ENGINEERING AND ECONOMIC FEASIBILITY STUDY
OF
FISSION PRODUCT PACKAGING

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PREFACE

This report is a summary of some technical and economic studies of various methods of separating and packaging fission products resulting from the operation of nuclear reactors. These studies are based on information which has been collected, analyzed, evaluated, and projected to the scale of operations required for The Dow Chemical Company's fields of interest in packaging fission products as industrial sources of radiation. Much of the information used was obtained from laboratories supported by the U. S. Atomic Energy Commission chiefly at Oak Ridge National Laboratory, Argonne National Laboratories, the National Reactor Testing Station, the Hanford Works, and Brookhaven National Laboratory. The workers in these laboratories and elsewhere have discussed the data available, and have given freely of their time in contributing information and ideas which have made possible this projection of the technical and economic feasibility of fission product packaging.

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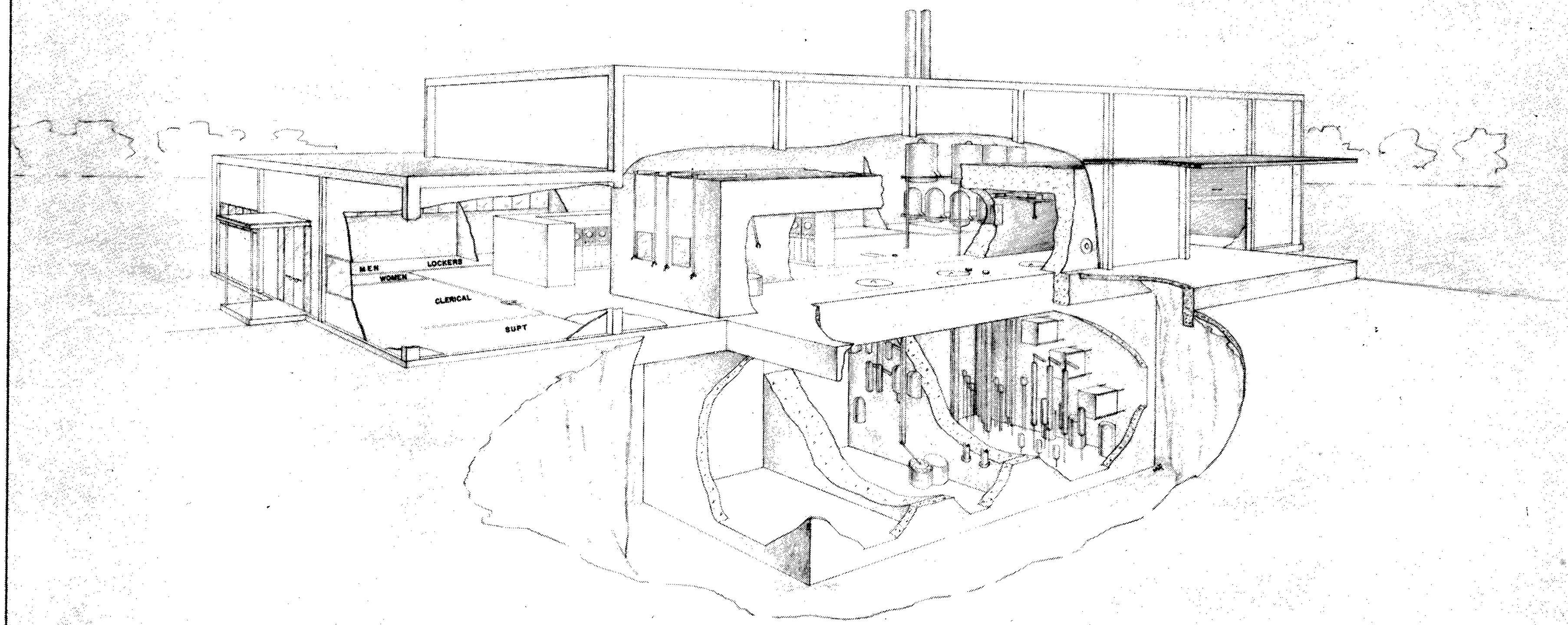


Figure 1

GENERAL VIEW

SOLVENT EXTRACTION PROCESS
FOR
FISSION PRODUCT SEPARATION AND PACKAGING

I. ABSTRACT

Fission products from the operation of nuclear reactors have value as sources of beta and gamma radiation for industrial, medical, and research uses. In this report, costs of separating cesium and strontium from the gross fission products and also of packaging the gross fission products have been estimated and reported.

Three main objectives were pursued in the present study. These were:

1. To compare with one another six methods of separating and packaging fission products and to make recommendations regarding the most desirable methodto pursue further.

2. To reduce volumes of undesired fission product wastes in order to permit more economical storage methods.

3. To remove from the fission products not packages those long-lived nuclides which are biologically hazardous, to sufficient degrees to permit discarding of the remaining fission products.

The technical aspects of the alternative methods of separation were examined and certain projections were made in technology based on assumed development. Operating costs were estimated for each of these alternative processes. Unit operating costs in terms of dollars per curie of radiation produced were then computed. An arbitrary production rate of ten million gamma curies per year of cesium was assumed at full design capacity for each plant. This rate of cesium processing corresponds to approximately four times the anticipated rate of fission product cesium production from all of the power reactors of the U. S. Atomic Energy Commission's five-year program of civilian power reactor development which should be in operation by 1960.

The following were six alternate methods studies for fractionating the gross fission product mixture into strontium, cesium, and into a third category consisting of the remaining fission products:

1. Co-precipitation for selective removal of cesium, possibly other alkali ions, and strontium.

2. Ion exchange for removal of cesium and probably other alkali metal ions from the alkali dissolution of aluminum fuel elements.

3. Procedures of fractional precipitation and crystallization with the ultimate separation of strontium and of cesium. Cesium would be removed in the final step by co-crystallization in ammonium alum.

4. Complexing and solvent extraction for the selective removal of alkali and alkaline earth ions present in the gross fission products.

5. Evaporation of aqueous and acid solvents from solutions of gross fission products.

6. The leaching of soluble oxides, such as cesium oxides, from a dried mass of oxides of the fission products resulting from the evaporation of a solution of gross fission products.

Based on a maximum production rate of 10^7 gamma curies of cesium per year, operating costs for all six of the processes mentioned above are roughly comparable. Total operating costs vary from a minimum of $717,530 per year at 25 percent of capacity up to $1,068,160 per year at 100 percent of design operating capacity for the gross fission product packaging process. This process represents the minimum operating costs of all processes, although it does not achieve separation of individual fission products. Total operating costs range from $923,570 per year at 25 percent, and $1,363,850 per year at 100 percent of design operating capacity for the solvent extraction process. Corresponding costs are $885,450 per year at 25 per cent and $1,286,000 per year at 100 percent of design capacity for the co-crystallization process. The solvent extraction or co-crystallization process. The solvent extraction or co-crystallization processes are the only ones which achieve the separation of gross fission products into a number of relatively pure fractions.

At full production rate in each process, the unit costs obtained on assessing all operations against cesium are $0.11 per gamma curie of cesium in the gross fission product packaging process; are $0.14 per gamma curie of cesium in the solvent extraction process; and are $0.13 per gamma curie of cesium in the co-crystallization process. Unit costs at full production per beta curie of strontium are $0.09 for solvent extraction and $0.09 for co-crystallization. The unit operating costs depend heavily upon the rate of processing in a given plant, since relatively large fixed investments are necessary for shielding and remote handling procedures.

Several of the processes studied are, within limits, of comparable operating costs. Further review of these processes should be considered on the technical merits and possible costs and timetables of development of the processes, as much as upon this preliminary economic analysis of operating costs.

The philosophy and ground rules of engineering design employed are described at length, since such considerations influence heavily the costs figures presented. The packaging plant was assumed to be located in a remote area and to be sufficiently near to an existing fuel separations plant to be able to use capital facilities for general services already in existence for the fuel processing plant.

The supply of gross fission products was assumed to cost nothing, and no credit was taken for the storage in dry form of waste products from packaging operations. No credit was taken for nitric acid recovered from gross fission product solutions during packaging operations.

A brief discussion is presented of factors likely to affect sales of fission products as sources of radiation.

II. INTRODUCTION

A study has been made to evaluate the separation of radioactive cesium and strontium from gross fission products from irradiated nuclear reactor fuels.

Provisions are made in this study for fractionating and packaging of fission products resulting from the aqueous processing of irradiated nuclear fuels. However, it is believed that only minor modifications would permit the treatment of fission products from alternative means of processing fuels.

The general scope of work described in this report is a preliminary technical and economic feasibility study of the separation and packaging of cesium, strontium, and the remaining gross fission products in dry form in metallic containers for use as sources of radiation or for storage. Most of the results and conclusions reported are based upon the chemical and engineering practices which have been developed, or are now under development, at various facilities of the U. S. Atomic Energy Commission. In addition to these practices, some of the study is based upon adaptations or extensions of present methods which may require some development.

Some specific objectives of this feasibility study are summarized as follows:

A. To produce a package of a desired fission product suitable for use in radiation procedures.

B. To reduce the storage cost of fission products remaining after the desired materials have been extracted.

C. To remove long-lived fission products from the aqueous waste to a degree which would permit accelerated disposal of the remaining waste to the environment.

The general approach has been to assume that the objectives (A), (B), and (C) can be achieved simultaneously if cesium and strontium are both removed from the gross fission products, and are packaged separately, or in combination with the other products in the gross fission product packaging procedure. When cesium and strontium have been removed, the remaining other fission products may be disposed of to the earth after relatively few years of storage in aqueous solution. As an alternative, if the remaining fission products are stored in dry form, their cost of continued storage is greatly reduced below that of aqueous methods, even though cesium and strontium are not completely removed.

The studies upon which this progress report is based have consisted of examination of the following alternative or supplementary methods of preparing fission products in the form of packages of solid salts:

1. A co-precipitation process in which cesium and strontium are simultaneously carried down from a solution of gross fission products by means of a ferrocyanide precipitate. The precipitate is destroyed and the desired materials recovered from the residue.

2. A co-crystallization process in which cesium is removed from the fission product solution by co-crystallization with alum, after strontium and some other fission products have been removed by various precipitation and crystallization procedures.

3. An ion exchange process for the removal of cesium from the caustic liquors resulting from dissolution of aluminum fuel elements in sodium hydroxide solution.

4. A solvent extraction process in which the various fission product elements are selectively removed from a solution of gross fission products by means of pH adjustments, followed by chelation with thenoyltrifluoroacetone dissolved in methyl isobutyl ketone. The ketone extracts the chelates selectively from aqueous fission product solutions, and the chelates may then be removed from the ketone into an aqueous solution by a further contacting procedure by aqueous solutions with adjustments of pH.

5. A gross fission product packaging process consisting in dehydrating and denitrating solutions of aqueous waste fission products from the aqueous solvent extraction of fuels and packaging the resulting dry powders.

6. An oxide leaching process based upon the gross fission product packaging process. In the leaching process, the gross fission product oxides are leached with water for the removal of cesium hydroxide, and possibly further treated for the removal of strontium hydroxide, and the cesium and strontium are then packaged. The oxides of the remaining fission products are converted to dry powders and stored as wastes.

The processing capacity of the fission product separation plants studied has been based upon published accounts (12) of the probable nuclear power generating capacity to be installed in this country by the year 1960. The operation of these reactors would yield approximately two and one-half million gamma curies per year of cesium-137 in the gross fission products, and the design capacity of the plants studied has been set at four times this figure, or ten million gamma curies per year of cesium.

A fission product processing plant might either be centrally located with respect to the proposed nuclear power generating system described above, or might be located near one of the U. S. Atomic Energy Commission fuels separation plants employing simplified aqueous solvent extraction methods of fuel separation, such as a Purex-type process.

The treatment of Purex-type wastes was studies in this report. These wastes are among the least complicated available, since they contain essentially fission products, water, nitric acid, small amounts of sodium, and small amounts of other impurities. (See (7). Variables affecting the choice of an optimum source of fission products are thought to be the following:

1. Concentration of the gross fission products in the waste solutions.

2. Percentage abundance of cesium and strontium in the gross fission products as affected by the length of reactor operation and cooling period.

3. The total quantities of fission products available.

4. Probable ease of removing fission products from the solutions of waste fission products.

5. Possibilities of agreements being reached with the U. S. Atomic Energy Commission or civilian nuclear power operators regarding supplies of fission products and disposal of wastes.

6. Costs of fission product separation and packaging by required methods.

7. Costs and schedules of development required for possible methods of separating and packaging fission products.

OUTLINES OF DEVELOPMENT WORK

It is intended that the designs of the fission product separation facilities presented in this report would be suitable for operation as producing units. These units would permit considerable variation in productive capacity and in the composition of the gross fission products. A prime objective in the preparation of this work was to provide designs which would permit the lowest capital and operating costs likely to be achieved. In order to realize the foregoing objectives, it was necessary to outline programs of development which can be achieved in accordance with the predetermined plan and schedule for an over-all facility. Problems must be solved, such as transfer of fission product solutions, removal of interfering ions such as iron, aluminum, and sodium, the kinetics of extraction, precipitation, and crystallization processes, optimum HTU values for extractions, concentration of gross fission products, and radiation damage. It should be understood that the results portrayed in this report are subject to the qualifications of successful achievement of such development programs. In certain cases, it has been necessary to make assumptions of optimum designs subject to achievement of adequate data and information.

The work of design and development which is described and summarized in this report is termed Phase I - Feasibility Studies. This work has consisted essentially of projecting available technology available on aqueous processing methods for gross fission products of compositions presently available. Endeavors have been made to incorporate sufficient flexibility in the designs of the processes so that a single plant can accommodate a wide range of chemical processing methods for fission products of different compositions. In general, the engineering studies which have been possible in this initial endeavor have portrayed systems and process designs which would permit conducting several different chemical processing steps alternatively in some of the equipment. The only limiting conditions which are imposed upon the achievement of such alternative chamical methods of fission product separation are the life and corrosion resistance of the process equipment and machinery. Industrial practices have been assumed where possible in the study described. Special consideration was given to equipment for which radiochemical and metallurgical problems necessitate special design consideration. It is hoped that the studies which have been completed and summarized in this report will serve as justification for instituting development and engineering activities with sufficient emphasis to permit the technological progress in fission product processing to be applicable either to the packaging of fission products as commercial sources of radiation or as offering attractive contributions to the technology and economics of fuels processing paralleling the efforts and achievements required in the reactor fuels development program.

The designs which are presented in this feasibility study possess flexibility of layout requirements. Essentially the same requirements for land and buildings and the same cell and handling layouts in operating areas, offices, and laboratories, etc., are required for all of the processes with the possible exception of the solvent extraction process. The solvent extraction process differs only in that it requires one separate cell for high temperature furnacing operations for the evaporation of fission products, in order to avoid explosion hazards inherent in operation of high temperature equipment near solvents. Consequently, any one of the five processes studied, with the exception of solvent extraction, could be placed in the same set of structures. If it is desired to produce fission product sources rapidly, initially one might start with the gross fission product packaging plant and by additions or alternations of equipment as developmental technology became available, add the facilities for separation and packaging of desired separate radioisotopes.

III. PHILOSOPHY OF ENGINEERING DESIGN

A. General

The philosophy of design established for fission product separations plants plays a significant role in the economic feasibility of such plants. Much of such philosophy is based upon judgment and experience with requirements of health and public safety, public relations, legal requirements, insurance regulations, and specific company policies. It is considered necessary to adopt engineering practices consistent with present industrial philosophies in order to achieve costs of capital and operations such that industry can afford to invest in such facilities. Many of the basic assumptions made in this study will require critical re-evaluations as the progress of future work unfolds. It is hoped that the data and information contained in this report will serve as a basis from which additional evaluations, extrapolations, and modified approaches or alternatives can be considered. However, in order to validate the capital and operating costs portrayed in this study, it is essential that the basic criteria of design and operation be stated rather specifically.

It is suggested that when reviewing estimates of the cost of plant and the cost of operation, that the scheduling of operations and considerations of safety and layout be reviewed carefully in detail before making extrapolations from the figures presented in this report.

The processing plants described in this report have been evaluated for a specific composition of waste fission products consisting of essentially the evaporated waste from a Purex-type of aqueous fuel separation process. The rate of production of packaged fission products has been based on feed containing ten million gamma curies per year of cesium, which is an arbitrary figure representing roughly four times the anticipated productive capacity of the civilian power reactors projected for operation in the year 1960. The fission product packaging plant is assumed to be located adjacent to a fuel processing plant which produces the fission product wastes. The coordination of location of activities of these facilities heavily influences the costs portrayed in this study. No allowance has been made in this study for the provision of general services such as steam and power generating equipment, potable and service water pumping facilities, utilities networks external to the processing plant, ultimate disposal of active wastes, sanitary sewage disposal, roads, railroads, the preparation of the site, perimeter fences, security guards, general administration, and fiscal matters related to the particular company policy. Several alternative methods of fission product packaging and separation of aqueous fission product solutions from processing plants were selected for study as possible methods of supplying industrial sources of radiation. Complete information regarding the kinetics and conditions of equilibrium for the various chemical steps portrayed in these processes are not now available. However, work is continuing in U.S. Atomic Energy Commission national laboratories in addition to promising results which have already been obtained, many in the pilot plant scale. It is hoped that further general information on this subject may be available under the general program of development of the U. S. Atomic Energy Commission.

The following are statements of design criteria which have been assumed and upon which costs and economics have been projected.

B. Requirements of Plant Design

Alternative methods of fission product packaging which have been studied under this program of work are specifically related to the aqueous acid solution of fission products resulting from the Purex-type of fuel element separation. Sources of fission products from other methods of fuel element separation could probably be handled with relatively minor modifications of the plants studied in this scope of work. As further information is developed about these systems, and possibly upon the basis of further studies which might be conducted at this time, alternative methods of separating fission products might be available for consideration from pyrometallurgical slags, or from fluoride volatility fission product fractions. Some of the special considerations inherent in the design philosophy employed in this study are the following:

1. Processing Rates

The total supply of fission product materials available exerts a limiting influence upon the economics of these studies, and the cost of structures and associated facilities for a given plant exerts a much greater influence upon capital cost than would relatively secondary adjustments in sizes and costs of equipment required for larger throughputs. In addition, requirements of operating personnel would probably not increase for greatly increased throughputs in such a plant.

Present considerations have based the separation of fission products upon those waste products available from the projected five-year plan of civilian power reactor operation of the U. S. Atomic Energy Commission and the interested utility concerns in the field. A figure of ten million gamma curies per year of cesium has been selected as representing design capacity of the plants studied. This rate of production of fission products is about four times that anticipated from all of the civilian power reactors to be developed within this five-year period. It is probable that the rate of fission product production will increase rapidly with increasing use of nuclear power in American industry.

2. Product Specifications

Throughout these studies, provisions nave been made to insure a pure fraction of strontium-90 for packaging as a beta source in order that contaminating gamma emitters would not require heavy shielding for the use of such beta sources. Similar standards of purity have been applied to the cesium separations in order to maintain the specific activity of the cesium sources at maximum values by eliminating all possible impurities. In the case of packaging of oxides of gross fission products, of course a wide spectrum of gamma and beta energies will be encountered, and such purity specifications are meaningless. However, such sources of radiation would probably have a much greater total radiation power than isolated fractions of specific long-life fission products, especially for short-cooled materials.

3. Supply of Raw Material Fission Products

It has been assumed in these studies than an aqueous acid solution of fission products would be supplied to the processing plant without charge by the fuels separation plant operator. No provisions are made for casks, carriers, or other elaborate provisions for the transport of such solutions, it being assumed that the solutions would be moved in underground shielded pipes from the fuel processing plant to the fission product packaging plant.

4. Disposal of Waste Materials

The active waste materials are assumed to be evaporated to the dry state and stored in containers either for use as lower level sources of radiation, sources with rapid decay characteristics, or as containers which might be stored underground in a dry state for permanent storage for reduced periods because of the removal of long-life fission products and at greatly reduced cost because of the reduced volumes of storage required.

5. Simplified Cell Structures

For the kind of facility discussed in this report, it is thought that the simplest, cheapest, and generally optimum design for a structure to house equipment for radioactive chemical operations consists in containing insofar as possible the entire set of fission product separations facilities in one cell and the storage of packaged product materials or dried waste materials in another cell. The only exception to this situation has been in the case of the solvent extraction plant, where a third cell was inserted for the high temperature operations of dehydrating and denitrating fission product salts in order to prevent the fire hazard associated with conducting these operations in equipment immediately adjacent to solvent extraction operations. The use of a minimum number of cells is predicated upon a number of basic considerations. These are as follows:

a. Preplanned and Scheduled Maintenance

The fission product packaging plants are essentially no-inventory plants and do not provide means by which certain operations can be continued while others are shutdown. Consequently, it is requisite that on a program of scheduled maintenance for major repairs, an entire unit must be shutdown and decontaminated.

b. Equipment Life

It is believed that through vigorous development and mechanical testing, the life of equipment which is contained in a given cell can be predicted with sufficient accuracy to permit the scheduling of shutdowns.

c. Decontamination

The remote operations, owing to levels of radioactivity associated with the processing operations, require that designs be achieved to permit decontamination of an entire processing unit if any part of these operations requires attention.

d. Structures

Because of the large portion of capital cost invested in structures, a processing plant contained in a minimum number of structural cells will minimize capital and operating requirements.

e. Common Remote Handling

Common remote handling of packaged fission product materials and dry packaged waste materials can be realized most economically through a common remote handling area such as that portrayed in this study. Mechanical equipment for remote handling is extremely expensive. Consequently, the reduction of remote handling facilities permits a decided economic advantage.

f. Multiple Use of Structures

In each plant studied, one cell is for the storage of packaged fission products and dry waste materials. The contents of this cell might be removed and replaced with other processing equipment while the original process is in operation, if it is desired to change, alter, or add to the processing facilities originally provided for in a plant.

g. Layout Simplification

The location of all equipment in a few cells eliminates the necessity of providing hot and cold pipe trenches and a labyrinth of inserts and intercell connections. A combination of remote and direct maintenance has been employed in these plants. Where equipment life can be predicted for long periods of time, provisions are made that such facilities be decontaminated and maintained by direct means. In remaining cases, where the equipment life cannot be predicted and yet regular maintenance is required, such equipment will be isolated and provisions made for remote-direct maintenance or for removal of such equipment in its entirety in coffins and replacement by remote means.

