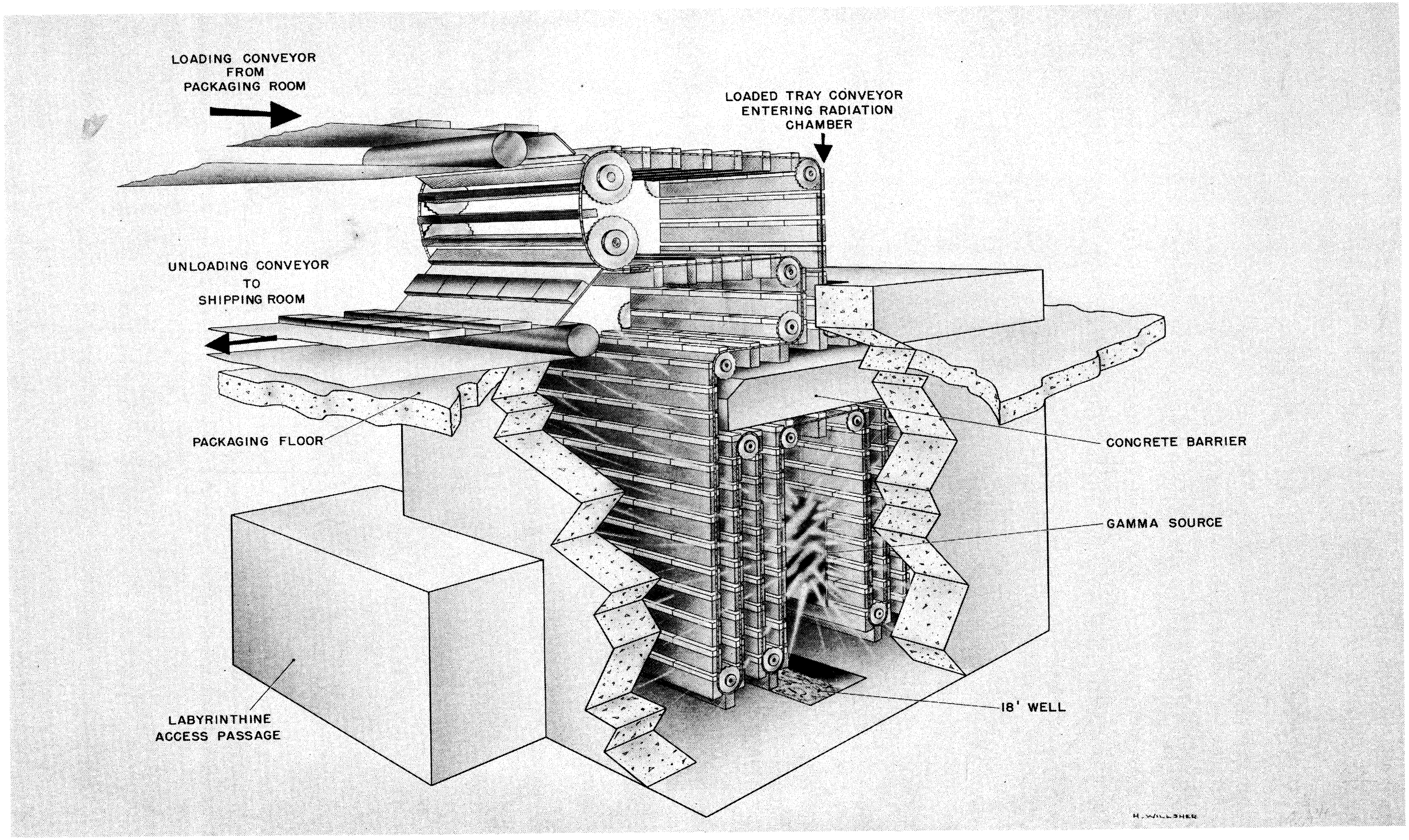

Fig. 3. Cut-away View of Radiation Chamber for Prepackaged Meat.

The radiation chamber is maintained at refrigerator temperature to reduce the rate of reproduction of the microorganisms during irradiation. After irradiation the cartons of "pasteurized" meat pass concrete shield D, travel through opening C out of the radiation chamber, and are dumped into slide Q. Conveyor R carries the cartons of pasteurized meat to refrigerator storage for subsequent shipping.

A plan view of the radiation chamber is presented in Fig. 2. 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", but more than one sprocket should be used as a "driver" so as to reduce the total tension in the conveyor. All drivers could be connected by either a common shaft or a chain drive to keep them synchronized.

As the trays of cartons pass around the arc at the end of each vertical pass, a sufficient arc must be maintained in order to prevent interference between the top of one tray of cartons and the bottom of the following tray of cartons. When the spacing between trays is decreased, a larger radius must be used on the sprockets to prevent interference. The optimum design for continuous absorption, however, requires minimum spacing between trays and, to minimize attenuation with distance, minimum spacing between passes. Thus some compromise must be made between minimum spacing of the trays and minimum spacing of the passes. Using a 4-1/2 inch free space between the trays will require a sprocket having a minimum diameter of about 18 inches to prevent interference between successive trays. The spacing between passes would be 18 inches at the lower limit between passes E and F, and G and H. As the trays would not interfere between passes F and G, the spacing between these passes at the lower limit may be less than 18 inches; a distance of 12 inches was selected. Similarly, the spacing at the upper limit can be 12 inches between passes E and F, and G and H, whereas the spacing between F and G must be 15 inches to avoid interference.

