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ISOTOPES—INDUSTRIAL TECHNOLOGY

PRELIMINARY DESIGN STUDY FOR A SODIUM-GRAPHITE-REACTOR IRRADIATION FACILITY

By
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CONTENTS

CONTENTS (Continued)

ABSTRACT

The results of an investigation to integrate a sodium-24 irradiation processing facility with an operating Sodium Graphite Reactor are presented. An irradiation facility incorporated into a reference SGR (Hallam Nuclear Power Facility, Hallam, Nebraska) is described. Development of the facility application, preliminary design criteria, and capital and operating costs are discussed. Recommendations for further development of the technology and economics of this type of irradiation facility are included.

I. INTRODUCTION

Both military and industrial interests have been studying the applicability and feasibility of radiation processing of foodstuffs and materials. Some of the uses of radiation being investigated are:

1) The preservation of foodstuffs,

2) Deinfestation of grain,

3) The inhibition of sprouts in various vegetables,

4) The sterilization of drugs,

5) Catalysis of chemicals.

As an example of this interest, radiation processing of food has been proposed as a method of sterilization or pasteurization.[1] In the process, the food is exposed to the ionizing effects of electromagnetic radiation of short wave lengths from gamma rays. The ionization destroys the microorganism that causes spoilage. The fraction destroyed depends upon the total exposure, or the quantity of radiation energy absorbed in the food.

The exposure (dose) is measured in reps (roetgens equivalent physical), the rep being a unit of energy absorbed per unit mass and is equivalent to 93 erg/gm. An absorbed dose of 10^6 rep represents 2.2 cal/gm or about 4 Btu/lb. The dose required to effect any desirable changes depends upon several variables, e.g., in the case of preserving foodstuffs, the dose would be high if the population density of microorganisms were high. The shelf life of meat can be extended by irradiation to a level of about 10^5 rep; a much higher dose is required for sterilization. Flours and grains can be deinfested with $1\text{-}3 \times 10^5$ rep. Sprouting in potatoes can be controlled with 1.5×10^4 rep.

Attention has been directed toward the radioactive sodium-24 isotope, an inherent byproduct in the coolant of sodium graphite reactors, as a potential source material in a gamma-ray irradiation facility. The study project with which this report is concerned has been undertaken to establish the overall feasibility of integrating such a facility with an operating SGR. For purposes of establishing reference facility design characteristics, the Hallam Nuclear Power Facility consisting of a 254-Mwt SGR has been used as the operating reactor providing the source material. The HNPF, located at Hallam, Nebraska, as part of the Sheldon Station of the Consumers Public Power District, has been authorized by the U.S. A.E.C. as part of the Central Station Power Demonstration Program.

The irradiation facility design also has been based on the consumer market potential peculiar to the Hallam, Nebraska, area. Market information has been incorporated into the facility design arrangement and capacity. The market survey also was used to determine logistics data for those products which might be expected to represent the most active market interests. The facility design arrangement has been developed to accommodate a wide variety of products and package configurations. The market survey was performed under subcontract by Nuclear Industries Corporation, Lincoln, Nebraska.

The arrangement of radiation source, the conveyor speed, and the source strength required for the process depend upon the exposure required and the density of the process material. Integrated doses from 10^4 to 3×10^6 rep have been considered. For design purposes, the densities of materials were assumed to be the same as water. The size and shape of the packages considered were No. 2 cans, No. 10 cans, plastic bags, 100-lb sacks, V-3 boxes, and bulk materials such as wheat. A V-3 box is a pressed paper carton with a volume of 1 ft^3 and measures 6 x 15-1/2 x 20-1/2 in. The conveyor systems could be designed to handle larger packages.

Development of a reference facility design has resulted in the determination of cost estimates associated with construction and operation of the irradiation processing plant. Cost estimates have been developed for the following items:

1) The Radiation Cell

   This includes the facility radiators (plaques), piping, pump, instrumentation, cell structure, and ventilation equipment necessary to provide controlled airflow in the cell at room temperature.

2) Materials Handling Equipment

   The conveyors provided are required for carrying a variety of packaged or bulk materials from a loading area into the radiation cell, through the exposure region of the cell, and back out of the cell into the loading area.

3) Auxiliary Refrigeration Equipment

   This includes additional refrigeration equipment necessary to maintain a temperature of as low as 20°F in the processing region of the cell. This cost is included to permit the processing of refrigerated or frozen foods.

4) Transportation and Handling Costs

An attempt has been made to estimate the additional transportation and handling costs incurred as the result of facility processing of various products. Transportation costs will vary according to the locations of the various production points and according to the flow pattern to the market distribution centers. Handling costs will vary according to the packaging techniques peculiar to each product.

5) Operating Costs

This includes the manpower cost, necessary to operate the facility conveyor systems, and the power cost required to operate the associated cell mechanical equipment.

No cost estimates were developed for personnel and control equipment housing, loading and unloading docks, storage facilities, and additional roadways and railroad sidings necessary to serve the facility. The extent to which the market could be developed would influence the design of these auxiliary installations. The limited extent to which irradiation processing has been developed on a commercial basis would make the task of predicting the requirements for these facilities difficult.

Since the facility feasibility determination is dependent on economic considerations, the above cost data were used to establish an estimate of processing costs. The cost for radiation processing is expressed in cents per pound per dose.

In making the estimates of unit processing costs, it was assumed that the Hallam Facility would be operating 80% of the time, and that the irradiation facility would be working only when the Hallam Facility would be operating. Since some downtime is required for maintenance in addition to the downtime when the Hallam Facility is not operating, the plant factor was taken to be 75%. The annual charge on capital investment was taken to be 15%.

The feasibility study, as reported herein, does not consider the sensitive areas of market development associated with radiation processing. Possible continuation of government control of irradiated food products has not been included as a factor in the feasibility determination. The study did not attempt to determine consumer reaction to products processed in the facility. A determination of exact savings which could be realized by use of facility processing for any particular product has not been developed. The major emphasis of the study, therefore, has been placed on the determination of facility feasibility based on technical and processing cost factors. In most cases the design described reflects an optimized facility arrangement which would reflect minimum processing costs.

The irradiation facility has been arranged in the most convenient location with respect to the HNPF process design. In addition to design convenience, an attempt has been made to locate the facility adjacent to an area on the HNPF site that could accommodate the necessary transportation and materials handling facilities. The main-plant rail siding would be in a convenient location to serve the facility. Adequate space is available for the installation of loading docks to serve both rail and motor freight shipments. In-transit material storage facilities also could be situated in this area.

Figures 1 and 2 illustrate the general arrangement of the facility located adjacent to HNPF.

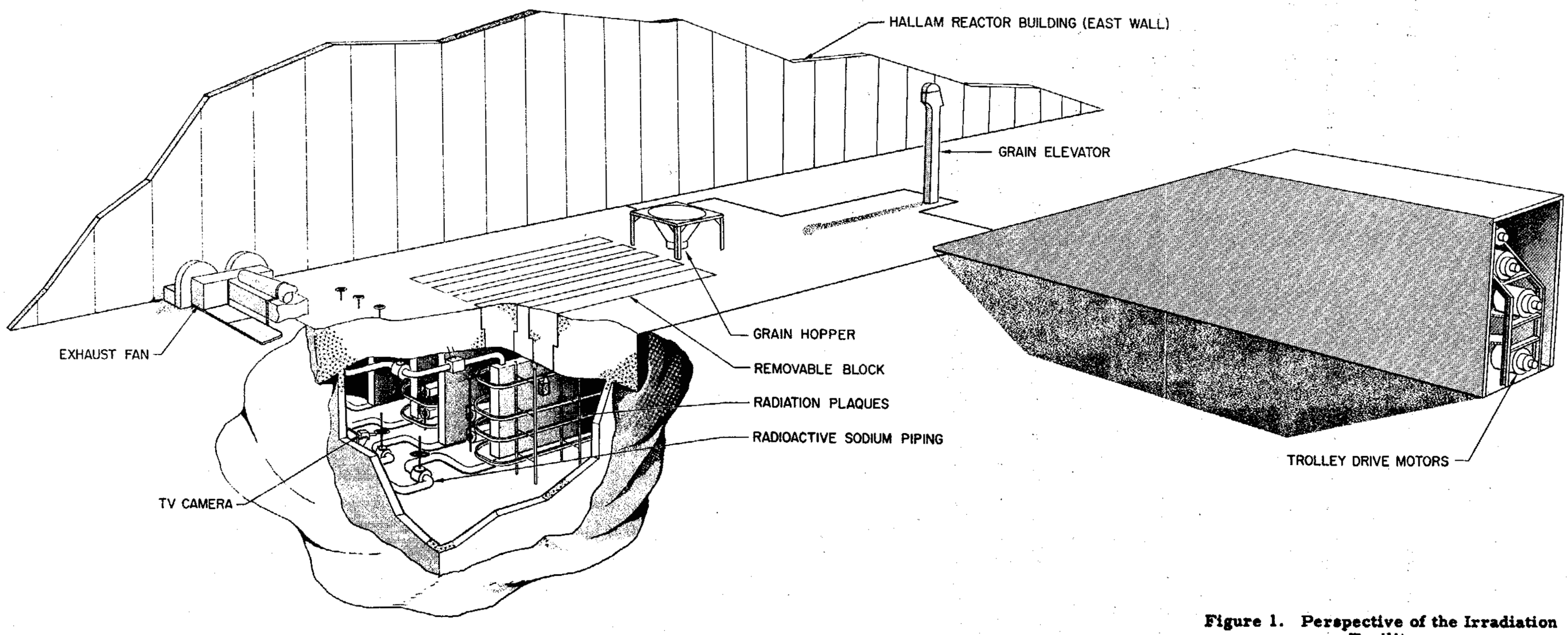


Figure 1. Perspective of the Irradiation Facility

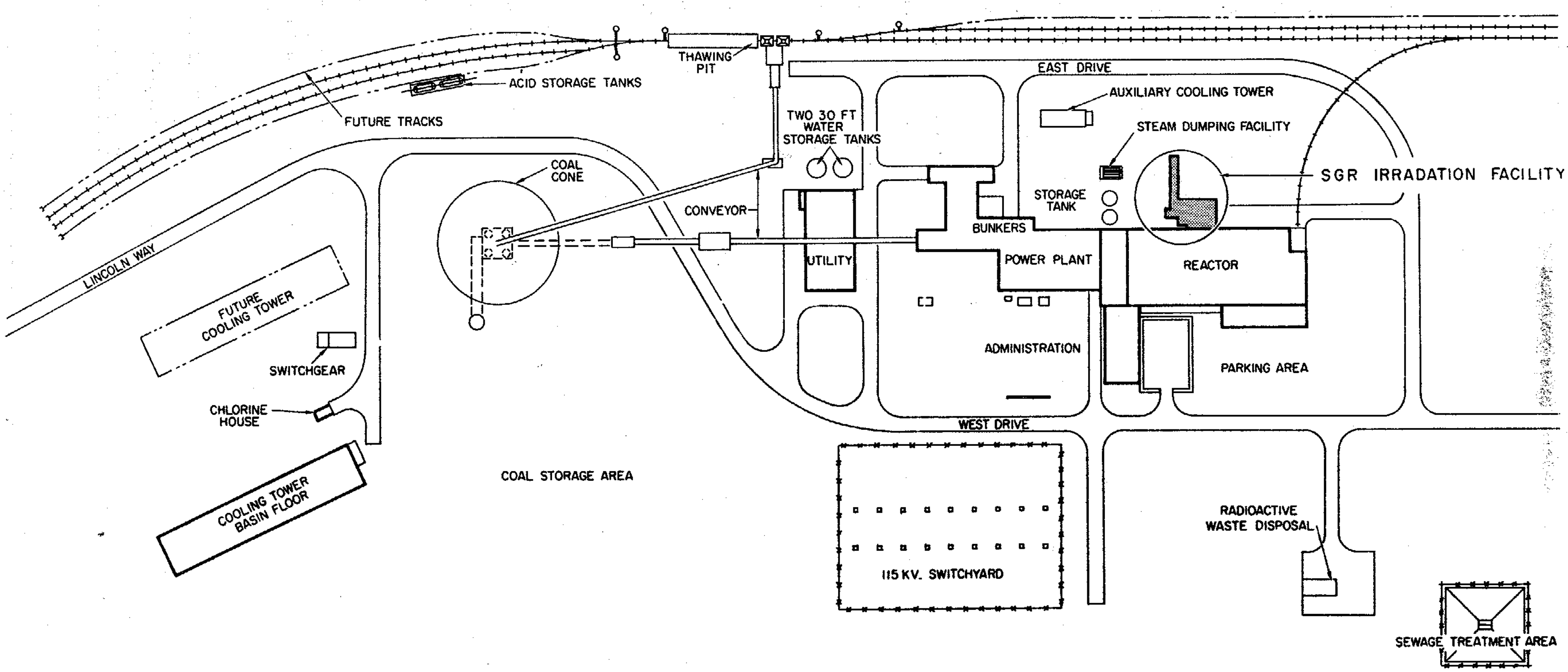


Figure 2. Plot Plan of the Irradiation Facility

II. RESULTS

A. GENERAL

The results of this study indicate that an irradiation facility using the sodium-24 source, inherent in SGR-type reactors, could be provided to process materials to a total dose level in the 10^6 rep range. The source strength of the facility described uses primary system sodium from the reference SGR and is calculated to be 2.11×10^5 rep/hr. This gamma-ray dose level results from a source density of 0.325 c/cm^3 in the primary system sodium. Total sodium-24 activity in the facility is approximately 3.5×10^6c.

The facility has a capacity to process an estimated 523 ton/day of a variety of materials to a total integrated dose of 10^5 rep. The design developed as a result of this study comprises four different types of conveyer systems to provide flexibility for handling different types of process material through the five-plaque cell. If process material involving standardized package configurations were to be processed through the facility, it is estimated that, by sacrificing flexibility, the capacity could be increased to approximately 800 ton/day at the same 10^5-rep dose level.

The installed cost of the facility is estimated at $770,000. This figure includes costs of facility piping, irradiation plaques, cell structure, engineering, and cell ventilation equipment necessary to provide controlled air flow in the cell at room temperature.

The installed cost of auxiliary equipment which is sensitive to market development has been estimated separately. A reference-material handling system consists of conveyors, drives, and controls; the cost is estimated at $120,000.

Additional refrigeration equipment to maintain a temperature of 20°F in the cell, if required, would cost an additional $125,000.

No estimates of the cost of materials loading, unloading and storage facilities have been determined because the size and arrangement of these installations would depend on customer requirements.

It is estimated that the operating costs for the facility would be $396.00/day. This figure includes the cost of the electrical power and manpower necessary to operate the conveyor systems and includes the handling of process materials through the facility.

The incremental processing costs for the reference facility (processing 523 ton/day at 10^5 rep) are listed as follows:

Fixed charges, facility (no auxiliaries)	0.0302 cent/lb/10^5 rep
Fixed charges, materials handling equipment	0.0047 cent/lb/10^5 rep
Fixed charges, refrigeration equipment	0.0049 cent/lb/10^5 rep
Operating costs, facility	0.0379 cent/lb/10^5 rep

These processing costs will vary directly with the integrated dose required by various products.

In addition to the above processing costs, consideration must be given to the extra transportation and handling costs which would be incurred by a given product made available for processing at the facility. Such costs will vary over a wide range. Transit privilege charges will vary from nothing for grain products to a range of from 0.063 cent/lb to 0.11 cent/lb for other commodities. If out-of-line hauls are required, the resulting charges would range from approximately 0.30 cent/lb for out-of-line hauls of 100 miles total for grain to approximately 1.40 cent/lb for out-of-line hauls of 500 miles total for meat. Handling costs will vary from a minimum charge for bulk materials to approximately 0.43 cent/lb for packaged materials.

B. FACILITY FEASIBILITY

The results of this study indicate that the technical feasibility of utilizing sodium-24 from an operating SGR in a materials irradiation facility has been established. Incorporation of the facility would necessitate no changes in the HNPF design or equipment. Therefore, construction of the facility would have no effect on the over-all HNPF scheduled activities. The facility is supplied by a small sidestream from the cold leg of the HNPF intermediate-heat-exchanger piping and, therefore, would not influence the operating efficiency of the reactor system. Sodium flow rate through the facility is 100 gpm and heat losses in the facility are negligible. The area at the HNPF site, in which the proposed facility would be located, is free from congestion; therefore, no interference with HNPF operations would be expected.

The facility capacity should be adequate to accommodate an initial market development program. If the market should increase, the facility capacity could be increased by enlargement of the irradiation cell and the installation of additional radiator plaques. Piping which supplies the facility with source material from the reactor system was sized to allow for such an increase.

The major emphasis of the study has been directed toward an analysis of processing costs connected with facility operation. It is shown that these processing costs would be relatively low if the facility capacity is fully utilized. This conclusion is based on the fact that the source material is a no-cost byproduct of the HNPF.

Whether the facility will be used at full design capacity is a question which will depend on the development of an active consumer market. The limited survey which was performed to develop the design arrangement of the reference facility has shown that a potentially active market might be developed for a facility located a at Hallam, Nebraska. However, the ultimate economic feasibility will depend on detailed analysis of marketing practices of each particular product. The extent to which an active market could be developed will depend on realistic evaluation of the benefits irradiation will afford each product and whether these desirable characteristics will justify sustaining the processing costs.

It would appear that the most favorable application of the facility located at Hallam, Nebraska, would be the processing of foodstuffs to the pasteurization or deinfestation dosages (10^4 to 10^5 rep). The second most favorable application would be the processing of foodstuffs and materials to higher dose-levels (10^6 rep). Dwell time for the higher dose levels (5 hr or more) might become a limiting factor for some products, however, it is not expected that processing costs at these levels would be prohibitive.

III. RECOMMENDATIONS

Since the ultimate economic feasibility of providing an incorporated irradiation facility at HNPF is dependent on market development, it is recommended that the facility be constructed as a demonstration plant to initiate market development studies. Commercial activity in products most attractive to irradiation processing in the Hallam area would seem to justify such a facility.

The facility should be carried through preliminary and final design stages by the earliest convenient date. The final design phase should progress on a schedule consistent with HNPF construction activities so that close coordination of the portions common to both facilities could be effected in a logical and convenient sequence.

It is recommended that the initial facility installation consist only of those portions of the facility necessary to provide the radiation source. This would include piping, plaques, cell structure and auxiliary instrumentation and ventilation. Additional facilities such as conveyors, refrigeration, housing for control equipment and personnel, loading docks, and storage facilities should be designed and constructed consistent with market development. Market development activities should be supported by giving consideration to research activities expected to be initiated by commercial interests.

IV. APPLICABILITY OF SODIUM-24 IRRADIATION PROCESSING

An integral part of the feasibility determination of sodium-24 irradiation processing of materials is the analysis of potential applications. Such an analysis must consider the following points:

a) An evaluation of the radiation characteristics of the source material,

b) An evaluation of desirable characteristics of processed materials exposed to practical dose levels in the facility,

c) An evaluation of the potential market peculiar to the location of the facility.

Development of application for sodium-24 irradiation processing is discussed below.

A. RADIATION CHARACTERISTICS OF SODIUM-24

1. Source Material Activity

Natural sodium consists of the single isotope, sodium-23, which upon neutron absorption, is transformed into the radioactive isotope, sodium-24. The half-life of sodium-24 is 15.06 hr. The isotope emits two gamma rays of 1.38 Mev and 2.76 Mev in essentially 100% of its disintegrations.

The specific activity of the HNPF coolant at full reactor power operation is calculated to be 0.325 c/cm^3. The specific activity of the sodium coolant is a direct function of the reactor power level and is determined also by the degree of dilution which is imposed on the coolant during its passage through the core and into the facility radiator system. The specific activity of 0.325 c/cm^3 is based on reactor coolant which has been diluted by the total 7100-ft^3 volume of the HNPF primary coolant system.

The specific activity of the sodium coolant has resulted in an estimated source strength in the facility in the range of 10^5 rep/hr. A more detailed analysis of the source strength is covered in section VI. Sudden changes in reactor power will produce slow changes in sodium activity because of the relatively long 15-hour half-life.

2. Induced Radioactivity

One of the characteristics of gamma-ray irradiation processing is the production of photo-neutrons in process materials. In the case of sodium-24 irradiation processing of foods, photo-neutrons can be produced through (γ-n) reactions in the absorbing material. The threshold energy, or minimum gamma-ray energy required for ejection of a neutron from a nuclei, will vary depending on the nuclear characteristics of the absorbing element. The level of such induced activity will depend on the (γ, n) reaction cross section as well as the weight fraction of each reacting element contained in the process material.

Several (γ, n) reactions having threshold energy levels of several Mev might be of concern in analyzing the technical aspects of irradiation processing. At approximately 9 Mev, iodine-127 undergoes a (γ, n) reaction resulting in a radioactive product with a half-life of 13 days. A minimum of 16 nuclear transformations occur in the 10- to 15-Mev range. In the range of 15- to 20-Mev, the (γ, n) reaction threshold for both carbon and oxygen is exceeded, and dangerous levels of radioactivity might be expected.

As stated above, the highest energy gamma-ray from sodium-24 is 2.76 Mev. Gamma-rays of this energy level are capable of producing neutrons in process material containing deuterium or beryllium. Most other elements have thresholds in excess of 6 Mev. The threshold energy for such reactions are 2.23 Mev for deuterium and 1.67 Mev for beryllium. The maximum (γ, n) cross sections over the range of 0- to 2.76-Mev photon energies are approximately 2×10^{-27} cm^2 for deuterium and 1×10^{-27} cm^2 for beryllium.[2] The weight fraction of these two elements in process materials (especially foodstuffs) would amount to only trace quantities in the case of deuterium and considerably less than trace quantities in the case of beryllium. Preliminary analysis of these data lead to the conclusion that the amount of induced radioactivity resulting from sodium-24 irradiation processing would be insignificant and would not present a health hazards problem.

B. CHARACTERISTICS OF PROCESSED MATERIALS

1. Wholesomeness of Irradiated Food[3, 4, 5, 6]

Foods given sterilization doses suffer vitamin loss comparable to that resulting from heat processing. Radiation sterilization has not been found to cause greater losses in the nutritive value of the protein of beef, beans, peas, and milk than are caused by other food processing methods.

Feeding tests of rats, mice and chickens led to the conclusion that no evidence indicating the presence of chronic or subacute toxicity, or indicating gross nutritional losses, other than vitamin losses, was apparent. Foods tested included standard poultry mashes, corned beef, pork sausage, salmon, shrimp, tuna, asparagus, brussel sprouts, cabbage, cauliflower, celery, mushrooms, peas, sweet potatoes, white potatoes, cherries, pears, crackers, macaroni, nutroll, and poundcake. Studies thus far have shown no evidence of carcinogens (tumor producing tissue) caused by radiation of food materials.

A short-term feeding test on human subjects indicated no toxic effects resulted from consumption of the 42 radiation-sterilized foods tested. These foods included white and sweet potatoes given 20,000 rep, since these were the doses required to inhibit sprouting.

Long term feeding of chickens, rats, and dogs has demonstrated that irradiated foods are equal to their respective nonirradiated controls as evaluated by rate of growth, reproduction, hematology, food consumption and food efficiency.

The Food and Drug Administration has outlined a test program which would have to be completed before they could permit irradiated food to be marketed.[7] This program includes animal-feeding studies to determine possible toxicity and nutritional adequacy of irradiated foods, tests to determine how storage affects irradiated foods, and tests given to "stress" groups of animals to determine how irradiated foods affect animals deviating from a normal health pattern. Final tests would then have to be conducted on human beings.