6. Plant Safety

It will be necessary to provide facilities which will permit the safe conduct of the operations just described. High levels of radioactivity must be dealt with in fission product packaging operations. In addition, the disposal of off-gases which may contain fission products and disposal of liquid and solid wastes containing both chemical and radioactive materials constitutes a major problem. Proper handling of solvents, acids, caustic soda, and other hazardous materials must be dealt with as in conventional chemical processing units.

7. Objectives of Analytical Laboratories

Analytical laboratories are considered to be adequate for establishment of operating controls on product quality and plant inventory balance and methods of plant maintenance.

The primary responsibility for continuous operating control would be placed upon the design instrumentation of the plant and upon the observations and proper execution of operating procedures by the plant personnel. Consequently, the analytical laboratories contain no provisions for the securing of data of a research or development nature.

C. Considerations of Development Work

The first objective in the preparation of this work was to provide a design which would permit the lowest capital and operating costs likely to be achieved. In order to realize optimized costs, it was necessary to assume the possibility of conducting certain operations which have not been demonstrated in their entirety, either in the laboratory or plant scale. Problems such as the continuous fluidized bed dehydration and denitration of highly active fission product solutions, the solvent extraction of highly active fission products, the evaluation of radiation damage, and remote handling and packaging of fission product dry solids, are all problems which must be solved. A program of development will probably be required in order to achieve a successful operating plant employing any of the alternative processes of fission product packaging portrayed in this report.

IV. DISCUSSION OF PROCESSES

A. General Aspects of Fission Product Separation and Packaging

The chemical processing plants for the separation and packaging of fission products from irradiated nuclear fuels covered in this study are based primarily upon the following steps.

Aqueous chemical operations are employed for the separation of cesium and of strontium from an acid-aqueous stream of gross fission product wastes in most of the processes. Exceptions are those involving the packaging of gross fission products without further separations. Complete data and descriptions of equipment and technologies employed are not available from government-owned laboratories for any of these processes. The only process projected for commercial operation is that being employed in the fission product pilot plant at the Oak Ridge National Laboratories employing a series of aqueous steps involving precipitation, filtering, crystallization operations, largely on a batch bases. Some departures are employed in the processes described in this study from practices currently employed in government-owned plants. Some of the departures employed will require programs of development in order to achieve plant designs projected in this engineering study. Certain developmental programs presently being conducted in the U.S. Atomic Energy Commission sites will provide basic data which will be useful in arriving at the detailed designs visualized for this type of facility.

The general categories of processing which are peculiar to this plant are outlined in detail under Section III entitled "Philosophy of Engineering Design , and under Section VIII entitled "Considerations of Development Programs".

An aqueous solution containing nitric acid, fission products, certain residual traces of source and fissionable material, some sodium ions added in processing, and some iron and other materials of construction dissolved from processing equipment makes up the feed material to all of these processes. Other alternative sources of feed materials such as those from fluoride volatility or pyrometallurgical processes might be employed in these plants by appropriate adjustments of composition to put them in an aqueous phase, or other methods of separation peculiarly applicable to these types of wastes might be employed. Generally, excess nitric acid is evaporated before commencement of processing, although this step is not specifically noted on all flowsheets.

B. Description of the Co-Precipitation of Cesium and Strontium from Fuel Processing Solutions - "CP Process"

See Figure 2 for a block flowsheet of the "CP Process". The aqueous solution of fission products is passed through an evaporation system where most of the nitric acid is boiled off, together with some water The solution is then re-diluted. This step removes most of the requirement for base in adjusting pH. Then sufficient sodium ferrocyanide is added to the solution to give a solution equivalent to one hundredth molar in nickel ferrocyanide, which will be formed later upon the addition of nickel salt. Then a twenty-fold excess of nickel sulfate is added, and the resulting precipitate of nickel ferrocyanide, if in solution, would constitute a .01 molar solution. Calcium nitrate is also added before the nickel sulfate in order to carry down strontium during this operation. It was found in some work that nickel compounds should be present in the concentration of .005 molar for a cesium content of .03 grams per liter. During this precipitation reaction, the temperature must be kept below 70° C. It is reported that more than 99 percent of the cesium is carried down with the precipitate in this operation. Precipitate is centrifuged from the supernatant liquor, and the resulting sludge is calcined at 600° C. in a fluidized bed evaporator. The calcining operation breaks down the complex cesium-sodium ferrocyanide, and strontium ferrocyanides so that strontium and cesium are available in ionic form. The nickel and iron appear as oxides after the calcination. The calcined sludge is then leached with water, and possibly with other solvents, and cesium and strontium taken into solution again. The separate solutions resulting from these leaching operations are then centrifuged to remove residual insoluble materials, and are then concentrated, transferred to small containers and transferred again to the finishing and packaging area.

Decontamination factors of other alkali ions compared with cesium as a result of the precipitation process are: sodium, 3×10^3; potassium, 400; and rubidium, 10. The superior decontamination factor to be achieved with sodium has resulted in the recommendation of the use of the sodium salt, rather than the potassium salt in the ferrocyanide addition. Recovery of cesium from the original waste stream with this process is greater than 90 percent, although the individual steps indicate higher recoveries than this. This process was developed at the Hanford Works (7), and is being studied at the National Reactor Testing Station (10). Additional work, still in the laboratory stage, at the National Reactor Testing Station is being conducted upon alternative means, other than calcination, of separating the cesium and strontium from the sludge.

C. Description of the Ion Exchange Method for the Removal of Cesium from Alkaline Fuel Processing Solutions - "IX Process"

Laboratory and preliminary pilot plant studies have been conducted at the Oak Ridge National Laboratory (9) on the recovery of cesium from the solutions resulting from alkaline dissolution of aluminum-bearing fuel elements. It should be said at this point that further work on this process has been dropped because the uranium from the fuel element dissolution by caustic appeared as fine particles of oxide which could not be recovered sufficiently completely from the fuel element solutions to permit general adoption of this process. In addition, methods for the recovery of ions other than cesium have not been worked out. However, the general aspects of this process were surveyed from an economic point of view to see what attraction it might have if the various problems could be resolved. Accordingly, a description of this process follows.

In the flowsheet used, (see Figure 4), the irradiated fuel elements, NP or MTR, are dissolved in sodium hydroxide, and the resulting solution contains sodium aluminate, cesium, rubidium, and some barium. The fuel element solution is then centrifuged to remove uranium oxide particles. The centrifuged solution is fed to a countercurrent ion exchange column in which the cesium is absorbed and then eluted selectively. It has been claimed that the continuous ion exchange equipment which has been developed solves the problem of radiation damage to the resin, in that resin may be continuously added to, and removed from, the column during operation. The ion exchange column consists of two parallel vertical columns. In one of the columns the absorption and elution is carried out. The other column serves as a mechanical transfer leg for the recycling of resin discharged from the top of the active section. This discharged resin is carried down the transfer column hydraulically and is re-introduced continually into the bottom of the absorption and elution column. The resin is thus transferred hydraulically in a path countercurrent to the liquid flows. Streams of all chemicals are metered into the absorption column leg for periods approximating one minute. At the end of the elapsed working time, a set of plug valves in the column and associate hydraulic transfer equipment opens and closes in appropriate sequence, and a hydraulic cylinder pulses the resin from one leg into the other leg. The streams flowing to and from the column and the pulse mechanism are connected through a timer in such a way that the unit operates automatically.

The operation of the ion exchange column is as shown in the accompanying Figures 8 and 9. Here the resin is shown entering the left-hand or absorption column at the bottom. In this column the alkaline solution of sodium aluminate and cesium ion is fed at a point about half way up the column. The cesium in the feed is absorbed by the resin which is continually moved bodily up the column, while the waste stream goes out the bottom of the column. The cesium is continuously eluted from the resin by means of an ammonium carbonate solution, and the cesium is carried off in a solution containing excess ammonium carbonate, from which it may be recovered as described later. After the elution operation, the resin is in the ammonium form. The resin must be converted to the sodium form from which the cesium then displaces sodium on the next cycle, and from which the cesium is in turn displaced by the ammonium ion. Streams of water are shown entering the column at various locations in order to preserve the hydraulic balance and to cause the various streams to flow in the desired directions. In addition, a stream of sodium hydroxide is added to the column directly above the feed entrance point in order to wash the aluminum solutions down the column and prevent hydrolysis of the aluminate.

The cesium-bearing ammonium carbonate solution is passed to a chemical recovery section, where the solution is boiled, and the ammonia and carbon dioxide released are re-combined in a scrubbing tower. Provision is made to make up any imbalance due to differential losses of these materials by the addition of more ammonia, carbon dioxide or ammonium carbonate. The remaining cesium solution is then concentrated and sent to the finishing and packaging operations, which are described in Section IV.H. In this case the cesium product from the separations operations is in the form of cesium hydroxide.

Cesium recovery of 99.99 percent is claimed in this unit. A topical report on this process has not yet been written by Oak Ridge National Laboratories. Some cognate data can be found in work by Blanco, et al., (9) and Higgins, et al., (14).

D. Description of the Co-Crystallization of Cesium and the Precipitation of Strontium from Fuel Processing Solutions - "CX Process"

The so-called co-crystallization process is one which has been developed at Oak Ridge National Laboratories, and is presently being placed in pilot plant operation by Rupp and co-workers, who have further described this process (19). The process actually consists of a means of separating a fission product waste solution rather completely into its various chemical components, and is suitable for recovery of many fission products in addition to cesium. Emphasis has been placed here on recovery of cesium and strontium. This process may operate upon feed from the caustic dissolution of fuel elements, or from the dissolution of fuel elements in acid, provided an acidity adjustment is made. If cesium only is required, the pH-adjusted solution may be treated with an ammonium alum. Cesium replaces the ammonium ion in the alum, and the cesium-ammonium alum can be crystallized out of the solution. Rubidium may may be separated from cesium by fractional crystallization of the alum. The crystals are separated from the mother liquor in the crystallizer by jetting the mother liquor from the crystals.

Cesium recovery from gross fission products is on the order of 85 to 90 percent.

Although the process described above will work on fission product feed, provided that cesium is the only desired operation, the process described in this study dealt with the more nearly complete flowsheet described by Rupp (19) for the separation of other radiochemicals from the gross fission products. The total flowsheet is rather elaborate and employs many techniques which have been developed for complex inorganic separation problems. The co-crystallization process appears in block flowsheet form in Figure 3.

The first step is that of evaporation of the feed solution since, in this case, acid feed was assumed and re-dilution, if necessary, to the required concentration. This step avoids loading the solution with sodium ions by direct neutralization.

The next step is that of precipitation of iron, which is said to be one of the major components of such a solution because of corrosion from process equipment. Iron concentration may approach one gram per liter concentration, while that of the fission products is much lower. Urea is used to raise the pH to a final value of about 2.5, at which granular iron hydroxide is precipitated. The iron hydroxide is filtered after this precipitation. The filter is then backwashed with acid for the removal of iron, which may be reduced to the solid form by fluidized bed evaporation for disposal as a waste. The iron precipitate also carries down much of the ruthenium, technetium, and some other materials which are here treated as wastes. The precipitate may be further treated with nitric acid and the filtrate from this step treated with permanganate, which distills off the ruthenium tetroxide, so that ruthenium recovery is possible. This step is indicated although it is not an essential part of this process. The filtrate from the iron precipitation, containing the fission product forms of rare earths, strontium and cesium, is subjected to a hydroxide-carbonate precipitation with 0.2 molar sodium carbonate. The precipitate contains some iron, some rare earths, calcium, and strontium. The rare earths and strontium are separated by hydroxide precipitation of the rare earths. The rare earth precipitate may be further elaborated for recovery of rare earths. The strontium hydroxide, barium hydroxide, and calcium hydroxide in the filtrate may be separated by acidification, carbonate precipitation of the alkaline earths. The precipitate of alkaline earths is treated with fuming nitric acid. The calcium salt is filtered off, leaving the strontium and barium salts behind. The mixture of strontium and barium salts is treated with 9.0 molar hydrochloric acid to precipitate barium chloride from strontium chloride. The inactive fission product barium chloride is then stored as a waste and the strontium chloride product is packaged. The recovery of strontium is about 90 percent.

The filtrate from the hydroxide-carbonate precipitation is then further treated with another hydroxide-carbonate precipitation, removing more iron, calcium, some ruthenium, strontium, and rare earths. This precipitate is then recycled back to the main stream. The filtrate from the hydroxide-carbonate purification step is sent to the ammonium alum crystallization operation for the separation of cesium. Here ammonium aluminum sulfate crystals are placed in a tank and the solution containing cesium is passed over these crystals. The mixture is heated and cooled again. In this operation the cesium replaces some of the ammonium ion in the ammonium alum and produces a cesium-aluminum sulfate. This operation is conducted several times, using the same batch of alum crystals, and different successive charges of cesium solution. As successive batches of cesium-bearing liquor are crystallized with the same alum crystals, the concentration of cesium in the residual liquor builds up, and this liquor is then passed on to additional crystallization operations with fresher alum crystals in other tanks until the desired recovery of cesium has been established. Consequently, a series of crystallization tanks, considered to be four in this study, are operated on a modified batch-countercurrent basis. This system permits the simultaneous recovery of cesium to design limits from the feed material. The subsequent elaboration of the cesium-bearing crystals remaining is described below.

Once the cesium concentration in the alum crystals has reached a proper value, a series of re-crystallizations with water is undertaken. In these operations, the pH is somewhat different from that of the crystallization operation. Cesium is removed selectively by the re-crystallization process and appears in the mother liquor rather than in the alum. The mother liquor is then concentrated. Fractional crystallization resulting in the separation of rubidium and cesium alums may be undertaken. Such re-crystallization was not contemplated in this process, although it might be conducted in the equipment shown.

Once the re-crystallized cesium alum is obtained, it is dissolved in hot water, and the aluminum precipitated in the form of aluminum hydroxide by means of ammonia gas. The aluminum hydroxide precipitate may be re-dissolved in nitric acid and recycled for cesium recovery, as it contains about 1 percent of the cesium. The supernatant liquor resulting from aluminum precipitation has a pH of about 6.5 to 7, and consists of cesium sulfate and ammonium sulfate. This liquor is then sent to an anion exchanger, and comes out as cesium hydroxide and ammonium hydroxide. The subsequent operations are then conducted in the finishing and packaging steps, but are described here for their unique aspects in addition to the other packaging and finishing steps described in Section IV.H.

The solution of cesium and ammonium hydroxides is evaporated to remove ammonium hydroxide, and is then treated with fuming nitric acid to drive out the remainder of the ammonium salts. Hydrochloric acid is then added and the solution again heated to drive off the nitric acid, resulting in a solution of cesium chloride which is evaporated to dryness, compressed into pellets, and packaged. By the use of all recycle techniques mentioned and assuming the best performance of the process, probably 99 percent recovery of the cesium from the original cesium in the fission products can be realized.

E. Description of the Complexing and Solvent Extraction of Fission Products from Fuel Processing Solutions - "SX Process"

A complexing and solvent extraction process was studies which has as its objective the removal of relatively pure chemical species from a stream of gross fission products in aqueous solution. This method has as its basis the use of a complexing agent or agents at selected values of pH. The complexing agents will combine with assorted chemical agents, and the resulting complexes may be separated from the remainder of the aqueous solution by solvent extraction, using an organic solvent. Some general information on such processes is given by Martell and Calvin (17). It was desired in this study to isolate selected alkaline earth and alkali metal ions in pure form, so that compounds of these materials might be packaged in the dry state. Some work of this nature has been done on rare earth compounds by Topp and Weaver (22).

A projection of the chemical methods studied to date in the terms of a commercial fission product separation and packaging plant has been analyzed in this scope of work, and a description of the contemplated processing arrangement follows. This solvent extraction process appears in block flowsheet form in Figure 5.

Methyl isobutyl ketone (MIBK) with thenoyltrifluoroacetone (TTA) dissolved in it is used as a solvent and chelating agent combination for all projected steps in this operation. The TTA will chelate most of the metal ions encountered in a waste fission product solution, and with appropriate adjustments of pH, concentrations, and other process variables, separations of the metal ions can be made from aqueous solutions. The metal ions may be removed from the organic phase by stripping the organic phase with water.

Waste fission product solutions in acid are received in the plant, most of the acid is evaporated, and then the solution is re-diluted to the appropriate concentration. This procedure avoids loading the solution with sodium ions by direct neutralization. The solution of fission products goes next to a pH adjustment step, in which sodium hydroxide is added to give the proper pH for the first complexing step desired.

Following the pH adjustment, the first complexing step is conducted, in which the MIBK-TTA solution is contacted countercurrently with the adjusted feed in a pulse plate column, with the use of a scrub solution of adjusted pH for removal of residual metal ions. The first extraction is conducted with a relatively low pH, so that only the iron, aluminum, and other structural and residual materials likely to be present in the waste solution will be removed in the organic phase, leaving behind the alkali and alkaline earth elements. The organic phase is then stripped free of metal ions, which are sent to waste treatment. This extraction should remove a great deal of the gross contamination in the solutions due to structural materials in the fuel elements or corrosion of process equipment from fuel element separation operations.

The aqueous bottoms from the first extraction column are then passed to another pH adjustment, the pH is increased, and a second fraction of fission products is extracted in another pulse plate column. This fraction will be mostly the rare earths, which are more easily chelated than the alkalies and alkaline earths. Scrub solution is also fed to this extraction column. In a subsequent column, a stripping solution consisting of water or pH-adjusted water will be fed to remove the rare earths from the organic phase. The rare earths may either be recovered or sent to radiochemical waste disposal.

The aqueous effluent from the second extraction step is increased in pH in an adjustment step and sent to a third extraction cycle where it is again contacted with the MIBK and TTA and a scrub solution. The alkaline earths here are extracted from the alkali elements. The alkaline earths are then stripped from the organic phase by means of a strip solution of appropriate pH, and the aqueous strip solution sent to evaporation. After evaporation, the solution is sent to another step, where the pH is increased. It is assumed that the strontium and barium, constituting the chief alkaline earth ions, would be separable in a concentrated solution, or by means of some step approximating in capital requirements the concentration step. Accordingly, the strontium and barium are separated from each other in extraction-stripping cycle, using the MIBK and TTA solution. The barium is more easily chelated and goes into the organic phase. The barium is then removed from the organic phase by the strip solution, and is sent as an aqueous solution to the finishing and packaging step. The strontium goes out the bottom of the extraction column in aqueous solution, is concentrated, and is then sent to the packaging and finishing operations described in Section IV.H.

The alkali ions are carried out in the aqueous bottoms from the alkaline earth extraction step previously described, and are fed to another pH adjustment tank where the pH is increased again. Another cycle of extraction and stripping is conducted. An aqueous solution of cesium is extracted and is removed from the organic phase by stripping. The aqueous cesium solution is then concentrated and sent to finishing and packaging.

F. Description of the Packaging of Gross Fission Products from Fuel Processing Solutions - "GP Process"

The objective of the gross fission product packaging process is simply to take an acid solution of gross fission products and to drive off all moisture and acid and to convert the resulting residual salts to the form of oxides. These oxides are then compacted and the gross fission product oxides are packaged in the dry state. This is a very straightforward process in concept and is attractive because of the probable minimum amount of development work required to realize an operating process.

The "GP Process" appears in block flowsheet form in Figure 6. Aqueous acid waste fission product solution is first concentrated to a value suitable for feed to the fluidized bed evaporator. The evaporator consists of a fluidized bed unit, possibly charged initially with sand or other refractory material to form an initial bed for fluidization operations. Temperatures approaching 600° C. are available in units such as this currently being investigated, and at these temperatures it is believed that the nitrates of the elements present in the fission product and structural materials will be decomposed to the oxides with the resultant release of moisture and nitric acid. The solids resulting from the operation may be dropped into packages through appropriate seals and then conveyed to finishing and packaging operations essentially the same as those described in Section IV.H. Quantities of nitric acid will be released from this operation and contaminated acid storage is provided. The contaminated acid might be returned to the fuel processing plant if suitable shielded make-up facilities were available, but might have to be disposed of after further purification, if this cannot be done.

One of the serious problems encountered in the past in producing packages of dry gross fission products has been that of removing water and other volatile materials from gross fission products. The usual types of evaporators may plug in evaporating solutions to dryness. If solid deposits of fission products are plated out on the evaporator parts, these materials will emit heat at such rates as to burn themselves into the reactor walls and otherwise cause undesirable or dangerous situations. The fluidized bed evaporator which has been developed at Argonne National Laboratories

(1) and further described by Jonke, et al. (2), appears to offer a promising method of solution of this difficulty. The fluidized bed employed at Argonne is shown in Figure 11, and that which has been recently constructed at the National Reactor Testing Station is shown in Figure 10. These are both very similar, being about six inches in diameter and constructed of stainless steel. Heated air is blown through a diffusion plate at the bottom of the equipment. An aqueous solution of the material to be dried is fed at a point part way up the fluidized bed, through special spray nozzles employing air for the spraying operation. Particles are removed from the exit gas stream at the top of the equipment by means of sintered stainless steel filters which may be blown back periodically with air during the operation of equipment to free the filters from particles of solids.