The conveyor trays are fabricated of 16-gauge rolled expanded steel lathe with a reinforcing steel strip 3 inches by 1/4 inch around the top. The trays are pivoted 13-1/2 inches from the bottom of the trays and 4-1/2 inches from the top of the cartons. The center of gravity is placed well below the pivot point, which aids in maintaining a vertical position. As an additional measure, guides may be used to keep the trays vertical while in the radiation chamber and while passing around the sprockets. Guides will be used outside the radiation chamber to unload the trays at position Q and to hold the trays at an angle while being loaded at position B. Figure 3 shows a cut-away view of the radiation chamber in perspective.

C. Optimum Activity Distribution in a Plaque Source

Consider the radiation field associated with an infinite strip of uniformly distributed radioactive material. Along any line parallel to the long axis of the source, the dosage rate would remain constant. Such a plaque would provide a radiation field admirably suited for the irradiation of packaged meat traveling on a conveyor system in a path perpendicular to the long axis of the source. While the meat would pass through a continuously varying field of radiation, each carton of meat would have accumulated the same total dose after passing through the radiation chamber, since each row of meat would be orientated with its long axis parallel to the long axis of the source.

Infinite plaques, of course, cannot be realized. The design of a plaque of finite length and uniform concentration has been presented previously.[4] However, if a uniform radiation dose is to be given to each carton of prepackaged meat, only the field directly opposite the middle section (about one-third of the total width) should be used. Even this portion of the field varies approximately 10 percent. Thus, in order to develop a uniform field 10 feet wide, a plaque at least 30 feet wide would be necessary. Such an installation would be quite inefficient, since well over two-thirds of the radiation from the plaque would be wasted.

By varying the specific activity over the length of the plaque, the radiation field can be made more uniform and the length of the plaque can be reduced with a resultant gain in efficiency.

The procedure for calculation of the dose rate at an arbitrary position is complicated by the nonuniformity in concentration of radioactive material. The total dose rate at a given point is the scalar sum of the contributions from each of the nonuniform portions of the plaque. The flux contributed by one portion is given by:

$$I_1 = \alpha_1 H_1 ,$$

where α_1 = concentration coefficient for this portion of the source.

$$H_1 = \int_{x_1}^{x_2} \int_{y_1}^{y_2} \frac{dydx}{x^2 + y^2 + 21^2}$$

for a point 21 inches from the source. After integrating this equation with respect to y:

$$H_1 = \int_{x_1}^{x_2} \frac{1}{\sqrt{x^2 + 21^2}} \left[\tan^{-1} \frac{y}{\sqrt{x^2 + 21^2}} \right]_{y_1}^{y_2} dx \quad .$$

This integral cannot be formally integrated; hence it was evaluated by numerical approximations.

This procedure was followed for each of the nine portions of the plaque to obtain the total dose rate at a point as

$$I = I_1 + I_2 + \ldots + I_9 \quad .$$

D. Capacity Calculations

The capacity of the radiation chamber shown in Figs. 1-3 will depend on the activity of the source and the dose required. The total activity of the source has been set at 1.5 megacuries so that this design can be compared with that presented previously.[6] Fixing this activity determines the magnitude of the radiation field in a plane perpendicular to the face of the source.

The radiation flux in a plane perpendicular to the face of the source at its center line was calculated for the lines 21 inches from the source and 83 inches from the source and for the points at the center line 36, 51, and 66 inches from the source. The values determined are plotted in Fig. 4. This figure shows that the radiation flux along the horizontal axis parallel to the source can be made approximately uniform by varying the activity of the source along the horizontal axis. The flux may be considered constant along the horizontal axis and this dimension may be eliminated from the calculations of radiation field, permitting the plotting of the radiation field in two dimensions.

As the conveyor passes are spaced at 21, 36, 51, and 66 inches from the source, the dose rates (in air) were calculated at these distances as a function of the vertical distance above the center line of the source. The dose rate curves calculated for 21, 36, 51, and 66 inches are shown in Fig. 5. These data were cross-plotted to give the isodose curves shown in Fig. 6. The dose rates shown in Fig. 6 are for radiation in air and must be corrected for absorption in the meat. This correction was made using 8 inches as the half-value thickness for meat absorbing gamma radiation from cesium-137 with an absorber efficiency of 85 percent. The isodose curves corrected for absorption are shown in Fig. 7.