2. Acceptability of Radiation Sterilized Foods

a. Meats

With doses required for sterilization in the range of 2×10^6 rep, an undesirable odor and flavor occur in most meats. Various treatments lessen, but do not eliminate, these effects. Among those treatments which have been investigated are irradiation in the frozen state, in an oxygen-free atmosphere and the use of chemical additives.[8, 9, 10] These procedures usually prevent the development of an off-color during irradiation. However, these methods would be difficult to apply commercially, and do not completely eliminate off-flavor and odor. The texture of meats is not affected for doses below 3.5×10^6 rep.[10]

The following meats have been found to be acceptable after receiving a sterilization dose: bacon, beef liver, chicken, corned beef, ham, pork, and pork sausage.[2, 11] However, the storage properties of these foods are not mentioned. It has been reported that a combination of radiation sterilization with heat processing or with refrigerated storage leaves bacon, ham, liver and poultry unchanged after 6 months storage.[12] Since the quality and storage life of unirradiated cured meats are adequate for many purposes, the need to irradiate bacon, pork sausage, and beef might be questioned.

b. Fish

As with meats, deleterious side-effects usually occur with sterilization doses. The texture is also affected. Halibut and codfish cakes were not adversely affected in flavor by irradiation doses necessary to prevent spoilage in such products when held at a temperature of 98°F. Fresh halibut was much less affected by irradiation treatment than was defrosted frozen halibut.[13] Radiation sterilization in conjunction with heat processing, or with refrigerated storage, leaves halibut unchanged after 6 months storage.[12]

c. Dairy Products

Deleterious side-effects are severe in dairy products. However, it has been reported that by distilling milk under high vacuum during irradiation, the off-flavors, most of which were volatile under these conditions, were removed. The sterilized milk was undistinguishable, in taste and appearance, from whole fresh milk.[8, 14]

d. Fruits and Vegetables

Odor and flavor changes in fruits and vegetables are not severe when the product is given a sterilization dose, but in many cases there is a loss of characteristic crispness and freshness.

The following vegetables have been found to be acceptable after radiation sterilization: asparagus, green beans, broccoli, brussel sprouts, carrots, and sweet potatoes.[11, 13] Sweet potatoes were still acceptable after 8 weeks storage at 68°F. The storage properties of the rest of these foods are not mentioned. Because of enzyme activity, it might be anticipated that some of these foods would not remain acceptable for long periods of time. Radiation sterilization in conjunction with heat processing or with refrigerated storage, either of which would prevent or slow enzyme action, leaves green beans, broccoli and spinach unchanged after 6 months storage.[12]

3. Low-Dose Treatments

a. Insect Deinfestation of Grain

It has been estimated that insect infestation of grain results in an annual loss of 500 million dollars. It is while the harvested grain is being stored at the farm that infestation begins. From the farm to terminal elevators, the gradual destruction of the grain by insects continues. If irradiation took place at the terminal elevator, therefore, some damage would already have been done. Present methods of chemical control are relatively unsatisfactory. The advantage of radiation is that it can treat infestation both inside and outside the kernel. In addition, radiation can prevent insect eggs from hatching, so that one treatment completely eliminates insects from the grain.

A dose of 10,000 rep will sterilize grain insects and prevent reproduction.[15] Tests have shown that the baking properties of wheat given a dose of 25,000 rep are satisfactory. There have been two proposals for a grain irradiation facility.[15, 16] In one proposal the grain itself is irradiated, in the other flour is irradiated. In both arrangements the grain was given 25,000 rep as a safety margin over the 10,000 rep required.

b. Extended Refrigerated Shelf-Life of Meat

Irradiation at 75,000 rep has been shown to extend the refrigerated shelf-life of fresh meat up to five-fold.[8, 17, 18] At these doses the meat shows no detectable off-flavor, odor, or discoloration.[8] Irradiation at 200,000 rep doubles the refrigerated shelf-life of cured meats.[17]

Brownell[19] has proposed a new method of wholesaling fresh meats based on low-dose treatments from gamma-rays. The method consists of prepackaging fresh meat at packing houses, irradiating the meat with a dose of 3 to 8 x 10^4 rep to extend refrigerated shelf-life, and shipping to retail outlets.

c. Breaking the Cycle of Trichinosis[18, 20, 21]

It has been estimated that 25% of the general population of the U. S. develops trichinosis infection during their lifetime. While the infection is rarely fatal, trichinosis is, nevertheless, considered to be one of the major health problems in the U. S. It is possible to break the cycle of trichinosis by irradiating pork with a dose of 30,000 rep. This dose prevents maturation of encysted trichinae and produces no deleterious side-effects in the pork itself.

d. Cereal Products[21]

Cereal ration bars, fruit ration bars, brownie mixes and gingerbread mixes have been irradiated with 100,000 rep without adversely affecting their sensory qualities. This dose will destroy all forms of insect life. Cereal bars so treated have been stored for one year at 100°F without significant changes.

e. Inhibiting Sprouting in Potatoes[22, 23]

Gamma radiation in the range of 1 to 2 x 10^4 rep can greatly prolong storage life of potatoes, especially the Katandin-variety tubers. Effects on taste, sprouting, shrinkage, internal black spotting and texture were followed for 18 months. A taste panel found no undesirable taste in any irradiated samples after this period of storage. Sprouting was reduced at dosages as low as 1250 to 5000 rep and completely inhibited at 20,000 rep. Weight loss during storage was greatly reduced. Potatoes given 20,000 rep were still firm and excellent in appearance after 18 months of storage. Although different varieties of potatoes may require different doses to inhibit sprouting, most authors quote a figure of 10 to 20 x 10^3 rep without mentioning variety, so that it may be assumed that a dose in this range will inhibit sprouting in most varieties of potatoes.

f. Miscellaneous

Onions receiving 8000 rep did not sprout after being stored 153 days at 55°F, 70 to 80% relative humidity. However, irradiation did not prevent the onions from rotting.[24]

Beets given 20,000 rep from a gamma-ray source can be stored for at least 5 months without sprouting.[25]

About 10 to 15% of strawberries rot in transit. Irradiated with 10^5 rep, berries stayed mold-free after two weeks cold storage. Flavor and appearance were unaffected.[26]

The flavor of dried prunes and raisins was not affected by irradiation doses sufficient for the destruction of molds and various forms of insects.[13]

At room temperatures, storage life of oranges and lemons was extended several weeks by irradiation at 1.5×10^5 rep; there was less deterioration from the action of fungi.[12, 27] Other tests have indicated that irradiation caused faster yellowing of green lemons, and one author reports that some skin damage occurs at this dosage.[17]

It is reported that the storage life of peaches can be increased three-fold without affecting quality.[17] The required dose was not given. It has also been reported that low dose treatments of peaches can result in surface tissue damage.[28]

Ripening of soft fruits can be delayed by low doses in the 10 to 50×10^3-rep range; however, information about this application is not extensive.

4. Irradiation of Materials

a. Irradiation of Drugs and Pharmaceuticals

The problems which arise in the radiation sterilization of foods do not arise in the sterilization of drugs and pharmaceuticals. This is due primarily to the fact that pharmaceutical products are not regularly consumed as is food. Many drugs already marketed, like streptomycin, have definite toxic effects, but they are clinically useful since the value to be gained far exceeds the damage caused. Less concern need be shown, therefore, for the possible toxic effects of the products. Drugs are also relatively expensive to begin with, so that any additional small cost due to radiation sterilization would not significantly affect the price. Resistance to acceptance from the public might not exist because of the very nature of drugs. Radiation sterilization is already being used in some drug products.

It has been reported that irradiating K-Penicillin "G", Streptomycin, Auremycin, Chloromycetin and Terramycin with a dose of 1.92 x 10^5 rep resulted in a sterilized product whose potency was essentially unaffected.[29] However, there was no indication that these products were being commercially sterilized in this manner.

In addition, a glass has been devised by the Corning Glass Works which is satisfactory for packaging these products and which shows no discoloration upon irradiation.

b. Irradiation of Plastics and Other Long-Chain Polymers

To produce new and useful products, radiation doses of the order of 5 to 500 x 10^6 rep are required.[30] It is claimed that the modification of plastics by radiation shows commercial promise, and that the grafting of monomers to polymers might develop into an important industrial process.[31]

Unirradiated polyethylene is soluble in many organic liquids, especially above room temperature. When heated above 240°F, it behaves as a viscous liquid. However, irradiated with a dose of 5 to 10 x 10^6 rep, polyethylene becomes cross-linked, and a new type of plastic is formed which does not dissolve in hot organic compounds and will not melt at 240°F. Above 240°F, the plastic exhibits rubber-like elesticity.[32]

c. Miscellaneous

The sterilization of blood, serum and plasma offers commercial promise as the product sterilization techniques currently used for these products are not entirely satisfactory.[16] The dose required is approximately 4 x 10^6 rep. As yet, a technique has not been found which would sterilize the product and still leave its protein components unaltered.

One group reports the following results of irradiating materials.[33] The doses are not given but, from previous work, it may be assumed that they are of the order of millions of rep. These applications are not considered to hold significant commercial interest at present.

1) Benzene hexachloride can be produced by exposing a mixture of benzene and chlorine to gamma-rays.

2) Rubber can be vulcanized using gamma-rays without benefit of heat or sulfur.

3) Hydrazine, a rocket fuel, can be produced by irradiating ammonia Production costs have been reduced considerably since this process was first developed.

Examination of metals after exposure to radiation has shown significant increase in such properties as hardness, tensile strength, and yield strength. This is especially true for aluminum alloys. It must be added that such changes may not always be desirable.

Normally, foundry shell molds are cured by baking for several hours. Irradiation of the molds has reduced the operation to minutes.

The speed of response of a germanium semiconductor to electrical impulses was considerably improved after irradiation. This change appeared permanent and the current-voltage characteristics were not changed by the radiation.

C. APPLICATION SURVEY

A survey has been made to develop information pertaining to the potential market for an irradiation facility located at Hallam, Nebraska. The objective of the survey was to establish production and marketing characteristics of those products for which irradiation processing might prove attractive. Major emphasis was placed on the foodstuffs and materials which might benefit from such processing (section IV. B.). The survey information was used primarily to assist in the development of the design arrangement of the facility. A secondary use to which the survey might be applied would be to determine the desirability of locating a processing facility at Hallam from the standpoint of later market development. Information developed in the survey outlines the level of production of the various products in the vicinity of Hallam.

Firms located in the 13 states lying within a 500-mi radius of Hallam were considered. More distant firms which customarily ship products through the area to marketing destinations were also considered. The 13 states surveyed were Arkansas, Colorado, Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, Wisconsin, and Wyoming.

The following is a discussion of the major items of interest pertaining to each of the products under consideration as developed by the survey.[34]

1. <u>Fresh Meats</u>

The area covered comprises the most important meat producing and slaughtering area of the United States. Table I shows the quantities and the percentages of dressed weight of meat animals and poultry slaughtered in 1957.

TABLE I

LIVESTOCK AND POULTRY SLAUGHTERED IN THE SELECTED 13 STATES AND THE UNITED STATES IN 1957

Animal		United States	13 States	% of U.S. Total
Cattle	Head (No.)	26,232,000	12,425,000	47.4
	Dressed weight (lb)	13,852,000,000	6,786,000,000	49.0
Calves	Head (No.)	11,904,000	3,796,000	31.9
	Dressed weight (lb)	1,442,000,000	425,000,000	29.5
Hogs	Head (No.)	72,595,000	39,511,000	54.4
	Dressed weight (lb)	9,579,000,000	5,453,000,000	56.9
Sheep and Lambs	Head (No.)	14,957,000	6,994,000	46.8
	Dressed weight (lb)	694,000,000	331,000,000	47.7
Fowl	Head (No.)	212,408,000	88,248,000	41.5
	Dressed weight (lb)	757,000,000	309,000,000	40.8
Broilers	Head (No.)	1,451,661,000	183,267,000	12.6
	Dressed weight (lb)	3,519,000,000	412,000,000	11.7
Turkeys	Head (No.)	80,481,000	30,841,000	38.3
	Dressed weight (lb)	1,101,000,000	419,000,000	38.1

Of the 17 major slaughter centers designated by the United States Department of Agriculture, eight are located within the 13-state area. Table II shows the quantities of meat slaughtered in these eight centers in 1957. Small plant operations are characteristic of the poultry industry. It is not concentrated to the extent found in the slaughter of meat animals.

TABLE II

MEAT ANIMAL SLAUGHTER AT 8 MAJOR CENTERS WITHIN THE 13-STATE AREA IN 1957

Area	Animals (thousands of head)			
	Cattle	Calves	Hogs	Sheep or Lambs
Chicago	1,355	444	2,503	326
St. Paul-Wisconsin	1,597	1,403	4,940	681
St. Louis	796	236	4,315	412
Sioux City-South Dakota	962	-	2,710	598
Omaha	1,623	30	3,664	677
Kansas City	704	136	1,536	423
Iowa-Southern Minnesota	1,499	680	13,516	1,484
St. Joseph-Wichita-Oklahoma City	921	184	2,268	574
U.S. Total	26,232	11,904	72,595	14,957
8-Center Total	9,457	3,112	35,452	5,175
% of U.S. Total	36.1	26.1	48.8	34.6

The transportation of the meat industry depends mainly on the geographic flow, the type of product involved, and the type of carrier used. There has been a considerable increase in volume of truck movement, while the volume of rail movement has decreased. For meats, movement is around 26% rail, 74% truck. Major packers choose carriers according to the location of the plant and the market served.

Most railroads and trucking companies allow some specified commodities to be stopped in transit at designated places for other processing, and then shipped on to their destigation at the through rate. Usually, there is a small charge for this privilege. Without a transit privilege, the shipper would have to pay two local rates. The through rate applies only in one direction. Transportation to and from the Hallam plant will require that arrangements for transit privileges be worked out with the carriers.

Almost all poultry is carried by truck. Most of it is marketed within 500 miles of the processors' plants.

Most interstate shipments of beef, veal, and lamb is in the form of whole, half or quarter carcasses, whereas pork is shipped in wholesale cut forms.

A boxcar or truckload of meat contains a mixture of carcasses, cuts and meat byproducts such as lard to fit a purchaser's order. Probably some of these products will not benefit from radiation. The meat industry is more and more packaging retail cuts of higher priced products in a manner similar to that of cured meats such as bacon.

About 71% of all slaughtered poultry is marketed as fresh. Fresh poultry shipped to the market is either ice-packed or dry-packed in boxes, barrels, or drums. The boxes are of many sizes ranging from 5-1/4 to 10 in. deep, 18 to 30 in. long, and 14 to 24 in. wide. Prevention of spoilage is essential in the meat industries. The meat industry is geared to an elaborate system combining rapid movement, temperature control, use of preservatives, special handling, inspection, careful market analysis, and sensitive pricing. Due to this care, very little spoilage occurs.

Factors favorable for irradiation processing are:

a) Hallam is close to large volume producing centers of meat (peculiar to HNPF),

b) Possibility of reducing refrigeration costs,

c) Complete purification obtained by irradiation would appeal to consumer,

d) Irradiated meat is easier to merchandise than frozen meat.

Factors unfavorable for irradiation processing are:

a) Higher costs of maintaining inventory by increasing shelf life,

b) Successful methods of present spoilage prevention,

c) The large sums of capital investment tied up in refrigeration,

d) New capital investment needed for storage and handling equipment,

e) Absence of a central market organization to provide systematic flow of meat shipments to and from Hallam (peculiar to HNPF),

f) The lack of concentration of production in poultry.

2. Cured Meats

Cured meat has been treated with chemical additives causing it to change color and flavor. Today, the bulk of cured meat still requires refrigeration.

About 2% of beef and 50% of dressed hog production is cured. The cured parts of pork are hams, bacon, picnics, loins, fat backs, and trimmings. Table III shows the figures recorded for meat and meat products prepared and processed under federal inspection in 1957.

TABLE III

SOME OF THE MEATS AND MEAT FOOD PRODUCTS PREPARED AND PROCESSED UNDER FEDERAL INSPECTION IN THE UNITED STATES IN 1957*

Product	Production (thousands of pounds)
Placed in Cure	
Beef	165,812
Pork	3,365,675
Other	1,417
Smoked and/or Dried	
Beef	55,370
Pork	2,416,210
Cooked	
Beef	88,445
Pork	307,431
Other	3,495
Sausage	1,651,415
Bacon, Sliced	932,264
Other, Sliced	223,415

* Canned meats are not included in Table III.

Of the United States cured-meat production, about 30% is produced in the 13-state area. Even though a good part of the production is used within the state produced, processors have to ship long distances to find markets.

Most cured meats are packaged by processors. The small packages are boxed in quantities up to 20 lb in fiberboard containers. These containers usually measure 6 by 12 by 14 in.

The dehydrating effect of salting, smoking or drying deters the growth of organisms which may cause spoilage. However, during transportation, storage, and display of these products, refrigeration is still required.

Factors favorable for irradiation processing are:

a) Hallam is reasonably close to processors who ship long distances (peculiar to HNPF),

b) Possibility of reducing refrigeration costs,

c) Ease of handling cured meat packages.

Factors unfavorable for irradiation processing are:

a) Production is not concentrated,

b) Curing partially deters spoilage.

3. Grain

The 13-state area produces wheat, corn, oats, barley and rye as shown in Table IV.

Grain moving to primary markets will be the most likely market for irradiation. Of the grain produced, the amounts moved to primary markets is shown in Table V.

Transportation is a major consideration in the grain industry. The quantities that are handled are large while the unit value is low. Transportation costs determine grain-industry decisions, because transportation costs are often higher than processing costs.

Production of grain is seasonal. Harvesting extends from May to November. It is during this period that grain has to be moved from the field to storage, although grain is shipped to the market all year round.

TABLE IV

PRODUCTION OF MAJOR GRAINS IN THE 13-STATE AREA IN 1957

Primary Market	Grain Production (thousands of bushels)		% of U.S. Total
	U.S.	13-State Area	
Wheat	947,102	519,467	54.8
Corn	3,060,485	2,061,849	67.4
Oats	1,308,360	958,577	73.3
Barley	435,695	174,792	40.1
Rye	26,528	18,410	69.4

TABLE V

RECEIPTS OF MAJOR GRAINS AT PRIMARY MARKETS IN THE 13-STATE AREA IN 1957

Primary Market	Grain (thousands of bushels)				
	Wheat	Corn	Oats	Barley	Rye
Chicago	24,236	137,577	16,160	12,116	3,988
Minneapolis	143,236	53,119	35,613	66,437	4,484
Duluth	85,844	3,013	9,040	26,644	2,458
St. Louis	31,999	44,911	2,888	2,246	96
Milwaukee	859	11,766	1,359	26,638	35
Kansas City	76,756	28,644	4,202	1,024	328
Omaha	24,678	24,320	4,964	499	905
Peoria	308	31,578	525	74	82
St. Joseph	9,722	7,464	5,407	201	14
Sioux City	4,406	13,441	5,780	236	224
Wichita	25,950	1,693	36	49	19
Hutchinson	18,292	1,160	6	152	52
U.S. Total	947,102	3,060,485	1,308,360	435,695	26,528
12-Market Total	446,286	358,686	85,980	136,316	12,685
% of U.S. Total	47.1	11.7	6.6	31.3	47.8

Most grain is carried from country elevators to terminal markets by railroad. During recent years motor and water carriers have increased their share.

The transportation pattern for grain products is complex, because it is affected by production, location of producing plants and consuming markets, and the end use of the product.

The grain industry has adopted its equipment and methods to accommodate bulk shipment. Mainly railroad boxcars or truck-trailers are used. Because of the high cost of transportation in comparison to the value of the grain, non-essential movements are resisted. Moreover, excessive handling increases the amount of kernel breakage. Damaged kernels are objectionable in grain.

Heat, molds, bacteria, insects, rodent filth, sprouting, odors and a number of other factors affect the condition of grain. The greatest amount of spoilage occurs during storage, while some might take place in the field or during transportation.

After harvest, the most serious threat to grain comes from beetles, weevils, borers, and moths. The yearly grain stores destroyed by these insects is enormous. Fresh grain from the combine has little infestation.

To minimize insect infestation, grain-elevator companies have used chemicals and the process of turning the grains. The main purpose of these grain protectants is to stop the life cycle reproduction of females and not to kill the live insects.

Terminal elevators carry on an active program of decontamination. The main danger comes from combining infested grain with noninfested. Elaborate inspection systems are operated at terminal markets by the Food and Drug Administration, Federal Grain Inspection Department, USDA, state inspection departments, and miller-owned laboratories. Any new treatment applied to grains, such as irradiation, would have to be approved by all the agencies concerned.

The use of fumigation is increasing. Although the cost of fumigation is nominal, because of the low margins of profit on grain, it is used only for grain intended for long-time commercial storage.

Factors favorable for irradiation processing are:

a) Hallam is in the center of grain producing areas (peculiar to HNPF).

b) Grain spoilage, because of strict regulations, may be considerable.

c) Well-defined geographic flow of grain.

Factors unfavorable for irradiation processing are:

a) High cost of transporting grain in comparison to its low value,

b) Necessity for bulk-handling equipment wherever handling is required,

c) Resistance of the trade to nonessential movement,

d) Increasing the possibility of downgrading because of kernel breakage,

e) Narrow profit margins and reluctance to incur added expenses,

f) Satisfaction with present low-cost spoilage-prevention methods,

g) Contamination may occur too early or too late to be remedied by radiation in transit.

4. Flour, Cereal Products, and Partially Baked Items

The 13-state area produces a considerable amount of these items, as shown in Table VI. The grain-using industries are of great importance to that area.

Partially baked items amount to less than 5% of the output of the bakery industry, and can be neglected.

All bakery products depend on freshness. Rapid and efficient transportation is essential; as a result, transportation of consumer products is primarily by truck. There is little interstate transportation of these goods. To provide fresh stocks regularly at literally thousands of retail outlets, these industries have tended to remain decentralized. For higher priced bakery products, such as cakes and pies, cross-country transportation is becoming increasingly important. As a result, it has turned the attention of bakery executives toward reduction of spoilage during long hauls.

TABLE VI

VALUE OF SHIPMENTS OF SELECTED FOOD PRODUCTS FROM MANUFACTURING PLANTS IN THE 13-STATE AREA, 1954

Products	Total Value (thousands of dollars)		% of U.S. Total
	U.S.	13-State	
Flour and Meal	1,858,000	643,542	34.6
Flour Mixes	254,000	67,464	26.6
Cereal Breakfast Foods	346,000	12,025	3.5
Bread and Related Products	3,067,000	582,180	19.0
Prepared Animal Feeds	2,702,000	779,005	28.8

Flour in large quantities is shipped in bulk carloads, mostly by rail; however, 100-lb bags are gaining popularity. Consumer packages range from a few ounces to 25 lb. These packages, in 12, 24 or 48 units are enclosed in corrugated shipping cartons.

For cereal products, little concern is expressed over shelf life in either the store or kitchen, because sale and consumption is expected to take place rapidly. Shipments of consumer packages enclosed in corrugated cartons are large in volume, but weigh relatively little and often are of low unit value.

Basket and wire racks have been developed for use in the baking industry. These racks have been developed for moving crushable packaged products to retail store by trucks, and also for maximum exposure to ventilation. Different sizes are made of both steel and aluminum. A steel wire basket measures 26-1/8 in. by 21-5/8 in. by 6-1/4 in. while an aluminum basket measures 24-1/2 in. by 21-1/2 in. by 6-1/4 in. The aluminum basket slides into grooved holders in truck trailers as well as push carts. They can be loaded and rolled directly into trucks without unnecessary handling.

Spoilage in flour shipped or stored in bulk occurs primarily through insect infestation and moisture condensation. Insects will breed in any location where accumulations of flour, grain, or other milling stock remains undisturbed. Some infestation will show up in every mill in spite of precautionany measures. Insects that feed externally on grain can be removed easily before milling. However, the industry is bothered by insects that feed within the wheat kernels, and by residual insect eggs that may later hatch.

The Entoleter, a device used for cracking insect eggs, is 90 to 99% effective in preventing egg hatching. Grains may be passed through this device before they are milled, and flour is run through before it is packed.

Reliance is placed on the package itself to keep the flour free of insects. A tight seal and multiwall paper are considered adequate to resist insect invasion until the seal is broken.

Cake, brownie and gingerbread mixes, and flour in consumer packages are preserved by the inherent dehydrating effects resulting from normal processing, such as boiling, drying or grinding of ingredients.

White bread has a 48-hr shelf life. This may be extended to 4 or 5 days by adding chemical mold inhibitors such as sodium or calcium propionate. "Brown'N Serve" products have a shelf life of 6 to 9 days. Sweet goods will remain salable for 6 to 10 days.