A possible alternative method for production of gross fission product oxides would be dehydration and denitration of solutions of fused fission product nitrates. This method was not further developed in detail in this series of studies.

G. Description of the Water Leaching of the Oxides of the Gross Fission Products from Fuel Processing Solutions - "OL Process"

Once gross fission products have been reduced to the form of a solid bed of oxides by means such as the gross fission product evaporation technique described above, (Section F), further separation of the fission product chemical species might be obtained by a series of leaching operations conducted upon the oxides. A particularly attractive possibility would be that of leaching the cesium oxides from the oxide beds, since the cesium would be highly water-soluble. Some strontium hydroxide could probably also be leached, and it is assumed that suitable recoveries of both cesium and strontium could be attained in this process.

The first step in the oxide leaching process is to evaporate the acid feed solution. The concentrated feed is then dried in a fluidized bed evaporator, resulting in the dehydration and denitration of fission product nitrates. This same fluidized bed evaporator is then used as leaching equipment in which first water, and then possibly other materials such as selected acids, might be added to leach out first the cesium and then the strontium, and possibly both together. The leached solutions are then centrifuged to remove particulates carried over from the leaching operation. The hydroxide solutions are concentrated and sent to finishing and packaging operations similar to those described in Section IV.H. This process appears in block flowsheet form in Figure 7.

H. Finishing and Packaging

The finishing and packaging operation has many common aspects for each of the processes discussed above. Consequently, the discussion of finishing and packaging is conducted in this section.

The common aspects of the finishing-packaging operation result partly from the fact that the total quantities in terms of weight and volume of the separated solutions of the various fission products reaching the finishing-packaging stage are relatively small, being of the order of a few liters per day. Since the value of the concentrated materials is high in terms of the effort expended in their obtaining, and since the quantities are so small, it is concluded that the batch-type of separation involving direct manipulation in the chemical hood would be the most practical approach. Consequently, the finishing and packaging operations are contemplated as being placed in the remote handling room subject to direct viewing and direct operation by master-slave manipulators, and subject to a variety of chemical steps. Generally the cesium and strontium will reach the finishing stage as solutions of the hydroxides or nitrates. These solutions may then be treated with hydrochloric acid and boiled to remove any nitric acid, and then concentrated down to the dry state as the cesium chloride or strontium chloride. The dried materials may then be scraped out into suitable pelleting or packaging equipment which will compact the dried material into packaging containers. A packaging container for the finished products appears in Figure 12. These containers are quite similar to those contemplated for the packaging of cesium chloride by Oak Ridge National Laboratory. Remote welding machines are placed in the packaging area. The containers are evacuated and the interiors are flushed with argon. The tops of the containers are sealed by installing welding caps on the containers using heliarc welding techniques. The closed containers are then collected and stored in the storage cell until required, or may be loaded directly into carrying casks which may be passed into the remote handling area through suitable radiation locks, loaded with their product containers and passed out again for shipment after health physics checks.

More voluminous quantities of material will probably result from the drying of waste solutions containing reagents recovered in the dry state from processing operations. These containers will probably be much larger pieces of pipe, on the order of six inches in diameter. Subject to further review of heat balances, these diameters may be sustained without overheating of contents. These larger containers may then be stored in the radiation materials storage cell directly below the remote handling room for suitable periods of time until other disposal arrangements are made.

I. Plant Layouts and Arrangements

Preliminary engineering studies have been conducted concurrently with the development of process designs in order to establish initial principles regarding layout and arrangement of buildings, yard, tank farm, storage, hot cell operation, laboratories, and general office and service facilities for the several chemical processing plants studied. These detailed layouts are available in pencilled form, but are not reproduced here because of limitations of the scope of project. However, Figure 1 shows a perspective of the process building selected for the solvent extraction process. The other processes differ from this arrangement by the omission of the center cell and a slight reduction in building size and remote handling area size. It is believed that layout engineering has been conducted on each alternative process sufficiently well to permit obtaining a reasonable order of magnitude estimate of structures, equipment supports, functional locations of equipment as presently conveived, general requirements of shielding, and the establishment of plant operating control centers.

Since costs of structures installed for radiochemical plants contribute a major portion of the capital cost requirements, it is considered essential that plant layouts be studied to assure optimum space requirements and equipment locations commensurate with good design. As progress is achieved in the field of industrial radiochemical processing, it is important to perform layout engineering studies in specific detail with parallel investigations and evaluations of optimum designs at lowest cost. It is believed that the layout engineering which has been conducted to date is an approach in this direction. However, the time and schedules do not permit conducting studies in extensive detail, but the effort has been to establish over-all space requirements that may be required for a workable plant.

For each of the six processes studied, the following drawings have been made in pencilled form and are referred to briefly below with respect to their general application to each of the processes. The following drawings briefly describe the concepts of layout engineering used in this feasibility study, although the drawings are not included in this report.

1. Plot Plan

Preliminary plot plans have been prepared to indicate the relative locations of buildings and facilities considered essential to a radiochemical processing plant employing the aqueous technologies studied in this scope of work. No detailed location of the radiochemical packaging plant was specified with respect to the fuel processing plant which would serve as the source of waste fission products. However, it is assumed that the fuel processing plant would be located sufficiently closely to the fission product packaging plant that the general facilities of the fuel processing plant could be used, in that active materials could be transferred to the packaging plant by shielded underground pipeline.

A wing is provided in the fission product packaging building containing a cell for equipment to treat vessel off-gases from radioactive vents. Some distance away, and in accordance with industrial practices, a tank farm with transfer pumphouse is located for the unloading and storage of railroad shipments of tank car quantities of solvents, acids, and other chemicals. Adjacent to the tank farm there is located the plant waste disposal facilities and provisions for burning waste solvents after decontamination. Provision is allowed for the use of a railroad loop system for the entire plant, to which spurs and switches from the loop to the tank farm areas, as well as the processing building, could be provided.

2. Tank Farm Plan

Tank farm layouts have been prepared which indicate the relative locations of the following equipment: waste disposal basin, control house, and storage tanks, combustion stack facilities for spent solvent in the solvent extraction process, the transfer pump house for unloading and storage of chemicals, and a tank farm area which is dyked for the storage of different types of solvents, acids, and caustic. Solvents are contained in an independent dyked area, and provisions are indicated for fire control by means of foam generating equipment and a fire pump located in the transfer pump house. Other materials such as acids and caustic are stored in a separate dyked area if solvent is used in a given process. Dyking has been provided primarily for containing the contents of tanks in case of leakage. Earthen dykes have been assumed as the most practical type of dyke walls. Provisions are allowed for fire hydrants and hose houses at different locations surrounding the tank farm area where flammable solvents are used in the process. A third dyked area, in the event solvents are used, is provided in a separate location for collecting solvent which is rejected from the solvent purification system in the main building. These facilities for solvents, where used, have been located in a separate area because they may contain traces of mild activity and require monitoring and decontamination before access.

3. Main Processing Building Cell Plan

Drawings have been made of the plan of the hot cells and main processing units of the separations plant. These cells are roughly twenty feet wide and thirty feet long, and are thirty feet in inside height. In the solvent extraction process, three cells have been provided: One cell contains the aqueous separations equipment; the second cell contains essentially a radiochemical disposal and drying system, in which high temperature fluidized bed equipment is employed for evaporating certain solutions to dryness. The waste disposal equipment is located in a separate cell in order to prevent contact of inflammable vapors with high temperature equipment. In the solvent extraction system a third cell is provided for the storage of finished-packaged separated fission products or for the packaged dried waste materials. In the co-precipitation process, the co-crystallization process, the ion exchange process, gross fission product packaging, and oxide leaching processes, only two cells are provided since no solvents are used, and high temperature equipment may be located in the same cell with the aqueous separation equipment. The second cell is employed for the storage of the finished materials and packaged waste materials in the dry state. All mechanical equipment, such as pulse generators where used, transfer pumps, controls, and electrical drives are located in trenches beneath the operating floor so that individual access for replacement or repair can be attained without shutdown. The cell walls adjacent to the earth were set at two feet in thickness of ordinary concrete primarily for strength, advantage being taken of the shielding properties of the earth surrounding the underground cells. Thus a saving of four feet in concrete thickness of all exterior cell walls underground is realized, compared with the alternative of providing underground walls six feet thick for full radiation shielding by means of concrete alone.

Preliminary shielding calculations have been made to provide shielding in the cell deck covering all of the cells and in the walls separating the cells from each other. These calculations indicate that the shields, when employing normal concrete for the cell walls and cell deck, should be about six feet thick. The over-all dimensions of the cell plan for the solvent extraction process are 34 feet in width by 70 feet in length. The over-all dimensions of cell plan for the other five processes studied are 34 feet in width by 50 feet in length. The vessel off-gas cell should be added to these general dimensions as wings to the main cell block.

4. Main Processing Plant Cell Elevations

One elevation of the cells showing elevation of all cells through the short dimension which is the long dimension of the building has been prepared for each type of building and cell arrangement. These elevations indicate the functional location of equipment to permit maximum utilization of gravity flows. In future work, it will be essential to prepare detailed calculations of hydraulics of equipment spacing, equipment supports, and further details in control lines. However, the elevation studies which have been made to date are considered representative for adequate capital cost and operating cost studies conducted to date.

5. Main Processing Plant - Processing and Service Area Floor Plan

Functional engineering layout studies have indicated for each of the six processes the rough relationship of plant operating areas, chemical make-up, laboratory and sample dilution facilities, radiation source dose rate checks, physical analyses facilities, utilities, lockers, showers, change rooms, shipping and receiving areas, and general plant offices. Areas are also indicated for storage, receiving, and transfer of materials. Raw materials and maintenance materials for the operation of the plants will be handled in these areas. Also studied in these layouts are the remote handling areas which are intended for the transfer of packaged fission products and waste materials from the processing cells into the storage areas, and for the transfer of finished products and radioactive materials from the plant to shipping casks for shipment. Remote handling areas are enclosed in a barytes concrete shield. Remote handling equipment consists of bridge crane hoists with manipulators for attaching the hooks for the removal of material from the cell bottoms, and of a general purpose manipulator carried on a bridge crane for medium duty work. This mechanism would be operated by means of a console located in the control room area, and therefore outside of the remote handling room. Inspection windows, probably of a combination zinc bromide and stabilized glass, have been assumed for observing operations in the remote mechanical operating area. Finishing operations requiring the handling of small amounts of materials in a number of chemical steps will be conducted by means of sets of master slave manipulators. Remote packaging and welding operations will be conducted by means of special jigs and fixtures in conjunction with remote welding machines.

Docks circumscribing portions of the building are provided for the shipment of casks and for the receiving of chemicals, either by truck of by rail. Hot and cold analytical laboratory work is conducted in one central plant laboratory which is provided with hoods, filters, and exhaust fans. Laboratory tables of a conventional type are provided. Centralized sampling in a sample dilution area is provided wherein samples from any required sampling point of the process can be obtained at a single point in the plant operating area. Behind barriers and hoods in this area, it is expected that samples can be diluted to permit conducting analyses of the required type.

6. Vessel Off-Gas Plan and Elevation

Process equipment for treating gas which is discharged from vessels and operations, such as hot laboratory samplers and supports, is located in a shielded cell. This cell is located as a wing attached to the cell wall of the main processing building. The structures in this cell provide areas for locating filters, off-gas fans, and circulating pumps so that such equipment can be replaced and repaired through roof hatches by using hoisting equipment.

The scrubbing tower is located in a shielded high bay. Provisions are made for access to the towers and roof. Concrete work will have smooth interior finishes coated with radiation-resistant surfacing.

Steel structural framing is provided over the fan and filter area with adequate structural design for live loads equivalent to five tons. Monorail hoists are provided for removal of roof hatches for replacement and general utility.

7. Plant Perspective

A perspective drawing, Figure 1, constitutes a drawing of the main processing building for a solvent extraction process. The building is similar to those for the other processes. Cutaways are shown of relative locations of equipment within the processing building, with certain conceptions of the flow of raw materials, maintenance materials, and finished product shipping casks to and from the processing building. This drawing is presented in order to provide general information and ideas as to how the fission product separation and packaging plant might appear from the over-all view and general facilities required in connection with it. It is to be noted that the perspective is not an accurately dimensioned drawing, and can show only portions of the processing units.

J. Plant and Public Safety

In undertaking the engineering, economic, and operational studies for the fission product packaging plant, the underlying principles of safety have been practiced throughout the studies covered in this scope of work. The fission product packaging plant may be considered as one of the more hazardous kinds of chemical processing operations. Careful consideration must be given to precautionary measures and safety practices for hazardous chemicals, radioactivity, and principles of good housekeeping. These considerations must be reviewed for all stages of development, engineering, procurement, construction, inspection, and plant operation. The practice of safety must achieve the protection of personnel engaged in plant operations, as well as of the general public. Safety considerations which have been studied involve evaluations of chemical hazards, radiation hazards, radiological hazards, and waste disposal hazards.

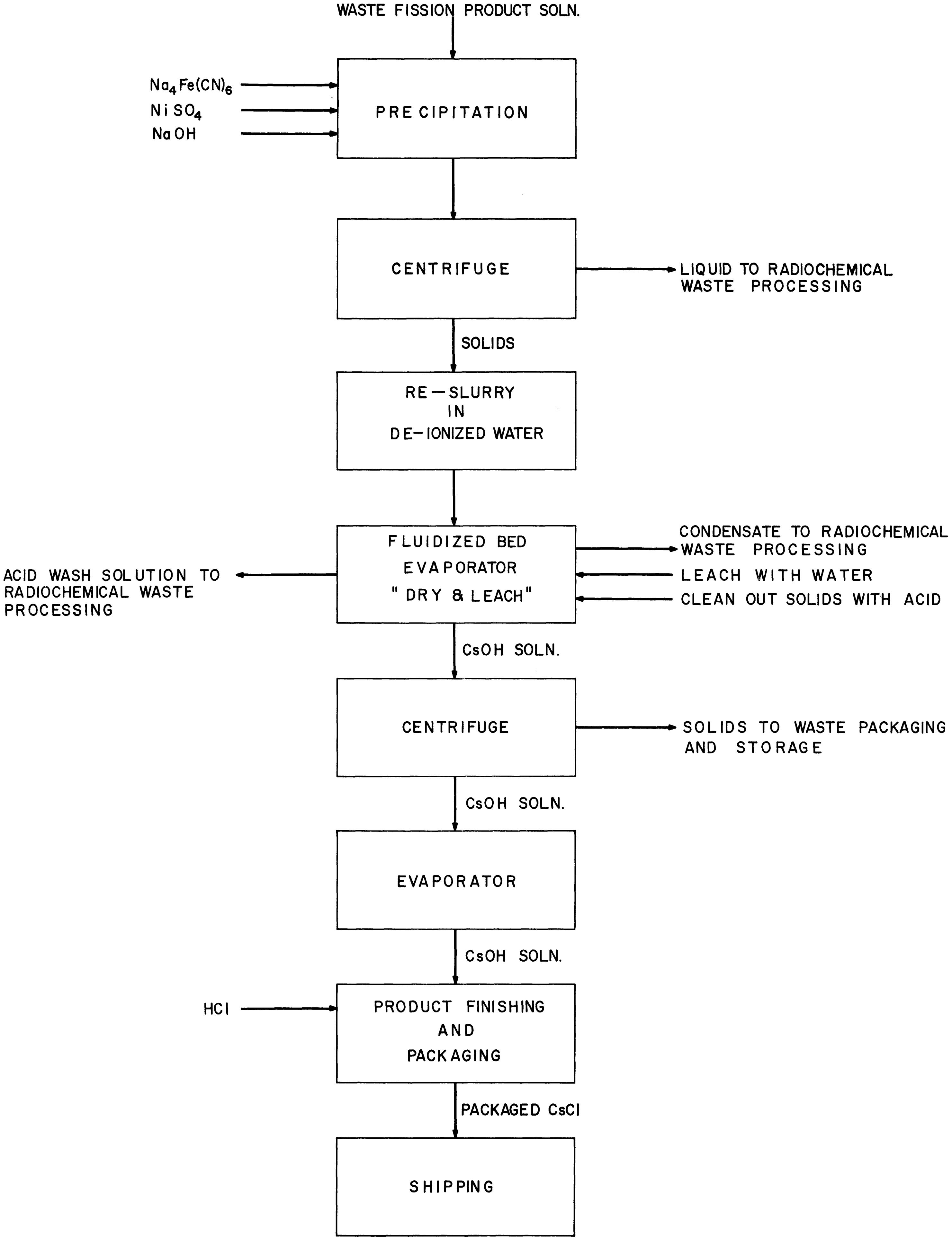
1. Chemical Hazards

The chemical hazards of the fission product packaging plant employing aqueous technology can be likened to the hazards encountered in some chemical plants. The handling of solvents, acid, caustic, and bottled gases under high pressure follow closely the precautions required in conventional chemical practice. In general, it has been considered essential to adhere closely to insurance regulations such as those published by "The Associated Factory Mutual" and "The National Bureau of Fire Underwriters", and to state, local, and federal codes, as well as to specific safety practices employed by the chemical industries.

2. Radiation Hazards

Superimposed upon normal safety practices are the practices necessary for the handling and processing of radioactive materials. In arriving at the engineering designs and process considerations presented here, every effort has been made to adhere to the type of safety principles which have presently been accepted and used in several of the government-owned production facilities for the handling of radioactive materials. These principles comprise health physics practices, monitoring devices, decontamination procedures, remote maintenance where required, and limitations regarding working time in areas, so that excessive dosage is not obtained.

The safety of a fission product packaging plant is contingent, of course, upon good housekeeping practices, rigid discipline regarding safety and access, practice of principles of health physics and health medicine, and accurate programs for preplanned and preventive maintenance. It is assumed that operating personnel in the area will be provided with proper safety clothing, safety shoes, masks, goggles, etc., when required to work in areas of limited exposure. It is believed that adequate ventilation, special filters, fire water systems, fire fighting materials, and generally safe equipment arrangements have been anticipated. It is suggested that these safety principles be carefully examined as development and designs proceed so that radical changes and alterations will be unnecessary if and when physical construction and operation become a reality.