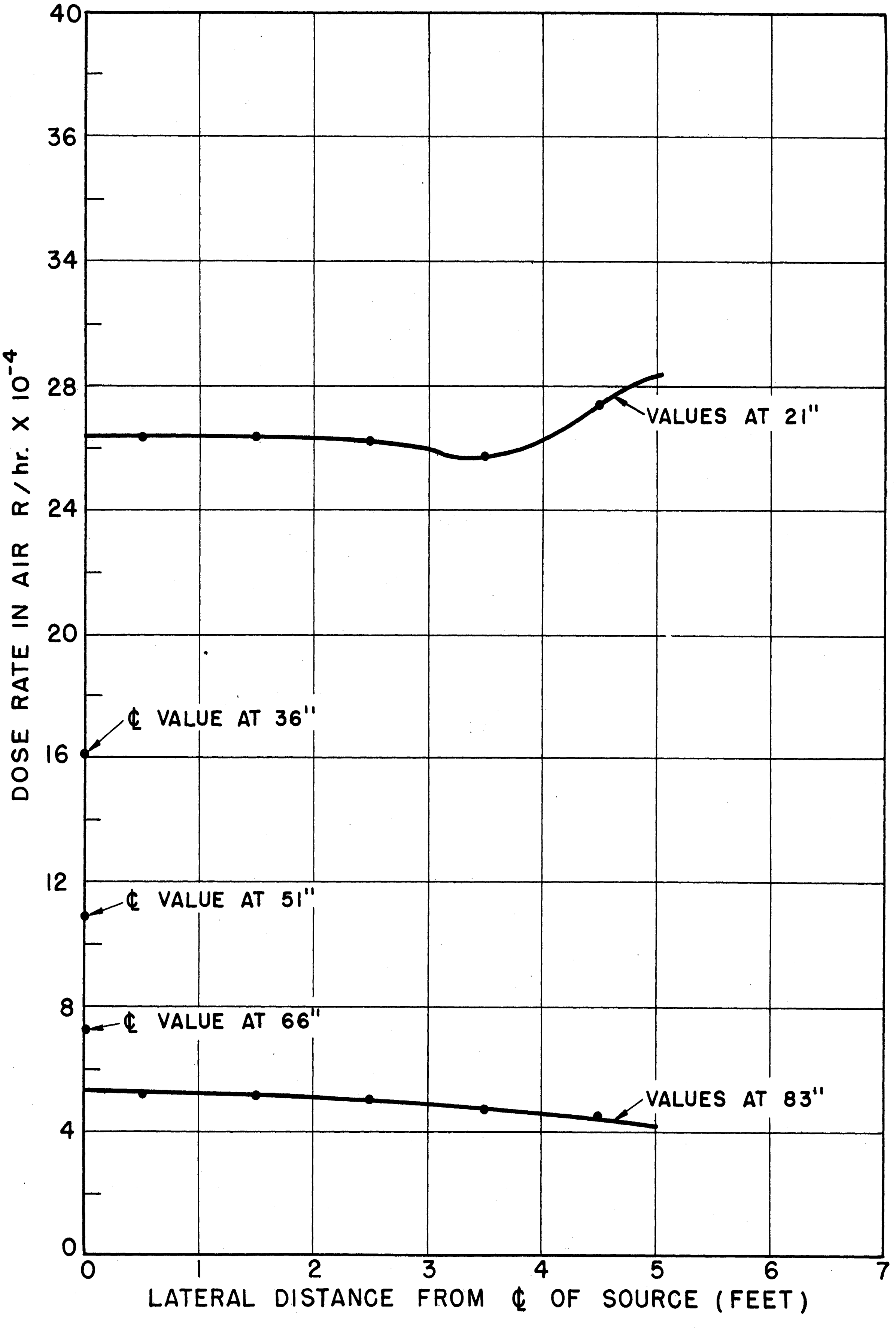

Fig. 4. Radiation Flux (r/hr in Air) in a Horizontal Plane at Center Line of Source for One Quadrant of Radiation Chamber.

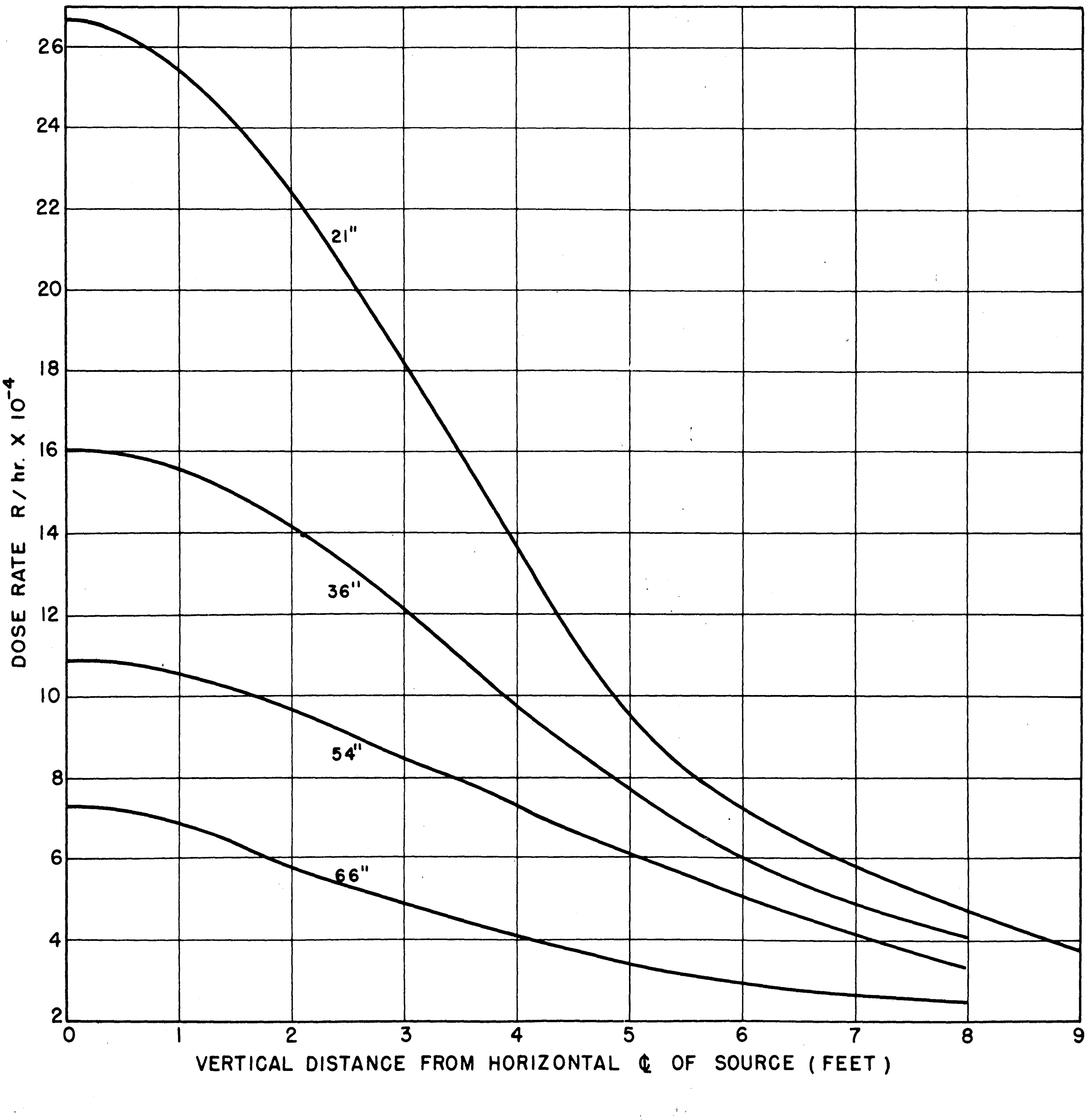

Fig. 5. Radiation Flux (r/hr in Air) in Vertical Plane (Perpendicular to Source at Center Line) for One Quadrant of Radiation Chamber.