Like fresh meats, the principal means of spoilage control for baked goods is a rapid system of distribution to retail stores. Stale items are removed promptly. The industry usually expects 6% staling losses of bread. Rapid turnover is accomplished by maintaining small inventories, frequent delivery, and restricting distribution to a small area. It is possible to double or treble shelf life by the use of packaging which is more efficient, but more costly, than those now used. However, because of the importance of freshness to consumers, it is felt that extension of shelf life is not necessary.

The United States Food and Drug Administration has placed restrictions on the use of chemical additives in products for interstate commerce. It is the belief of the federal authorities that these chemicals may be injurious to health.

Refrigeration, especially quick freezing and quick defrosting, is popular in the bakery industry. Freezing extends storage life of baked goods up to 6 months. Refrigeration must be used in transportation of "Brown'N Serve" items to preserve moistness. However, the industry does not have large sums of money tied up in refrigeration equipment.

Factors favorable for irradiation processing are:

a) These industries produce a very large volume.

b) The production of cereal breakfast foods and flour mixes is concentrated.

c) There is a growing tendency toward concentration of production in higher priced baked goods.

d) Concern for various forms of spoilage and interest of spoilage control without heavy investment.

e) Using present containers, consumer-packaged products can be easily handled at the radiation plant.

Factors unfavorable for irradiation processing are:

a) Production of most baked goods, flour, meal, and animal feeds is among smaller firms with limited markets.

b) Freshness is preferred to extended shelf life.

c) Current means of spoilage control are deemed satisfactory.

d) Unfavorable opinion based on reports of early experiments with irradiation.

5. Potatoes, Onions and Beets

The U. S. production of Irish potatoes during 1957 was almost 24 billion pounds. Sweet potatoes accounted for another 1.8 billion pounds. Production in the 13-state area occurs mostly in the late summer and fall. Growers in this area shipped 16.3% of the U.S. potato crop in 1957. Table VII give the data on rail shipments during 1957. Besides the 29,000 rail carlots, another 25,000 were reported moved by truck.

The production of onions has varied and there has been a shift in production areas. The Midwest has accounted for about 20% of the total U.S. production. Rail shipments of dry onions in the 13-state area is shown in Table VII. More than 1400 rail carlots were reported in 1957, and another 3329 carlots were reported as truck shipments.

TABLE VII

RAIL SHIPMENTS OF POTATOES, ONIONS, AND BEETS BY GROWERS IN THE 13-STATE AREA IN 1957

Crop	Shipments (carlots)		% of U.S. Total
	U.S.	13-State Area	
Potatoes	178,808	29,155	16.3
Onions*	16,576	1,434	8.7
Beets†	115	0	0.0

* Dry only, excluding green or sets
† Exclusive of sugar beets

About 160,000 tons of beets were produced in the U.S. in 1957. Beet production in the 13-state area was negligible.

Present trends indicate that family size packaging will be almost universal in the future marketing of items of fresh produce. This is especially true of commodities to which packaging gives protection from bruising, preservation of quality, sanitation, consumer appeal, and consumer convenience. Currently, packaging is done to some extent at all levels, namely, by the producer, packaging plant, wholesaler, and the retail store. The point at which packaging should be done is still a controversial issue.

Most bulk potatoes are carried in 50-to 100-lb bags or sacks. The most widely used 100-lb bag measures approximately 36 in. long and 23-1/2 in. wide. The 50-lb bag measures about 29 in. long and 9 in. wide. A fiberboard box holding 50 lb of potatoes is also in wide use. The approximate dimensions of the box are 17-1/8 in. by 13 in. by 9-1/2 in.

Studies indicate that potatoes shipped in fiberboard boxes bruise less than in burlap bags. Bruising of potatoes averages about 15% in bags, but less than 1% in boxes. Moreover, bruising gets progressively worse in burlap bags from the top layer to the bottom layer on the floor of the railroad boxcar. Boxes are not significantly affected by their location or position in the railroad car. Some experiments have indicated that irradiated potatoes have a tendency to bruise more easily.

Bulk dry onions are usually shipped in 50-lb crates. Also, 50-lb sacks are used to a limited extent.

For bulk beets, exclusive of sugar beets, the bushel bag capable of containing 50 lb is the usual shipping container.

Antibiotics have been tested as a post-harvest dip for various fresh vegetables including potatoes to reduce seed piece decay. Some potatoes deteriorate from insect infestation originating during transit. Fumigation can reduce these losses. Sprout inhibitor sprays are used to minimize losses from sprouting. Refrigeration is considered most important after packaging of potatoes, onions, and beets.

Factors favorable for irradiation processing are:

a) Handling of most consumer packages and most master containers is easy.

b) The industry seems willing to adopt new methods.

c) There is a constant struggle to prevent all types of spoilage.

Factors unfavorable for irradiation processing are:

a) Production of potatoes, onions and beets in the 13-state area is small compared to total U.S. production.

b) The possibility of bruising potatoes by extra handling.

c) The possibility of reducing the "healing" power of potatoes after irradiation.

6. <u>Citrus Fruits, Peaches and Strawberries</u>

California and Florida grow approximately one-half of the nation's commercially produced fruits and vegetables. There is a vast transportation system linking specialized growing areas with centers of population. Today, fresh fruits and vegetables are available year-around.

The 13-state area does not produce any citrus fruit. All fruit movements are coordinated by the California Fruit Growers Exchange. Movement of fruit is planned in advance in such a manner that, insofar as possible, no market will be over or under supplied at any given time. Table VIII gives the production of citrus fruits in 1957.

TABLE VIII

PRODUCTION OF CITRUS FRUITS IN 1957

Fruit	Production (boxes)
Oranges	131,690,000
Tangerines	4,500,000
Grapefruit	44,700,000
Lemons	14,700,000
Limes	400,000

In 1957, the total production of peaches in the U.S. was 61 million bushels. The 13-state area produced slightly over 4 million bushels, which is 6.8% of the U.S. production.

The total U.S. production of strawberries in 1957 was 62,335,000 bu. The 13-state area produced 4,255,000 of this, or 6.8%.

Almost all fresh produce moves to market either by rail or by truck. Transportation by truck has been increasing and that has tended to decentralize marketing institutions. Trucks possess two distinct advantages in competing for fresh produce traffic. Their speed minimizes the need for refrigeration in transit and reduces the risk of sudden price drops. Fresh fruits at times are shipped before a buyer is found. They are sold while they are "rolling".

Most citrus fruit is packed in 1-3/5 bu wirebound boxes. The use of 4/5-bu wirebound boxes has been on the increase. Wirebound boxes account for more than 61% of shipments. Less than 10% has been shipped in mail boxes. Five and 8-lb bags have been used for about 8 to 10%. Bulk shipments have accounted for less than 4%. A recent development is the 4/5-bu fiberboard box. For close to 15% of shipments, the fiberboard box was used.

Peaches are usually shipped in the conventional 3/4-bu basket. Experiments are being conducted to package peaches in celled cartons ready for the consumer.

The recent advances made in maintaining the quality of fresh fruit have been significant. Chemicals are being used to extend the market life of citrus fruits. Antibiotics have been tested as a post-harvest dip for fresh fruits and vegetables. Besides chemicals and antibiotics, new packaging materials are being developed to maintain quality. Some spoilage occurs from the blue mold of citrus fruits, the brown rot of peaches, and the gray mold and Rhizopus rot of strawberries.

A critical factor in both fresh and frozen citrus fruits, peaches and strawberries is temperature control. If the temperature of the fruit is raised several times during processing after the fresh fruit is first chilled, there is a good chance for deterioration and spoilage. It is not possible to repair the damage once it has occurred.

Factors favorable for irradiation processing are:

a) Hallam is on the normal rail route of citrus fruit from California, Texas, and Arizona (peculiar to HNPF).

b) There are well defined arrangements with rail carriers to permit diversion, reconsignment, and elastic routing.

c) Shipping containers are easy to handle.

d) The supply is concentrated and cooperatives do most of the distribution of fresh fruits.

Factors unfavorable for irradiation processing are:

a) Other means to control and prevent various forms of spoilage are successful.

b) Processing will consume valuable time; this might upset the closely coordinated scheduling of movement of fruit to market.

c) The need of using trucks will increase, with lack of scheduled transportation routes in many instances.

7. Chemicals, Plastics, and Rubber Vulcanizing

Market factors involved in the potential usage of radiation to chlorinate benzene, to make hydrazine, to polymerize monomers, to crosslink polyethylene, and to vulcanize rubber by using gamma-ray irradiation has been investigated.

Most products that could employ radiation as a catalyst are low-yield products. Handling of very large amounts of materials are required to produce small amounts of the desired compounds. Therefore, plant equipment and processes will be completely different from those required merely to expose products to radiation plaques.

Detailed figures on production of chemicals are not given. Table IX gives some figures to illustrate the magnitude of these industries. Plastics production and rubber manufacturing are on the upswing.

Manufacturers' interest in rubber vulcanization by radiation centers upon the possibility that vulcanizing could be accomplished without using heat or curing ingredients. B.F. Goodrich Company successfully vulcanized a full-size passenger tire in this manner in 1957. Sales of rubber products in 1957 was over 4.5 billion dollars.

TABLE IX

UNITED STATES PRODUCTION OF PLASTIC MATERIALS AND SYNTHETIC RUBBER IN 1957

Material	Production (thousands of lbs)
All Synthetic Plastics and Resin (Excluding cellulosics)	4,231,000
Polyethylene	682,800
Urea and Melamine	308,500
Vinyls	841,200
Phenolics, etc.	475,900
Polyesters	94,800
Polystyrene	635,400
Synthetic Rubber	2,822,400

To make hydrazine and benzene hexachloride, benzene, ammonia, and chlorine are needed. Rail tankcars are the most common carriers for the three raw materials. Hydrazine is shipped in carboys or metal drums. It is highly unstable and must be treated as an explosive. Benzene hexachloride is customarily shipped in drums after it has been ground into a powder.

It is expected that to both plastics and rubber products, radiation will be applied to finished articles. These come in a variety of shapes, sizes, and containers.

Factors favorable for radiation processing are:

a) The volume of plastics and rubber goods production is growing rapidly.

b) There is a widespread interest in radiation experiments.

Factors unfavorable for radiation processing are:

a) For chemical processing, large scale, special equipment is necessary.

b) Chemical, plastics, and rubber products industries are scattered over a wide area.

c) The industry feels that irradiation processing is prohibitively expensive in the present state of development.

d) The industry is of the opinion that low-dosage sources are adequate.

8. Drugs and Pharmaceuticals

Manufacturers of pharmaceutical preparations in the 13-state area accounted for 14.6% of the total U.S. production in 1954. The value of the 13-state production exceeded 240 million dollars.

Drugs and pharmaceuticals are mainly transported by rail. Air shipments are playing an increasingly important role. All interstate shippers must conform to the provisions of the Federal Food, Drug and Cosmetic Act. The law governs the packaging and labeling of these products. For a drug product to be marked "sterile" on the package, it must be sterile at the time it is shipped. This is an important item because radiation to attain sterilization would have to take place before final packaging. Under existing regulations, a manufacturer outside Nebraska would not be able to package his product, mark it "sterile", and ship it to Hallam unsterilized.

Containers for drugs come in all variations, but ususally are small, less that 1/2 pint in volume. The variation in containers should not cause a problem.

If products were shipped from drug manufacturers to Hallam, there should be strict control. Detrimental biological actions could take place if these products were shipped without prior sterilization. Quality control would have to be established at the radiation facility for such shipments.

Heat-sensitive drugs are costly to sterilize. The pharmaceutical industry has been on the outlook for less detrimental methods of sterilization. At the present time, sterilization is accomplished either by autoclaving, gas sterilization, or bacteriological filters. The heat-sensitive products are the ones most likely to lend themselves to radiation sterilization.

Radiation sterilization is not a new idea in the pharmaceutical industry. One manufacturer did market a product sterilized with the use of an electrostatic generator. The product was an ointment for the eyes that was heat sensitive. It was price competitive and a logical product for radiation sterilization. The product did not sell well; it has been withdrawn from the market.

A linear accelerator is currently used to sterilize sutures. This product is the only one known to have received wide acceptance after being sterilized by radiation.

Experiments have shown that some products, like penicillin, change color when irradiated; also, irradiation of aqueous sterile solutions tends to reduce potency.

Factors favorable for irradiation processing are:

a) Consumer reaction to radiation of drugs may be favorable.

b) Heat-sensitive drugs are difficult to sterilize under present methods.

c) Industry is willing to accept changes and improvement.

d) The size of the containers are adaptable for radiation.

e) The industry is concentrated.

f) The unit value of the products is high.

Factors unfavorable for irradiation processing are:

a) The manufacturers desire to provide radiation processing in their own production lines.

b) Biological actions could take place during shipment of unsterilized products.

c) The present methods of sterilization are successful.

d) The position the United States Food and Drug Administration and other authorities will take is uncertain.

V. RADIATOR DESIGN AND ARRANGEMENT

The following is a discussion of those factors which must be considered in establishing the most efficient radiator design and arrangement within the process cell. Several types of radiators were analyzed. Having chosen the type of radiator, consideration was then given to selecting an optimum arrangement of the radiators (plaques) in the facility. Of special interest in determining the number and arrangement of the plaques were (a) maximum dose rate, (b) capacity of the facility, and (c) materials handling convenience.

A. SOURCE CONFIGURATION

Several geometrical configurations of gamma-ray sources for irradiation processing are possible. When making the selection of a source geometry, materials handling convenience, uniformity of exposure, and maximum utilization of available gamma energy must be considered. Source configuration possibilities include a long cylinder, a sphere, a hollow cylinder or drum, and a spiral or rectangular slab.

The long cylinder, sphere, and hollow cylinder appear to be impractical because of the problem of low gamma utilization as well as the nonuniformity of exposure levels. The relative construction problems connected with those geometries were considered to be another disadvantage.

For uncollimated gamma-ray sources, which produce radiation in all directions, an arrangement of a slab geometry has been selected as the most efficient type of configuration. Exposure rate variations across the face of the slab would be less severe than with other configurations considered. Preliminary calculations indicate that the gamma-ray dose rate from a spiral slab radiator would be lower than the exposure level obtained from an equivalent rectangular type. Detailed treatment of this analysis is included in subsection D. Cost of fabrication and the simplicity of cell component arrangement also would indicate that a rectangular slab type of source configuration is more desirable. The facility design, therefore, has been developed around the rectangular-slab (plaque) type radiators.

The rectangular slab or plaque used as the radiator for this design is double walled. Figure 3 shows details of the plaque. The inner shell which holds the sodium is made of 3/8 in. stainless steel, is 19 ft 4 in. long, 12 ft high, 4 in. wide, and has 27 baffles spaced 8 in. apart. The plaque will contain 70-1/3 ft^3 of sodium. The outer shell is the secondary containment tank. The outer containment is made of 1/4 in. stainless steel, and is 19 ft 8 in. long, 12 ft 4 in. high and 8-3/4 in. wide. Outside the containment tank, there are 27 alloy sheath tubular heaters capable of raising the temperature of the plaques to 560°F. The plaques are provided with 3 in. of insulation external to the containment tank to minimize heat transfer to the cell from the hot liquid sodium. A nitrogen atmosphere is maintained in the containment tank and is monitored for activity. Any activity present would indicate a sodium leak. There are also probe and grid type leak detectors at the bottom of the containment tank.

The 4-in. thick sodium region of the plaque is considered to be an optimum dimension. Different widths of plaques were considered. Taking into consideration costs, fabrication difficulties, and sodium residence time, a 4-in. wide plaque was selected. As the width of the plaque is increased, the amount of contained sodium increases; therefore, a higher dose rate is obtained. At the same time, the following are raised: (1) self-absorption of gamma-rays, (2) required sodium volume in the system, and (3) the cost of each plaque. Unless the capacity of the pump is changed, the residence time of the sodium inside the plaque is higher and lowers the dose rate.

The distance between baffles is not critical. If the baffles are spaced too far apart, channeling of the sodium might take place. If they are spaced close together, the fabrication price, the ratio of the volume of metal to sodium inside the plaque, and the pressure drop across the plaque would increase. From an engineering point of view, an 8-in.-baffle spacing was found to be satisfactory.

B. SOURCE STRENGTH

Source strength is the gamma energy available per unit time. It is the product of the number of radioactive disintegrations per unit time multiplied by the average gamma energy emitted per disintegration.[35]

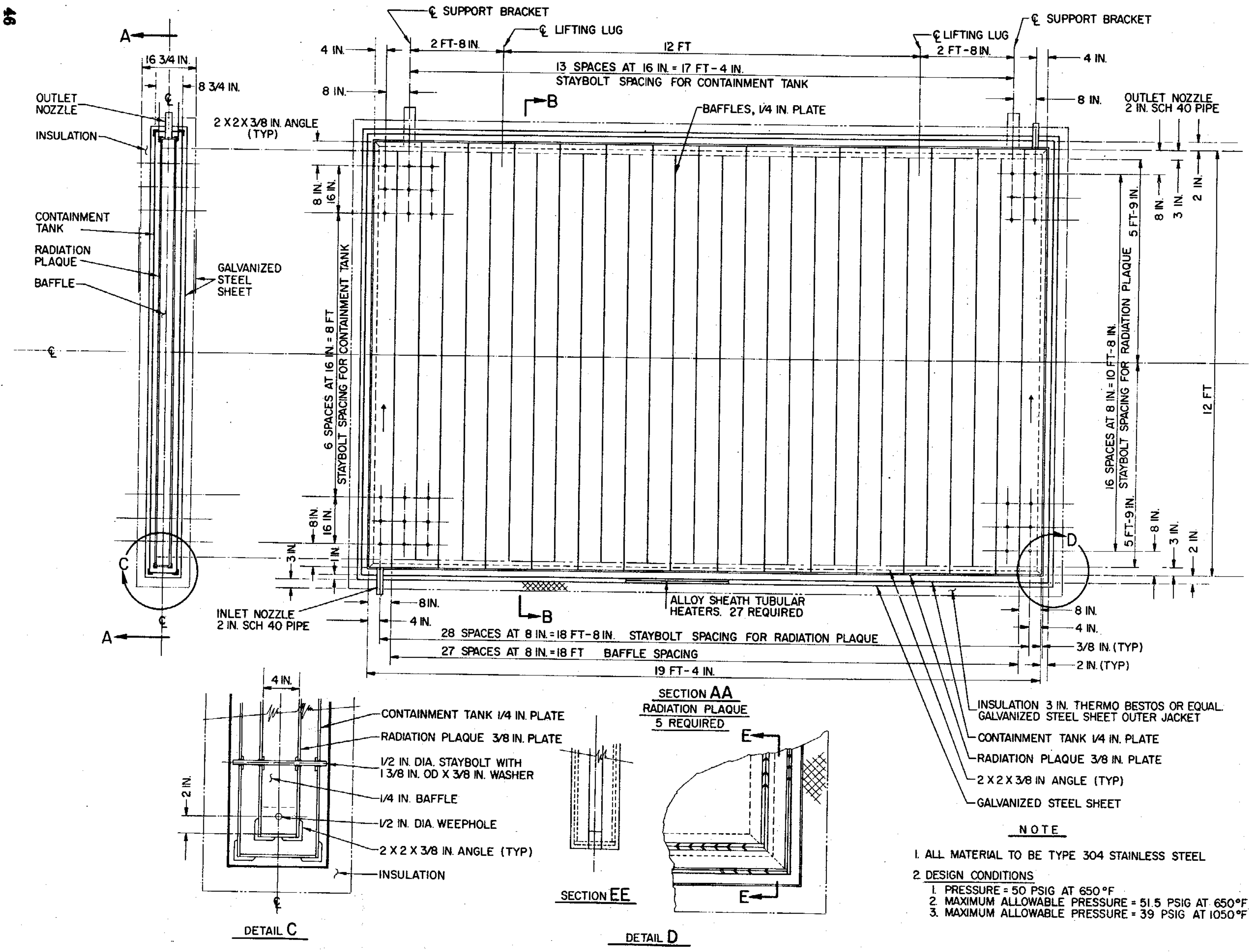


Figure 3. The Radiation Plaque

The processing capacity of an irradiation plant is proportional to the source strength. Because of losses, the radiant energy absorbed in the process item is always less than the source strength. The radiant energy is lost by (1) self-absorption in the source, (2) missing the process item completely and, (3) by-passing through the process item without complete absorption.

For this design, the sodium-24 from the return leg to the reactor from the HNPF is used. The sodium used as source material is a small part of the sodium coolant of the power reactor.

The specific activity of the sodium-24 coolant in the HNPF is calculated to be 0.325 c/cm^3 when the reactor is operating at full power. The volume of the sodium-24 in the primary system of the HNPF is approximately 7100 ft^3. The sodium volume in the irradiation facility is approximately 380 ft^3.

The integrated gamma-ray dose for the conveyor system is based primarily on the average gamma-ray dose rate in the plaques, the length of the conveyor system, and the speed of the conveyor.

The following assumptions and data were used to determine the source strength in the irradiation plaques.

1) Specific activity of sodium = 0.325 c/cm^3,
2) Sodium volume in each plaque = 70-1/3 ft^3,
3) Total volume in each plaque = 77 ft^3,
4) Effective source strength of plaque = 0.915,
5) Sodium gamma-ray energies: E_1 = 1.38 Mev (100%) and E_2 = 2.76 Mev (100%),
6) Effective volume source strength: S_{V_1} = 1.53 x 10^{10} Mev/cm^3-sec and S_{V_2} = 3.06 x 10^{10} Mev/cm^3-sec,
7) Sodium thickness = 4 in.,
8) Steel plate thickness = 0.625 in.,
9) Plaque presents an infinite slab source to material being irradiated.

The following equation for an infinite slab source is used to calculate the gamma-ray dose rate at the surface of the plaque:[36]

$$D = \frac{BS_V}{2\mu_s K} \left[E_2(b_1) - E_2(b_3)\right] \quad , \qquad \text{...(1)}$$

where

B = dose build-up factor

S_V = volume source strength (Mev/cm^3-sec)

μ_s = source linear absorption coefficient (cm^{-1})

K = gamma-ray flux to dose rate conversion constant (Mev/cm^2-sec)/(r/hr)

$$E_2(b) = b \int_b^{\infty} \frac{e^{-t}}{t^2}\, dt$$

$b_1 = \mu t$ (mfp)

μ = linear absorption coefficient of shield (cm^{-1})

t = thickness of shield (cm)

$b_3 = b_1 + \mu_s h$ (mph) where h = thickness of source

The following values were determined for the plaques:[37]

$K_1 = 5.6 \times 10^5$ (Mev/cm^2-sec)/(r/hr)

$K_2 = 6.72 \times 10^5$ (Mev/cm^2-sec)/(r/hr)

$\mu_{s_1} = 0.044$ cm^{-1}

$\mu_{s_2} = 0.038$ cm^{-1}

$t_{1,2}(Fe) = 1.59$ cm

$h_{1,2} = 10.2$ cm

$\mu_1(Fe) = 0.39\ cm^{-1}$

$\mu_2(Fe) = 0.286\ cm^{-1}$

$B_1(Fe) = 1.8$

$B_2(Fe) = 1.5$

The resulting gamma-ray dose rates at the surface of the plaque are 7.9×10^4 r/hr from the 1.38-Mev gamma-ray photons and 1.56×10^5 r/hr from the 2.76-Mev gamma-ray photons. The total gamma-ray dose rate at the surface of the plaque would be 2.35×10^5 r/hr. Since the conversion factor for gamma radiation from roentgens to roentgen equivalent physical (rep) is 1, the gamma-ray dose rates can be converted directly to rep/hr.

The specific activity of the sodium coolant is taken as 0.325 c/cm^3. This may be an erroneous assumption. Preliminary results for the SRE primary sodium specific activity indicate that the value calculated will be high by less than 10%. The results for the HNPF sodium system may vary due to errors in the neutron flux distribution, sodium flow patterns in the core, and sodium volume in the system.

With respect to the irradiation facility, two errors may be introduced due to the assumptions made in the calculation. The first uncertainty is the configuration of the plaque components and the effect they could have on the source strength of the plaque. However, supports and baffles are present in the plaque, which may or may not attenuate the source strength of the sodium according to the volume that they occupy in the plaque.