CP PROCESS

Figure 2

CX PROCESS

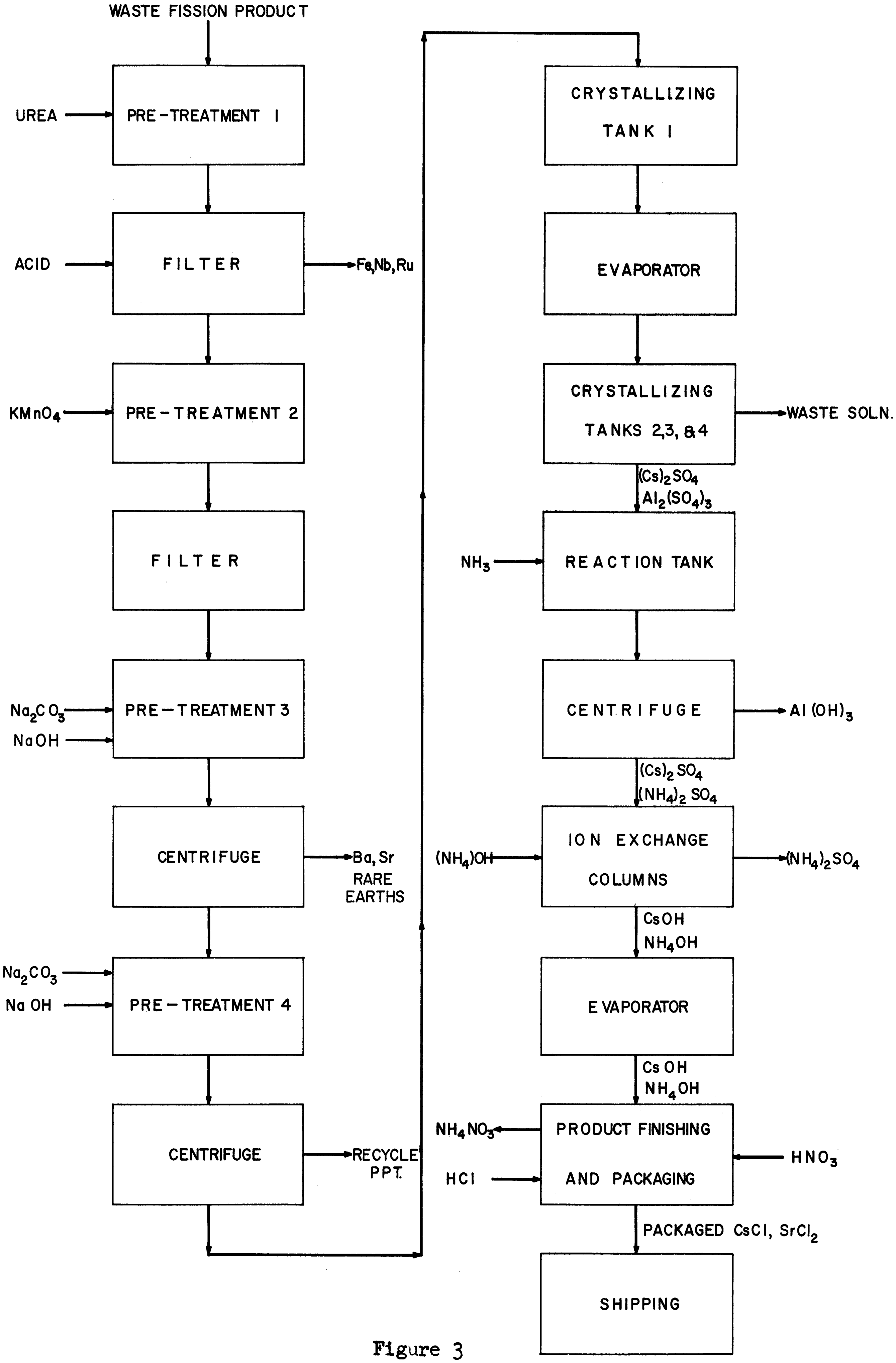


Figure 3

IX PROCESS

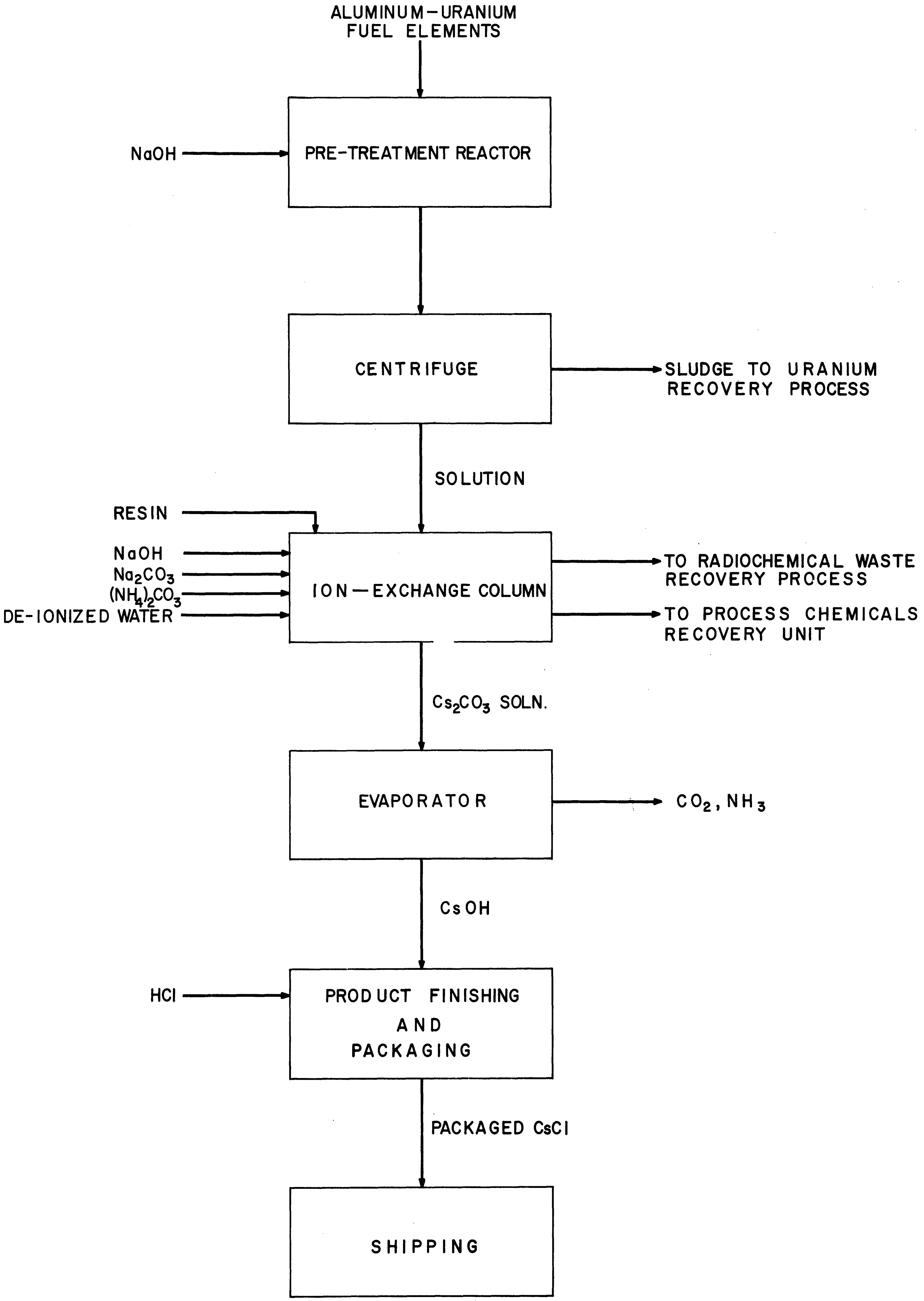


Figure 4

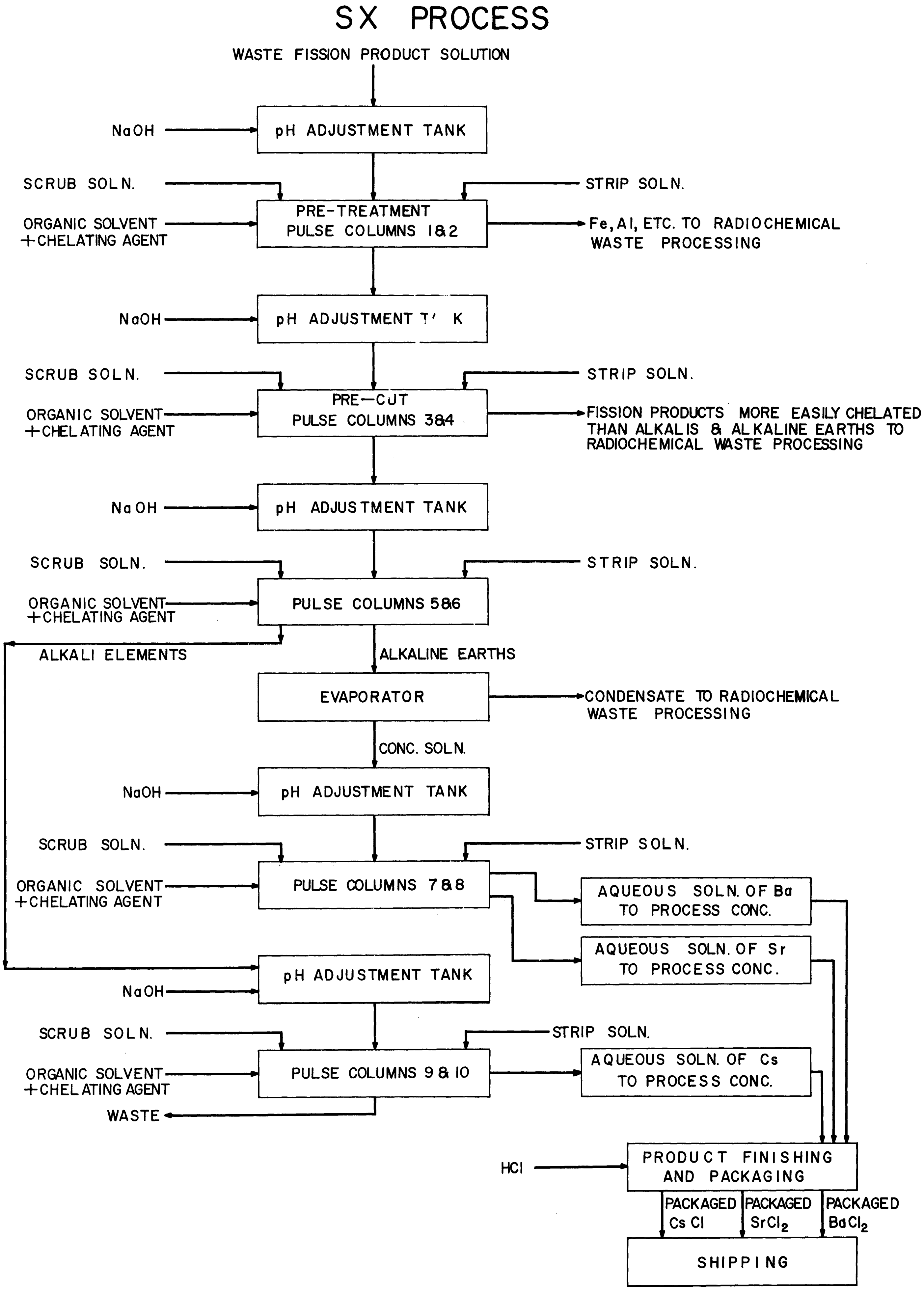

SX PROCESS
WASTE FISSION PRODUCT SOLUTION
NaOH
pH ADJUSTMENT TANK
SCRUB SOLN.
STRIP SOLN.
ORGANIC SOLVENT +CHELATING AGENT
PRE-TREATMENT PULSE COLUMNS 1&2
Fe, Al, ETC. TO RADIOCHEMICAL WASTE PROCESSING
NaOH
pH ADJUSTMENT TANK
SCRUB SOLN.
STRIP SOLN.
ORGANIC SOLVENT +CHELATING AGENT
PRE—CUT PULSE COLUMNS 3&4
FISSION PRODUCTS MORE EASILY CHELATED THAN ALKALIS & ALKALINE EARTHS TO RADIOCHEMICAL WASTE PROCESSING
NaOH
pH ADJUSTMENT TANK
SCRUB SOLN.
STRIP SOLN.
ORGANIC SOLVENT +CHELATING AGENT
PULSE COLUMNS 5&6
ALKALI ELEMENTS
ALKALINE EARTHS
EVAPORATOR
CONDENSATE TO RADIOCHEMICAL WASTE PROCESSING
CONC. SOLN.
NaOH
pH ADJUSTMENT TANK
SCRUB SOLN.
STRIP SOLN.
ORGANIC SOLVENT +CHELATING AGENT
PULSE COLUMNS 7&8
AQUEOUS SOLN. OF Ba TO PROCESS CONC.
AQUEOUS SOLN. OF Sr TO PROCESS CONC.
pH ADJUSTMENT TANK
NaOH
SCRUB SOLN.
STRIP SOLN.
ORGANIC SOLVENT +CHELATING AGENT
PULSE COLUMNS 9 & 10
AQUEOUS SOLN. OF Cs TO PROCESS CONC.
WASTE
HCl
PRODUCT FINISHING AND PACKAGING
PACKAGED Cs Cl
PACKAGED SrCl2
PACKAGED BaCl2
SHIPPING

Figure 5

GP PROCESS

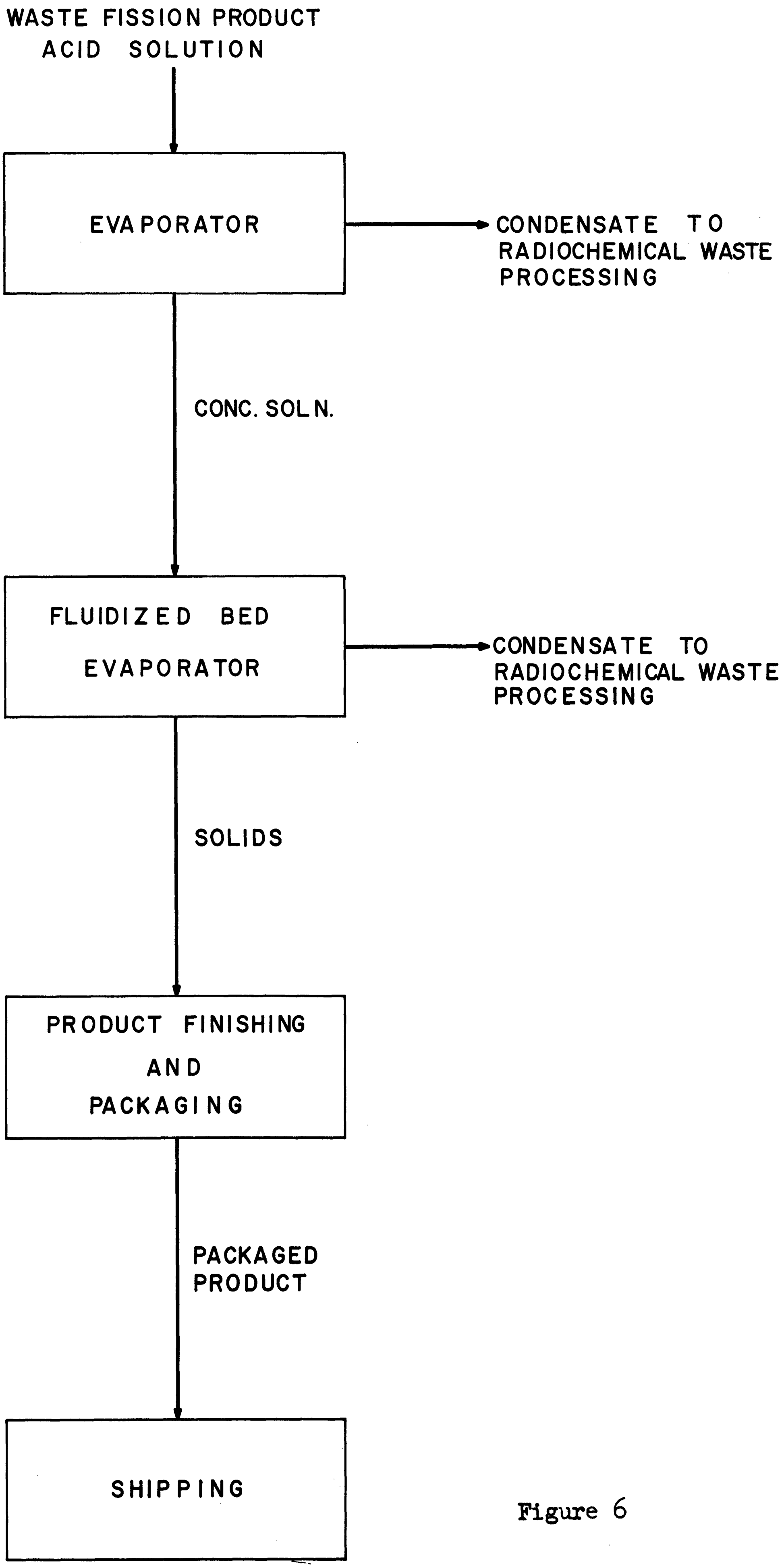


Figure 6

OL PROCESS

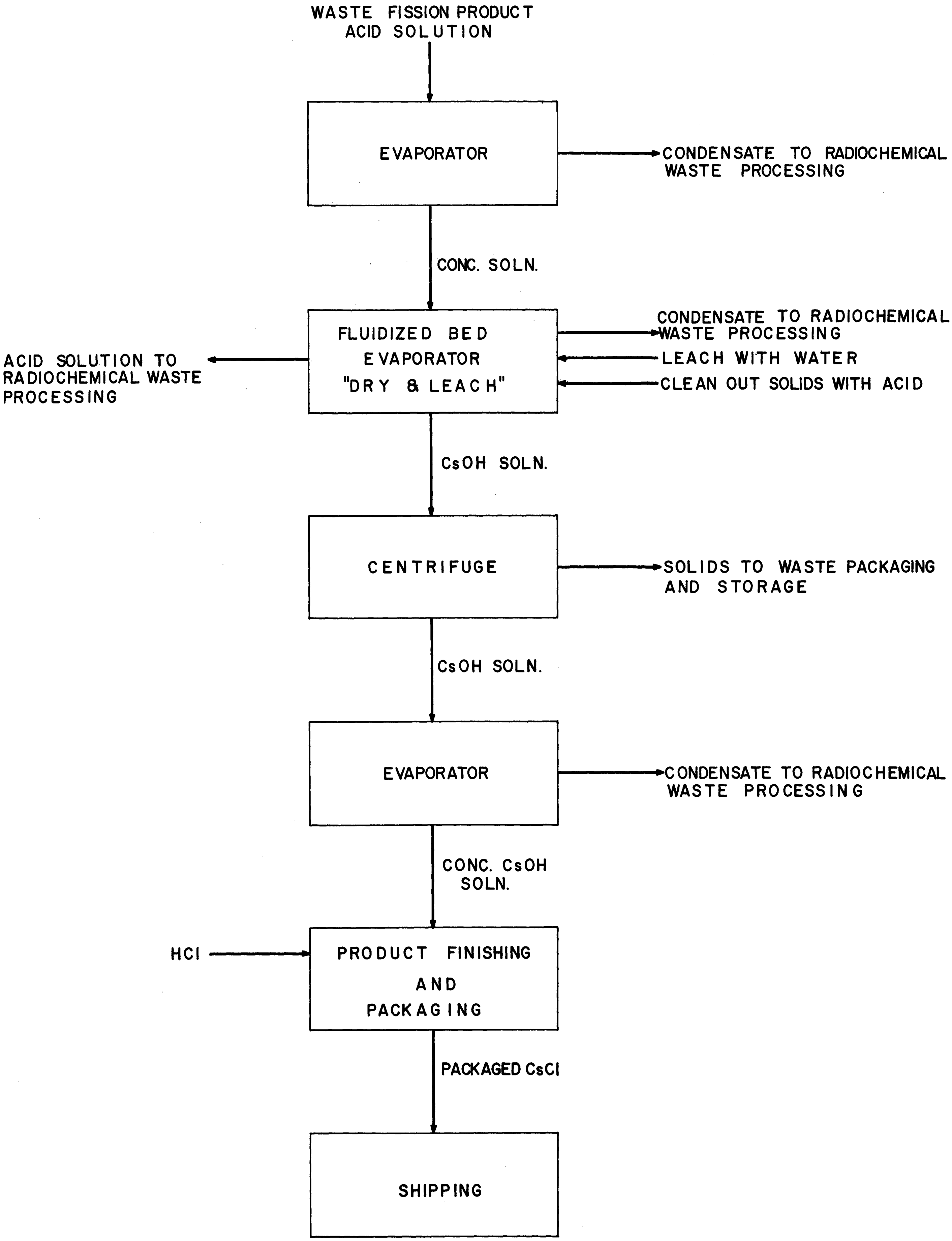
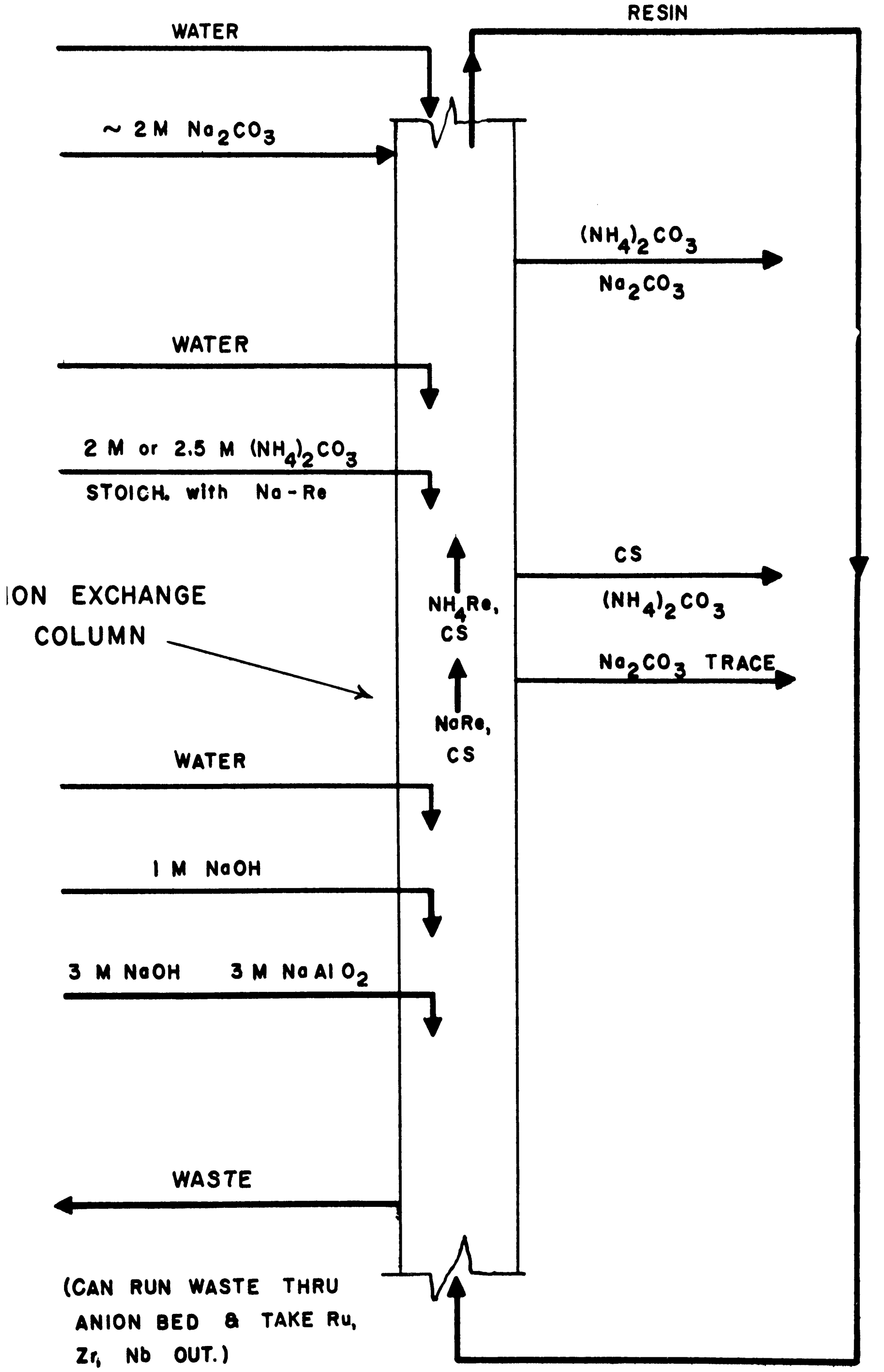