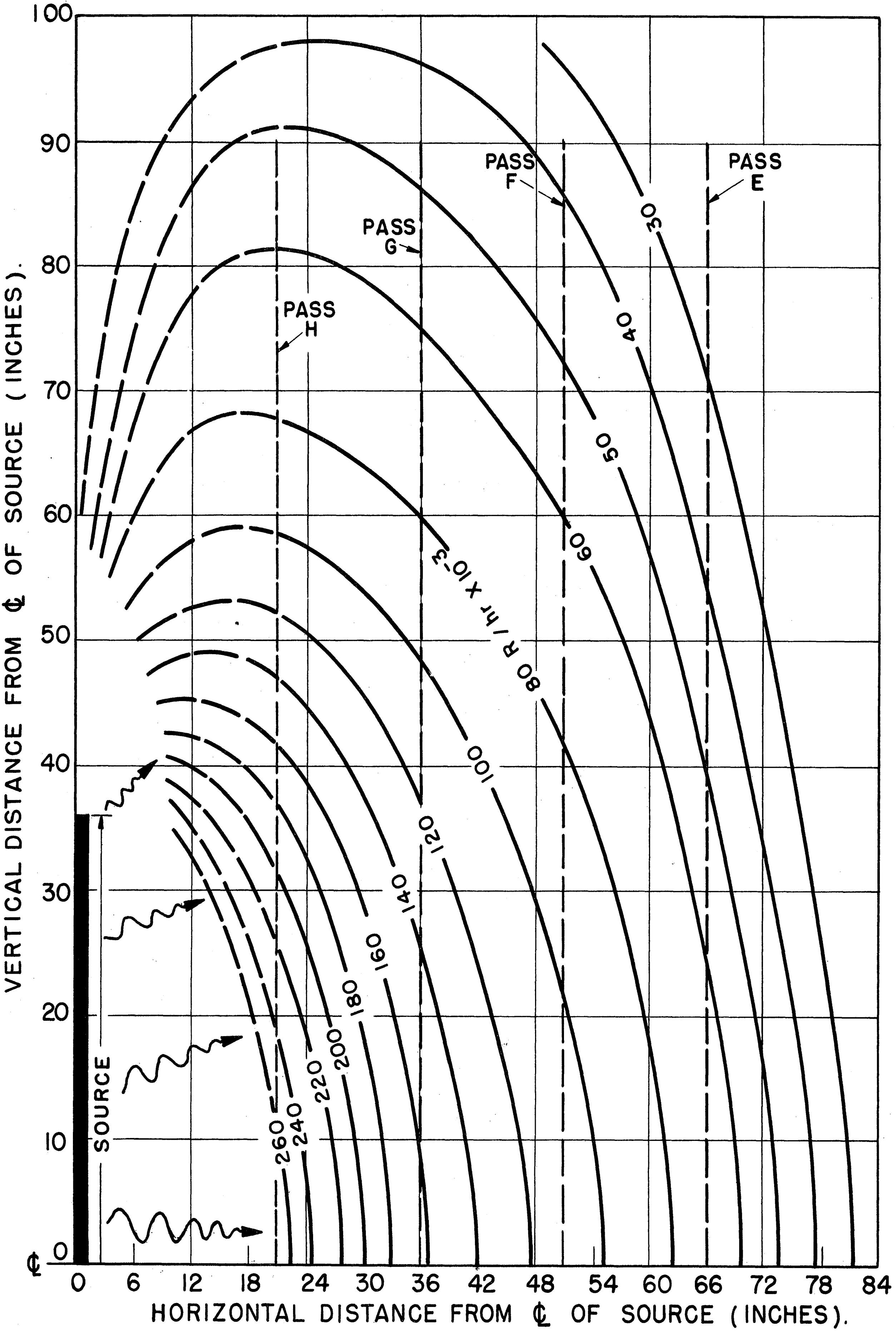

Fig. 6. Isodose Curves (r/hr in Air) in Vertical Plane Perpendicular to Source at Center Line for One Quadrant of Radiation Chamber.