Another error that may be introduced into the facility gamma-ray dose rates concerns the accuracy of the attenuation factors calculated for the different shield regions in the facility configuration. The maximum error that will be introduced by a combination of all these errors will not decrease the calculated average gamma-ray dose rates by more than 45%. This maximum error is based on possible errors of 10% in the specific activity of the sodium-24, 20% in the attenuation calculations, and 10% for the plaque configuration and components uncertainties. All of these errors are independent errors and, therefore, will be multiple and not additive errors.

A rectangular plaque made of pipes was also considered. The plaque would contain 39 ft^3 of sodium in a 118 ft^3 plaque. Thus, the source strength of the solid plaque was calculated to be 2.8 times greater than the pipe-type plaque. Other considerations for the two designs indicate that the overall advantage of the solid plaque source is approximately a factor of 1.6 over that of the pipe-type plaque source.

C. DOSE VARIATION WITH DEPTH IN IRRADIATED MATERIALS

In processing with gamma-rays, the radiation intensity and, therefore, exposure rate follows a variation which is roughly exponential with **depth in the** process material.

Three possible shields may be present between the center of the package to be irradiated and the surface of a plaque. The first postulated shield will be the package, conveyor bucket, and half the thickness of the material to be irradiated. The above shield thickness was assumed to be equivalent to 5 in. of water. The attenuation factor for the first shield was determined by calculating the total gamma-ray dose rate using equation (1) with the following values for the water shield:

$t'_{1,2}$ = thickness of water shield (12.7 cm)

μ'_1 = linear absorption coefficient for 1.38 Mev photons through water ($0.058\ cm^{-1}$)

μ'_2 = linear absorption coefficient for 2.76 Mev photons through water ($0.041\ cm^{-1}$)

$b_1 = (\mu' t') + \mu t \quad (mfp)$

$b_3 = b_1 + \mu_s h \quad (mfp)$.

When the above data, together with that given for the source strength of the plaque, is substituted into equation (1), the total gamma-ray dose rate through the 5 in. of water was calculated to be 1.21×10^5 rep/hr. Thus, the attenuation factor for the 5 in. of water can be determined from the ratio of the plaque surface gamma-ray dose rate (1.21×10^5 rep/hr), which is equal to an attenuation factor of 1.95.

The second postulated shield would be material being irradiated in an adjacent channel located between two plaques. Since half of the shielding due to such a channel was assumed to be equivalent in 5 in. of water in the above calculation, the total shielding present in such a channel would be equivalent to 10 in. of water. Using the same constants as given above, with a change in the water thickness ($t_{1,2} = 25.4\,cm$) and substituting into equation (1), the total gamma-ray dose rate after the 10 in. of water was calculated to be 6.55 x 10^4 rep/hr, corresponding to an attenuation factor of 3.6 for the package, conveyor bucket, and the material in the channel.

The third postulated shield could be a plaque shielding the material from the source strength of another plaque in the configuration. The following values were used to determine the shielding due to such a plaque.

$t'_{1,2}$ = thickness of sodium shield (10.2 cm)

$t''_{1,2}$ = thickness of steel container (3.08 cm)

$\mu'_1 = 0.044\ cm^{-1}$

$\mu'_2 = 0.0308\ cm^{-1}$

$\mu''_1 = 0.39\ cm^{-1}$

$\mu''_2 = 0.286\ cm^{-1}$

$b_1 = \mu t + \mu' t' + \mu'' t''$

$b_3 = b_1 + \mu_s h$.

Again, substituting these values together with the values used in determining the gamma-ray dose rate at the surface of a plaque into equation (1), the total gamma-ray dose rate through the second plaque was calculated to be 4.8 x 10^4 rep/hr, corresponding to an attenuation factor of 4.9 for the second plaque shielding the source plaque.

By applying the above calculated attenuation factors for the shielding that is actually present between the source plaque and the material to be irradiated, the contribution from each source plaque to the dose rate of the channel being used can be determined. Once all of the gamma-ray dose rates present in a channel due to the plaque configuration are calculated, the total gamma-ray dose rate in a given channel for a specific plaque configuration was calculated at the center of an average packaged material with an equivalent total water thickness of 10 in.

Table X gives gamma-ray dose rate variation with depth in materials between two source plaques. It is based on the assumption that the materials to be irradiated in the facility will contain mostly water. On this basis, the results of the calculations are based on varying thicknesses of water of the irradiated material. The ratio of maximum to minimum gamma-ray dose is determined for an infinite slab source on both sides of the irradiated material. The gamma-ray dose rate variation for a 10-in. thick, water-equivalent material is graphically shown in Figure 4.

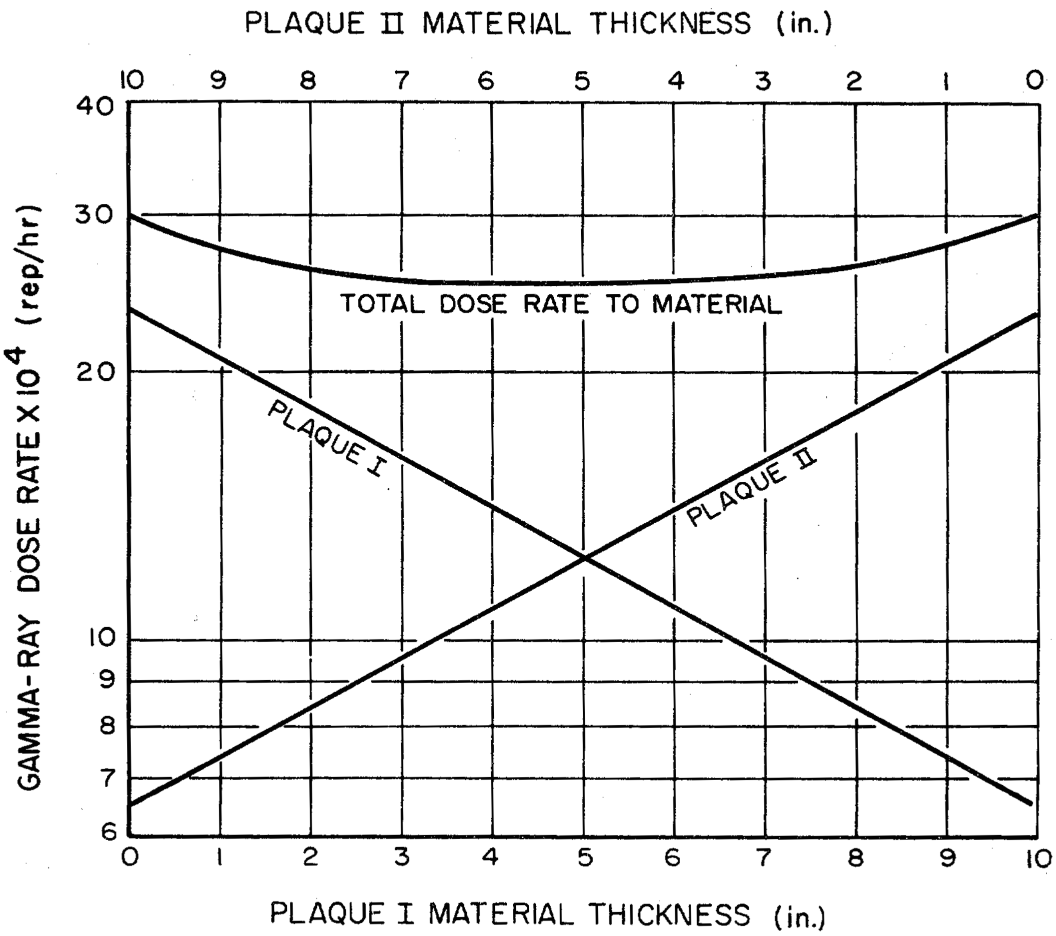


Figure 4. Depth Dose Variation for Typical 10-in. Thick, Water-Equivalent Material

TABLE X

DEPTH GAMMA-RAY DOSE RATE VARIATION IN MATERIAL BETWEEN TWO SOURCE PLAQUES

Thickness of Irradiated Material (Equivalent in. H_2O)	Maximum Gamma-Ray Dose Rate of Surface Material (10^5 rep/hr)	Minimum Gamma-Ray Dose Rate of Center of Material (10^5 rep/hr)	Differential* (%)
5	3.55	3.28	8
10	3.00	2.42	24
15	2.69	1.78	51
20	2.53	1.3	94

* Based on variation from center of material, (maximum - minimum/minimum) 100 .

The maximum allowable percentage differential for most materials to be irradiated will probably be 50%. If this is correct, the maximum material thickness in water equivalent will be 15 in. in a facility using sodium-24 as the radiation source.

The gamma-ray dose rate variation for water equivalent material using a typical sodium-filled plaque is shown in Figure 5.

D. DETERMINATION OF DOSE RATES IN SIX PRELIMINARY DESIGNS

The gamma-ray dose rates in the six preliminary designs were determined by calculating the gamma-ray dose rate in each channel of the given design configuration. Each channel calculation is designated in the chronological order of the pass made by the conveyor system as the material passes through the configuration. The contribution made by each source plaque is based upon the attenuation factors which were calculated. Gamma-ray dose rates were not calculated for the end passes or passes which are not immediately in the region of a source plaque. Although gamma-ray dose rates in these locations will be low when compared to those expected in the plaque channels, the integrated dose from these passes may add up to 10% of the total integrated gamma-ray dose for a given design configuration. This contribution is not included in the calculations.

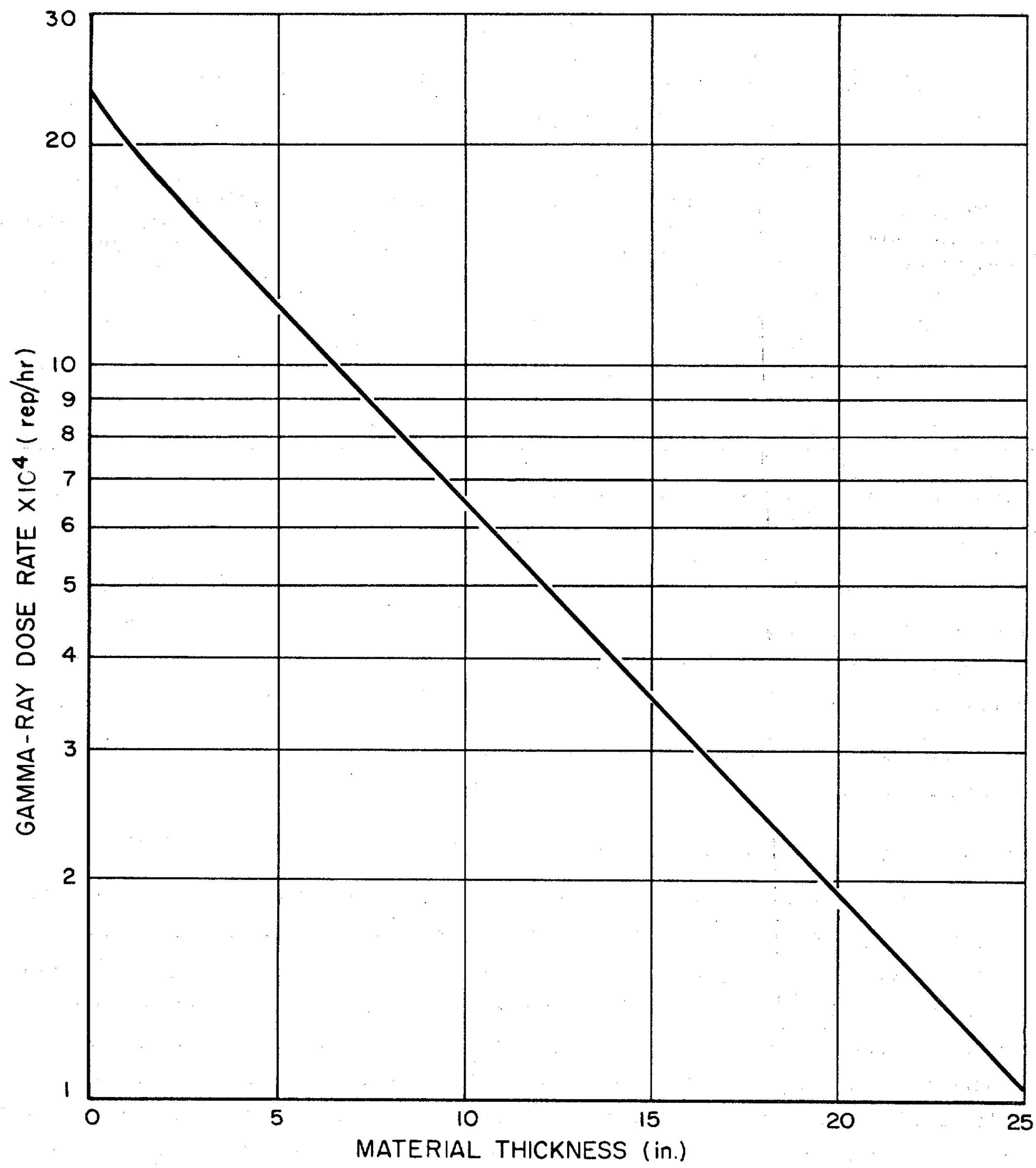


Figure 5. Typical Gamma-Ray Dose Rate Attenuation in Water Equivalent Material (Sodium Source)

In order to simplify the complexity of these analyses, the gamma-ray dose rates at the center of the source plaques were used as the average dose rate across the face of each plaque. It is expected that the gamma-ray dose rate near the inner edge of the plaques might be 10 to 20% lower than the level at the center plaque region. It was assumed that neglect of the end-pass contribution from the plaques, mentioned above, would compensate for the neglect of the gamma-ray flux depression at the inner edge of each plaque in calculating the total integrated dose received by the process material.

The feasibility of these designs for an irradiation facility should be based on the following basic criteria: (1) the integrated gamma-ray dose for the conveyor system, (2) the irradiation time or the residence time of the conveyor in the irradiation chamber to obtain a given irradiated gamma-ray dose, (3) the maximum capacity of the conveyors for a given time, and (4) the maintenance and operation of the system.

The first of six preliminary designs of plaque configurations for an irradiation facility that has been evaluated consists of four plaques. Each conveyor makes two passes across each face of the four plaques as shown in Figure 6. The second design has the same kind of arrangement with five plaques. The third evaluated design also has four plaques, but the conveyor moves only once between plaques as shown in Figure 7. The fourth design is the same as the third but has five plaques as shown in Figure 8. Figure 9 shows the fifth design, which has six plaques and is a combination of single-and double-conveyor passes. A spiral single-pass conveyor is shown in Figure 10. The reason for considering these designs is that they offer reasonable residence time in the irradiation chamber for doses in the range of 10^4 to 3×10^6 rep. Tables XI through XVI give the values determined for the gamma-ray dose rates from each plaque in each channel and the maximum gamma-ray dose rate for the six preliminary designs. Also included in the tables are the average gamma-ray dose rate and the necessary time in the facility required to obtain an integrated gamma-ray dose of 10^6 rep.