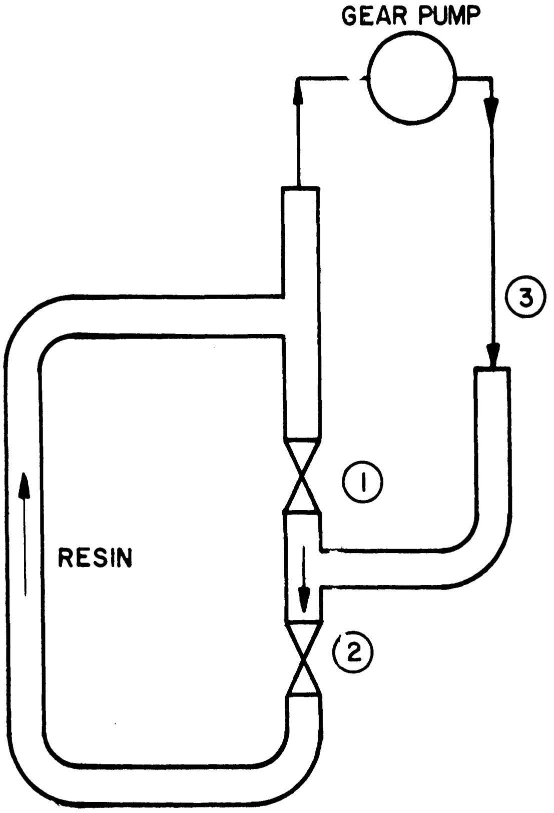
Figure 7



ION EXCHANGE COLUMN
FOR CESIUM REMOVAL FROM ALKALINE SOLUTIONS

Figure 8

SCHEMATIC DIAGRAMS OF MOVING BED ION EXCHANGE COLUMNS

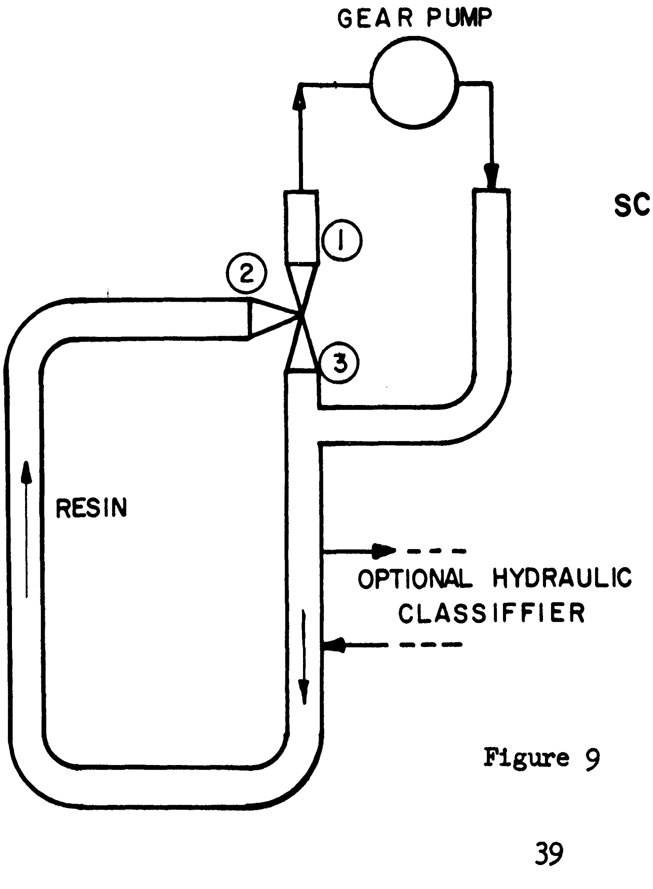


SCHEME WITH 2 SEPARATE VALVES

STEP I - RUN
1) CLOSED
2) CLOSED
3) NOT RUNNING

STEP II - MOVE BED
1) CLOSED
2) OPEN
3) DOWN

STEP III - RESIN SETTLING
1) OPEN
2) CLOSED
3) OFF



SCHEME WITH A 3-WAY VALVE

STEP I - RUN
1) OPEN
2) CLOSED
3) OPEN

STEP II - MOVE BED
1) OPEN
2) OPEN
3) CLOSED

Figure 9

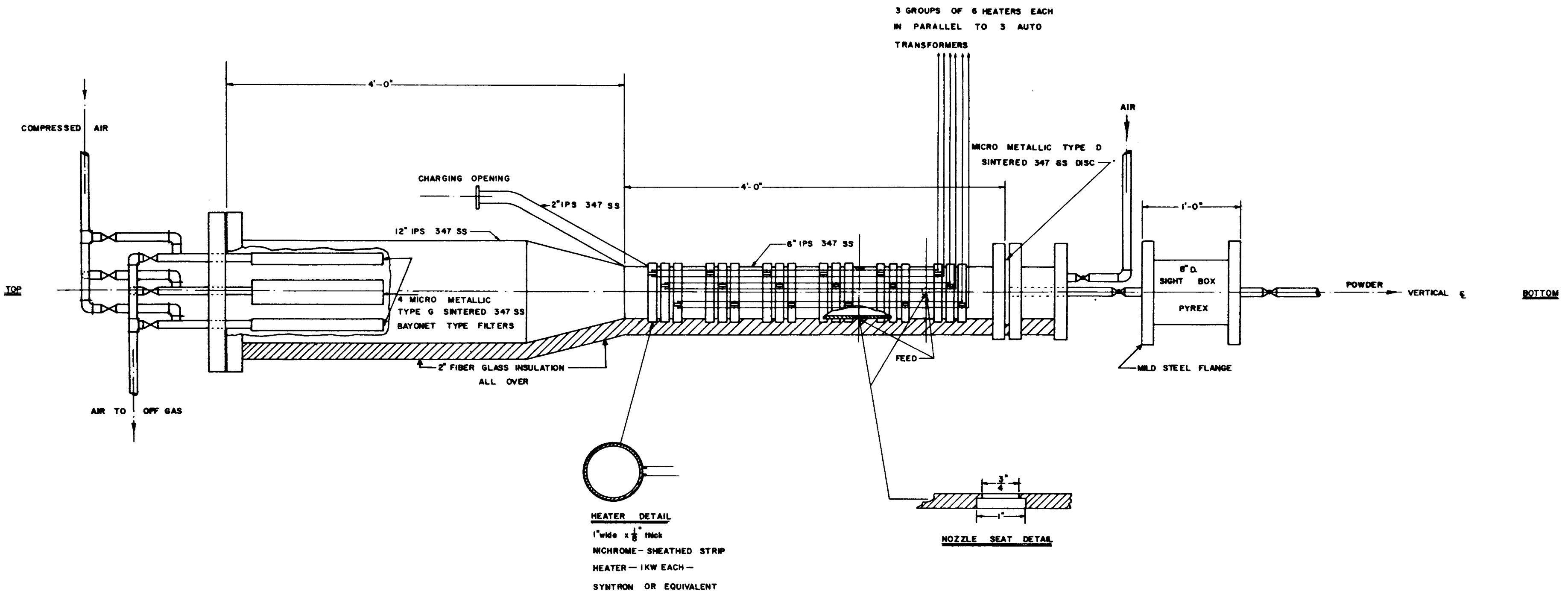
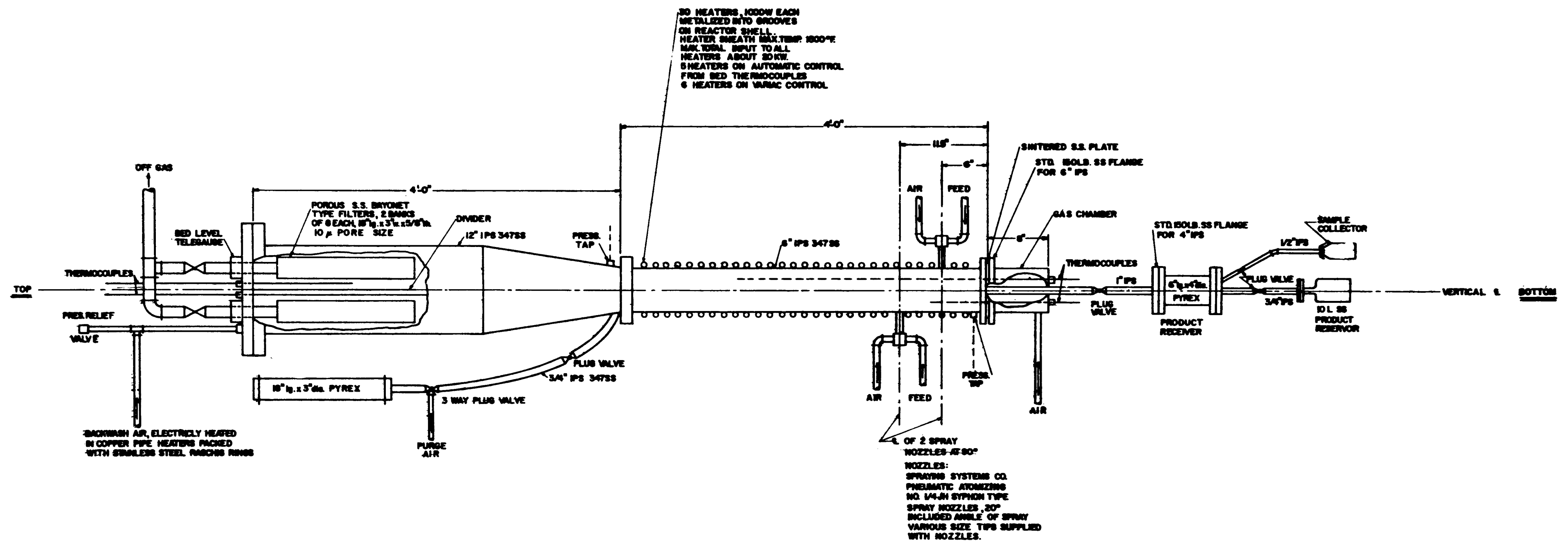

3 GROUPS OF 6 HEATERS EACH
IN PARALLEL TO 3 AUTO
TRANSFORMERS
4'-0"
COMPRESSED AIR
AIR
MICRO METALLIC TYPE D
SINTERED 347 SS DISC
CHARGING OPENING
4'-0"
2" IPS 347 SS
1'-0"
12" IPS 347 SS
6" IPS 347 SS
6" D.
SIGHT BOX
PYREX
TOP
POWDER
VERTICAL ℄
BOTTOM
4 MICRO METALLIC
TYPE G SINTERED 347 SS
BAYONET TYPE FILTERS
2" FIBER GLASS INSULATION
ALL OVER
FEED
MILD STEEL FLANGE
AIR TO OFF GAS
HEATER DETAIL
1" wide x 1/8" thick
NICHROME-SHEATHED STRIP
HEATER — 1KW EACH —
SYNTRON OR EQUIVALENT
3/4"
1"
NOZZLE SEAT DETAIL

Figure 10



OFF GAS
THERMOCOUPLES
TOP
BED LEVEL TELEGAUGE
PRES. RELIEF VALVE
BACKWASH AIR, ELECTRICLY HEATED IN COPPER PIPE HEATERS PACKED WITH STAINLESS STEEL RASCHIG RINGS
4'-0"
POROUS S.S. BAYONET TYPE FILTERS, 2 BANKS OF 8 EACH, 18" lg. x 3" w. x 5/16" th. 10 μ PORE SIZE
DIVIDER
12" IPS 347SS
18" lg. x 3" dia. PYREX
3 WAY PLUG VALVE
PURGE AIR
3/4" IPS 347SS
PLUG VALVE
PRESS. TAP
30 HEATERS, 1000W EACH METALIZED INTO GROOVES ON REACTOR SHELL. HEATER SHEATH MAX. TEMP. 1500°F. MAX. TOTAL INPUT TO ALL HEATERS ABOUT 30 KW. 5 HEATERS ON AUTOMATIC CONTROL FROM BED THERMOCOUPLES 6 HEATERS ON VARIAC CONTROL
4'-0"
6" IPS 347SS
11.5"
6"
AIR
FEED
AIR
FEED
℄ OF 2 SPRAY NOZZLES AT 90°
NOZZLES: SPRAYING SYSTEMS CO. PNEUMATIC ATOMIZING NO. 1/4-JH SYPHON TYPE SPRAY NOZZLES, 20° INCLUDED ANGLE OF SPRAY VARIOUS SIZE TIPS SUPPLIED WITH NOZZLES.
PRESS. TAP
AIR
SINTERED S.S. PLATE
STD. 150LB. SS FLANGE FOR 6" IPS
GAS CHAMBER
6"
THERMOCOUPLES
1" IPS
PLUG VALVE
STD. 150LB. SS FLANGE FOR 4" IPS
6" lg. x 4" dia. PYREX
PRODUCT RECEIVER
PLUG VALVE
1/2" IPS
SAMPLE COLLECTOR
3/4" IPS
10 L SS PRODUCT RESERVOR
VERTICAL ℄
BOTTOM

Figure 11

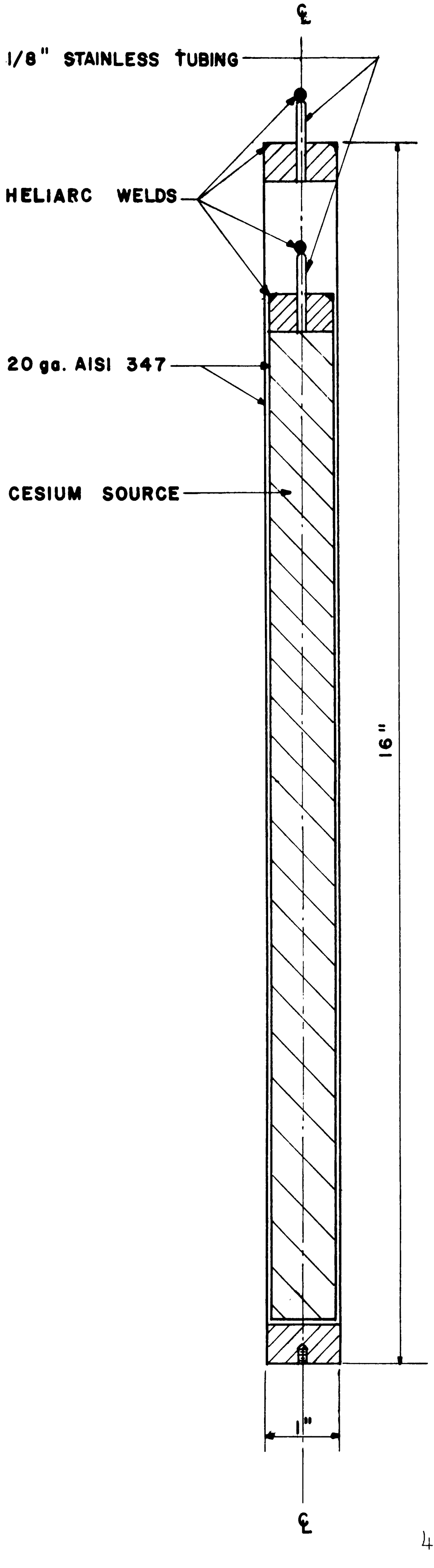


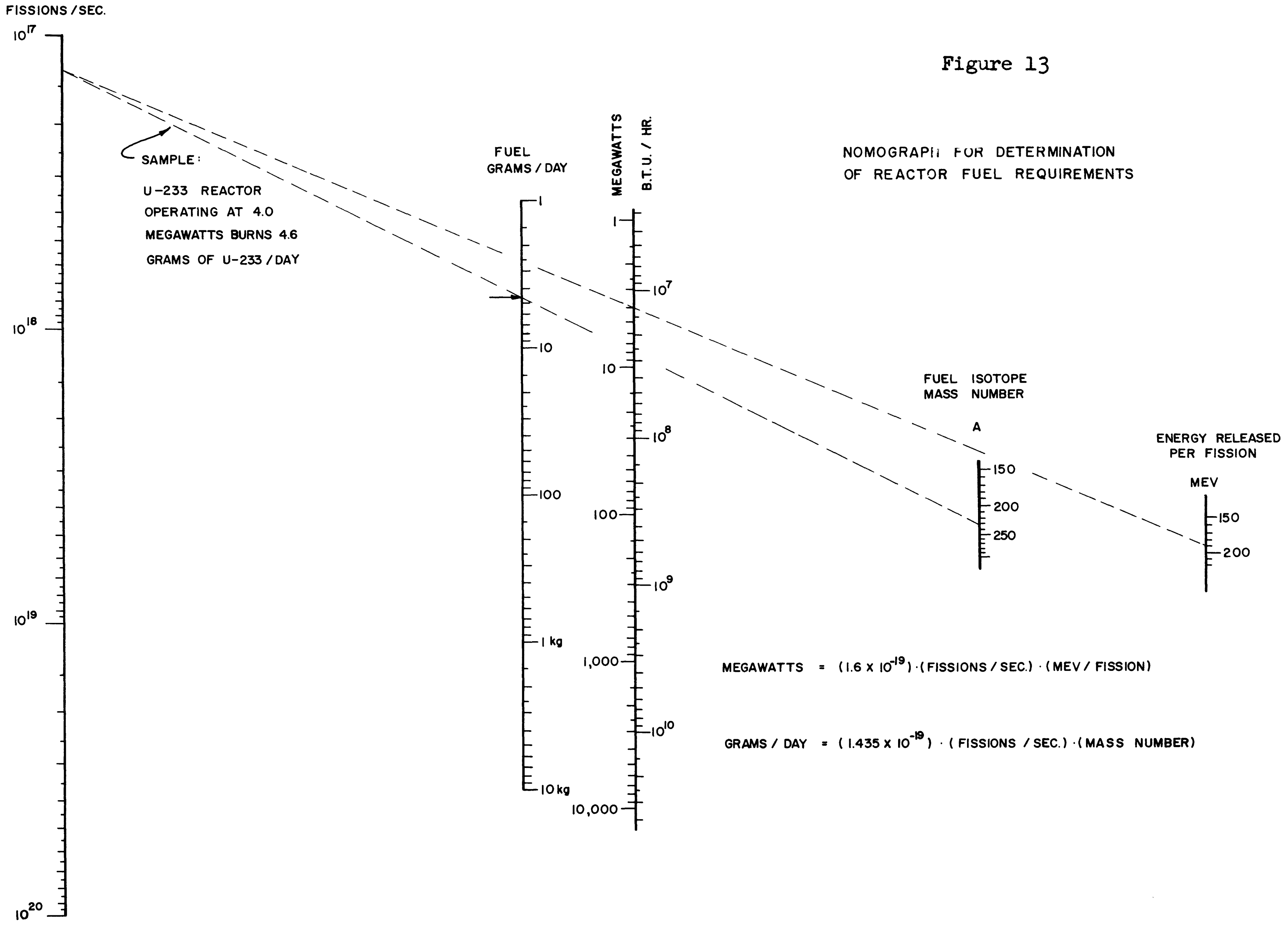
Figure 12

TYPICAL CONTAINER FOR RADIO-CESIUM

SCALE : HALF SIZE

Figure 13

NOMOGRAPH FOR DETERMINATION OF REACTOR FUEL REQUIREMENTS



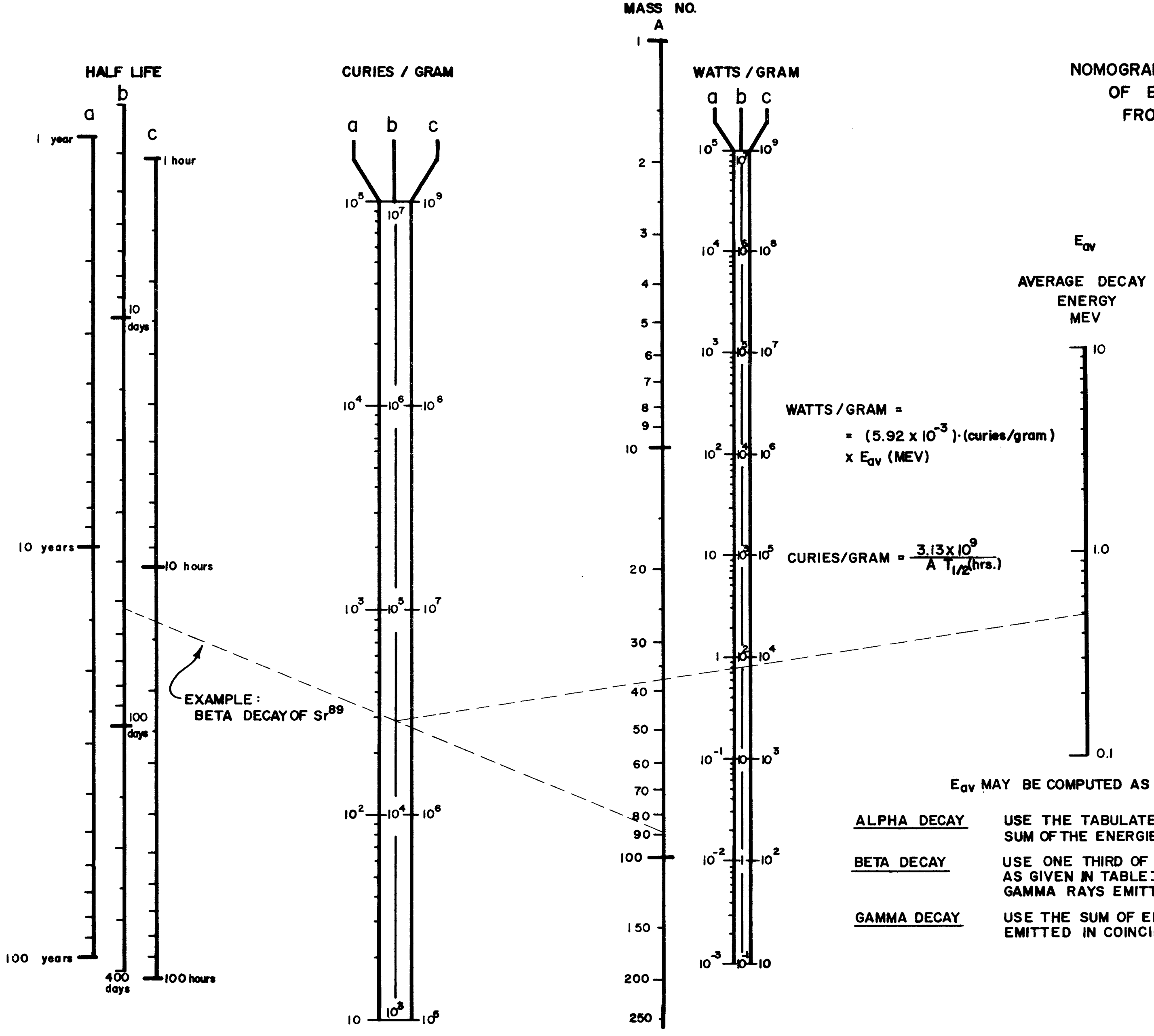
SAMPLE:
U-233 REACTOR
OPERATING AT 4.0
MEGAWATTS BURNS 4.6
GRAMS OF U-233 / DAY

$$\text{MEGAWATTS} = (1.6 \times 10^{-19}) \cdot (\text{FISSIONS / SEC.}) \cdot (\text{MEV / FISSION})$$

$$\text{GRAMS / DAY} = (1.435 \times 10^{-19}) \cdot (\text{FISSIONS / SEC.}) \cdot (\text{MASS NUMBER})$$

Figure 14

NOMOGRAPH FOR CALCULATION OF ENERGY AVAILABLE FROM RADIOACTIVE NUCLIDES



WATTS / GRAM =

$$= (5.92 \times 10^{-3}) \cdot (\text{curies/gram}) \times E_{av}\ (\text{MEV})$$

$$\text{CURIES/GRAM} = \frac{3.13 \times 10^9}{A\ T_{1/2}(\text{hrs.})}$$

IN USING THIS NOMOGRAPH, CARE MUST BE TAKEN TO BE CONSISTENT IN USING THE SAME SET OF SCALES (a, b, or c) THROUGOUT A GIVEN CALCULATION. FOR EXAMPLE, THE HALF LIFE OF Sr^{89} IS 53 DAYS, ENTER COLUMN b AND USE COLUMN b IN READING CURIES/GRAM AND WATTS/GRAM.