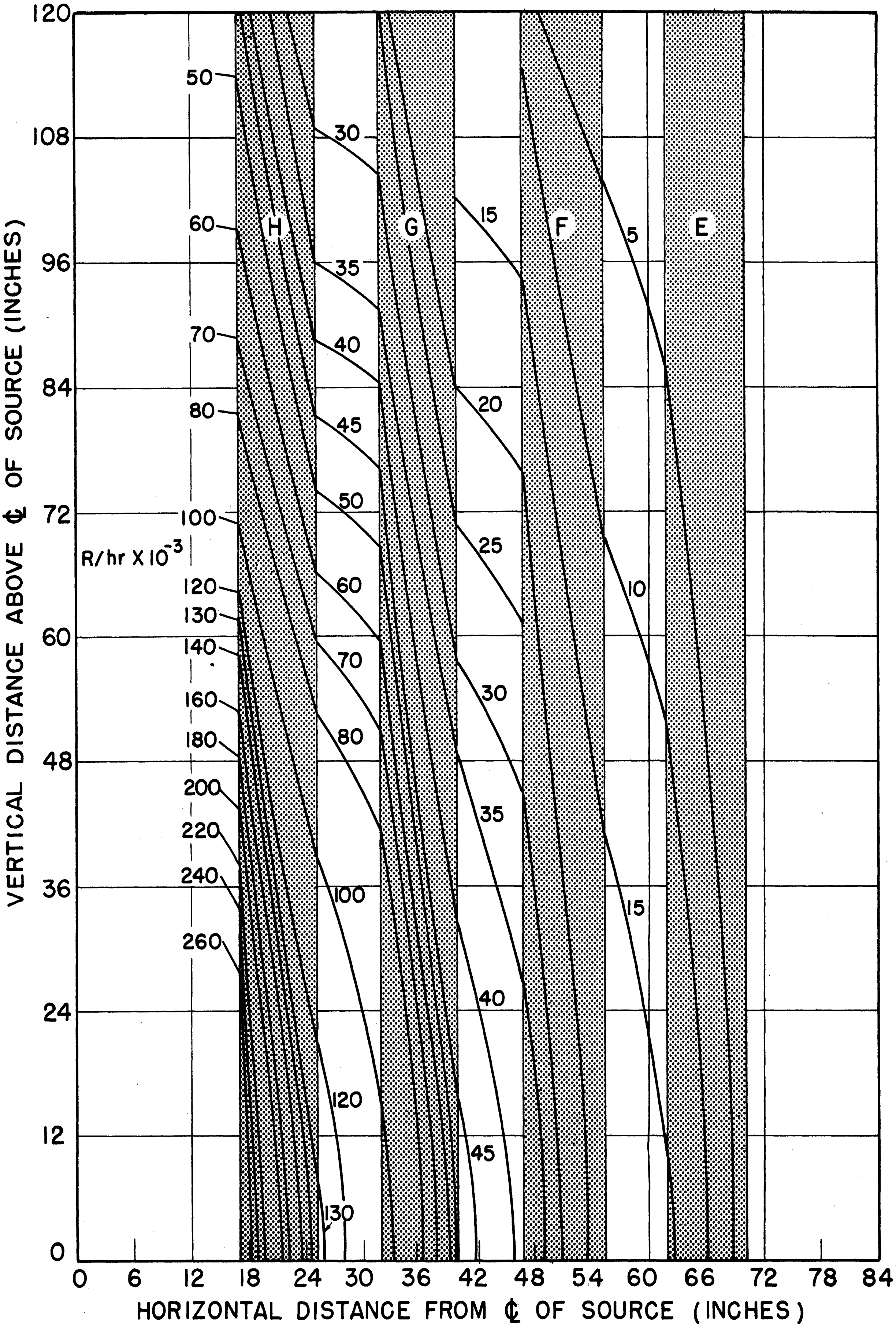

Fig. 7. Isodose Curves (rep/hr) from Fig. 6
Corrected for Absorption.

For purposes of comparison a dose of 30,000 rep, the dose selected for a pork irradiation facility,[4] will be used in capacity calculations; also, capacities will be compared for a dose of 80,000 rep, which is considered a more suitable dose for pasteurization of prepackaged fresh meat.

Figure 8 shows a plot of the radiation flux in rep/hr at the center of meat after corrections are made for absorption plotted as a function of the length of path traveled through the first half of the radiation chamber. This figure was obtained by use of Fig. 1 and Fig. 7. The plot of radiation flux for the second half of travel through the radiation chamber would be a mirror image of this curve and therefore is not shown. To determine the time required to absorb a given dose, the curve must be integrated graphically. This was accomplished by employing the Trapezoidal Rule. Twice this integral gives the accumulated dose for the meat in the center of the carton as a function of the tray speed through the chamber. The radiation dose received by the meat near the surface of the carton is calculated to be approximately 10 percent higher than the dose received by the meat at the center of the carton as a result of less absorption. The accumulated dose may be expressed as:

$$\text{Accumulated dose in rep} = 2\,\frac{\text{rep ft/hr}}{x \text{ ft/hr}} \ ,$$

where x = tray speed in ft/hr.

From the plot of dose rate versus length of path traveled, Fig. 8, the accumulated dose at a tray speed of 1 ft/hr was determined to be 7×10^6 rep.

Dividing the specified dose by the accumulated dose as a function of tray speed yields a value which has the reciprocal units of tray speed. Multiplying this value times the length of path traveled in feet gives the time required for each cycle for the meat to obtain a specified dose.

$$\begin{array}{l} \text{Radiation time/cycle} \\ (\text{for a dose of } 3\text{x}10^4 \text{ rep}) \end{array} = \frac{3 \times 10^4 \text{ rep}}{7 \times 10^6 \text{ rep ft/hr}}\ 140 \text{ ft} = 0.60 \text{ hr}$$

$$= 36 \text{ min} \ .$$

There are 74 trays within the chamber with 5 cartons of meat/tray, each weighing approximately 116 lbs. The capacity in lbs of meat/cycle would then be:

$$\text{Capacity/cycle} = \frac{74 \text{ trays in chamber}}{\text{cycle}} \times \frac{5 \text{ cartons}}{\text{tray}} \times \frac{116 \text{ lbs}}{\text{carton}}$$