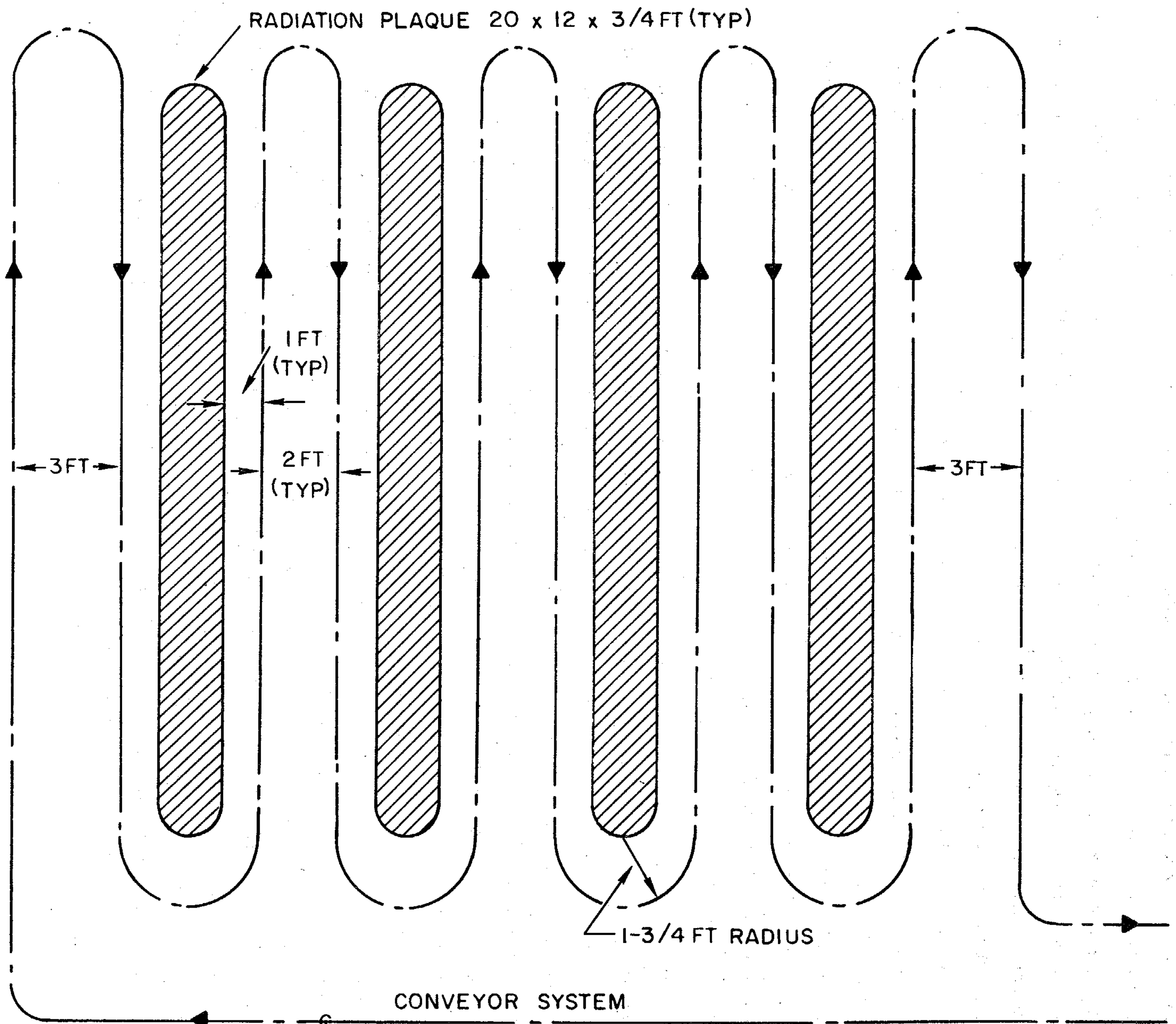


Figure 6. Plan View of Double-Pass Conveyor System with 4 Plaques

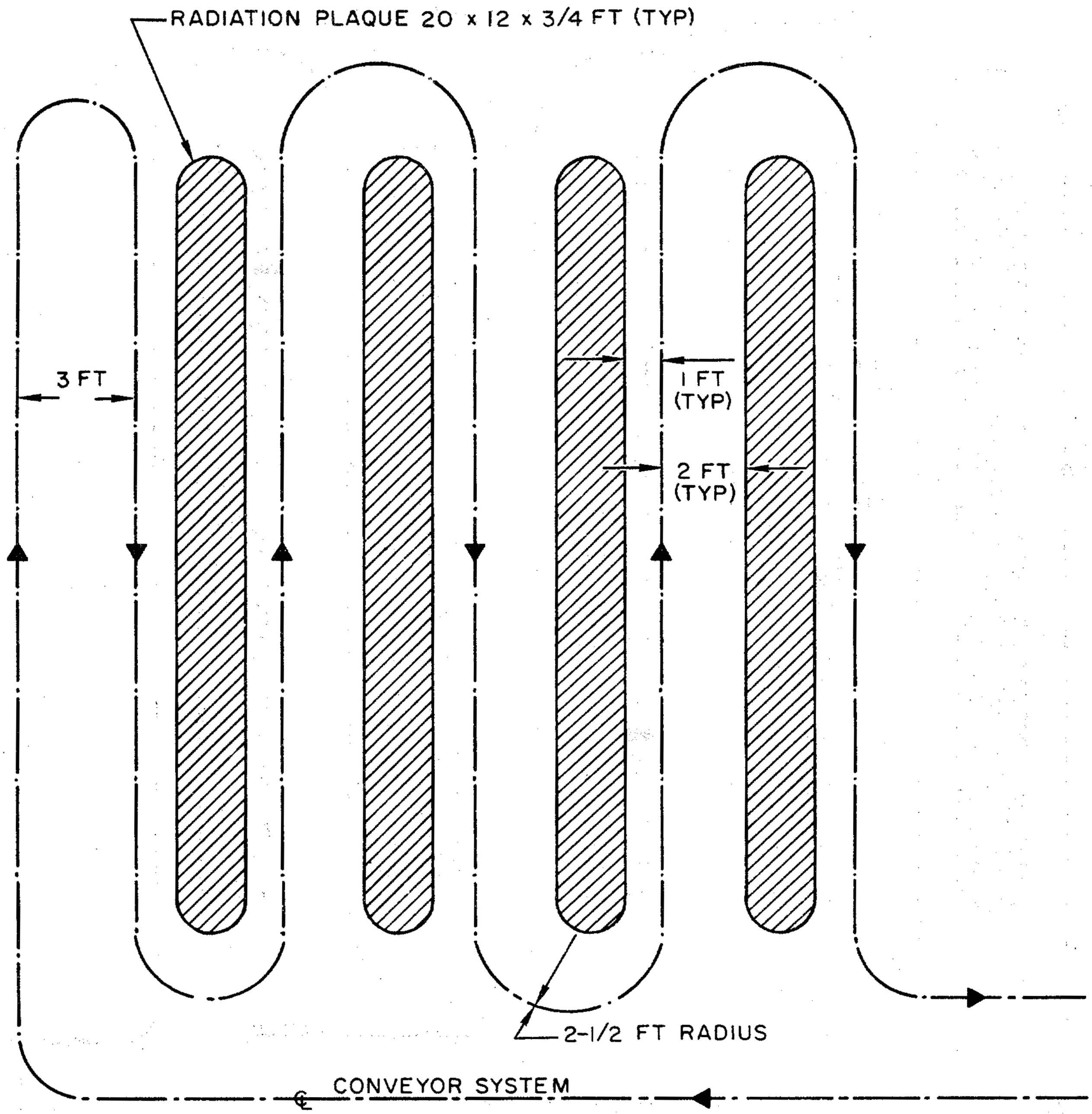


Figure 7. Plan View of Single-Pass 4-Plaque Conveyor System

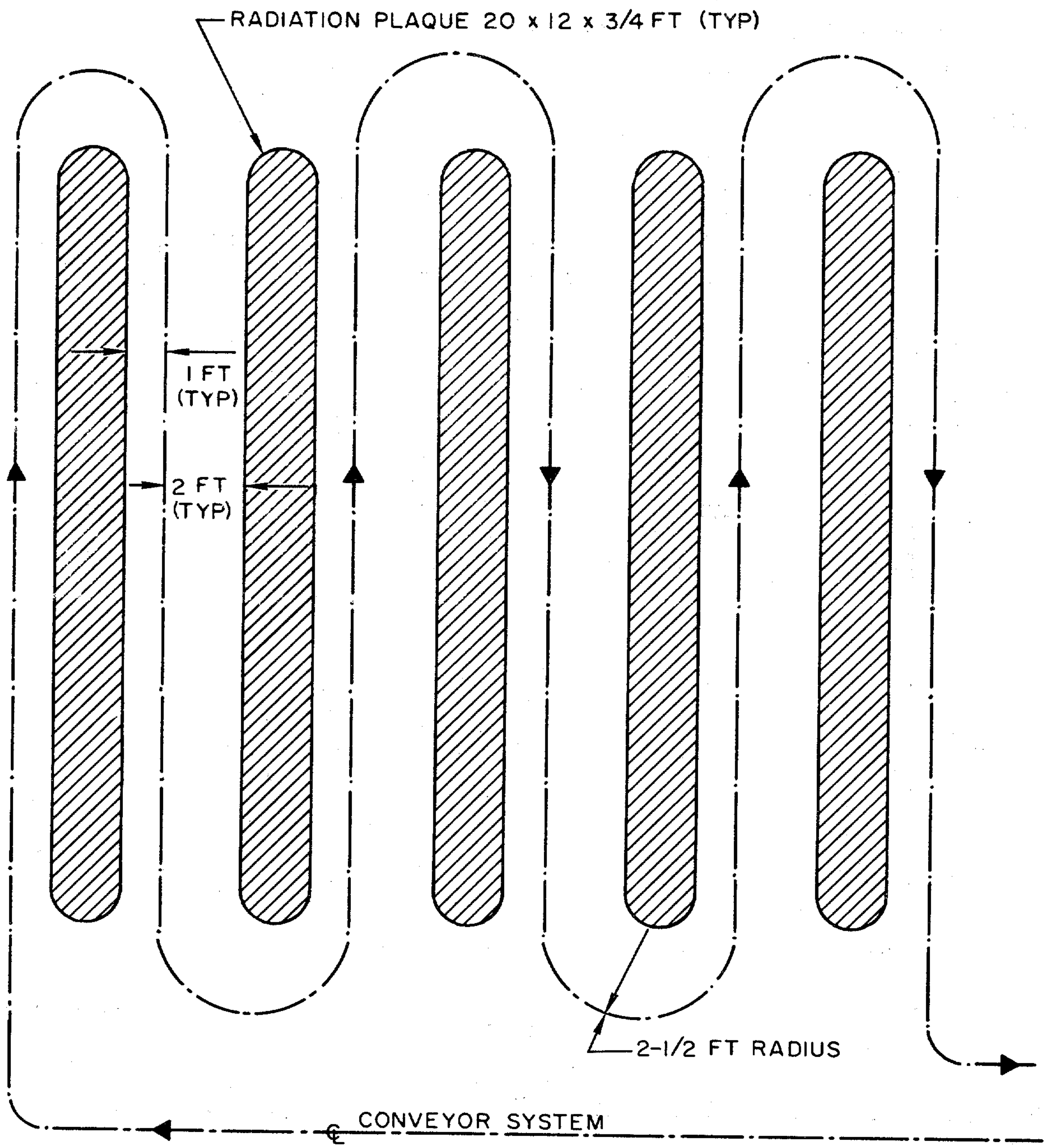


Figure 8. Plan View of Single-Pass 5-Plaque Conveyor System

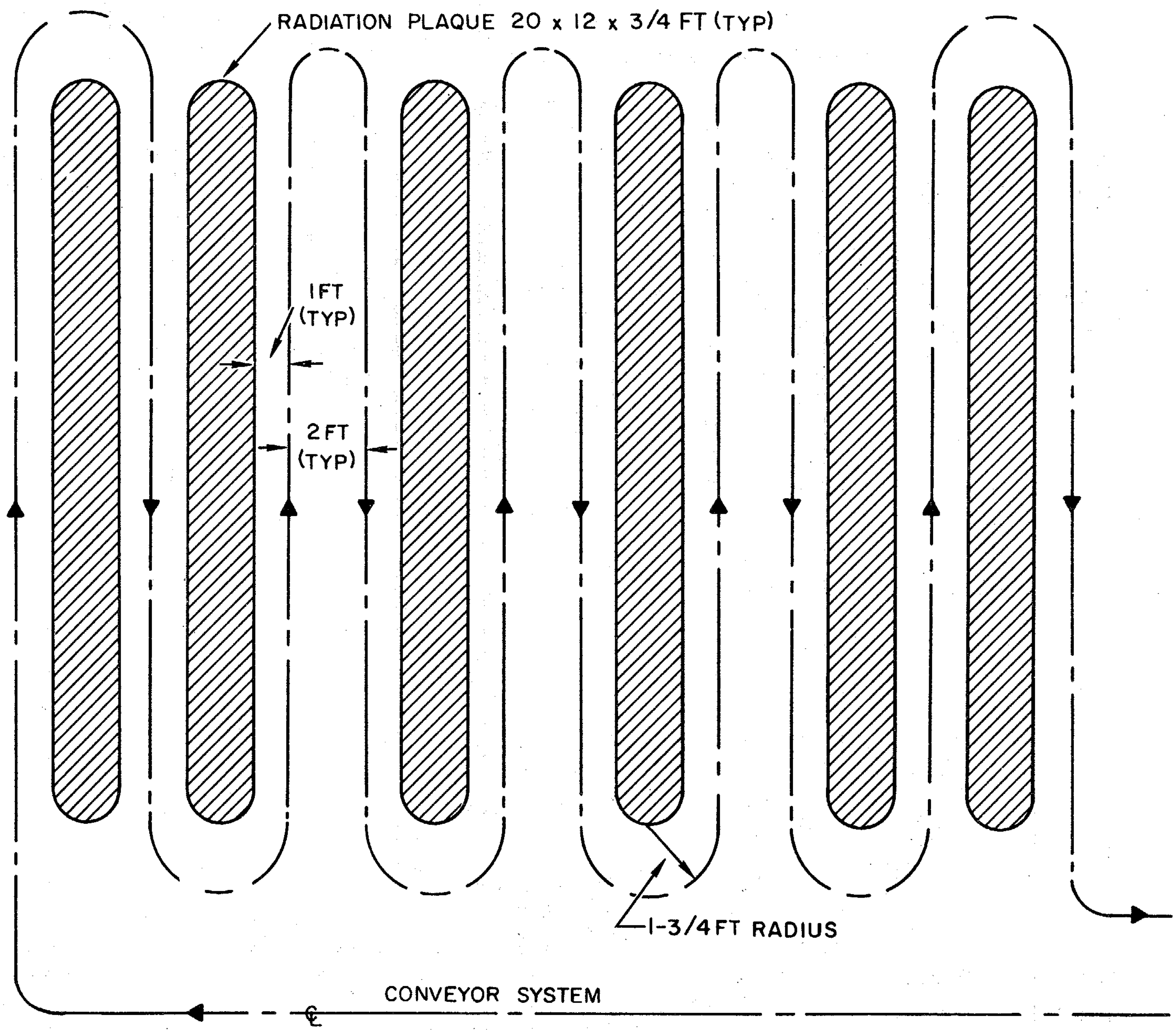


Figure 9. Plan View of Single-Double-Pass 6-Plaque Conveyor System

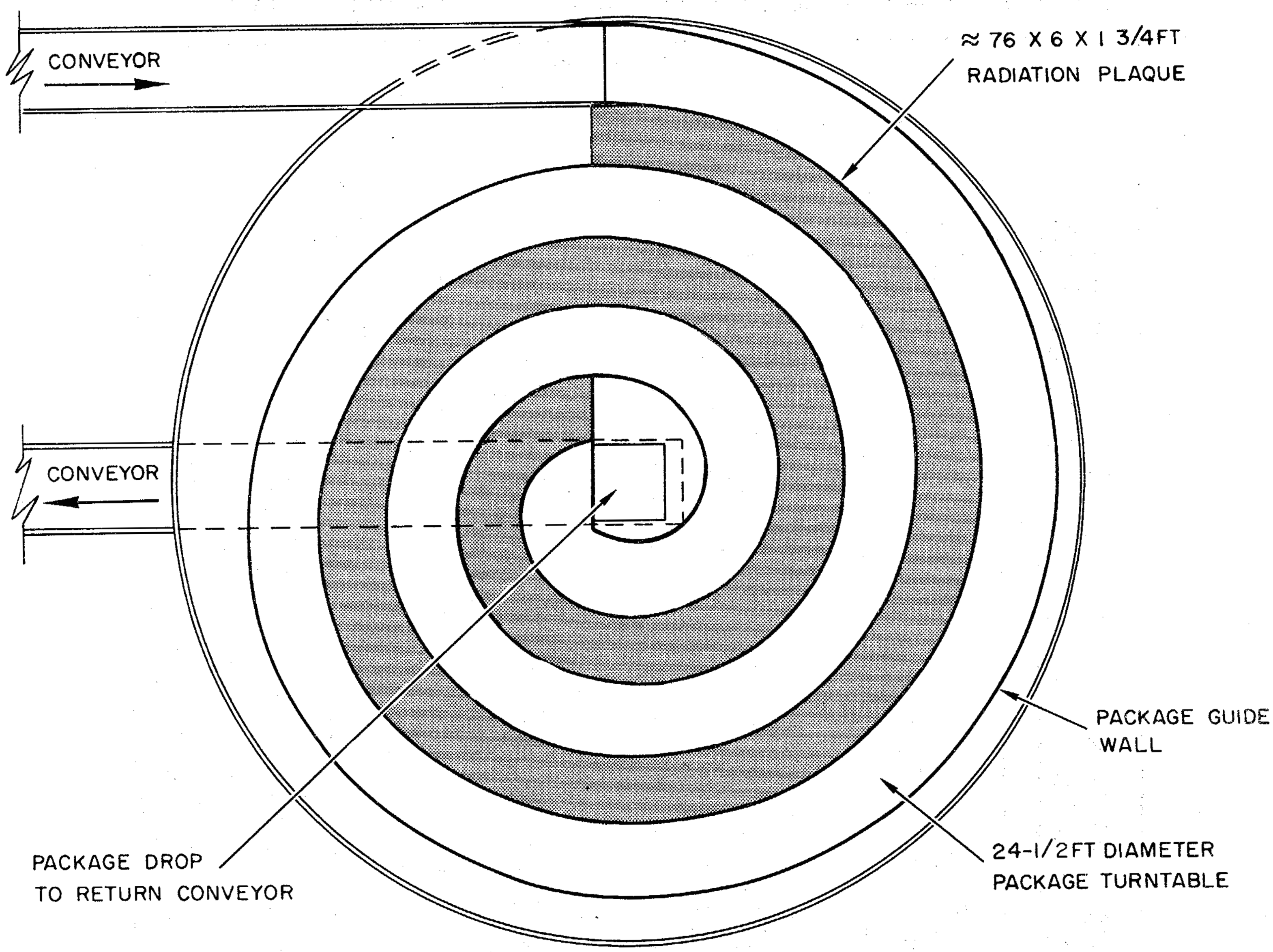


Figure 10. Spiral Single-Pass Conveyor System

TABLE XI

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN I

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)				
	Plaque I	Plaque II	Plaque III	Plaque IV	Total
1	1.210	0.019			1.23
2	1.210	0.336			1.55
3	0.336	1.210	0.019		1.57
4	0.019	1.210	0.336		1.57
5		0.336	1.210	0.019	1.57
6		0.019	1.210	0.336	1.57
7			0.336	1.210	1.55
8			0.019	1.210	1.23

Maximum gamma-ray dose rate = 1.57×10^5 rep/hr
Average gamma-ray dose rate = 1.48×10^5 rep/hr
Necessary time for 10^6 rep = 6.75 hr

TABLE XII

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN II

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)					
	Plaque I	Plaque II	Plaque III	Plaque IV	Plaque V	Total
1	1.210	0.019				1.23
2	1.210	0.336				1.55
3	0.336	1.210	0.019			1.57
4	0.019	1.210	0.336			1.57
5		0.336	1.210	0.019		1.57
6		0.019	1.210	0.336		1.57
7			0.336	1.210	0.019	1.57
8			0.019	1.210	0.336	1.57
9				0.336	1.210	1.55
10				0.019	1.210	1.23

Maximum gamma-ray dose rate = 1.57×10^5 rep/hr
Average gamma-ray dose rate = 1.5×10^5 rep/hr
Necessary time for 10^6 rep = 6.70 hr

TABLE XIII

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN III

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)				
	Plaque I	Plaque II	Plaque III	Plaque IV	Total
1	1.210	0.069			1.28
2	1.210	1.210	0.069		2.49
3	0.069	1.210	1.210	0.069	2.56
4		0.069	1.210	1.210	2.49
5			0.069	1.210	1.28

Maximum gamma-ray dose rate = 2.56×10^5rep/hr
Average gamma-ray dose rate = 2.02×10^5rep/hr
Necessary time for 10^6rep = 5 hr

TABLE XIV

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN IV

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)					
	Plaque I	Plaque II	Plaque III	Plaque IV	Plaque V	Total
1	1.210	0.069				1.28
2	1.210	1.210	0.069			2.49
3	0.069	1.210	1.210	0.069		2.56
4		0.069	1.210	1.210	0.069	2.56
5			0.069	1.210	1.210	2.49
6				0.069	1.210	1.28

Maximum gamma-ray dose rate = 2.56×10^5rep/hr
Average gamma-ray dose rate = 2.11×10^5rep/hr
Necessary time for 10^6rep = 4.75 hr

TABLE XV

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN V

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)						
	Plaque I	Plaque II	Plaque III	Plaque IV	Plaque V	Plaque VI	Total
1	1.210	0.069					1.28
2	1.210	1.210	0.019				2.44
3	0.069	1.210	0.336				1.62
4	0.019	0.336	1.210	0.019			1.58
5		0.019	1.210	0.336			1.57
6			0.336	1.210	0.019		1.57
7			0.019	1.210	0.336	0.019	1.58
8				0.336	1.210	0.069	1.62
9				0.019	1.210	1.210	2.44
10					0.069	1.210	1.28

Maximum gamma-ray dose rate = 2.44×10^5 rep/hr
Average gamma-ray dose rate = 1.70×10^5 rep/hr
Necessary time for 10^6 rep = 5.90 hr

TABLE XVI

COMPILATION OF GAMMA-RAY DOSES AND DOSE RATES IN PRELIMINARY DESIGN VI

Channel	Gamma-Ray Dose Rate (10^5 rep/hr)		
	Helix I	Helix II	Total
1	1.210	0.069	1.28
2	1.210	1.210	2.42
3	0.069	1.210	1.28

Maximum gamma-ray dose rate = 2.42×10^5 rep/hr
Average gamma-ray dose rate = 1.66×10^5 rep/hr
Necessary time for 10^6 rep = 6 hr

From the data presented in the above tables, the most feasible plaque configuration for achieving a maximum gamma-ray dose rate and thus requiring a minimum time in the facility would be the five-plaque, single-pass system shown in Figure 8. If design VI, shown in Figure 9 were used, the capacity of the facility could be increased. However, such a design requires an extra plaque, longer conveyors and, most probably, more complicated drive mechanisms for the conveyors due to their increased length.

E. RESIDENCE TIME OF THE MATERIAL IN THE IRRADIATION CHAMBER

The time necessary to obtain a gamma-ray dose of 10^6 rep for the six evaluated designs is shown at the bottom of Tables XI through XVI. The double-pass system would need an irradiation time of about 6.7 hr for a gamma dose of 10^6 rep. The single-pass system would need an irradiation time of 5 hr for the four-plaque source and 4.75 hr for the five-plaque source for a gamma-ray dose of 10^6 rep. The single-double-pass system would need an irradiation time of 5.9 hr for the same gamma-ray dose. The spiral single-pass system would need an irradiation time of 6 hr for a gamma-ray dose of 10^6 rep.

For this study, the five-plaque, single-pass system is being considered for total gamma-ray dose ranges from 10^4 to 3×10^6 rep. For a dose of 10^4 rep, the material in the irradiation chamber would move at a speed of 53 ft/min and for a dose of 3×10^6 rep, the speed would be 0.2 ft/min.

F. MAINTENANCE AND OPERATION OF THE IRRADIATION CHAMBER

In selecting a design the following should also be analyzed: (1) ease of maintenance of the conveying system, (2) length of the conveying system, (3) complexity of the conveying system, (4) shielding of source and conveying system, (5) design and maintenance of plaque configuration, and (6) hazards of plaque configuration.

The first five preliminary designs will have about the same maintenance problems. The conveying system for the spiral type design is too complex for consideration.

The double-pass conveyor systems naturally will have longer conveying systems than single-pass systems. Of course, four-plaque configurations have shorter conveying systems than five-plaque systems for the same type designs. On the other hand, the capacity of the irradiation facility can be increased considerably by additional plaques.

The complexity of the conveying system would be similar for the first five preliminary designs, although the single pass would be less complex. The spiral type design would be more complex.

The shielding of the source would be the same for the first five preliminary designs. The shielding of the source for the spiral type would be very simple as shown in Figure 10. The shielding of the conveyor system would be similar for all six preliminary designs.

The design and maintenance of the plaque configuration would be similar for the first five preliminary designs. The spiral type would probably be more difficult to maintain, and since the design has never been used, this problem would take time to solve.

The hazards associated with the radioactive liquid sodium source would be nearly the same for all six preliminary designs.

Preliminary design VI, which has been selected for this study, compares favorably with other preliminary designs with respect to maintenance and operational characteristics.

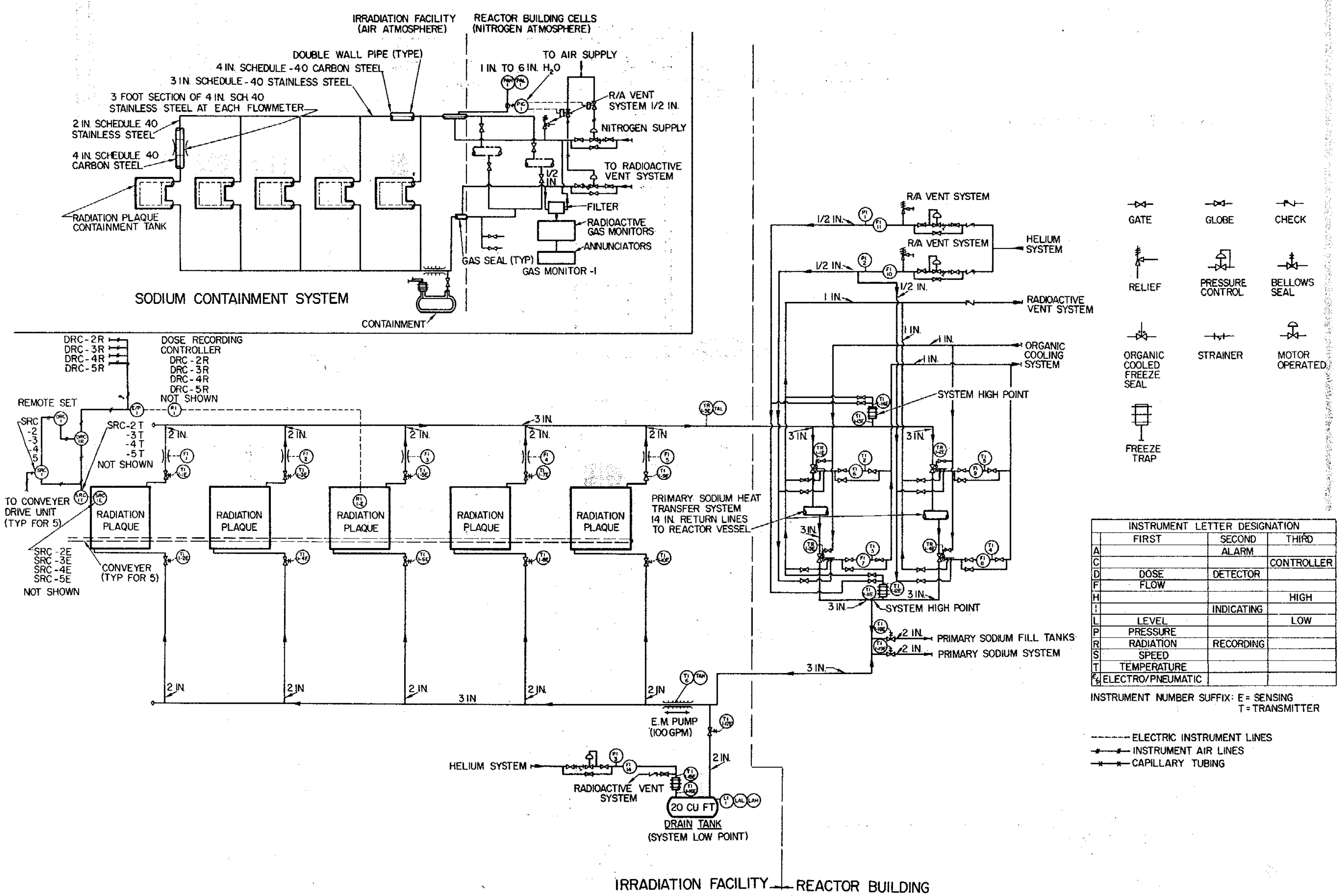
VI. FACILITY DESIGN AND ARRANGEMENT

A. PROCESS DESCRIPTION

The flowsheet of the irradiation facility is shown in Figure 11. The facility consists of sodium radiation plaques, an electromagnetic pump, drain tank, and five conveyors for transporting materials through the radiation field. The system includes the controls for regulating the radiation dosages by conveyor speed and the instrumentation required for process control. The equipment is located in a concrete cell below grade and adjacent to the reactor facility.

The Hallam Nuclear Power Facility reactor is designed to operate with a minimum of two of the three primary coolant loops. Outlets for sodium for the radiation plaques are made in two of these loops, as indicated in the piping drawing, Figure 12. The sodium is taken from the "cold" side of the heat exchanger, where the design temperature of the sodium is 607°F. The fluid is circulated, by means of a 3 in. electromagnetic pump, through the five plaques and returned to the same primary coolant loop. The flow of 100 gpm through the system is negligible, compared to the flow in the primary loop of the Hallam Facility. At this flow rate, the sodium is changed in each of the five plaques every 28 min. Since sodium-24 loses 5% of its activity at the end of the first hour, there will not be any appreciable change in the activity of the sodium in the plaques. At a flow rate of 100 gpm, the pressure drop in the system is about 5 psi. The temperature of the sodium is expected to drop less than 25°F from the point it is taken from the Hallam Facility to the point of its return to the reactor coolant loop.

The system is filled initially with sodium from the Hallam Facility primary system fill tanks, using the primary system service pumps. The sodium supply to the radiation cell is divided into five lines, each line supplying a radiation plaque. The sodium enters each plaque at the bottom and passes vertically through the 27 compartments, formed by baffles 8 in. apart, and passes to the return line from the top of each plaque. The velocity of the sodium inside the plaque is less than 1 fps. As long as the electromagnetic pump is functioning, there is no problem of stagnation. Differences in velocity from one plaque to the next are unimportant because of the 15-hr half-life of sodium-24.



INSTRUMENT LETTER DESIGNATION			
	FIRST	SECOND	THIRD
A		ALARM	
C			CONTROLLER
D	DOSE	DETECTOR	
F	FLOW		
H			HIGH
I		INDICATING	
L	LEVEL		LOW
P	PRESSURE		
R	RADIATION	RECORDING	
S	SPEED		
T	TEMPERATURE		
E/P	ELECTRO/PNEUMATIC		

Figure 11. Process and Instrumentation Flow Diagram

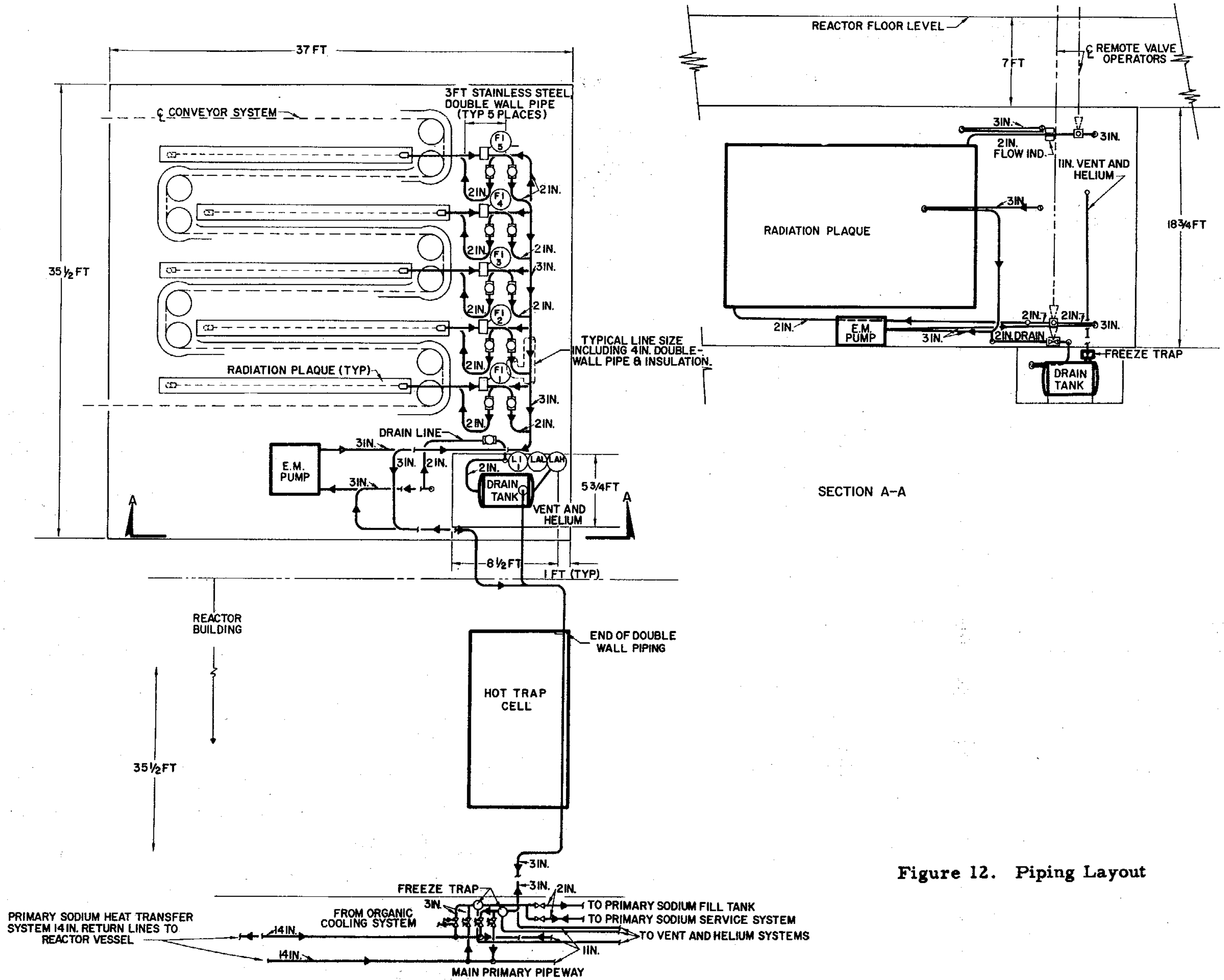


Figure 12. Piping Layout

Before filling, all piping and equipment containing sodium must be purged with helium to minimize the oxygen content. The helium used is taken from the Hallam Facility, introduced either at the freeze traps on the sodium lines or at the drain tank, and exhausted through a similar connection.