E_{av} MAY BE COMPUTED AS FOLLOWS:

<u>ALPHA DECAY</u>	USE THE TABULATED ALPHA PARTICLE ENERGIES PLUS THE SUM OF THE ENERGIES OF ANY GAMMA RAYS EMITTED IN COINCIDENCE.
<u>BETA DECAY</u>	USE ONE THIRD OF THE TABULATED DATA DECAY ENERGIES SUCH AS GIVEN IN TABLE II. ADD THE SUM OF THE ENERGIES OF ANY GAMMA RAYS EMITTED IN COINCIDENCE.
<u>GAMMA DECAY</u>	USE THE SUM OF ENERGIES OF THE GAMMA RAYS WHICH ARE EMITTED IN COINCIDENCE IN A CASCADE.

V. PLANNING AND SCHEDULING

A. General

For the six alternative fission product separation and packaging processes studied, plans and schedules have been drawn up for development, process engineering, detailed engineering designs, procurement and construction, inspection, plant start-up, and for initial hot-running of the chemical processing facility. These planning studies have indicated that the most economical method of project execution within a reasonable period of time consists of performing various functions pertaining to and necessary to a successful operating plant in an orderly manner. If plans and schedules are accelerated to the point of a "crash" program, it is anticipated that capital costs will be considerably higher, optimum designs will probably not be achieved, and longer periods will be required for plant start-up and to achieve normal operations. On the other hand, if a schedule is extended so that much time elapses between successive phases of effort, then the transmittal of information from one group to another will probably become inefficient, changes in technology will delay freezing of designs, overhead and administrative charges continue, and much time will be expended upon indecisions regarding optimum designs. For the purpose of these feasibility studies then, a middle course has been adopted in order to reflect an orderly program of work and to provide some basis from which capital and operating costs can be adjudged. It should be emphasized that the capital and operating costs portrayed in these estimates are dependent heavily upon the adherence in principle to a schedule such as that portrayed in Figure 15.

The development programs required to achieve optimum designs for chemical fission product separation and packaging facilities employing aqueous separation techniques have been reviewed. If it is possible to make early decisions regarding the type of fission product packaging process to employ, and if, in addition, aqueous technology is selected as a means of processing, about twelve to eighteen months of engineering development are needed. The purpose of such a program would be to develop those data adequate for production design for the separation and packaging plant. In addition to the period of development, it is expected that about six months of effort will be required to test mechanically equipment components and instruments. This testing program would enable a prediction of life of equipment and institution of a preplanned and preventive maintenance program for the ultimate production facility.

B. Planning and Scheduling of Engineering

Engineering planning can be divided into essentially two categories; process engineering and detailed design engineering.

1. Process Engineering

Chemical process engineering studies will be required to establish heat, energy, and material balances, equipment design calculations, engineering flowsheets, layouts, plot plans, and final requirements of utilities, as well as to prepare design information needed to permit detailed designs to proceed in an uninterrupted manner. Consequently, it appears desirable to have the process engineering functions parallel certain phases of engineering development and mechanical testing. During the course of such process engineering, it would appear desirable to permit key personnel ultimately responsible for plant operations to undertake the preparation of operating manuals for normal operations, maintenance, laboratories, warehousing, store keeping, preplanned schedules of maintenance, corrosion testing, etc. It would appear that about six months of process engineering would be required in order to establish designs to the point that detailed engineering could begin. Another six months of rather intensive endeavor would be required to establish necessary manuals to permit engineered plant start-up calibrations, cold runs, tracer runs, and ultimately hot runs.

2. Detailed Design Engineering

Detailed design engineering comprises architecture and engineering for buildings and structures; mechanical designs for process vessels, mechanical equipment, instrumentation, and piping; the design of electrical power installations, the provision for building furnishings, requisitioning of spare parts, establishment of procedures for welding, and establishment of procedures for inspection and testing. The schedules arrived at in this study are premised upon engagement of an engineering construction firm to perform the work in such a manner that materials and major equipment items can be requisitioned and purchased during the course of detailed engineering. It appears that a logical schedule of about twelve to thirteen months of effort would be required to achieve the necessary fabrication and construction drawings, during which time the peak manpower requirement for engineers and draftsmen may approach a total of one hundred for a short time period. The studies which have been made for equipment deliveries and major equipment components are based upon present-day mill deliveries, lead times, and shop fabrication times for general alloy type of fabricated equipment, materials, and supplies.

C. Plans and Schedules for Construction

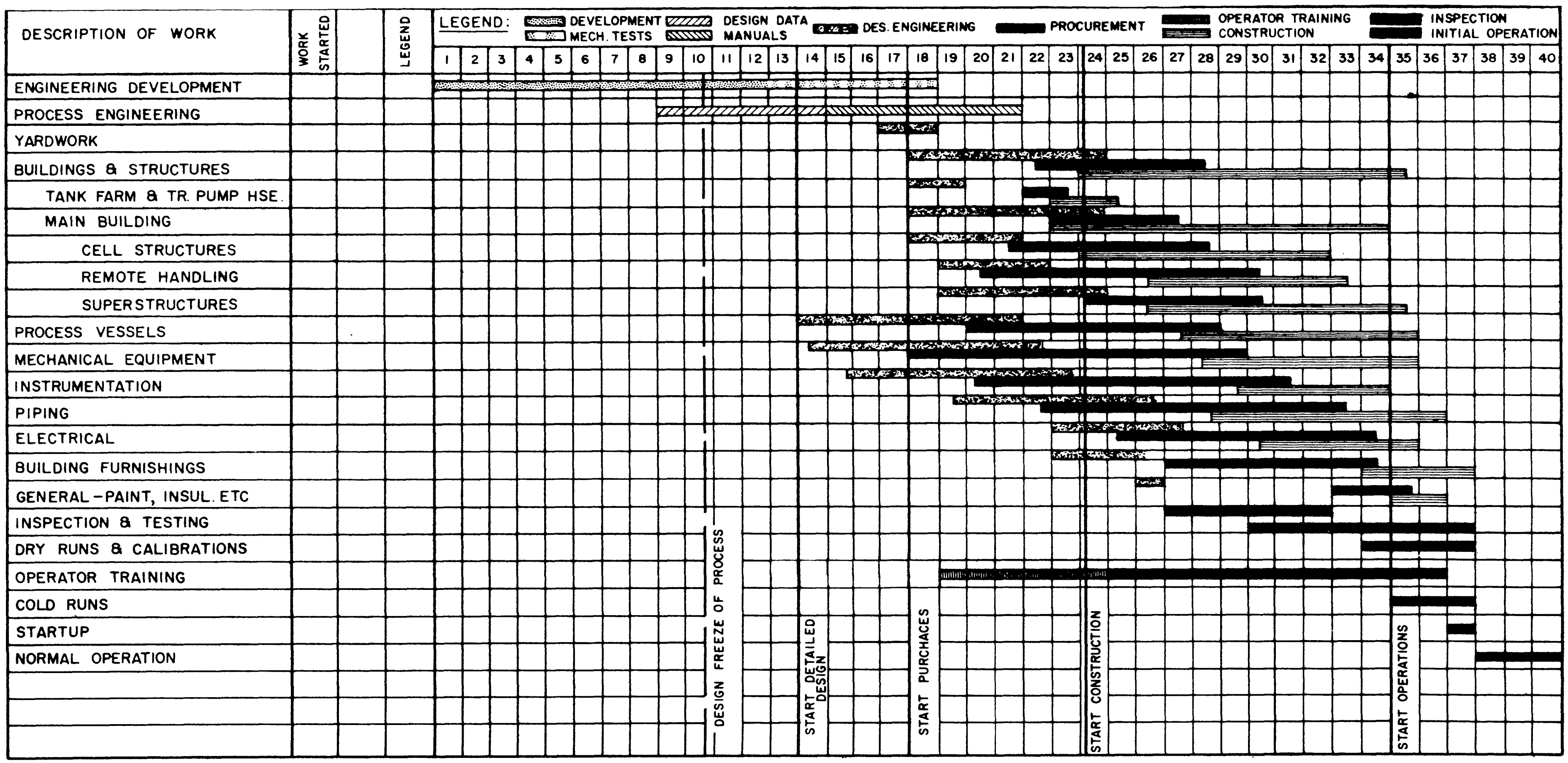
It is premised that construction activity would not start in the field until such time as adequate stocks of equipment, materials, and supplies would have been warehoused to permit construction activities to proceed on an uninterrupted basis. Under these conditions, it appears that the construction time would be about twelve months in the field. This twelve-month period, of course, would include the time necessary for inspection, dry running, calibration of equipment, and general plant clean-up.

D. Planning and Scheduling for Plant Start-up

Since one of the most difficult types of planning and scheduling consists in that required for plant start-up, it is believed advisable to give serious consideration to selection of key personnel in the early stages of development so that these people can ultimately assume supervisory responsibilities for plant operations. Thus it is believed that an operator training program of about six months duration would be adequate to qualify supervisory personnel in laboratories, plant operations, plant maintenance, and general administration in such a way as to minimize plant start-up time. If this can be done, and if inspection, dry running, and calibrations can be done during various completion stages of the construction program, it appears that with a cold running time of about three months, the latter month of which can be conducted at the tracer levels, a plant could be operated at the scheduled production rates within a period of four months after construction completion and acceptance.

The proposed schedule of work for phases of development, process engineering, detailed design, procurement, construction, inspection, and plant start-up is indicated in bar graph form in Figure 15. Capital estimates which have been made for the installed costs of plant, plant start-up, and expendable charges for development are premised upon schedules portrayed herein. A conservative estimate of the over-all time from that at which development is initiated until that at which the plant is in full operation is expected to be about thirty-eight to forty months.

FISSION PRODUCT PACKAGING PLANT



NOTE: CAPITAL COSTS PROJECTED PREMISED UPON ABOVE TIME TABLE.

PROPOSED SCHEDULE OF WORK

Figure 15

VI. ESTIMATES AND PROJECTIONS OF CAPITAL INVESTMENTS AND EXPENDITURES

A. Basis of Estimates

The accuracy of determination of capital requirements for plant facilities is largely dependent upon the accuracy and degree of completion of engineering designs and establishment of engineering philosophy, subject to schedules of work and contingent upon a successful execution of development programs. Estimates are presented of the capital investments and expenditures for fission product separation and packaging plants to convert Purex-type wastes from a fuel processing plant into dry packaged fission products and dry packaged waste materials. The estimates for capital requirements have been premised upon process designs, flowsheets, layouts, preliminary specifications, materials, and equipment, which are available in draft form for inspection and are not reported in detail here.

In general, the capital requirements which are portrayed cover the following categories:

1. Installed equipment and machinery
2. Buildings and structures
3. Electrical power and lighting
4. Spare parts
5. Plant start-up

Expenditures which may be required for development programs or certain portions of operator training are being considered as expendable costs. The estimates for capital have been prepared from a rather detailed take-off of materials, equipment, structual components, and a general review of construction practices. For the purposes of this feasibility study, an effort has been made to cover all categories of engineering, procurement, construction, inspection, and plant start-up. In order to permit utilization of the cost information calculated and to evaluate alternative methods of plant installations, as changes in design concepts and development data dictate, the estimate is summarized in a series of tables which will permit the evaluation of the costs in terms of operating centers of the plant, as well as categories of equipment and machinery installations. The operating areas of the processing plant have been divided arbitrarily into the following categories, which may differ somewhat from process to process as detailed on the accompanying analysis of capital requirements:

1. Tank farm
2. Chemical make-up areas
3. Separations
4. Radiochemical waste disposal
5. Solvent purification practices (if required)
6. General plant services

The individual operating areas have been subdivided into classifications as follows:

1. Vessels
2. Mechanical equipment
3. Instruments
4. Piping
5. Structures
6. Electrical

Allocations of such costs as engineering, field and direct charges, and contingencies have been made with respect to categories on a percentage basis. These same costs have allocated to the operating areas of the process plant in order to indicate totals of allocated erection costs.

Estimates for plant start-up and partial operator training programs have been added to the erection costs of facility for total capital costs, and some of the accompanying tables do not include these costs, but only the costs of the erected plant ready to start up. These estimates are based upon the planning and scheduling presented earlier in this report. Estimates for plant start-up are based upon specific plans for utilizing personnel who will eventually assume the responsibility for supervising plant operations and tasks of preparation of operating manuals, inspection in the shop, field inspection, calibration and testing, cold running and plant start-up. General contingencies for error of omission have been assumed at ten percent of total erection costs. Estimates for engineering of the plant and plant components are based upon engineers well qualified in radiochemical technology, utilizing established standards of industrial engineering practice. No allowance has been made for the training of engineers to the design principles necessary for radiochemical processing plants. For proper evaluation of the capital costs portrayed in this study, it is essential to have a comprehensive understanding of the basic philosophy of plant designs and plant operations. As such an engineering philosophy becomes modified and its policies become more firmly established, it will be necessary to re-evaluate capital requirements continuously.

B. Estimate Summaries

In the following pages, there appear a series of tables in which are presented summaries of estimates of capital costs in such a way as to provide breakdowns of these costs in several alternative manners.

Tables No. 1 through 6 are summaries of estimated capital cost requirements for the several alternative fission product packaging plants, including all charges for all areas which the facility comprises. These tables include total installation costs of plant start-up charges which have been estimated. It is to be noted that the total capital cost estimates provided are as follows:

1.	Co-Precipitation Process	$4,584,593
2.	Co-Crystallization Process	5,125,444
3.	Ion Exchange Process	4,780,596
4.	Solvent Extraction Process	5,849,137
5.	Gross Fission Product Packaging Process	4,334,303
6.	Oxide Leaching Process	4,564,016

Tables No. 7 through 12 are estimates of capital costs in terms of process, process auxiliaries, and general plant services. These tables have been prepared so that the effects of the elimination of process cycles and the substitution of others may be estimated for order of magnitude comparisons. It is to be noted that process cycle costs vary from a minimum of 26.92 percent of the total installed cost for the gross fission product process to a maximum of 40.88 percent of the total installed cost for the co-crystallization process.

Tables No. 13 through 18 present summaries of capital costs by functional operating areas as described above. These areas are detailed further on the individual estimates since the process areas differ from plant to plant. The tables indicate total installed costs exclusive of development and plant start-up. Percentages due to the individual processing steps have been calculated, and allocations have been made to installed costs for working inventory, processing units, process auxiliaries, and general plant facilities.

Tables No. 19 through 24 present capital estimate summaries by equipment categories for all portions of the several alternative fission product packaging plants. These plants contain reallocated field and indirect charges, engineering costs, and purchase of spare parts. These costs are allocated into categories of vessels and mechanical equipment, instruments, piping, structures, and electrical. It can be observed here that the costs of structures make up a significently large proportion of the total cost, varying from a minimum proportion of 55.64 per cent for the co-crystallization process to a maximum of 65.55 percent for the gross fission product process.

Itemized estimates of the various categories of cost discussed above, as applied to the individual processing steps for each of the plants, are available in draft form for review if desired, but are not included here.

Tables No. 25 through 30 present summary estimates of the cost of electrical lighting and power wiring. Costs for a central substation and switch gear have not been included in these costs. The estimates do include, however, provisions for the necessary transformers for lighting circuits and controls, and are based on take-offs from flowsheets and layouts.

Tables No. 31 through 36 present summaries of estimates for engineering costs. These estimates include costs for process engineering, costs for control engineering, project engineering, detailed design engineering, piping, structures, and electrical. Allowance has been made in these estimates for engineering overhead based upon normal charges of design engineering firms. These estimates are based upon establishing process designs which are frozen prior to detailed design engineering efforts. Required engineering varies from minimum of $340,100 for the gross fission product process, up to a maximum of $571,600 for the solvent extraction process.

Tables No. 37 through 42 consist of estimates for field supervision and indirect costs for construction. These costs are contingent mostly upon the method of negotiating construction contracts. In the event that multiple construction contractors are employed for erection of facilities, reconsideration of field supervision and indirect costs of construction must be made.

TABLE NO. 1

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
CO-PRECIPITATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installations		
Vessels	$ 193,315	$
Mechanical Equipment	342,120	
Instruments	63,565	
Piping	324,125	
Spare Parts	268,880	
		1,192,005
Buildings and Structures	1,662,855	
Electrical Power and Lighting	102.820	1.765,675
Field Indirect Costs	440,700	
Engineering	433,000	
Contingencies	383,138	
		1,256,838
Total Installation		4,214,518
Plant Start-up	370,075	
Total Capital Estimate		4,584,593

---

*Costs of development excluded.

TABLE NO. 2

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
CO-CRYSTALLIZATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installation		
Vessels	$ 323,325	$
Mechanical Equipment	376,070	
Instruments	81,875	
Piping	440,195	
Spare Parts	298,837	
		1,520,302
Buildings and Structures	1,662,855	
Electrical Power and Lighting	104,050	
		1,766,905
Field Indirect Costs	489,500	
Engineering	518,000	
Contingencies	429,471	
		1,436,971
Total Installation		$4,724,178
Plant Start-up	401,266	
Total Capital Estimate		$5,125,444

* Costs of development excluded.

TABLE NO. 3

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
ION-EXCHANGE PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installations		
Vessels	$ 193,315	$
Mechanical Equipment	322,355	
Instruments	68,465	
Piping	360,540	
Spare Parts	270,098	
		1,214,773
Buildings and Structures	1,662,855	
Electrical Power and Lighting	93,450	
		1,756,305
Field Indirect Costs	444,900	
Engineering	444,000	
Contingencies	385,998	1,274,898
Total Installation		4,245,976
Plant Start-up	534,620	
Total Capital Estimate		$ 4,780,596

---

*Costs of development excluded.

TABLE NO. 4

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installations		
Vessels	$ 331,580	$
Mechanical Equipment	472,545	
Instruments	106,705	
Piping	392,665	
Spare Parts	345,576	
		1,649,071
Buildings and Structures	2,043,490	
Electrical Power and Lighting	124,150	
		2,167,640
Field Indirect Costs	555,500	
Engineering	571,600	
Contingencies	494,381	
		1,621,481
Total Installation		5,438,192
Plant Start-up	410,945	
Total Capital Estimate		$ 5,849,137

---

*Costs of development excluded

TABLE NO. 5

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
GROSS FISSION PRODUCT PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installations		
Vessels	$ 150,785	$
Mechanical Equipment	290,290	
Instruments	39,725	
Piping	304,575	
Spare Parts	255,770	
		1,041,145
Buildings and Structures	1,676,605	
Electrical Power and Lighting	95,720	
		1,772,325
Field Indirect Costs	419,800	
Engineering	390,100	
Contingencies	362,337	
		1,172,237
Total Installation		3,985,707
Plant Start-up	348,596	
Total Capital Estimate		$ 4,334,303

---

*Costs of development excluded.

TABLE NO. 6

ESTIMATE SUMMARY
CAPITAL COST REQUIREMENTS FOR*
OXIDE LEACHING PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	SUB-TOTAL	PROCESS TOTAL
Process Installations		
Vessels	$ 205,780	$
Mechanical Equipment	338,120	
Instruments	49,315	
Piping	318,575	
Spare Parts	269,012	
		1,180,802
Buildings and Structures	1,676,605	
Electrical Power and Lighting	101,720	
		1,778,325
Field Indirect Costs	439,800	
Engineering	428,400	
Contingencies	382,733	
		1,250,933
Total Installation		4,210,060
Plant Start-up	353,956	
Total Capital Estimate		$ 4,564,016

---

*Costs of development excluded.