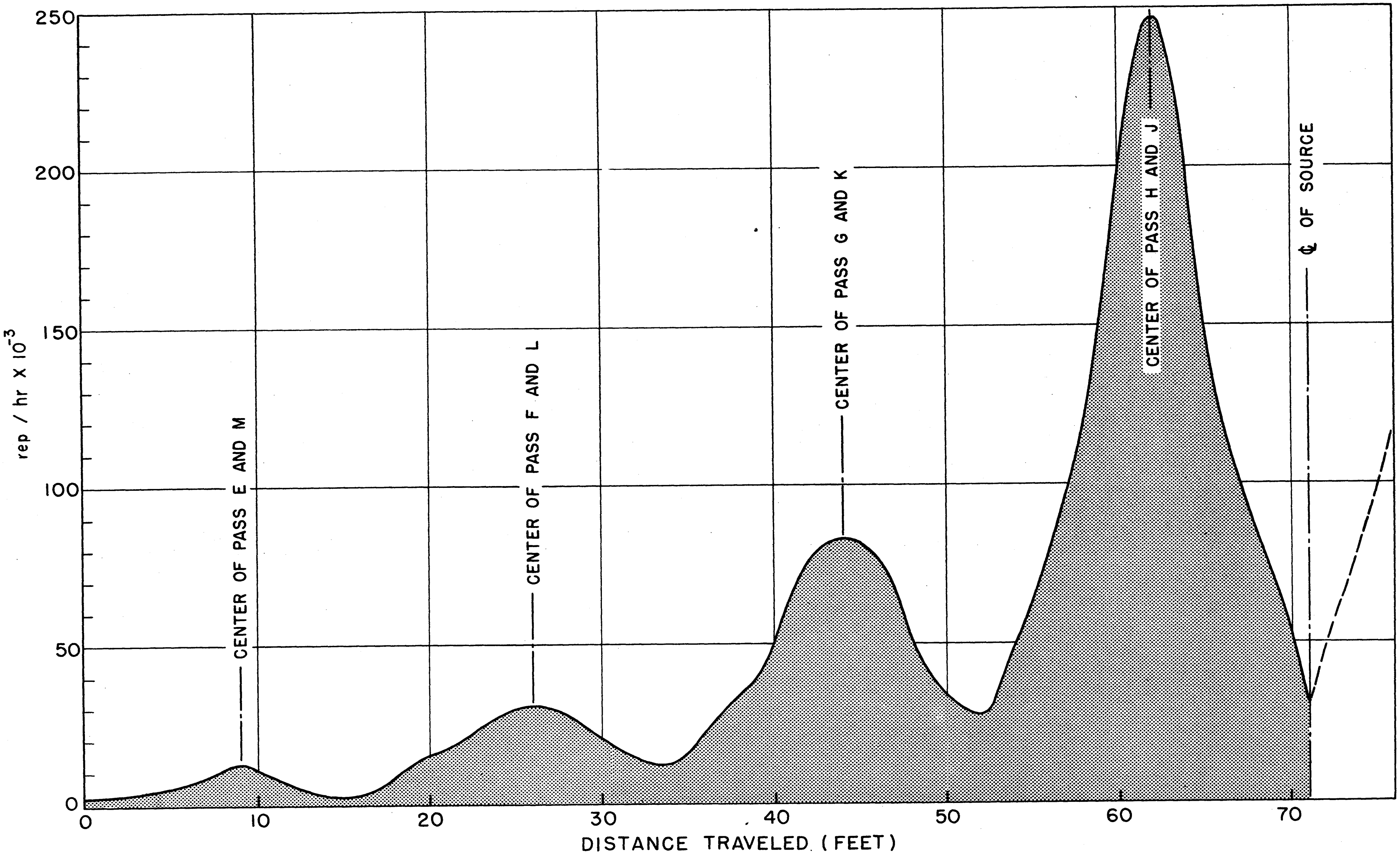

Fig. 8. Dosage Rate Received at Center of 8-Inch Carton of Meat as a Function of Distance along Path in Radiation Chamber.

$$= 4.3 \times 10^4 \text{ lbs/cycle} \quad .$$

The capacity in lbs/hr may be obtained by dividing by the exposure time required for each cycle.

$$\text{Capacity/hr} = 4.3 \times 10^4 \frac{\text{lbs}}{\text{cycle}} \cdot \frac{1}{0.6 \text{ hrs/cycle}}$$

$$= 7.16 \times 10^4 \frac{\text{lbs}}{\text{hr}} \frac{1}{2000 \text{ lbs/ton}}$$

$$= 35.8 \frac{\text{tons}}{\text{hr}} \text{ (for a dose of } 3 \times 10^4 \text{rep)} \quad .$$

Similar calculations may be performed to determine the radiation time required to obtain 80,000 rep. A new computation of the capacity of the radiation facility may then be made utilizing the different exposure time.

With the same source design and source strength any increase in dose would be a function of the exposure time for the same path of travel through the chamber. The time required to obtain 80,000 rep would then be equal to:

$$\begin{matrix}\text{Radiation time per cycle} \\ \text{(for a dose of } 8 \times 10^4 \text{ rep)}\end{matrix} = \frac{80{,}000 \text{ rep}}{30{,}000 \text{ rep}} \times 0.6 \text{ hr}$$

$$= 1.6 \text{ hr} \quad .$$

The capacity of the plant will be reduced due to the longer radiation time necessitated by the larger dose.

$$\frac{\text{Capacity}}{\text{hr}} = \frac{30{,}000 \text{ rep}}{80{,}000 \text{ rep}} \cdot 35.8 \frac{\text{tons}}{\text{hr}} = 13.4 \frac{\text{tons}}{\text{hr}} \text{ (for a dose of } 8 \times 10^4 \text{ rep)} \quad .$$

The new radiation facility for the pasteurization of meat is obviously more efficient than the earlier design,[4] as evidenced by the increased capacities. For a similar dose of 30,000 rep an increase of over 5 times the production is realized with the new chamber design. For a dose of 80,000 rep the new facility has double the capacity of the previous pork irradiation facility, which was designed to give a radiation dose of only 30,000 rep.

E. Cost Estimates

1. Total Investment. The cost of the radiation facility, exclusive of the radiation source, was estimated to be $82,500. This estimate is itemized in Table I.