In order to insure sodium flow and prevent thermal shock, all equipment and piping can be electrically preheated to 560°F.

In the event that personnel need to enter the radiation chamber, the sodium is drained from the plaques and replaced with helium. To remove entrained radioactive sodium from the plaque cells, the system can be flushed with fresh sodium from the primary fill tanks of the Hallam Facility. In this procedure, the reserve coolant of the reactor coolant storage system would be used.

Draining of the sodium is accomplished either with the irradiation facility electromagnetic pump or with the Hallam Facility primary service pumps. The drain tank collects the portion which the electromagnetic pumps do not remove from the piping because of low suction head. Helium over-pressure is used to transfer the sodium from the drain tank into the primary fill tanks of the Hallam Facility.

Sodium from the irradiation facility can be sent directly to the primary fill tanks, so as not to disrupt the reactor facility operation. During filling or draining, the piping may be vented through the freeze traps which are placed at the high points of the system.

Because of hazards considerations, all sodium piping entering the irradiation facility from the Hallam Facility is double walled. The inner pipe is either 3 in. or 2 in., schedule 40, stainless steel. The outer pipe is 4 in., schedule 40, carbon steel. The electromagnetic pump, drain tank and valves are equipped with a carbon steel envelope. The outer carbon steel envelope constructed around this equipment is used for containment. A nitrogen gas mantle is maintained between the sodium equipment and its containment. The amount of nitrogen used is very small, and is obtained from the Hallam Facility.

Design allows for two methods to detect a sodium leak. First, there are leak detectors 20 ft apart and at all low points. Secondly, there is a continuous monitoring of the nitrogen gas for radioactivity. The nitrogen may be vented to either the plant stack or the Hallam Facility radioactive decay tanks, depending on its activity.

B. INSTRUMENTATION

Instrumentation for the irradiation facility is designed to provide all the indicating, recording, and controlling functions necessary for good operating control. The panel is shown in Figure 13 and the instruments are listed in Table XVII. The control functions include:

1) Automatic dose control for each conveyor,

2) Indications of process variables for sodium, organic, and helium systems,

3) Control and continuous radiation monitoring for the nitrogen in the double-walled piping,

4) Alarms in the event of "off normal" or dangerous conditions.

Automatic dose control is achieved by using a cascade control system made up of commercially available process and radiation detection instruments. The total dosage given to an irradiated item is the product of the dose rate and the time irradiated. A tachometer on the conveyer and an electrical-to-pressure (E/P) converter are used to provide a pneumatic signal, inversely proportional to the time irradiated. The recorder output of a ratemeter, which reads the average dose rate within the cell, and an E/P converter are used to provide a pneumatic signal, proportional to the dose rate. These two signals, when multiplied together, measure the total dose received. The dosage is recorded on a dose recording controller. This controller provides a remote set point for the conveyer speed controller. The required dose is achieved by changing the set point on the dose controller.

Instrumentation for the sodium loop consists of indicators for flow through each plaque, level of the drain tank, and important temperatures throughout the system. Flow indicators are of the 2 in. permanent magnet type, with millivolt calibrations. Temperature sensing elements are chromel alumel (C/A) thermocouples, with the exception of those on the electromagnetic pump, and are

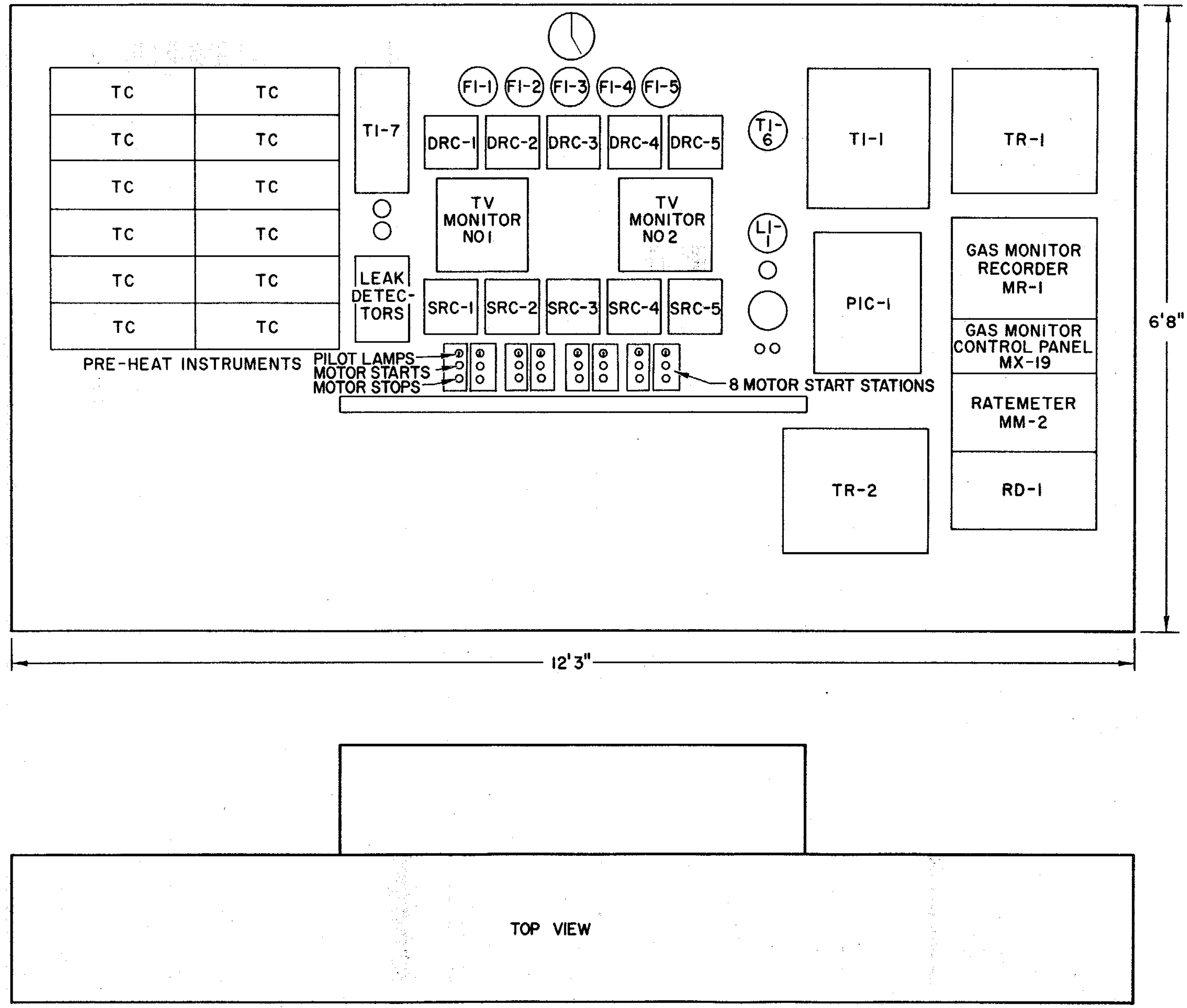


Figure 13. Instrumentation Panel

read on a null-balance, multi-point indicator. Temperature indication for the electromagnetic pump will be a class IV system, with a special 1/8-in.-OD inconel capillary bulb. The sodium-drain-tank level indicator has an induction-coil type pickup; and has board-mounted vacuum-tube volt meters, which provide the readings. Conventional, locally mounted, pressure and flow indicators are provided for the helium and organic coolant supplied to freeze seals and freeze traps.

The nitrogen in the double-walled piping is controlled by a duplex action controller which operates both the inlet and bleed valves to maintain the desired pressure. A continuous gas analyzer monitors a sample of the nitrogen from within the piping to detect leaks.

Probe and grid type leak detectors are provided throughout the system. In the event of a sodium leak, an alarm is operated on the control board.

All instrument parts which come in contact with sodium are stainless steel, and are designed to include bellows seals or some method of double containment. Indicating devices operate at room temperature. Sensing elements operate at temperatures ranging from 30 to 700°F, depending on their location within the system.

Two TV monitors are provided for inspection and operation purposes. The receivers are panel mounted. Radiation protection is provided to the cameras within the cell when the monitors are not in operation.

A list of instruments is shown in Table XVII.

C. FACILITY LAYOUT

The location of the irradiation facility under study, in respect to the Hallam Nuclear Power Facility, is shown in the plot plan, Figure 2. The irradiation facility is located adjacent to the east side of the reactor building of the Hallam Nuclear Power Facility.

The layout of the irradiation facility is shown in Figure 14. The irradiation facility is comprised of the principal areas listed in Table XVIII.

TABLE XVII

INSTRUMENTATION LIST (Sheet 1 of 3)

Tag No.	Description	Services	Manufacturers Data
DRC-1 thru 5	3 to 15 psig dose recorder controller	Conveyors 1 to 5	Foxboro M-54 with M-58 controller or equal
DRC-1R thru 5R	Dose recorder controller computing relay		Bailey No. 531575 OA5 or equal
SRC-1 thru 5	3 to 15 psig speed recorder controller receiver	Conveyor 1 to 5	Foxboro M-54 with M-58 controller or equal
SRC-1T thru 5T	Electric to pneumatic converter transmitter		Foxboro E. M. E. transmitter or equal
SRC-1E thru 5E	Tachometer		Bristol model 750 or equal
E/P-1	Electric to pneumatic converter	Radiation Ratemeter output	Foxboro E. M. F. transmitter or equal
RI-1	Radiation indicator	Irradiation facility	Keithley model 411
RI-1E	Area radiation pickup indicating element	Irradiation plaque area	G. E. gamma ion chamber No. 5467870G10
RI-1Ea	Radiation indicator element power supply	Gamma ion chamber power	800 v dc power supply
PIC-1	3 to 5 psig pressure indicator controller receiver	Nitrogen to double-walled piping	Foxboro Rotax Duplex with elec. outputs or equal
PIC-1E	Pressure indicator controller D/P cell transmitter sensing		Foxboro model 29 D/P cell transmitter
TI-1	Temperature null balance indicator	Irradiation facility	Brown M-156 24 point indicator or equal
TI-1-1E thru 10E	Thermocouples	Plaques, inlet and outlet sodium valves	C/A thermocouple fabricated into valve

TABLE XVII

INSTRUMENTATION LIST (Sheet 2 of 3)

Tag No.	Description	Service	Manufacturers' data
TI-1-11E thru 16E	Thermocouples	Freeze traps	C/A thermocouple fabricated into freeze traps
TI-1-17E	Thermocouple	Sodium drain tank valve	
TI-1-18E & 19E	Thermocouples	Primary sodium fill tank valves	
TI-2 thru 5	Bulb and helical spring temperature indicator	D/C coolant outlet freeze seal valves	Foxboro stem typo or equal
TI-6	Temperature indicator	E. M. pump coil temperature	Foxboro class IV with special bulb
TI-7	Temperature indicator, multi-point	Preheat	Brown vertical scale null balance multipoint indicator or equal
TI-7-1E thru 30E	Thermocouples	Preheat	C/A Thermocouples
TC-1 thru 12	Temperature controller, millivoltmeter receiver	Preheat	Brown Pyr-o-Vane model 105C8 or equal
TC-1E thru 12E	Temperature controller sensing element	Preheat	C/A thermocouple CES-04-18CT therms electric or equal
TR-1	Null balance temperature receiver recorder	Irradiation facility	Foxboro M-40 5-point recorder or equal
TR-1-1E thru 4E	Thermocouple	Sodium valve freeze seal temperature	C/A thermocouple fabricated into freeze seal
TR-1-5E	Thermocouple	Sodium outlet header temperature	C/A thermocouple in brown type D welded well
TR-2	Null balance temperature receiver recorder	Radiation cell refrigeration system	Brown model 153X or equal

TABLE XVII

INSTRUMENTATION LIST (Sheet 3 of 3)

Tag No.	Description	Service	Manufacturers data
PI-1 thru 3	Bourdon tube pressure indicator	Helium system	6-in. Helicord or equal
FI-1 thru 5	Millivoltmeter flow indicator	Radiation plaques sodium outlets	4-1/2 in. G. E. DB18 or equal
FI-1E thru 5E	Magnetic pickup flow indicator sensing element	Radiation plaques sodium outlets	2-in. A. I. permanent magnet pickups
FI-6 thru 12	Rotameter	Helium flow	
LI-1	Level indicator electrical receiver	Sodium drain tank	4-1/2 in. G. E. DB18 or equal
LI-1E	Level indicator, electrical receiver sensing element		A. I. induction coil sensing element 1 in. O. D., S. S.
PAL-1	Low pressure alarm switch	Nitrogen input to double-walled piping	Meletron model 424 or equal
PAH-1	High pressure alarm switch	Nitrogen input to double-walled piping	Same as PAL-1
TAH	High temperature alarm annunciator	E. M. pump windings	Operated by TI-6
BD-1 thru 10	Probe type sodium leak detectors	Bellows seal valves provided with 1/4-in. NPT probe ports	Ceremo conn. 11752-4 with CES-04-18CT probe, 1 ft average length
BD-11 and 12	Probe type sodium leak detectors	Irradiation cell	Spark plug type
BD-13 thru 45	Grid type sodium leak detectors	Cell sodium piping, valves & vessels	A. I. saturable insulated grid type
GM-1	Continuous gas monitor	Irradiation facility	Tracer lab model MGP-1 or equal

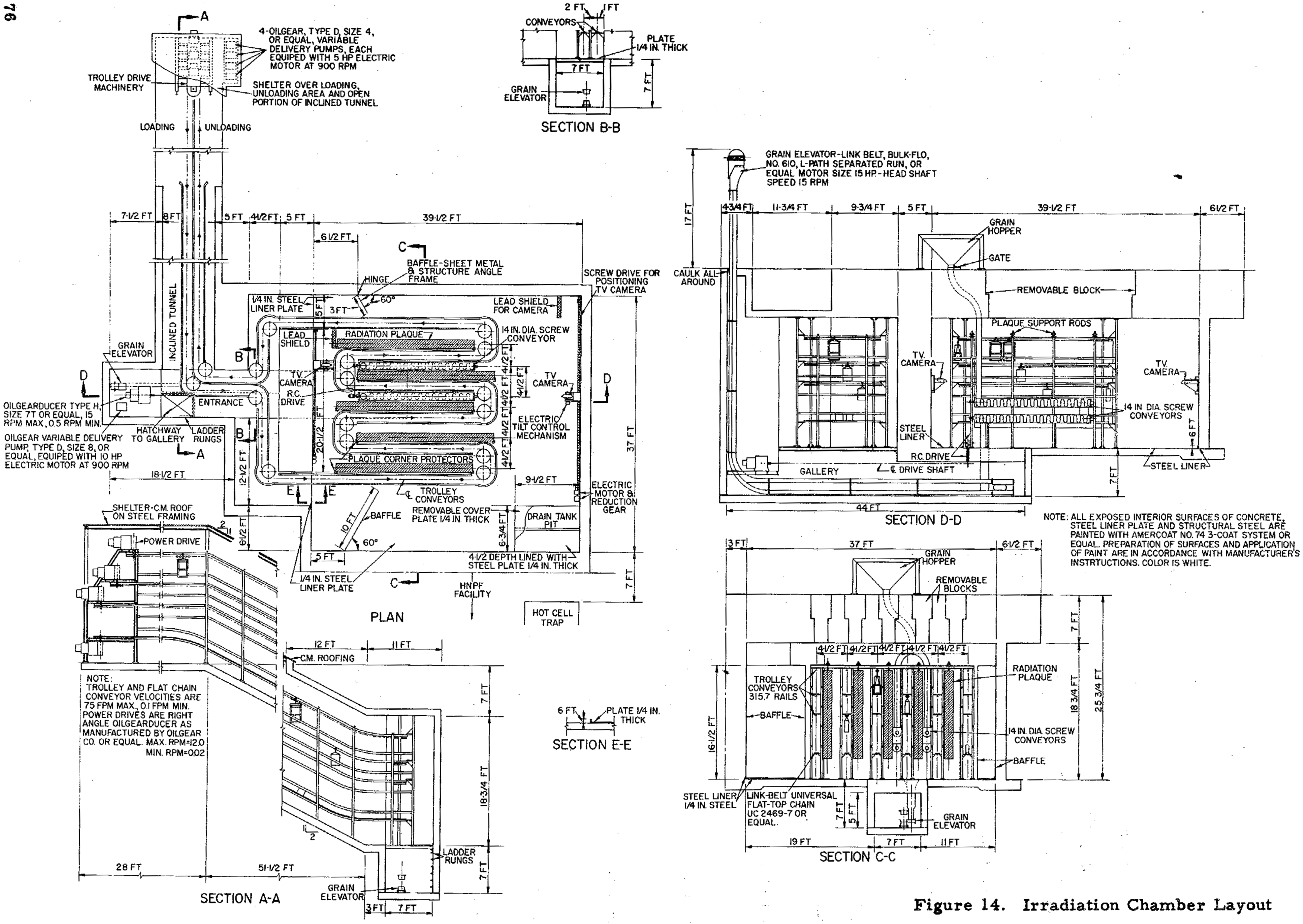


Figure 14. Irradiation Chamber Layout

TABLE XVIII

PRINCIPAL AREAS OF THE IRRADIATION FACILITY

Area	Size: Length x Width x Height	Floor Elevation
Trolley Drive Machinery	8 ft 0 in. x 12 ft 6 in.	1440 ft 6 in. (Grade)
Loading-Unloading	20 ft 0 in. x 10 ft 0 in.	1440 ft 6 in. (Grade)
Inclined Tunnel	51 ft 6 in. x 8 ft 0 in. x 18 ft 9 in.	1414 ft 9 in. to 1140 ft 6 in.
Entrance	14 ft 8 in. x 30 ft 6 in. x 18 ft 9 in.	1414 ft 9 in.
Irradiation Room	39 ft 6 in. x 37 ft 0 in. x 18 ft 9 in.	1414 ft 9 in.
Gallery	44 ft 0 in. x 7 ft 0 in. x 7 ft 9 in.	1407 ft 9 in.

A corrugated-metal roof on structural steel framing shelters the trolley drive machinery, conveyer terminal areas, and the portion of the inclined tunnel which extends above ground level. A concrete roof, 7 ft thick, shields the underground portion of the plant. A labyrinth type shield, with 5-ft thick walls, is located at the entrance to the irradiation room. Nine removable blocks in the roof slab provide access to equipment in the irradiation room. Each block is 22 ft long, 3 ft wide, 7 ft thick, and weighs approximately 28-1/2 tons. The blocks have stepped joints to prevent radiation streaming.

A steel-plate liner 1/4-in. thick covers the irradiation room floor and the walls, to a height of 6 in. above the floor, to contain the sodium in case of spillage. All exposed interior surfaces of concrete, steel-plate liner, and structural steel are painted with a catalyzed-epoxy coating which is nontoxic and resistant to chemicals and gamma radiation.

The facility structure is 77 ft long by 46-1/2 ft wide. The inclined tunnel housing the trolley and flat chain conveyors, runs 111-1/2 ft eastward from the HNPF reactor building.

Access for maintenance personnel into the plant is via a 3-ft walkway along the inclined tunnel and the entrance to the irradiation room. Access to the grain elevator in the galley is through a hatchway in the floor of the entrance area. Outside the irradiation chamber itself, there is adequate shielding for the protection of personnel. Machinery in these shielded areas can be inspected and maintained during plant operation. Some motors are in areas above minimum human tolerances for long periods of time, but are shielded enough so that personnel could remain in these areas for a limited period of time.

In the event maintenance of the conveyor system is required, either the source material must be removed from the radiation cell or the conveyor must be removed from the cell. In this facility, the sodium is drained to remove the activity. It may be necessary to wait for trace amounts of activity to decay before entry into the irradiation chamber is safe. Provisions are made to remove the conveyor system from the radiation cell, if necessary, for ease of maintenance.

On the north and south walls of the irradiation room, a TV camera is mounted for remote observation. Electro-mechanical controls govern camera tilting and horizontal travel. Lead shielding protects the lenses from radiation damage when the cameras are not in use.

D. CONVEYOR ARRANGEMENT AND CAPACITY OF THE FACILITY

The design for this study consists of five conveyors moving horizontally between the irradiation plaques. One conveyor is a special tray type, capable of carrying bags, boxes, or cans. Two conveyors are of the basket type, to carry No. 10 or No. 2 cans, packages, and V-3 or smaller size boxes. One flat-chain conveyor, with guides, carries boxes or cans. A screw conveyor system handles bulk granular materials. Each conveyor is equipped with an independent drive. All conveyors can be operated simultaneously, each being irradiated to a different dose.

The conveying system has not been designed to meet a specific work load. Instead, it is a flexible system, that can irradiate a large number of different types and sizes of materials, to dosages between the range of 10^4 and 3×10^6 rep. A more efficient conveying system could be designed to meet a definite market requirement consisting of a limited number of products and package configurations.

From the conveyor terminal area above ground, the packaged material is transported down the inclined tunnel, around the labyrinth-type shield, and in and out between the five radiation plaques in the irradiation chamber. It is then returned through the labyrinth, and up the inclined tunnel to the conveyor terminal zone. The total length of each conveyor is approximately 380 ft, of which 140 feet is inside the irradiation chamber. Steel guides along the conveyor route are designed to prevent misalignment of packages.

Some loss and degradation of material in the conveyors is expected. Losses will be due mainly to mishandling. Degradation will occur, especially for materials passing through the screw conveyor.

The special tray-type conveyor is basically a trolley conveyor. It can carry up to 100-lb potato bags, or packages spaced 2 ft between centers. For an integrated dose of 10^5 rep, the capacity of this conveyor is 16,800 lb/hr. For this dose, the speed of the conveyor would be about 5 fpm. Assuming potatoes are being irradiated, the required dose to inhibit sprouting is 2×10^4 rep. The capacity of the conveyor for this dose would be 84,000 lb/hr, or 840 100-lb bags an hour. This rate is higher than can be handled by the available manpower.