TABLE NO. 7

CAPITAL COST ESTIMATE SUMMARY*
(IN TERMS OF PROCESS, PROCESS AUXILIARIES, AND GENERAL PLANT SERVICES)
CO-PRECIPITATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Facilities for Chemicals and Raw Materials		
Tank Farm	$ 195,506	$
Chemical Make-up # 1	211,235	
Chemical Make-up # 2	238,979	
		645,720
% of Total	(15.32)	
Process Cycle		
Separations	483,857	
Finishing and Packaging	809,320	
		1,293,177
% of Total	(30.68)	
Process Auxiliaries		
Radiochemical Waste Disposal	383,413	
Vessel Off-Gas	237,780	
Waste Disposal	314,584	
		935,777
% of Total	(22.20)	
General Plant Facilities		
Plant Utilities	700,470	
Heating and Ventilating	639,374	
		1,339,844
% of Total	(31.79)	
Total (100%)		$ 4,214,518

---

*Excluding costs of development and plant start-up.

TABLE NO. 8

CAPITAL COST ESTIMATE SUMMARY*
(IN TERMS OF PROCESS, PROCESS AUXILIARIES, AND GENERAL PLANT SERVICES)
CO-CRYSTALLIZATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Facilities for Chemicals and Raw Materials		
Tank Farm	$ 212,301	$
Chemical Make-Up # 1	409,272	
Chemical Make-Up # 2	168,975	790,548
% of Total	(16.83)	
Process Cycle		
Pre-treatment	469,113	
Product Removal	404,038	
Salt Removal	372,362	
Finishing and Packaging	674,455	1,919,968
% of Total	(40.88)	
Process Auxiliaries		
Radiochemical Waste Disposal	313,052	
Vessel Off-Gas	239,818	
Waste Disposal	317,277	870,147
% of Total	(18.52)	
General Plant Facilities		
Plant Utilities	581,566	
Heating and Ventilating	534,949	1,116,515
% of Total	(23.77)	
Total (100%)		$ 4,697,178

---

*Excluding costs of development and plant start-up.

TABLE NO. 9

CAPITAL COST ESTIMATE SUMMARY*
(IN TERMS OF PROCESS, PROCESS AUXILIARIES, AND GENERAL PLANT SERVICES)
ION-EXCHANGE PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Facilities for Chemicals and Raw Materials		
Tank Farm	$ 167,180	$
Chemical Make-up # 1	252,601	
Chemical Make-up # 2	305,656	
% of Total	(17.09)	725,437
Process Cycle		
Separations	254,320	
Chemical Recovery	251,714	
Finishing and Packaging	786,411	
% of Total	(30.44)	1,292,445
Process Auxiliaries		
Radiochemical Waste Disposal	373,274	
Vessel Off-Gas	238,481	
Waste Disposal	315,509	
% of Total	(21.84)	927,264
General Plant Facilities		
Plant Utilities	679,159	
Heating and Ventilating	621,671	
% of Total	(30.63)	1,300,830
Total (100%)		$ 4,245,976

---

*Excluding costs of development and plant start-up.

TABLE NO. 10

CAPITAL COST ESTIMATE SUMMARY[*]
(IN TERMS OF PROCESS, PROCESS AUXILIARIES, AND GENERAL PLANT SERVICES)
SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Tank Farm	$ 209,278	
Chemical Make-up # 1	215,414	
Chemical Make-up # 2	269,696	
% of Total	(12.77)	694,388
Process Cycle		
Separations # 1	495,924	
Separations # 2	531,722	
Finishing and Packaging	749,692	
% of Total	(32.68)	1,777,338
Process Auxiliaries		
Solvent Purification	671,107	
Radiochemical Waste Disposal	350,981	
Vessel Off-Gas	237,093	
Waste Disposal	459,708	
% of Total	(31.61)	1,718,889
General Plant Facilities		
Plant Utilities	647,615	
Heating and Ventilating	599,962	
% of Total	(22.94)	1,247,577
Total (100%)		$ 5,438,192

---

[*] Excluding costs of development and plant start-up.

TABLE NO. 11

CAPITAL COST ESTIMATE SUMMARY*
(IN TERMS OF PROCESS, PROCESS AUXILIARIES, AND GENERAL PLANT SERVICES)
GROSS FISSION PRODUCT PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Facilities for Chemicals and Raw Materials		
Tank Farm	$ 244,609	$
Chemical Make-up	259,182	503,791
% of Total	(12.64)	
Process Cycle		
Separations	327,783	
Finishing and Packaging	749,997	1,072,780
% of Total	(26.92)	
Process Auxiliaries		
Radiochemical Waste Disposal	316,251	
Vessel Off-Gas	236,356	
Waste Disposal	312,685	865,292
% of Total	(21.71)	
General Plant Facilities		
Plant Utilities	808,122	
Heating and Ventilating	735,722	1,543,844
% of Total	(38.73)	
Total (100%)		$ 3,985,707

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*Excluding costs of development and plant start-up.

TABLE NO. 12

CAPITAL COST ESTIMATE SUMMARY*
(IN TERMS OF PROCESS, PROCESS AUXILIARIES,
AND GENERAL PLANT SERVICES)
OXIDE LEACHING PROCESS
FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Facilities for Chemicals and Raw Materials		
Tank Farm	$ 245,825	$
Chemical Make-up	234,575	
% of Total	(11.41)	480,400
Process Cycle		
Separations	467,788	
Finishing and Packaging	827,612	
% of Total	(30.77)	1,295,400
Process Auxiliaries		
Radiochemical Waste Disposal # 1	346,290	
Radiochemical Waste Didposal # 2	168,350	
Vessel Off-Gas	237,370	
Waste Disposal	314,028	
% of Total	(25.32)	1,066,038
General Plant Facilities		
Plant Utilities	714,714	
Heating and Ventilating	653,508	
% of Total	(32.50)	1,368,222
Total (100%)		$ 4,210,060

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*Excluding costs of development and plant start-up.

TABLE NO. 13

CAPITAL ESTIMATE SUMMARY BY[*] FUNCTIONAL OPERATING AREA CO-PRECIPITATION PROCESS FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 195,506	4.64
2	Chemical Make-up # 1	211,235	5.01
3	Chemical Make-up # 2	238,979	5.67
4	Separations	438,857	11.48
5	Radiochemical Waste Disposal	383,413	9.10
6	Finishing and Packaging	809,320	19.20
7	Plant Utilities	700,470	16.62
8	Heating and Ventilating	639,374	15.17
9	Vessel Off-Gas	237,780	5.64
10	Waste Disposal	314,584	7.46
	Total	$ 4,214,518	100.00

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[*] Excluding costs of plant start-up.

TABLE NO. 14

CAPITAL ESTIMATE SUMMARY BY* FUNCTIONAL OPERATING AREA CO-CRYSTALLIZATION PROCESS FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 212,301	4.49
2	Chemical Make-up # 1	409,272	8.66
3	Chemical Make-up # 2	168,975	3.58
4	Pre-treatment	496,113	10.50
5	Product Removal	404,038	8.55
6	Salt Removal	372,362	7.88
7	Radiochemical Waste Disposal	313,052	6.63
8	Finishing and Packaging	674,455	14.28
9	Plant Utilities	581,566	12.31
10	Heating and Ventilating	534,949	11.32
11	Vessel Off-Gas	239,818	5.08
12	Waste Disposal	317,277	6.72
	Total	$ 4,724,178	100.00

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*Excluding costs of plant start-up.

TABLE NO. 15

CAPITAL ESTIMATE SUMMARY BY[*]
FUNCTIONAL OPERATING AREA
ION EXCHANGE PROCESS
FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 167,180	3.94
2	Chemical Make-up # 1	252,601	5.95
3	Chemical Make-up # 2	305,656	7.20
4	Separations	254,320	5.99
5	Radiochemical Waste Disposal	373,274	8.79
6	Chemical Recovery	251,714	5.93
7	Finishing and Packaging	786,411	18.39
8	Plant Utilities	679,159	16.00
9	Heating and Ventilating	621,671	14.64
10	Vessel Off-Gas	238,481	5.62
11	Waste Disposal	315,509	7.43
	Total	$ 4,245,976	100.00

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[*] Excluding costs of plant start-up.

TABLE NO. 16

CAPITAL ESTIMATE SUMMARY BY[*]
FUNCTIONAL OPERATING AREA
SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 209,278	3.85
2	Chemical Make-up # 1	215,414	3.96
3	Chemical Make-up # 2	269,696	4.96
4	Separations # 1	495,924	9.12
5	Separations # 2	531,722	9.78
6	Solvent Purification	671,107	12.34
7	Radiochemical Waste Disposal	350,981	6.45
8	Finishing and Packaging	749,692	13.79
9	Plant Utilities	647,615	11.91
10	Heating and Ventilating	599,962	11.03
11	Vessel Off-Gas	237,093	4.36
12	Waste Disposal	459,708	8.45
	Total	$ 5,438,192	100.00

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[*] Excluding costs of plant start-up.

TABLE NO. 17

CAPITAL ESTIMATE SUMMARY BY[*]
FUNCTIONAL OPERATING AREA
GROSS FISSION PRODUCT PROCESS
FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 244,609	6.14
2	Chemical Make-up	259,182	6.50
3	Separations	327,783	8.22
4	Radiochemical Waste Disposal	316,251	7.94
5	Finishing and Packaging	744,997	18.69
6	Plant Utilities	808,122	20.28
7	Heating and Ventilating	735,722	18.46
8	Vessel Off-Gas	236,356	5.93
9	Waste Disposal	312,685	7.84
	Total	$ 3,985,707	100.00

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[*] Excluding costs of plant start-up.

TABLE NO. 18

CAPITAL ESTIMATE SUMMARY BY[*] FUNCTIONAL OPERATING AREA OXIDE LEACHING PROCESS FISSION PRODUCT PACKAGING PLANT

AREA NO.	DESCRIPTION OF AREA	TOTAL COST ESTIMATE	PERCENT OF WHOLE
1	Tank Farm	$ 245,825	5.84
2	Chemical Make-up	234,575	5.57
3	Separations	467,788	11.11
4	Radiochemical Waste Disposal # 1	346,290	8.23
5	Radiochemical Waste Disposal # 2	168,350	4.00
6	Finishing and Packaging	827,612	19.66
7	Plant Utilities	714,714	16.98
8	Heating and Ventilating	653,508	15.52
9	Vessel Off-Gas	237,370	5.64
10	Waste Disposal	314,028	7.46
	Total	$ 4,210,060	100.00

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[*] Excluding costs of plant start-up.

TABLE NO. 19

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
CO-PRECIPITATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 193,315	$ 109,694	$ 303,009	7.19
400	Mechanical Equipment	342,120	194,131	536,251	12.72
600	Instruments	63,565	36,069	99,634	2.36
700	Piping	324,125	183,919	508,044	12.05
800	Structures	1,662,855	943,562	2,606,417	61.84
900	Electrical	102,820	58,344	161,164	3.82
	Totals	$2,688,800	$1,525,718	$ 4,214,518	100.00

TABLE NO. 20

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
CO-CRYSTALLIZATION PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 323,325	$ 187,805	$ 511,130	10.82
400	Mechanical Equipment	376,070	218,442	594,512	12.58
600	Instruments	81,875	47,557	129,432	2.74
700	Piping	440,195	255,689	695,884	14.73
800	Structures	1,662,855	965,877	2,628,732	55.64
900	Electrical	104,050	60,438	164,488	3.48
	Totals	$ 2,988,370	$ 1,735,808	$ 4,724,178	100.00

TABLE NO. 21

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
ION EXCHANGE PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 193,315	$ 110,577	$ 303,892	7.16
400	Mechanical Equipment	322,355	184,391	506,746	11.93
600	Instruments	68,465	39,163	107,628	2.53
700	Piping	360,540	206,234	566,774	13.35
800	Structures	1,662,855	951,176	2,614,031	61.56
900	Electrical	93,450	53,455	146,905	3.46
	Totals	$ 2,700,980	$1,544,996	$ 4,245,966	100.00

TABLE NO. 22

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 331,580	$ 187,903	$ 519,483	9.55
400	Mechanical Equipment	472,545	267,786	740,331	13.61
600	Instruments	106,705	60,469	167,174	3.07
700	Piping	392,665	222,519	615,184	11.31
800	Structures	2,043,490	1,158,025	3,201,515	58.87
900	Electrical	124,150	70,355	194,505	3.58
	Totals	$ 3,471,135	$1,967.057	$ 5,438,192	100.00

TABLE NO. 23

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
GROSS FISSION PRODUCT PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 150,785	$ 84,186	$ 234,971	5.90
400	Mechanical Equipment	290,290	162,074	452,364	11.35
600	Instruments	39,725	22,179	61,904	1.55
700	Piping	304,575	170,049	474,624	11.91
800	Structures	1,676,605	936,077	2,612,682	65.55
900	Electrical	95,720	53,442	149,162	3.74
	Totals	$2,557,700	$1,428,007	$3,985,707	100.00

TABLE NO. 24

CAPITAL ESTIMATE SUMMARY
BY EQUIPMENT CATEGORIES
INDIRECT CONSTRUCTION COSTS ALLOCATED (ALL AREAS)
OXIDE LEACHING PROCESS
FISSION PRODUCT PACKAGING PLANT

CODE	CLASSIFICATION	DIRECT	ALLOCATED INDIRECT	TOTALS	%
100,200 300,500	Vessels	$ 205,780	$ 116,268	$ 322,048	7.65
400	Mechanical Equipment	338,120	191,042	529,162	12.57
600	Instruments	49,315	27,863	77,178	1.83
700	Piping	318,575	179,998	498,573	11.84
800	Structures	1,676,605	947,301	2,623,906	62.33
900	Electrical	101,720	57,473	159,193	3.78
	Totals	$ 2,690,115	$ 1,519,945	$ 4,210,060	100.00

TABLE NO. 25

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS FOR CO-PRECIPITATION PROCESS FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 3,800	$ 2,250	$ 6,050
92-2	Chemical Make-up #1	3,500	2,850	6,350
92-3	Chemical Make-up #2	4,000	3,100	7,100
92-4	Separations	8,400	4,450	12,850
92-5	Radiochemical Waste Disposal	8,000	3,600	11,600
92-6	Finishing and Packaging	6,500	5,750	12,250
92-7	Plant Utilities	6,550	5,270	11,820
92-8	Heating and Ventilating	10,800	6,500	17,300
92-9	Vessel Off-Gas	4,300	3,000	7,300
92-10	Waste Disposal	6,300	3,900	10,200
	Total	$62,150	$40,670	$102,820

TABLE NO. 26

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS
CO-CRYSTALLIZATION PROCESS
FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 4,400	$ 2,750	$ 7,150
92-2	Chemical Make-up #1	5,500	3,600	9,100
92-3	Chemical Make-up #2	2,200	1,300	3,500
92-4	Pre-treatment	4,600	3,250	7,850
92-5	Product Removal	2,600	1,850	4,450
92-6	Salt Removal	2,750	1,900	4,650
92-7	Radiochemical Waste Disposal	5,300	3,180	8,480
92-8	Finishing and Packaging	6,500	5,750	12,250
92-9	Plant Utilities	6,550	5,270	11,820
92-10	Heating and Ventilating	10,800	6,500	17,300
92-11	Vessel Off-Gas	4,300	3,000	7,300
92-12	Waste Disposal	6,300	3,900	10,200
	Total	$ 61,800	$ 42,250	$104,050

TABLE NO. 27

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS FOR ION EXCHANGE PROCESS FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 3,400	$ 2,250	$ 5,650
92-2	Chemical Make-up #1	4,000	3,100	7,100
92-3	Chemical Make-up #2	3,200	1,800	5,000
92-4	Separations	2,800	2,400	5,200
92-5	Radiochemical Waste Disposal	5,300	3,180	8,480
92-6	Chemical Recovery	1,700	1,450	3,150
92-7	Finishing and Packaging	6,500	5,750	12,250
92-8	Plant Utilities	6,550	5,270	11,820
92-9	Heating and Ventilating	10,800	6,500	17,300
92-10	Vessel Off-Gas	4,300	3,000	7,300
92-11	Waste Disposal	6,300	3,900	10,200
	Total	$ 54,850	$ 38,600	$ 93,450

TABLE NO. 28

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS
SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 4,400	$ 2,750	$ 7,150
92-2	Chemical Make-up #1	3,500	2,850	6,350
92-3	Chemical Make-up #2	3,300	1,700	5,000
92-4	Separations #1	7,800	6,100	13,900
92-5	Separations #2	6,900	4,750	11,650
92-6	Solvent Purification	4,250	2,600	6,850
92-7	Radiochemical Waste Disposal	5,300	3,180	8,480
92-8	Finishing and Packaging	6,500	5,750	12,250
92-9	Plant Utilities	6,550	5,270	11,820
92-10	Heating and Ventilating	12,500	8,100	20,600
92-11	Vessel Off-Gas	4,300	3,000	7,300
92-12	Waste Disposal	8,200	4,600	12,800
	Total	$ 73,500	$ 50,650	$124,150

TABLE NO. 29

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS FOR GROSS FISSION PRODUCT PROCESS FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 4,400	$ 2,750	$ 7,150
92-2	Chemical Make-up	4,000	3,100	7,100
92-3	Separations	9,300	3,600	12,900
92-4	Radiochemical Waste Disposal	6,500	3,200	9,700
92-5	Finishing and Packaging	6,500	5,750	12,250
92-6	Plant Utilities	6,550	5,270	11,820
92-7	Heating and Ventilating	10,800	6,500	17,300
92-8	Vessel Off-Gas	4,300	3,000	7,300
92-9	Waste Disposal	6,300	3,900	10,200
	Total	$ 58,650	$ 37,070	$ 95,720

TABLE NO. 30

ESTIMATE OF ELECTRIC POWER AND WIRING COSTS FOR OXIDE LEACHING PROCESS FISSION PRODUCT PACKAGING PLANT

AREA	DESCRIPTION	MATERIAL	LABOR	TOTAL
92-1	Tank Farm	$ 4,400	$ 2,750	$ 7,150
92-2	Chemical Make-up	4,000	3,100	7,100
92-3	Separations	9,300	3,600	12,900
92-4	Radiochemical Waste Disposal #1	9,800	4,700	14,500
92-5	Radiochemical Waste Disposal #2	800	400	1,200
92-6	Finishing and Packaging	6,500	5,750	12,250
92-7	Plant Utilities	6,550	5,270	11,820
92-8	Heating and Ventilating	10,800	6,500	17,300
92-9	Vessel Off-Gas	4,300	3,000	7,300
92-10	Waste Disposal	6,300	3,900	10,200
	Total	$ 62,750	$ 38,970	$ 101,720

TABLE NO. 31

SUMMARY TABLE OF ESTIMATES[*] OF ENGINEERING COSTS FOR CO-PRECIPITATION PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 76,000
Costs and Control Engineering		24,508
Project Engineering		54,500
Detailed Engineering		
Vessels	40,000	
Mechanical Equipment	53,000	
Instruments	26,500	
Piping	58,000	
Buildings and Structures	73,000	
Electric Power and Lighting	27,500	
Total Detailed Engineering		278,000
Total Engineering Costs		$ 433,000

[*] Allowance made for engineering overhead.

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime premium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 32

SUMMARY TABLE OF ESTIMATES* OF ENGINEERING COSTS FOR CO-CRYSTALLIZATION PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 91,200
Costs and Control Engineering		27,300
Project Engineering		60,600
Detailed Engineering		
Vessels	66,900	
Mechanical Equipment	58,300	
Instruments	34,100	
Piping	78,800	
Buildings and Structures	73,000	
Electrical Power and Lighting	27,800	
Total Detailed Engineering		338,900
Total Engineering Costs		$ 518,000

*Allowance made for engineering overhead.

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime permium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 33

SUMMARY TABLE OF ESTIMATES* OF ENGINEERING COSTS FOR ION EXCHANGE PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 83,600
Costs and Control Engineering		24,600
Project Engineering		54,800
Detailed Engineering		
Vessels	40,000	
Mechanical Equipment	50,000	
Instruments	28,500	
Piping	64,500	
Buildings and Structures	73,000	
Electrical Power and Lighting	25,000	
Total Detailed Engineering		281,000
Total Engineering Costs		$ 444,000

*Allowance made for engineering overhead

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime premium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 34

SUMMARY TABLE OF ESTIMATES* OF ENGINEERING COSTS FOR SOLVENT EXTRACTION PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 91,200
Costs and Control Engineering		31,500
Project Engineering		70,100
Detailed Engineering		
Vessels	68,600	
Mechanical Equipment	73,200	
Instruments	44,500	
Piping	70,300	
Buildings and Structures	89,000	
Electrical Power and Lighting	33,200	
Total Detailed Engineering		378,800
Total Engineering		$ 571,600

*Allowance made for engineering overhead.

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime premium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 35

SUMMARY TABLE OF ESTIMATES* OF ENGINEERING COSTS FOR GROSS FISSION PRODUCT PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 68,400
Costs and Control Engineering		23,300
Project Engineering		51,900
Detailed Engineering		
Vessels	31,200	
Mechanical Equipment	45,000	
Instruments	16,600	
Piping	54,500	
Buildings and Structures	73,600	
Electrical Power and Lighting	25,600	
Total Detailed Engineering		246,500
Total Engineering Costs		$ 340,100

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*Allowance made for engineering overhead.