TABLE I. ESTIMATED COST OF RADIATION FACILITY

Excavation and shoring for footings and well	$ 800	
Concrete for 12-1/2 x 18 x 3-ft well (60 yds at $20/yd)	1200	
Reinforcing for well (4000 lb at $0.10/lb)	400	
Asphalt lining for well	200	
Forms for well (1300 bd-ft at $100/M)	130	
Labor for forming and pouring well	600	
Concrete for walls and footings (300 yds at $20/yd)	6000	
Forms for wall (6000 bd-ft at $100/M)	600	
Labor for forming and pouring wall	2200	
Concrete for access passage (50 yds at $20/yd)	1000	
Forms for access passage (1000 bd-ft at $100/M)	100	
Labor for forming and pouring access way	800	
Concrete for floor (6 yds at $20/yd)	120	
Reinforcing for floor (500 lb at $0.10/lb)	50	
Labor for pouring floor	100	
Concrete for barrier wall (20 yds at $20/yd)	400	
Forms for barrier wall (1000 bd-ft at $100/M)	100	
Reinforcing for barrier wall (2000 lbs at $0.10/lb)	200	
Labor for forming and pouring barrier wall	400	
Concrete for roof (70 yds at $20/yd)	1400	
Forms for roof (1000 bd-ft at $100/M)	100	
Reinforcing for roof (3000 lb at $0.10/lb)	300	
Labor for forming and pouring roof	600	
Elevator mechanism	5600	
Ion-exchange system for well water	3000	
Monitoring equipment	4000	
Chain conveyor (2 x 244 ft at $5.00/ft)	2440	
Conveyor sprockets and stud shafts	3000	
Conveyor drive	6200	
Conveyor trays (110 trays at $20/tray)	2200	
Dump mechanism	3000	
Loading mechanisms	5600	
Conveyor control mechanism	4200	
Access doors (with safety interlock)	1400	
Ventilating and refrigeration of air	6000	
Wiring	600	
Water lines and labor for pipe fitting	800	
Backgrading	200	
Painting	600	
Subtotal for labor and materials		63,640
Miscellaneous contingencies (10% of subtotal)		6,360
Engineering costs (7% of labor and materials)		5,000
Contractor's fee (10% of costs)		7,500
Total		$82,500

Using the 0.6 scaling factor,[5] for estimating the installed cost of the radiation source and using the figure $6,000 for a 1000-curie cesium-137 source, the installed cost of 1.5 megacuries of cesium-137 is estimated to be

$$x = \$6{,}000\left(\frac{1.5 \times 10^{6}}{1000}\right)^{0.6}$$

$$= \$483{,}000 \quad .$$

The cost of a steel-reinforced lead container for shipping the source in sections is estimated to be $5,000. Thus, the total investment becomes:

Cost of radiation chamber and accessories	$ 82,500
Installed cost of 1.5-megacurie cesium-137 source	483,000
Cost of shipping container	5,000
	$570,500

2. <u>Operation Costs Based on Purchase of Source</u>. If the radiation facility were operated as a part of a large meat processing plant, the annual operating costs might be estimated as shown in Table II.

In computing the annual cost of operation it was estimated that the services of one health physicist would be required on a half-time basis. Other research activities or duties would occupy the remainder of his time. Assisting the health physicist would be a maintenance engineer whose duties at the radiation facility would also occupy him only half-time. These duties would consist of servicing the mechanical equipment and aiding in replacement of the source. Included in the estimate are allowances for cleaning and maintaining sanitation in the chamber, as well as for clerical and supervisory labor.

Alterations to existing refrigeration and conveying equipment in a processing plant would have to be made to accommodate the radiation facility. Allowances were made in the estimate so that part of the conveying and refrigerating costs would be charged to the chamber.

Replacing a portion of the source every five years restricts the maximum fluctuation of the source strength to 10 percent. This is necessary to maintain the capacity of the facility at an economic level. One-fifth of this replacement cost is charged each year.

Overhead on the payroll, general plant operation, and general administration was estimated according to recommended methods for chemical plants.

TABLE II. ESTIMATED ANNUAL OPERATING COSTS FOR MEAT-IRRADIATION FACILITY USING CESIUM-137

WAGES, SALARIES		
Experienced health physicist (half-time)	$ 4,000	
Maintenance engineer with health physics training (half-time)	3,000	
Cleaning and sanitation (part-time)	1,000	
Supervision and clerical labor (10 percent of operational labor)[6]	800	
Salaries and wages not associated with operation of radiation chamber (50 percent of direct labor and supervisory costs)[6]	4,400	
		$13,200
OPERATING COSTS OTHER THAN WAGES AND SALARIES		
Maintaining source activity ($125,000 every 5 years)	25,000	
Refrigeration	2,000	
Utilities	1,000	
Conveying	1,000	
Repairs and maintenance of chamber (5 percent of chamber costs)	4,100	
Miscellaneous contingencies	1,500	
		34,600
OVERHEAD		
Payroll overhead (15 percent of direct labor and supervision)	1,980	
General plant overhead (50 percent of cost of labor and operation)	23,900	
General administration overhead (10 percent of cost of labor and operation)	4,530	
		30,410
TAXES, INTEREST, AND INSURANCE		
Property taxes (2 percent of cost of radiation chamber)	1,650	
Income tax (2-1/2 percent of total investment)	14,260	
Interest (5 percent of total investment)	28,520	
Insurance (1 percent of total investment)	5,700	
		50,130
DEPRECIATION AND OBSOLESCENCE		
Radiation facility (8 percent of chamber cost)	6,600	
Radiation source (8 percent of initial cost minus the salvage value)	19,260	
		25,860
Total cost for year		$154,200

The radiation chamber was considered taxable as property, but the radiation source was considered to be a piece of equipment and not subject to property tax. Income tax should be calculated on the basis of profits or estimated as a percentage of annual sales; however, no calculation was made of the profit to be realized. Therefore, it was estimated that 2-1/2 percent of the total investment might be considered chargeable to the radiation facility for income tax.