The speed of the special tray-type conveyor can be varied from 0 to 75 fpm. At 0.1 fpm, the material will be irradiated to more than 6×10^6 rep. The material will be in the conveyor for more than 63 hr. Of this time, about 23 hr will be spent in the irradiation chamber. At a speed of 75 fpm, the integrated irradiation dose is calculated to be 7000 rep. The conveyor will pass through the irradiation chamber in less than 2 min, and the total time in the conveyor would be about 5 min.

The two smaller basket-type trolley conveyors are identical. They are designed to carry packages, boxes, or cans spaced 18 in. between centers. The maximum size box that can be carried is 6 in. by 16 in. by 21 in. The V-3 size boxes fall in this category. The capacity of each of these conveyors, loaded with V-3 boxes for a dose of 10^5 rep, is 15,200 lb/hr, moving at a speed of about 5 fpm.

The two conveyors, although identical, are completely independent of each other. Each has a speed range from 0 to 75 fpm. The speeds of the conveyors and the time spent inside the irradiation chamber are the same as for the special tray-type conveyor.

The flat chain conveyor is similar to a flat belt conveyor but is capable of following horizontal curves. It is 7 in. wide, and can carry boxes or cans of various dimensions, including orange crates. Assuming that it is loaded at 25 lb/ft, the capacity at 10^5 rep dose is 7600 lb/hr. The speeds of the conveyor and the time inside the irradiation chamber for a given dose is the same as for the trolley conveyors.

The screw conveyor is for bulk material which is dumped into a hopper directly over the irradiation cell. The material flows through a chute into two sets of screw-type conveyors, installed horizontally between radiation plaques. These conveyors move the material slowly from one end of the radiation plaques to the other and back again. The material is then discharged into an elevator conveyor in the gallery below floor level, which raises it above ground for truck loading. The chute is 10 in. in diameter. The screw conveyor is 14 in. in diameter and has a 14-in. pitch. The conveyor elevator is 10-3/4 in. by 6-1/2 in. To minimize maintenance, the return leg of the conveyor elevator is separated from the incoming leg.

Assuming that wheat is being irradiated to 10^5 rep, the capacity of the bulk type conveyor is 3,350 lb/hr. However, for deinfestation, only 2.5×10^4 rep is necessary. For that dose, the capacity of the conveyor is 6.7 ton/hr, and the speed of the screw conveyor would be about 5 fpm. The speed range of this conveyor is 0.5 to 15 fpm, which would provide a dose from 8×10^3 to 2.5×10^5 rep.

The capacity for irradiating bulk material can be increased by installing additional screw conveyors and increasing the speed of the elevator conveyor. Here again, the limiting factor will be handling and storage facilities, rather than conveying capacity.

The power units of the conveyor systems are outside the irradiation chamber. Any power needed inside the irradiation chamber is transmitted by shafts and cams. Hydraulic variable speed drives for the four package conveyors, or other type power units having equal performance characteristics, are located above ground. Each conveyor is individually controlled, with speed variation between 0.1 and 75 fpm. The drive units are powered by 5 hp motors. Also, a hydraulic variable speed drive with a 10 hp electric motor is located at the north end of the gallery, and powers the screw conveyor system through shafting, roller chains, and sprockets. Speed may be varied from 0.5 to 15 rpm. Drive machinery for the bulk elevator includes a 15 hp electric motor and a gear box mounted on the elevator head. Head shaft speed is 15 rpm.

Table XIX summarizes the capacities of each conveyor for a given dose rate and the total capacity of the irradiation facility, assuming all conveyors are operating at full capacity. Table XX summarizes the capacity of the facility, assuming a 75% plant factor. It is assumed that 25% down time will result either due to the unavailability of sodium, because the Hallam Facility is not operating, or due to shutdown for maintenance of the irradiation facility.

TABLE XIX

CAPACITIES AND SPEEDS OF CONVEYORS AT VARIOUS DOSES

Dose (rep)	Special Tray		Bucket		Flat Chain		Screw		Total
	Capacity (lb/hr)	Speed (ft/min)	Capacity (lb/hr)	Speed (ft/min)	Capacity (lb/hr)	Speed (ft/min)	Capacity (lb/hr)	Speed (ft/min)	All Conveyors (lb/hr)
10^4	168,000	53	152,000	53	76,000	53	33,500	12	581,000
10^5	16,800	5.3	15,200	5.3	7,600	5.3	3,350	1.2	58,100
10^6	1,680	0.5	1,520	0.5	760	0.5	335	0.1	5,810
3×10^6	560	0.2	500	0.2	250	0.2	111	0.04	1,921

TABLE XX

CAPACITY OF THE IRRADIATION FACILITY

Dose (rep)	Capacity		
	lb/hr	ton /day	ton/month
10^4	436,000	5,230	157,000
10^5	43,600	523	15,700
10^6	4,360	52	1,570
3×10^6	1,450	17.5	523

The capacity of the irradiation facility can be increased by designing the conveyors for a double-pass arrangement, instead of the present single pass. Such an arrangement would complicate the drive mechanism of the conveying system.

Another way to increase the capacity would be to make the plaques larger. The length of the plaques can be increased, thereby increasing the time of irradiation. Also, the height of the plaques can be increased, to accommodate additional conveyors. The height of the plaques has to be increased by about 3 ft 1 in., for each additional basket or flat chain conveyor, or 3 ft 11 in. for a special tray-type conveyor.

A less expensive means of increasing the capacity would be to install additional plaques in the system; this would necessitate increasing the conveyor speed. With 5 plaques, the speed of a conveyor, for a dose of 10^4 rep, is about 53 fpm. Since conveyor speeds of 100 fpm are common, the capacity of the facility can be doubled. This can be done by adding five plaques to the present design, for a total of ten plaques.

Likewise, if the design capacity is considered to be high, the capacity could be reduced by removing a plaque, or any of the conveyors not needed.

The total surface area of each plaque is 485 ft^2, or a total of 2425 ft^2 for the five plaques. The special tray conveyor, with 100-lb potato sacks, covers 47.5 ft^2 of each face of a plaque. The trolley-type conveyors take 33 ft^2 each. The flat chain, filled with V-3 boxes, covers 26.9 ft^2. Thus, these conveyors cover a total of 140.4 ft^2 per pass. For six passes, the covered area is 842 ft^2. The total area covered by the bulk conveyors is 187 ft^2. Therefore, the maximum useful area covered by the conveyors is 1029 ft^2, or a maximum plaque efficiency of 42.4%.

E. FACILITY VENTILATION AND AIR CONDITIONING

The sodium-24 source material contained in the radiation plaques will require cooling. The heat generation will result from beta- and gamma-ray absorption within the plaques and gamma-ray absorption in the shield structure. Considerable heat generation also will result, through thermal radiation and convection, from the thermally hot sodium carried in the process equipment in the cell.

To maintain the irradiation chamber atmosphere at a required design temperature, two different designs have been analyzed. The first of those designs will maintain the cell atmosphere at approximately room temperature. The second design will maintain the cell atmosphere at any desired temperature, from just below room temperature to as low as 20°F. This second design will require refrigeration equipment to replace the arrangement designed to meet the first condition.

1. Ventilation Design for Room Temperature

Calculations indicate that approximately 300,000 Btu/hr will be produced, as a result of radiation absorption in the cell structure and process equipment. Another 300,000 Btu/hr heat load will be generated, through thermal radiation and convection from the thermally hot sodium in the process equipment. This design has been established around requirements that limit the cell air temperature to a level no higher than 20°F above the outdoor ambient air temperature. This requirement is satisfied by the ventilation equipment. Figure 15 shows the arrangement of this design.

The system consists of the following principal items:

a) One operational exhaust fan on the regular electrical distribution system, rated 28,800 cfm at 9-1/2 in. of water static pressure, complete with a 75-hp, 480-v, 3-phase, 60-cycle drip-proof motor, having a water-cooled variable-torque fluid coupling and scoop tube, a 32-lb torque, and a 4-in. travel.

b) One standby exhaust fan on the diesel emergency electric system, identical to the one described in item a.

c) Two lever motors, Taylor 40 VF6 or equal.

d) One recorder, Taylor 91 JF 141-100 or equal, having a 0-200°F range, and a 1-in./hr, 30-day chart.

e) One controller, Taylor 402 RF 1041 or equal, having fully adjustable proportional response with automatic reset.

f) One temperature transmitter, Taylor 316 RG 120 or equal, with 200°F span, and local mount.

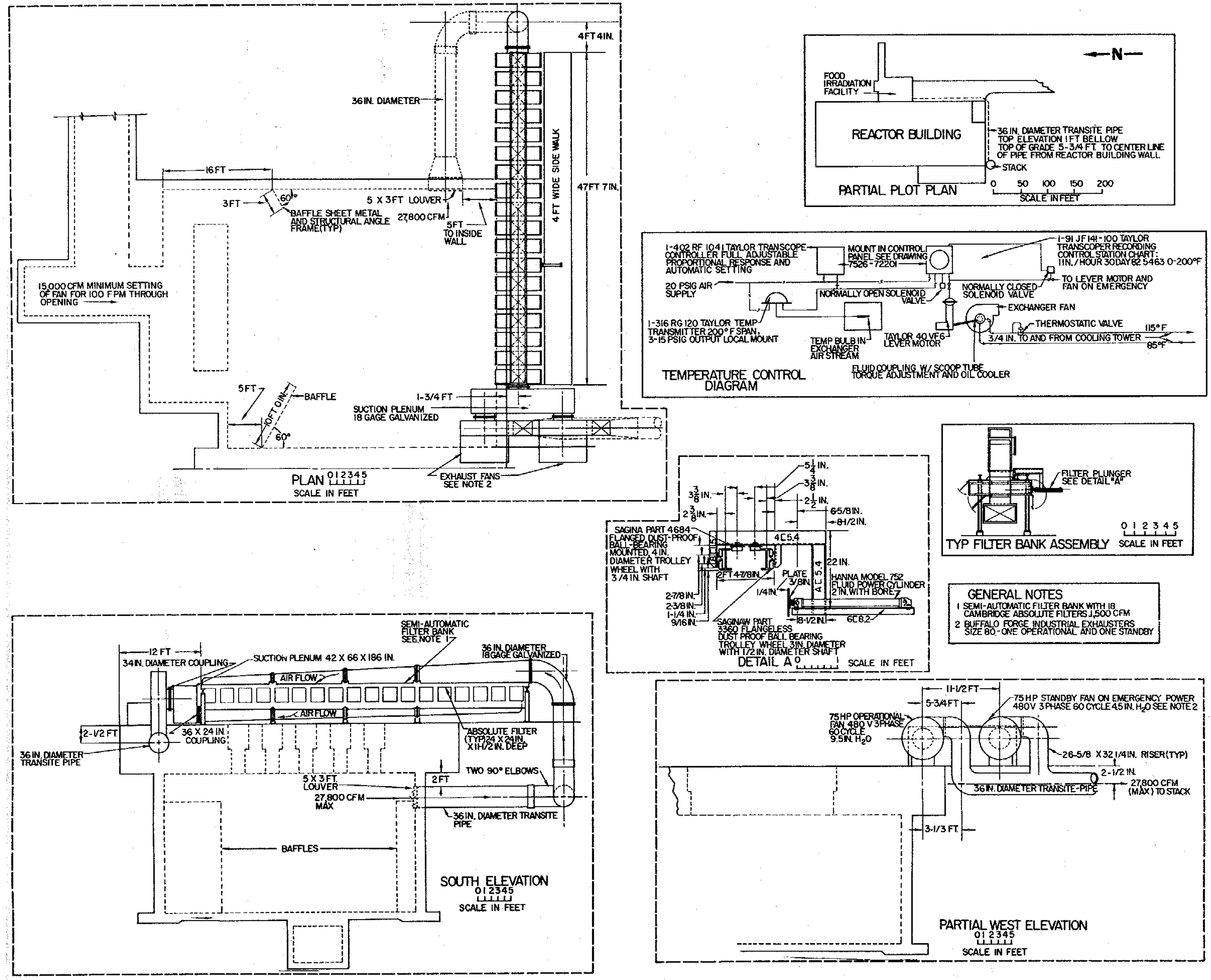


Figure 15. Ventilation

g) One complete semiautomatic filter changing mechanism.

h) Thirty-six fireproof "absolute" filters, Cambridge 1B or equal, rated at 1500 cfm.

A thermostatically-controlled, variable-speed exhaust fan and "absolute" filter system will draw unfiltered makeup air into the cell through the entry tunnel and labyrinth. The incoming air will be of sufficient quantity to provide a minimum average face velocity of 100 fpm through the entry. This will ensure a positive air flow direction, which will always be into the cell. The air is not cooled; no refrigeration is used. Only filtered air will be exhausted to the environment. The Hallam Facility effluent stack will be used to exhaust the air.

There are 18 filters in a bank. They can hold a minimum of 9000 grams of particulate material. The filters can be changed semiautomatically, in a reasonably short period of time, thus doubling the capacity of the filtering system.

A fire protection system has been included as part of the ventilation system. Inside the cell, a dry-chemical fire suppression system is used. The system, equivalent to Ansul's Met-l-x type, will flood the irradiation chamber with a mixture of finely powdered anhydrous metal and metal chlorides, in the event of a sodium fire. This system will extinguish a fire by a smothering action.

The dry chemical is injected through a fixed piping arrangement, designed to totally flood the cell. The chemical is propelled by dry nitrogen from a reservoir maintained at a pressure of approximately 250 psi. A temperature-sensitive monitor automatically actuates the injection mechanism. The system is actuated by a temperature-rise rate in excess of 15°F/min, or at a maximum temperature of 190°F. The capacity of the system permits control of a fire resulting from sodium leakage in the cell for a period of approximately 1 hr.

Design of the dry-chemical fire suppression system will be in accordance with requirements of the NFPA, Pamphlet No. 17.

2. Refrigeration System

A refrigeration system cools the air for the irradiation cell. The air exhaust capacity insures a positive air flow into the cell by providing a minimum average face velocity of 100 fpm through the entry. The refrigeration capacity is designed to offset all system heat gains and maintain the following average cell temperatures:

a) 20°F, for 24.8 ton/hr of frozen meat products having an entering temperature not more than 20°F.

b) 75°F, for 28 ton/hr of wheat or 41.4 ton/hr of potatoes having an entering temperature not more than 95°F.

Only filtered air is exhausted to the environment. The air is exhausted through the building effluent stack.

A sketch of the refrigeration system is shown in Figure 16.

Approximately 5,000 cfm of fresh air enters the system through an intake louver, roughing filter bank, and supply fan. The design conditions for the incoming air are 95°F dry bulb (DB) and 78°F wet bulb (WB) temperatures, and a moisture content of 118 grains per pound (gr/lb) of air. A direct-expansion precooling coil cools the air to 41 DB, 40 WB, 35 gr/lb, and passes it to a Kathabar dehumidification unit. In the unit, the air is further cooled and dried to 15 DB, 11 WB, and 4 gr/lb. In this condition, makeup air for the exhaust system enters the conveyor tunnel near the material carrier end. It passes the length of the tunnel and labyrinth. The air enters the irradiation cell through an entry door at a minimum average velocity of 100 fpm. It mixes with the cell atmosphere, and finally is filtered for particulate and exhausted to the building stack. A separate 62,000-cfm recirculating, refrigerated air system maintains the irradiation chamber at a constant 20°F.

The labyrinths and tunnels will have a vapor barrier and insulation to maintain an over-all heat transfer coefficient factor of 0.05 Btu/ft^2/°F. Flexible neoprene and canvas closure materials will connect the tunnel to freight or motor carrier door openings in such a way as to limit air intake to not more than 100 cfm. Any moisture which may occur at the car end of the tunnel, as a result

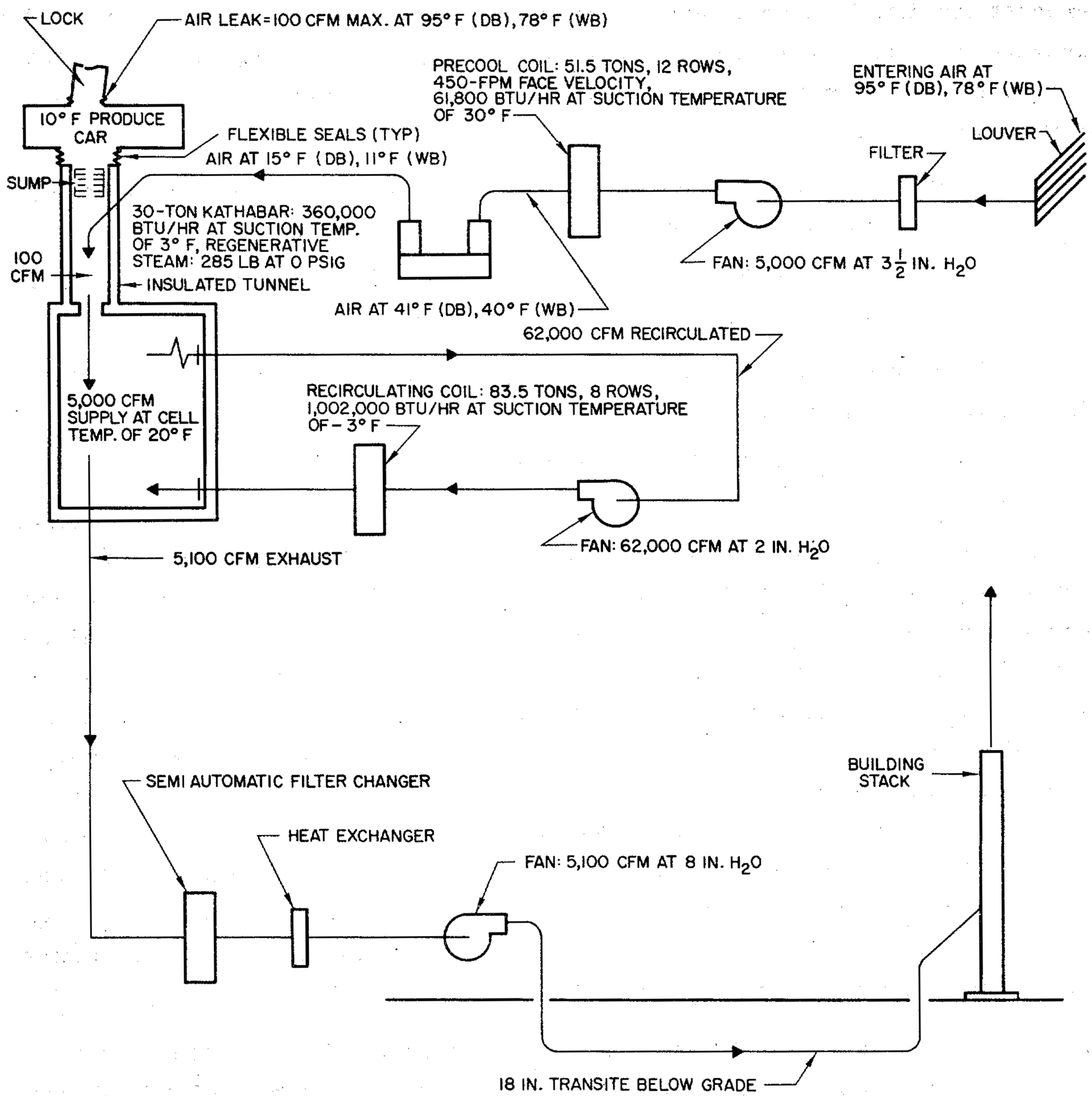


Figure 16. Air-Conditioning Sketch

of entering air, will be collected in a floor sump and drained to the sanitary waste system. A personnel air lock will minimize air intake resulting from employees entering and leaving cold areas.

The system would be exhausting 20°F air to the stack and environment. In order to utilize the cooling effect of this air, and deliver air at essentially atmospheric temperature to the stack, an air-to-water heat exchanger will be installed in the exhaust piping downstream from the filters. This installation will lower the temperature of the 85°F cooling tower water, and also raise the discharge temperature of the irradiation-chamber exhaust air.

Small amounts of frost will occur on the coils of the recirculating cold-air system. No special defrosting equipment is necessary, since normal shutdowns will be adequate to keep the coils clean. Moisture collected from these coils will be monitored for radioactivity, prior to release to the sanitary waste system.

The cell ceiling will have a vapor barrier, and will be lined with cork, to give an effective heat transfer coefficient factor of 0.05 $Btu/ft^2/°F$. The walls will have a vapor barrier, but will not be insulated.

Moisture in the cell which may result from complete system shutdown will be collected in a floor sump and monitored for radioactivity, prior to release to the sanitary waste system.

The refrigeration system will consist of the following principal items of equipment:

a) Inlet air louver, 48 in. by 48 in., fixed louver type, with bird screen

b) Roughing filters, 2 in. thick, throwaway type, fiber glass

c) Supply fan, 5000 cfm, 3-1/2 in. water static pressure, with a 7-1/2-hp, 480-v, 3-phase, 60-cycle motor

d) Precooling coil, 51.5 ton, 12 row, 450 fpm, 61,800 Btu/hr at 30°F suction temperature

e) Kathabar dehumidifier, 30 ton, 340,000 Btu/hr at -3°F suction temperature, requiring 285 lb/hr regeneration steam at 10 psig

f) Recirculation fan, 62,000 cfm, 2 in. water static pressure, with a 40-hp, 480-v, 3-phase, 60-cycle motor

g) Recirculation cooling coil, 83.5 ton, 8 row, 450 fpm, 1,000,000 Btu/hr at-3°F suction temperature

h) Semiautomatic filter changer, custom-designed, modified Argonne push-through type, 5000 cfm, complete with 5 active and 5 spare Cambridge 1B or equal "absolute" fireproof filters

i) Exhaust fan, 5100 cfm, 8 in. water static pressure with a 15-hp, 480-v, 3-phase, 60-cycle motor

j) Heat exchanger, galvanized finned tube type, 35 gpm

k) Refrigeration compressors, one 51.5 ton, 60 hp, 480 v, 3 phase, 60 cycles, and one 113.5 ton, 200 hp, 480 v, 3 phase, 60 cycle

F. ELECTRICAL

The electrical load consists of the motors to drive the conveyors, the blower for the ventilation of the irradiation chamber, heating of the sodium piping and plaques, lighting the facility, and the two TV cameras. A one-line electrical diagram is shown in Figure 17.

The power to the facility comes from the Hallam Facility through a 480/277v, 4-wire feeder. This feeder terminates at the motor control center.

Each of the three trolley conveyors and the flat chain conveyor is operated by a 5-hp motor. The screw conveyor has a 10-hp motor, and a 15-hp motor is needed for the bulk elevator. Therefore, a total of 45 hp is required for the conveying system.

To keep the irradiation facility at room temperature, a blower with a 75-hp motor is needed. If air conditioning is required, to keep the irradiation chamber at 20°F, a 200-hp and a 60-hp compressor, a 15-hp exhaust fan, a 40-hp recirculation fan, and a 7-1/2-hp supply fan are needed.

These motors are all single speed, squirrel cage, and splash proof or explosion proof, as required for use on full voltage starting. Power to the motors will be 480 v, 3 phase, 60 cycle. Across-the-line combination starters for all motors will be mounted in a free standing, metal enclosed, unit-type motor control center.

Start-stop pushbuttons will be provided on the remote control panel for all motors in this sytem. Amber pilot lights, to indicate when motors are running, will also be located on the panel.

Enough electric heaters are being provided to be able to preheat the sodium piping, plaques, and any other equipment containing sodium, to 560°F. Temperature controllers, mounted on the instrument panel, control the heaters. The power supply for the heating load is a 480/277-v, 3-phase system. The power will be fed from contactors, mounted in the motor control center which is located in the control room. A typical drawing of the heater installation on the sodium pipes and other equipment is shown in Figure 18.

Under operating conditions, there will be no need for room lighting, since there will be no personnel in the vault. However, provisions are made for illumination for inspection, maintenance, and repair work. Receptacles will also be provided for 120-v hand tools. Because of the grain handling system, all lighting fixtures and receptacles will be suitable for use in a class II, group G hazardous area. Figure 19 shows the lighting installation.

Power for all lighting circuits will be distributed from a 120/240-v, 3-wire, S/N lighting panel mounted in the motor control center. This panel will be fed from a 480-120/240-v, single-phase, dry type lighting transformer. This transformer will also be mounted in the motor control center.