In estimating depreciation and obsolescence the radiation chamber and radiation source were considered to have useful lives of 10 years. The total investment would be amortized over a 10-year period by use of a sinking fund. The interest on the cash paid into the sinking fund would reduce the percentage of the initial investment chargeable each year from 10 percent to about 8 percent. This depreciation would provide for complete replacement of the radiation chamber after 10 years. The source is assumed to have a salvage value of only 50 percent at the end of the 10-year amortization period even though, through activity replacement, it will be at full strength.

The annual capacity for a dose of 30,000 rep would be

$$7.16 \times 10^4 \text{ lbs/hr} \times 20 \text{ hrs/day} \times 260 \text{ days/yr} = 3.72 \times 10^8 \text{ lbs/yr} .$$

The cost per pound to be added to meat for a radiation dose of 30,000 rep would therefore be

$$\frac{\$154{,}200/\text{yr}}{3.72 \times 10^8 \text{ lbs/yr}} = \$0.000415/\text{lb} = .415 \text{ mills/lb} .$$

Using a pasteurization dose of 80,000 rep, the annual capacity becomes:

$$3.72 \times 10^8 \times 3/8 = 1.4 \times 10^8 \text{ lbs/yr} .$$

In this case the cost per pound to be added to meat for a radiation dose of 80,000 rep would be:

$$0.415 \times 8/3 = 1.1 \text{ mills/lb} .$$

3. Estimated Cost of Irradiation of Meat Based on Rental of Source and Shipping Container. The rapid strides made by industry in developing new techniques necessitate amortization of new processes over a short period, usually 5 years, because a process which is successful today may be obsolete and have to be abandoned in less than 5 years, in the interests of new developments. However, it is not realistic to amortize a cesium-137 source in 5 years, as this radioisotope has a half-life of 33 years. Thus, it is believed that the fission product sources might be rented by the AEC or by a contractor

rather than sold, if an amortization realistic with the actual useful life of the source is to be realized.

After two half-lives or a total of 66 years, 75 percent of the cesium-137 will have decayed. Therefore, it would be more realistic to amortize the source over say a 33-year or a 50-year period or a rate of 3 or 2 percent, respectively, rather than 20 percent per year. Also, interest on a long-term investment might be 4 percent rather than 6 percent, making the annual cost of the source only 6 or 7 percent of the initial cost.

It was estimated that the shipping and installation costs would be approximately 1/6* of the installed costs, or in the case of the 1.5-megacurie cesium source the cost of installation would be approximately $80,500 and the cost of the source itself would be $402,500. If the source were rented, the annual rental should include the use of the shipping container. Therefore, the annual cost for rental would be 0.06 x (402,500 + 5,000) = $24,450/yr. On this basis the operational costs per year were revised to $88,460. The cost/lb to be added for an irradiation dose of 80,000 would be:

$$\frac{\$88{,}460/\text{yr}}{1.4 \times 10^8 \text{ lb/yr}} = \$0.000632/\text{lb} \quad \text{or} \quad 0.63 \text{ mills/lb} \quad .$$

F. Discussion

There are many problems that must yet be solved before it will be possible to pasteurize prepackaged meat on a commercial basis with gamma radiation. In the opinion of the personnel of this laboratory, the chief problem to be solved before gamma radiation may be used by the food industry is the establishment of the wholesomeness of irradiated food. This opinion is based on the fact that there are many applications of gamma radiation to the food industry in which flavor is not a major problem, i.e., pasteurization of prepackaged meats, irradiation of grains to prevent insect damage, treatment of potatoes and onions, etc.

After conducting pilot animal-feeding experiments for about one year the personnel of the Phoenix project 41 have yet to find any reason why irradiated food should not be considered wholesome. However, long-term feeding studies with significant numbers of animals must be completed before the wholesomeness (or toxicity) of irradiated food can be reliably established. It is gratifying to learn that the Surgeon General's Office is considering the investigation of this problem.

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*This ratio is undoubtedly high for a 1.5-megacurie source.

Many other problems exist, such as color changes, which are particularly noticeable on the surface of irradiated raw beef. More taste-panel studies are required on different types and cuts of meat, including fish and other sea foods. More data are needed on the increase in shelf-life that can be expected using different radiation dosages and different storage conditions.

In addition to the need for more information on irradiated products, there also should be more information on the sources of radiation, the design of radiation facilities, and the cost of irradiation. This design was made with the intention of exploring some of these questions. It is obvious to those who have worked with this design that it could be improved considerably. More attention should be given to using separated cesium-137 and possibly cerium-144, as this appears more feasible than attempting to use the gross fission products. If the radioisotopes with long half-life such as these two and strontium-90 could be put to industrial use, the remainder of the gross fission products could be discarded after storage for a limited time. Different designs of sources should be made so as to determine the optimum conditions for preparing and handling the sources.

Although the design shown was intended for the pasteurization of meat, it might be used for the irradiation of bags of potatoes and onions to prevent sprouting or for the sterilization of canned food. The cartons could be filled with No. 10 cans of food rather than prepackaged meat. If a radiation dose of 3.2×10^6 rep were used for sterilization rather than the 8×10^4 rep used for pasteurization, the capacity would be reduced by a factor of 40, or to about 1/3 tons/hr or about 8 tons for a 24-hour day. The cost/lb for irradiation would be increased to about $0.03/lb if a rented source were used. If the capacity were tripled by using 4.5 megacuries, the cost/lb for irradiation would be approximately halved. These figures show that radiation sterilization at least is economically feasible.

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