Two closed-circuit TV cameras will be installed for remote viewing of the conveyor system during operation. One will be at the north wall, and the other at the south wall. The cameras will be mounted on adjustable tilt heads which, in turn, are mounted on motor-driven screws for east-west traversing across the ends of the conveyors. To minimize the exposure of the lenses to damaging radiation, the cameras will be stored behind lead shielding when not in use. To provide proper lighting for the TV cameras, a battery of suitable fixtures will be mounted on the camera carriage. These fixtures will traverse with the camera, and will concentrate the lighting where needed. The use of PAR projector-type lamps is contemplated, to provide the foot-candle requirements with a minimum of fixtures. The amount of light output may be varied by adjusting the two variable-voltage transformers mounted on the remote control panel. Controls for tilting and traversing the TV cameras will also be mounted on the panel.

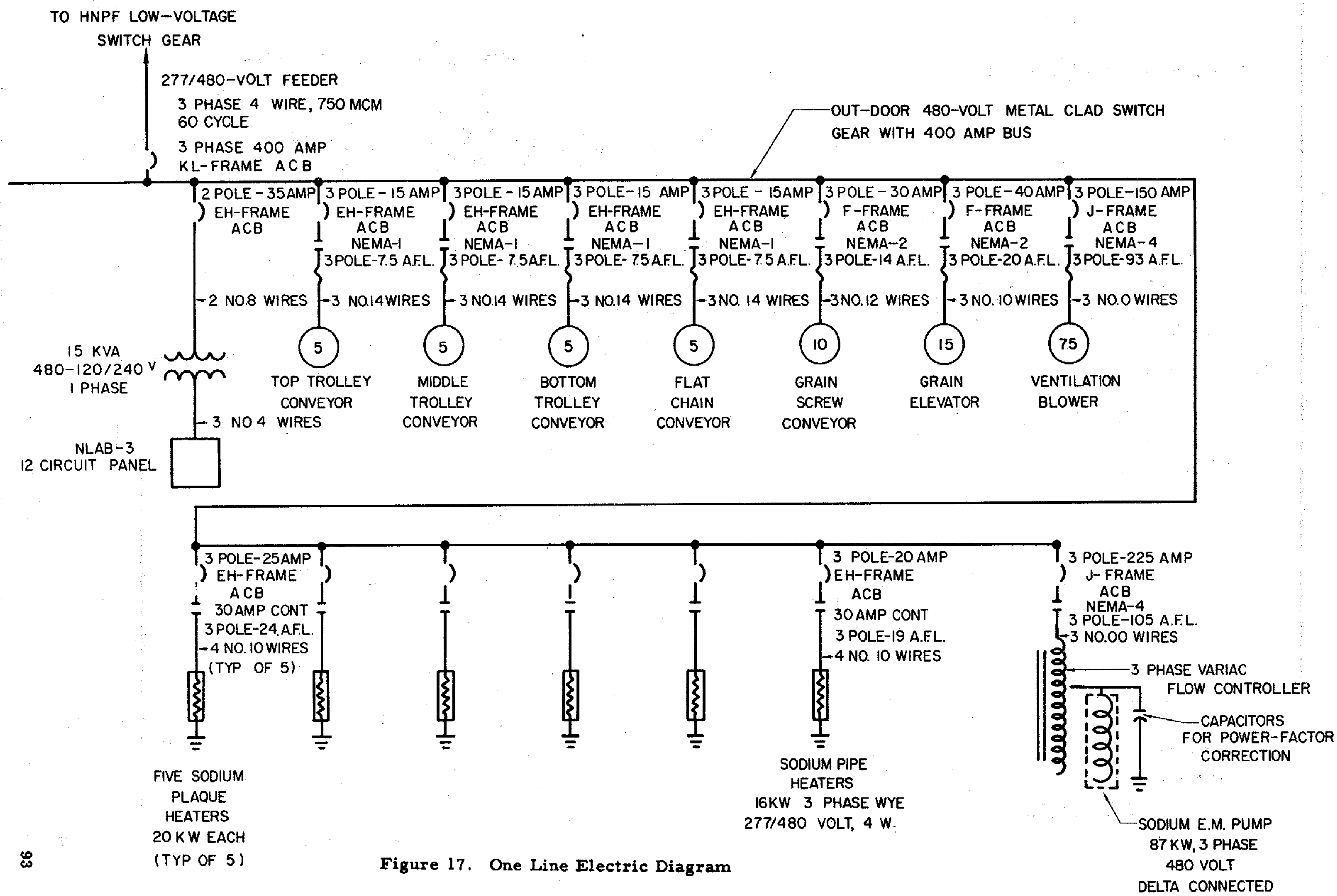
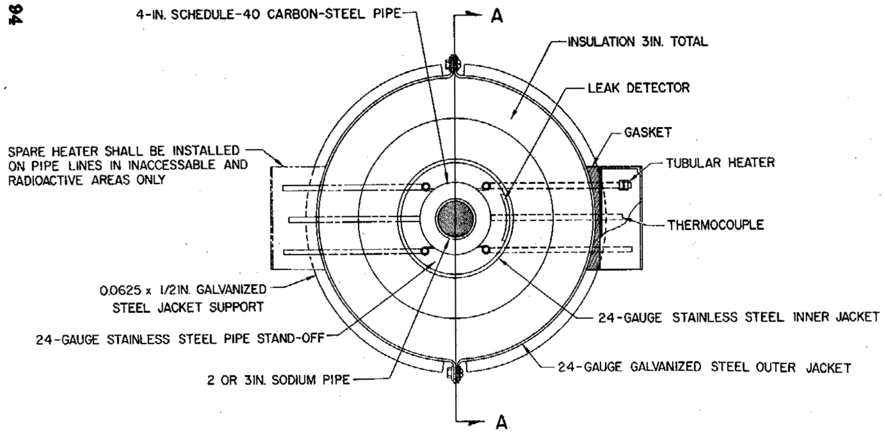
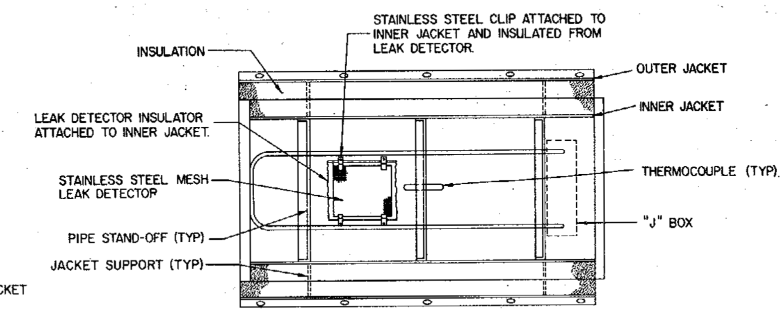


Figure 17. One Line Electric Diagram

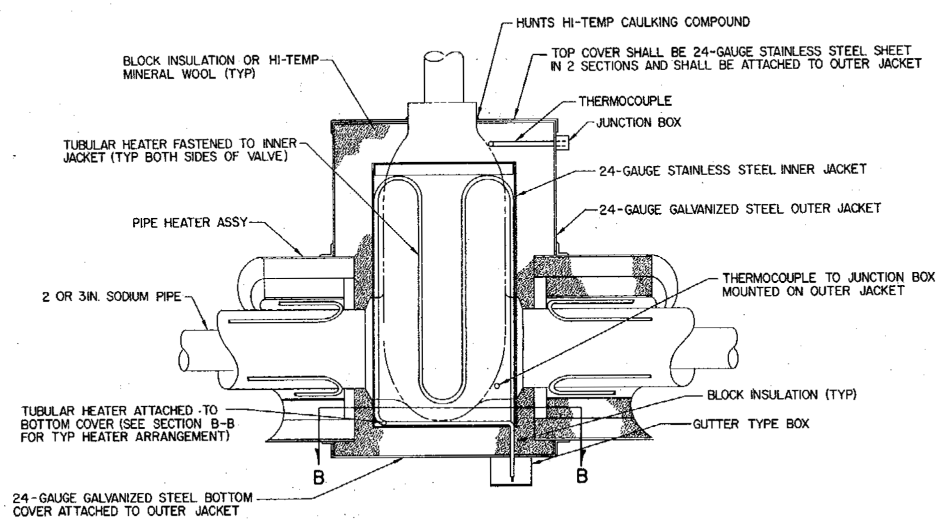


TYPICAL HEATER INSTALLATION FOR 2 AND 3 IN. PIPE LINES

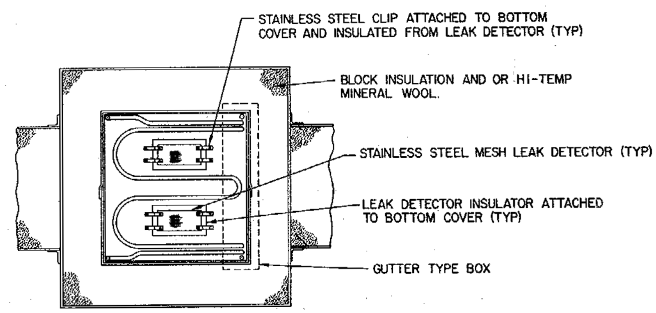


SECTION A-A

(HEATER AND THERMOCOUPLE INSTALLATION ONLY)

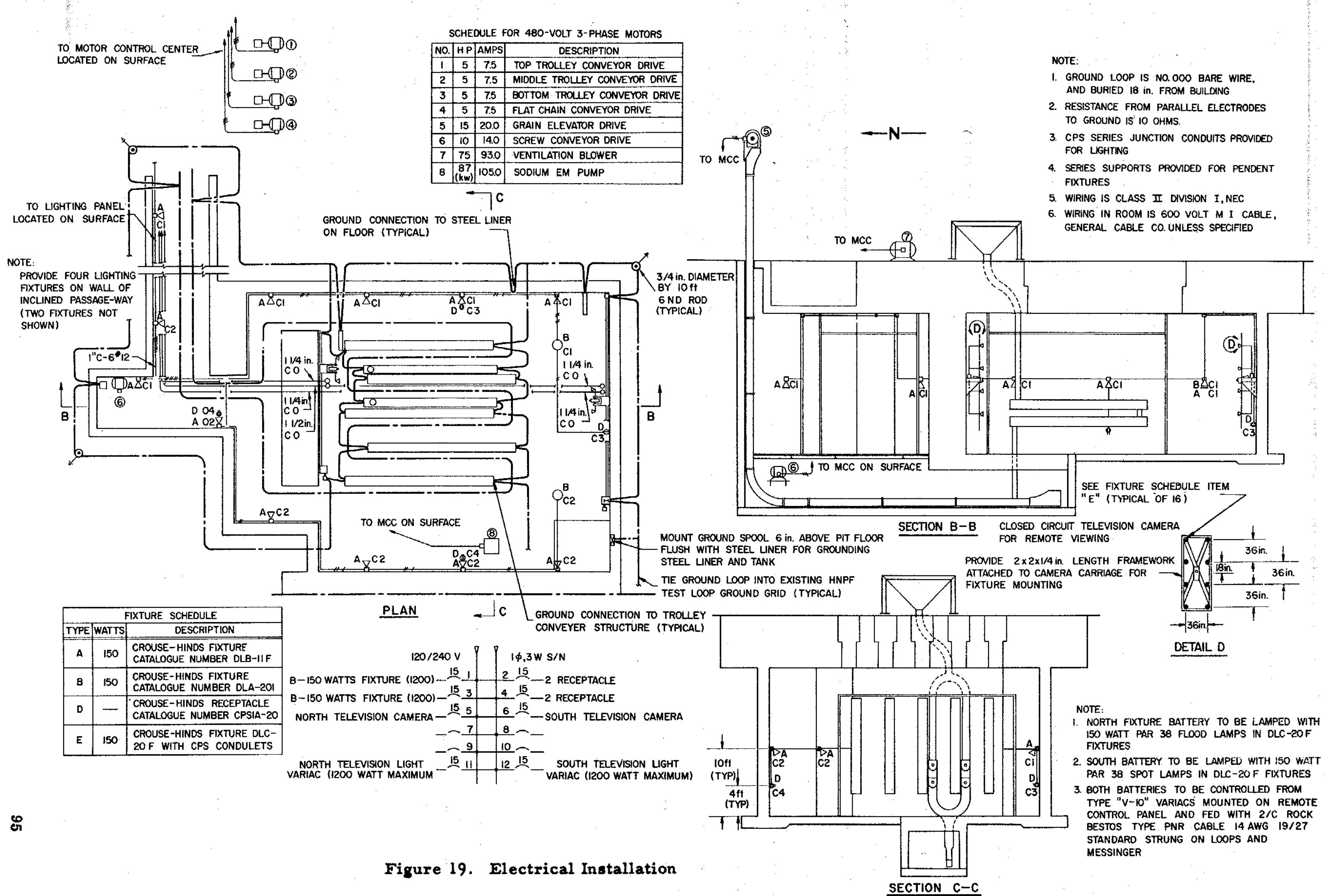


TYPICAL HEATER INSTALLATION FOR VALVES



SECTION B-B

Figure 18. Heater Installation



SCHEDULE FOR 480-VOLT 3-PHASE MOTORS

NO.	HP	AMPS	DESCRIPTION
1	5	7.5	TOP TROLLEY CONVEYOR DRIVE
2	5	7.5	MIDDLE TROLLEY CONVEYOR DRIVE
3	5	7.5	BOTTOM TROLLEY CONVEYOR DRIVE
4	5	7.5	FLAT CHAIN CONVEYOR DRIVE
5	15	20.0	GRAIN ELEVATOR DRIVE
6	10	14.0	SCREW CONVEYOR DRIVE
7	75	93.0	VENTILATION BLOWER
8	87 (kw)	105.0	SODIUM EM PUMP

FIXTURE SCHEDULE

TYPE	WATTS	DESCRIPTION
A	150	CROUSE-HINDS FIXTURE CATALOGUE NUMBER DLB-11F
B	150	CROUSE-HINDS FIXTURE CATALOGUE NUMBER DLA-201
D	—	CROUSE-HINDS RECEPTACLE CATALOGUE NUMBER CPSIA-20
E	150	CROUSE-HINDS FIXTURE DLC-20 F WITH CPS CONDULETS

Figure 19. Electrical Installation

VII. SAFEGUARDS CONSIDERATIONS

The release of airborne sodium-24 activity to the environment is the only hazard associated with operation of the irradiation facility. Sodium leakage from the process equipment could expell limited quantities of radioactivity to the cell atmosphere which would be released to the environment by normal diffusion; this release would be accelerated if a fire occurred.

A. CONTAINMENT FEATURES

Containment features associated with the irradiation facility are reflected in the design of the separate components within the cell. These features are considered adequate from a safeguards standpoint.

All piping and equipment containing sodium in the irradiation cell are double walled. The annuli between the primary and secondary containment is continually purged with nitrogen gas and monitored for any indication of sodium leakage. Rupture of a primary pipe should be detected in time to prevent leakage of sodium through the secondary containment into the cell atmosphere.

The atmosphere inside the cell is also monitored. Should any quantity of sodium leakage into the cell atmosphere occur, the cell monitor will initiate an alarm at the control panel.

To protect the irradiation plaques from possible damage, resulting from a malfunctioning conveyor system, structural members have been installed where-ever necessary. All package conveyor systems operating within the cell are provided with guard rails to serve as a separation barrier between the plaque surface and the moving process material. If a conveyor chain breaks, the conveyor drive is automatically stopped.

The closed-circuit television system will serve as an additional monitoring device to permit close surveillance of the conveyor and process systems within the cell.

B. HAZARDS PROTECTION

The irradiation facility was designed to control potential radiation releases as well as to control fire hazards which might result from sodium leaks within the cell. The primary objective of each of these control measures would be to limit the amount of radioactivity released to the atmosphere outside the facility. Special consideration has been given to the fire hazard potential.

In the event of sodium leakage into the cell atmosphere, primary control of radiation release is achieved by the ventilation system. This system will control air flow through the cell by continuously drawing outside air into the cell through the labyrinth. The air stream is discharged from the cell to the HNPF building stack through a filter bank.

The capacity of the ventilation-system filter bank is sufficient to remove a maximum of 18,000 grams of sodium oxidation products from the airstream. The small amount of radioactivity which is not entrained in the filter bank will be discharged to the building stack. This small percentage of activity would undergo sufficient dilution at the discharge point to reduce the specific activity release to an insignificant level. Filtration of activity through the ventilation-system filter bank is considered to be effective for those partial sizes associated with sodium oxidation products.

As a further protection against sodium activity release from the cell, a dry-chemical fire-suppression system, equivalent to Ansul's Met-L-x system, has been included in the facility design. If a sodium fire occurred, this system would flood the irradiation chamber with a mixture of finely powdered anhydrous metal chlorides and metal. The propellant used in this system is dry nitrogen, maintained at a pressure of approximately 250 psi. The injection of the fire suppressant is initiated remotely from a temperature-sensitive monitor in the cell. Actuation of the system is automatic.

The metal chloride flooding of the irradiation cell will control and suppress any sodium fire for a period in excess of the time required to drain all the process sodium from the irradiation-facility system. The capacity of the dry-chemical system will offer fire protection by intermittant injection of chemicals over a period of up to 1 hr. The facility sodium system can be drained in approximately 4 min.

During a fire hazard, the ventilation system should be in operation. This procedure will prevent dispersion of radioactivity to the environment through the cell labyrinth and will maintain normal flow of any particulate material from the irradiation cell to the ventilation-system filter bank.

VIII. COST ESTIMATES

A. CAPITAL COSTS

The estimated cost for the Irradiation Facility is $770,000. This figure includes installed costs of the cell structure, irradiation plaques, piping, ventilation, and all monitoring and control instrumentation.

The conveyor systems (described in section VI) are estimated to cost $120,000. This figure includes the total installed cost of the conveying equipment necessary to carry process materials through the cell structure terminating at a point near the mouth of the labyrinth. Extensions to these conveyor systems will be required to transfer materials to and from the carrier loading and unloading areas.

The refrigeration system, if necessary, is estimated to cost an additional $125,000. This system (described in section VI) would maintain the cell atmosphere to as low as 20°F.

B. OPERATING COSTS

The irradiation facility operating costs have been estimated according to separate categories which include (1) power costs, (2) manpower costs, and (3) fixed charges on the capital investment of the facility, conveyor systems, and refrigeration system.

Power costs have been estimated at 96 $/day. This figure represents the power necessary to operate all facility equipment, the conveyors, the ventilation system.

As presently conceived, it is estimated that 3 men per 8-hr shift will be required to operate the facility. The cost of maintaining this staff would cost an estimated 300 $/day. This manpower cost represents a requirement over and above the handling costs listed in part D of this section.

Fixed charges on the capital investment have been calculated at an assumed 15 %/yr on the capital cost estimate of the major portions of the facility. Fixed charges on the facility (estimated cost of $770,000) would be 115,500 $/yr, or

316 $/day. Fixed charges on the conveyor systems would be 18,000 $/yr or 49 $/day. Similarly, the fixed charges on the refrigeration system would be 18,750 $/yr or 51 $/day.

C. PROCESSING COSTS

To arrive at an approximate cost of processing materials in the Irradiation Facility, the following assumptions were made:

1) The integrated dose exposed to each conveyor system is 10^5 rep.

2) The plant factor of the facility is 75%.

3) The conveyor systems (described in section VI) are operated at full capacity.

The capacity of the facility, processing materials to a total dose of 10^5 rep, is 523 ton/day. This production rate was used to develop the following processing costs in cents/lb:

Power costs	0.0092
Manpower costs	0.0287
Fixed charges, facility	0.0302
Fixed charges, conveyors	0.0047
Fixed charges, refrigeration system	0.0049

D. TRANSPORTATION AND HANDLING COSTS

A preliminary and approximate estimate of added transportation and handling costs associated with radiation processing of products at Hallam, Nebraska, has been made. Such costs would reflect the added charges for transporting and handling of products over and above the carrier costs for various commodities moving in current flow patterns. It is felt that the degree of accuracy of these estimates does not warrant their use in developing a strict economic evaluation of offering radiation processing to any one particular product. These figures are presented to offer some means of assigning that percentage of processing costs which might be represented by extra transportation and handling operations.

1. Transportation Costs

Information indicates that, in most cases, truck transportation would be used for shipments moving within a 500-mi radius of Hallam because of the flexibility of motor-carrier operation and the generally accepted way of transporting these products. Rail service would be used as a general rule for the longer hauls.

If the through freight rate from origin to destination can be applied, the motor carriers will charge about $15.04 per truck load to stop the vehicle at the processing point. In such instances, the through freight rate from origin to destination may be used for a period of 1 yr. Should the products be stored for more than 1 yr at Hallam, a combination of freight rates would then apply. It is obviously much cheaper to use the through rate from origin to destination even though the vehicle is unloaded, and the material is processed and reloaded onto another vehicle at Hallam. While the motor-carrier tariffs do not show Hallam as a transit point, it is believed that very little difficulty would be encountered in obtaining a transit privilege at Hallam if there were any volume of business to offer the carriers. The minimum truckload weight for most of these products is 24,000 lb.

No railroad transit privileges are in effect at Hallam, Nebraska, on any commodities in the tariffs currently on file with the Interstate Commerce Commission.

All of the rates shown in Table XXI are in effect at Kansas City, Missouri, a point which was chosen for analogy because of the wide diversity of commodities being transited by rail at that point.

There are no charges for transit privileges on grain, cereal products, or partially prepared cereals. The through rate from origin to destination applies except where a back haul is required. The minimum carload weight for a back haul is 24,000 lb.

TABLE XXI

TRANSIT-PRIVILEGE CHARGES AT KANSAS CITY, MISSOURI

Commodity	Minimum Carload Weight (lb)	Rate ($/cwt)	Privilege
Meats, all kinds	30,000	26.86*	Storage and freezing
Potatoes	36,000	0.10	Storage, sorting, and grading
Onions	24,000	0.11	Storage, sorting, and grading
Beets	20,000	0.11	Storage, sorting, and grading
Strawberries	17,000	0.11	Storage, sorting, and grading
Citrus fruits	36,000	0.10	Storage, sorting, and grading
Deciduous fruits	24,000	0.10	Storage, sorting, and grading
Pharmaceutical drugs	30,000	0.10	Storage
Blood plasma	24,000	0.10	Storage
Chemicals	24,000	0.10	Storage
Polymer plastics	30,000	0.10	Storage

* $ per car.

For box and standard refrigerated cars, railroads allow 48 hr for unloading. Detention of the cars beyond 48 hr is assessed at a rate of 4 $/day for the first 4 days and 8 $/day thereafter. If an "average agreement" is entered into with the carrier at Hallam and if a car is unloaded in 24 hr, one credit is received which may be applied against a car that was detained over 48 hr, on which one debit was charged.

On a per pound basis the transit privilege charges will vary from nothing (for grains) to approximately 0.063 to 0.11 cents (for other commodities).

Out-of-line transportation charges to Hallam will need to be considered as an added expense. Table XXII lists the carload mileage rates in effect from Hallam to hypothetical points.

TABLE XXII

TOTAL OUT-OF-LINE HAUL RATES

Item	Cost ($/cwt)				
	For 100 mi	For 200 mi	For 300 mi	For 400 mi	For 500 mi
Grain	$0.285	$0.345	$0.445	$0.49	$0.565
Vegetables	0.55	0.72	0.83	1.00	1.25
Meats	0.67	0.90	1.10	1.25	1.35

For relatively short hauls, within the 500-mile radius, it is expected that motor freight rates would vary within 15% of the listed rail rates in Table XXII.

On a per-pound basis the out-of-line carrier charges would vary from approximately 0.3 cents for grains at total out-of-line distances of 100 miles to approximately 1.4 cents for meats at total out-of-line distances of 500 miles.

2. Handling Costs

Extra handling costs should be included in an analysis of charges if a commodity were to be made available for processing at Hallam, Nebraska. These costs would result if an extra unloading and loading operation were performed.

Handling costs will vary over a considerable range, depending on the type of packaging. An average of 32 man-hr was assumed to cover unloading and loading of a rail car carrying 30,000 lb of a packaged commodity. Products shipped in bulk probably would require less effort. At a labor charge of 4.00 $/man-hr, the handling operations at the facility would amount to approximately 0.43 cents/lb. This figure should represent an upper limit.

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