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime premium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 36

SUMMARY TABLE OF ESTIMATES[*] OF ENGINEERING COSTS FOR OXIDE LEACHING PROCESS FISSION PRODUCT PACKAGING PLANT

CLASSIFICATION	SUB-TOTAL	TOTAL
Process Engineering	$	$ 76,000
Costs and Control Engineering		24,500
Project Engineering		54,500
Detailed Engineering		
Vessels	42,600	
Mechanical Equipment	52,400	
Instruments	20,600	
Piping	57,000	
Buildings and Structures	73,600	
Electrical Power and Lighting	27,200	
Total Detailed Engineering		273,400
Total Engineering Costs		$ 428,400

[*] Allowance made for engineering overhead.

Estimate is based on qualified engineering concern experienced in remote operations.

No allowance made for overtime premium.

Estimate based on a "frozen" process.

Development costs not included in this table.

TABLE NO. 37

SUMMARY TABLE OF ESTIMATES OF FIELD SUPERVISION AND CONSTRUCTION INDIRECT COSTS FOR CO-PRECIPITATION PROCESS FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	125,000
Construction Supplies	18,000
Rental of Construction Equipment	14,500
Maintenance and Repair of Construction Equipment	9,500
Payroll Taxes	95,000
Local Taxes and Permits	52,000
Bonds and Insurance	2,900
Field Office Supervision and Engineering	7,500
Telephone and Telegraph	5,100
Travel and Living Expenses	35,500
Inspection and Testing	14,400
Field Engineering	26,000
Total	$ 440,700

TABLE NO. 38

SUMMARY TABLE OF ESTIMATES OF FIELD SUPERVISION AND CONSTRUCTION INDIRECT COSTS FOR CO-CRYSTALLIZATION PROCESS FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	139,000
Construction Supplies	20,600
Rental of Construction Equipment	16,100
Maintenance and Repair of Construction Equipment	10,600
Payroll Taxes	103,200
Local Taxes and Permits	57,800
Bonds and Insurance	3,200
Field Office Supervision and Engineering	8,400
Telephone and Telegraph	5,100
Travel and Living Expenses	42,700
Inspection and Testing	19,100
Field Engineering	28,900
Total	$ 489,500

TABLE NO. 39

SUMMARY TABLE OF ESTIMATES OF FIELD SUPERVISION AND CONSTRUCTION INDIRECT COSTS FOR ION-EXCHANGE PROCESS FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	125,600
Construction Supplies	18,600
Rental of Construction Equipment	14,600
Maintenance and Repair of Construction Equipment	9,600
Payroll Taxes	96,700
Local Taxes and Permits	52,200
Bonds and Insurance	2,900
Field Office Supervision and Engineering	7,600
Telephone and Telegraph	5,100
Travel and Living Expenses	36,400
Inspection and Testing	14,700
Field Engineering	26,100
Total	$ 444,900

TABLE NO. 40

SUMMARY TABLE OF ESTIMATES
OF FIELD SUPERVISION AND CONSTRUCTION
INDIRECT COSTS
FOR SOLVENT EXTRACTION PROCESS
FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	160,700
Construction Supplies	23,800
Rental of Construction Equipment	18,600
Maintenance and Repair of Construction Equipment	12,200
Payroll Taxes	119,500
Local Taxes and Permits	66,800
Bonds and Insurance	3,700
Field Office Supervision and Engineering	9,700
Telephone and Telegraph	5,100
Travel and Living Expenses	46,900
Inspection and Testing	20,300
Field Engineering	33,400
Total	$ 555,500

TABLE NO. 41

SUMMARY TABLE OF ESTIMATES OF FIELD SUPERVISION AND CONSTRUCTION INDIRECT COSTS FOR GROSS FISSION PRODUCT PROCESS FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	119,000
Construction Supplies	17,600
Rental of Construction Equipment	13,800
Maintenance and Repair of Construction Equipment	9,100
Payroll Taxes	92,000
Local Taxes and Permits	49,500
Bonds and Insurance	2,800
Field Office Supervision and Engineering	7,100
Telephone and Telegraph	5,100
Travel and Living Expenses	32,000
Inspection and Testing	12,300
Field Engineering	24,700
Total	$ 419,800

TABLE NO. 42

SUMMARY TABLE OF ESTIMATES OF FIELD SUPERVISION AND CONSTRUCTION INDIRECT COSTS FOR OXIDE LEACHING PROCESS FISSION PRODUCT PACKAGING PLANT

CATEGORY	TOTAL
Temporary Buildings	$ 27,000
Temporary Utilities and Fencing	7,800
Tools and Equipment	125,000
Construction Supplies	18,500
Rental of Construction Equipment	14,500
Maintenance and Repair of Construction Equipment	9,500
Payroll Taxes	94,700
Local Taxes and Permits	52,000
Bonds and Insurance	2,900
Field Office Supervision and Engineering	7,500
Telephone and Telegraph	5,100
Travel and Living Expenses	35,100
Inspection and Testing	14,200
Field Engineering	26,000
Total	$ 439,800

VII. COSTS OF PACKAGING FISSION PRODUCTS AND ECONOMIC FORECASTS

Consideration has been given to variable operating costs as well as to partial fixed costs which might be expected in chemical processing plants separating gross fission products from the various required components, and packaging these as well as waste materials in the dried form.

Processing facilities described are intended to separate packaged fission products. It is not possible to treat all of the economic aspects of the chemical processing being conducted without giving consideration to the provisions for obtaining the solution of waste fission products, to the provisions for disposal of the undesired fractions of the fission products, to the operation of power generating **facilities**, and to the general business cost for the management and administration of the business enterprise. The discussions which are presented herein therefore are confined to the specific costs and charges which can be calculated as attributable to the chemical processing facilities.

A. Alternative Requirements Affecting Designs and Estimates

In the present stages of development, there are uncertainties in the chemical processing facilities presented, as well as in arrangements to be made for the procurement of the raw materials and disposal of the waste products. Continued considerations should probably be given to possible alternatives of fission product separation and packaging, so that ultimate achievement of optimum designs and operations at minimum cost may be achieved. Some of the alternatives and variables which can influence unit costs of fuel processing may be summarized as follows:

1. Fixed Charges

Fixed charges have been estimated for presentation in this study in the form of amortization of the capital facilities required. The costs presented for this category are intended to provide for the retirement of the process, considering the life of equipment and structures, replacements of entire components because of corrosion and general obsolescence due to process improvements development, and alternative schemes for fission product packaging. The following fixed charges have not been included: those attributable to the interest on money, inventories estimates, local and federal taxes, insurance, and other charges for money and over-all business management. It has been assumed that assessments of this nature can be calculated on a fractional basis and that such allocations can be added to the costs which are presented.

2. Direct Costs of Operations

Approximate ranges of estimated annual operating costs for materials, purchases, payroll costs, maintenance, plant utilities requirements, and the above-described fixed charges have been made. The costs presented in Figures 16 through 21, and in Tables 43 through 48, for the several alternative processes show that the annual costs for production, including amortization, range from $600,651 per year when the plant is idle and in standby condition to $1,068,160 per year operating at design capacity for the least costly process, that is the "GP" process, and range from $776,812 per year at standby condition to $1,363,848 per year at full production for the most costly plant, that is the "SX" process. The design capacity employed in this feasibility study is about four times the processing rate anticipated for the civilian power reactors scheduled to be in operation by 1960.

B. Estimated Annual Production Costs for Packaging Fission Products

The design capacity for processing fission products through the aqueous plants portrayed in this feasibility study is equivalent to about ten million gamma curies per year of cesium, corresponding to 174,800 grams of fission product cesium chloride, for a total of 4,370,000 grams of fission product nuclides in the solid state. In addition to this design capacity, it appears to be possible to process fission products of a variety of compositions from volatility or pyrometallurgical separation techniques. However, the processing of fission products of different compositions would require some modifications of the chemical methods employed, and might require some chemical development to achieve these modifications.

Some factors which influence the possible production schedules obtainable are concentrations of fission products in aqueous solution, concentrations of other components in aqueous solutions, limits of activity levels of specific concentrates, solvent damage, and storage of fission products in concentrated form.

1. Unit Costs Per Curie of Cesium and Strontium Processed at Various Plant Throughputs

Figure 22 and Table 79 show the costs in dollars per curie of packaged cesium and strontium as the dry chlorides in containers ready for use as radiation sources, at selected values of the production index defined above. At full productive capacity of ten million gamma curies of cesium per year, the unit costs for the processes vary from $0.11 to $0.15 per gamma curie of cesium if all production costs were allocated aginst cesium. Unit costs for the process vary from $0.07 to $0.09 per beta curie of strontium if all production costs were allocated against strongtium. It should be noted that the high fixed cost of the plant due to the capital investment decreases the unit costs per curie of packaged fission products as the amount of throughput through the chemical process increases.

Therefore, costs of processing and packaging fission products and resultant economic forecasts of operating cost are contingent to a large degree upon rates and throughputs of materials processed.

2. Cost Per Equivalent Curie of Gross Fission Products as a Function of Time and Production Rates

In the case of the gross fission product packaging plant, the gamma activity, as well as beta activity, will drop off rapidly with time after the fission products are packaged. Approximations have been made of this rate of decay by means of the Way-Wigner formula (23), and the corresponding costs in dollars per equivalent gamma curie are as follows:

It was assumed that a nuclear reactor would operate on a 42-day loading cycle. Upon unloading, the fuel would be allowed to cool for ninety days. Then the fuel would be separated and the fission products packaged within a negligibly short time interval. The activity upon packaging of the gross fission products containing one-twelfth (corresponding to one month's operation) of 10,000,000 gamma curies of cesium, would be about 90,000,000 to 100,000,000 equivalent gamma curies. One year after packing, these same fission products would have about 15,000,000 to 20,000,000 equivalent gamma curies. If all costs of packaging are charged against this gross fission product package, the corresponding unit costs would be about $.0009 per equivalent gamma curie at packaging and about $0.005 per equivalent gamma curie at one year after packaging. The change in unit costs is due entirely to estimated reduction in activity.

An equivalent gamma curie is considered to be the number of curies of a .75 Mev mono-energetic decaying nuclide which, if it emitted two gamma rays per disintegration, would produce the same total gamma energy output as the fission product source actually under consideration.

3. Estimate of Annual Production Costs When the Plant is Idle

The costs of maintaining a radiochemical plant in an idle or standby condition are relatively high compared with the standard industrial practice. These costs are indicated graphically in Figures 16 through 21 as the intercept on the cost axis of total operating cost at zero production index.

4. Estimate of Schedule for Plant Amortization

Tables 49 through 54 are presented to show the basis for estimating plant amortization. They have been used in this feasibility study with respect to equipment, machinery, structures, and plant start-up costs. Development costs have not been included as an amortization item in this study. Allowances in dollars per year have been made for each process as a function of the calculated capital invested charges for vessels, mechanical equipment, instruments, piping, structures, and electrical facilities. Direct charges only were amortized. If amortization of allocated indirect charges is desired, unit operating costs would be increased above those values given in this report by factors ranging from about 30 percent at 25 percent production index down to about 15 percent at full production. It is to be noted that for each process studied, the allowance made for plant amortization in dollars per year is equivalent to about 10 percent of the total capital cost estimate presented. It is believed possible to design structures in such a manner so that they will not require an evaluation of obsolescence. It is believed that the layout studies which have been achieved to date indicate the possibility of replacing completely the chemical processing facilities by new processes in such a way as not to require serious modifications to the structural components. Furthermore, it is believed that the greatest proportion of instrumentation and control, as well as mechanical equipment and electrical power and wiring, will have considerable utility in any substitute processes which may be achieved as potential replacements to any of the processes evaluated in this scope of work.

5. Materials for Processing

The initial procurement of materials for plant start-up and for inventory of chemicals and supplies is considered to be a capital item under the capital cost estimates. Materials for processing are determined as requirements consumed during the course of separating and packaging fission products. The annual requirements of chemicals have been extracted from calculations for material balances, in accordance with the chemical flowsheets prepared for the separating and packaging operations. Cost for such materials and chemicals consumed in the processing are summarized in Tables 73 through 78 for the various processes considered. At the presently scheduled rate of fission product processing, it is seen that the process chemicals vary from a minimum of $247,497 per year at productive capacity for the "GP" and "OL" processes, to a maximum of $684,078 per year at productive capacity for the "IX" process. The requirements for decontamination chemicals are considered to be constant for all processes as functions chiefly of the frequency of shutdown and of the detailed design of the plant. These costs are estimated at $49,800 per year.

6. Estimate of Payroll Costs

Manning tables have been prepared for each of the alternative processes studied, and assumed salary scales have been employed in arriving at estimates of payroll costs for the several alternative fission product packaging plants studied. These schedules and wages may be considered as arbitrary, and appropriate corrections can be made from the detailed breakdowns presented here. Direct salaries and wages have been calculated for those personnel who will be directly associated with the separations plant.

Direct payroll costs were calculated to be $296,500 per year at operating production capacity for all processes except the "CX" process, and $338,500 per year at operating productive capacity for the "CX" process.

Percentage allocations and additions have been made to the direct charges for social security, workmen's compensation, and insurance in order to reflect total costs of direct payroll chargeable to the plant. No additional charges have been superimposed upon the direct payroll costs for other administrative overhead not included in these schedules. Thus the total payroll estimate, including indirect charges, is calculated to be $326,220 per year at productive capacity for all processes except the "CX" process, and $372,390 per year at productive capacity for the "CX" process. These manning requirements involve respectively fifty-two persons for all processes except the "CX" process, and sixty persons for the "CX" process at productive capacities. The average payroll cost is $6,273 per person per year for all processes except the "CX" process, and $6,207 per person per year for the "CX" process, all processes at design capacity.

The estimated direct payroll costs and summary estimates of payroll are given in Tables No. 61 through 72.

7. Estimates for Annual Cost of Utilities

In this series of studies, it has been assumed that the process cooling water, treated water, steam and electrical power and lighting, as well as plant air, would be available on a unit cost basis from capital facilities owned and operated by others, based upon the arbitrary unit costs which are presented in their respective tables and upon calculations which have been made for utility requirements. Tables No. 55 through 60 summarize the estimates of annual costs of utilities for the several processes. These calculations indicate that $40,997 per year at productive capacity for the "GP" process and $62,669 per year at productive capacity for the "SX" process, indicated the minimum and maximum values, respectively, of utilities costs to be anticipated.

8. Estimates of Maintenance Materials and Supplies

Estimates of maintenance materials and supplies based on capital investment have been made for each of the operating areas of the processing plant, and totals for these items appear in Tables No. 43 through 48, portraying estimates of total annual operating costs. Allowances for maintenance materials and supplies have been set equal to five percent of the yearly allocated process capital requirements, and to about two and one-half percent per year of materials and supplies of a structural nature. Premised upon these assumptions, the calculations indicate that the maintenance materials and supplies cost per year is $166,251 per year for the "GP" process and $225,624 per year for the "SX" process, which represent minimum and maximum values, respectively, both plants operating at productive capacity. Use factors have been applied to the base numbers, and indicate differentials between 25 percent of capacity operation and design capacity operation in those areas of plant operation where corrosion, decontamination, or replacement of equipment influenced the cost.

TABLE NO. 43

ESTIMATE OF ANNUAL OPERATING COSTS
CO-PRECIPITATION PROCESS

		at 25%	at 100%
1.	Amortization	$ 279,193	$ 311,497
2.	Utilities	28,216	47,027
3.	Maintenance Materials and Supplies	134,440	174,772
4.	Payroll Costs	232,560	326,220
5.	Materials Costs	85,403	290,315
		$ 759,812	$1,149,831

TABLE NO. 44

ESTIMATE OF ANNUAL OPERATING COSTS
CO-CRYSTALLIZATION PROCESS

		at 25%	at 100%
1.	Amortization	$ 339,380	$ 372,299
2.	Utilities	31,237	52,062
3.	Maintenance Materials and Supplies	149,419	194,244
4.	Payroll Costs	278,820	372,390
5.	Materials Costs	86,590	295,065
		$ 885,446	$1,286,060

TABLE NO. 45

ESTIMATE OF ANNUAL OPERATING COSTS
ION EXCHANGE PROCESS

		at 25%	at 100%
1.	Plant Amortization	$ 292,384	$ 349,265
2.	Utilities	28,886	48,144
3.	Maintenance Materials and Supplies	135,049	175,564
4.	Payroll Costs	232,560	326,220
5.	Materials Costs	184,619	684,078
		$ 873,498	$1,583,271

TABLE NO. 46

ESTIMATE OF ANNUAL OPERATING COSTS
SOLVENT-EXTRACTION PROCESS

		at 25%	at 100%
1,	Plant Amortization	$ 364,282	$ 399,493
2.	Utilities	37,600	62,668
3.	Maintenance Materials and Supplies	173,536	225,624
4.	Payroll Costs	246,200	319,550
5.	Materials Costs	101,953	356,513
		$ 923,571	$1,363,848

TABLE NO. 47

ESTIMATE OF ANNUAL OPERATING COSTS
GROSS FISSION PRODUCT PROCESS

		at 25%	at 100%
1.	Plant Amortization	$ 257,786	$ 287,195
2.	Utilities	24,598	40,997
3.	Maintenance Materials and Supplies	127,885	166,251
4.	Payroll Costs	232,560	326,220
5.	Materials Costs	74,699	247,497
		$ 717,528	$1,068,160

TABLE NO. 48

ESTIMATE OF ANNUAL OPERATING COSTS
OXIDE LEACHING PROCESS

		at 25%	at 100%
1.	Plant Amortization	$ 278,643	$ 308,408
2.	Utilities	32,296	53,827
3.	Maintenance Materials and Supplies	134,506	174,857
4.	Payroll Costs	232,560	326,220
5.	Materials Costs	74,699	247,497
		$ 752,704	$1,110,809

TABLE NO. 49

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION CO-PRECIPITATION PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 193,315	$ 38,663
Mechanical Equipment	10	342,120	34,212
Instruments	10	63,565	6,357
Piping	5	324,125	64,825
Structures	20	1,662,855	83,143
Electrical	10	102,820	10,282
Initial Plant Start-up	5	370,075	74,015
Total		$ 3,058,875	$ 311,497

Average Percent 10.18%

TABLE NO. 50

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION CO-CRYSTALLIZATION PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 323,325	$ 64,665
Mechanical Equipment	10	376,070	37,607
Instruments	10	81,875	8,187
Piping	5	440,195	88,039
Structures	20	1,662,855	83,143
Electrical	10	104,050	10,405
Initial Plant Start-up	5	401,266	80,253
Total		$ 3,389,636	$ 372,299

Average Percent 10.98%

TABLE NO. 51

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION ION EXCHANGE PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 193,315	$ 38,663
Mechanical Equipment	10	322,355	32,236
Instruments	10	68,465	6,846
Piping	5	360,540	72,108
Structures	20	1,662,855	83,143
Electrical	10	93,450	9,345
Initial Plant Start-up	5	534,620	106,924
Total		$3,235,600	$ 349,265

Average Percent 10.79%

TABLE NO. 52

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION SOLVENT EXTRACTION PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 331,580	$ 66,316
Mechanical Equipment	10	472,545	47,254
Instruments	10	106,705	10,670
Piping	5	392,665	78,535
Structures	20	2,043,490	102,174
Electrical	10	124,150	12,415
Initial Plant Start-up	5	410,945	82,129
Total		$ 3,882,080	$ 399,493

Average Percent 10.29%

TABLE NO. 53

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION GROSS FISSION PRODUCT PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 150,785	$ 30,157
Mechanical Equipment	10	290,290	29,029
Instruments	10	39,725	3,973
Piping	5	304,575	60,915
Structures	20	1,676,605	83,830
Electrical	10	95,720	9,572
Initial Plant Start-up	5	348,596	69,719
Total		$ 2,906,296	$ 287,195

Average Percent 9.88%

TABLE NO. 54

ESTIMATE OF SCHEDULE FOR PLANT AMORTIZATION OXIDE LEACHING PROCESS

Classification	Life in Years	Capital Cost Estimate	Allowance Per Year
Vessels	5	$ 205,780	$ 41,156
Mechanical Equipment	10	338,120	33,812
Instruments	10	49,315	4,932
Piping	5	318,575	63,715
Structures	20	1,676,605	83,830
Electrical	10	101,720	10,172
Initial Plant Start-up	5	353,956	70,791
Total		$ 3,044,071	$ 308,408

Average Percent 10.13%

TABLE NO. 55

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES CO-PRECIPITATION PROCESS FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.		$ 2,352
Treated Water at 12 cents/M. gal		435
Steam at 60 cents/M. lb		18,909
Power and Lighting at 1 cent/kwh		23,681
Plant Air at $1/M.C.F.		1,650
	$ 28,216	$ 47,027

TABLE NO. 56

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES
CO-CRYSTALLIZATION PROCESS
FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.		$ 2,358
Treated Water at 12 cents/M. gal		435
Steam at 60 cents/M. lb		20,335
Power and Lighting at 1 cent/kwh		26,294
Plant air at $1/M.C.F.		2,640
TOTAL ESTIMATE FOR UTILITIES	$ 31,237	$ 52,062

TABLE NO. 57

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES
ION EXCHANGE PROCESS
FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.		$ 2,270
Treated Water at 12 cents/M. gal		435
Steam at 60 cents/M. lb		19,527
Power and Lighting at 1 cent/kwh		24,592
Plant Air at $1/M.C.F.		1,320
TOTAL ESTIMATE FOR UTILITIES	$ 28,886	$ 48,144

TABLE NO. 58

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES
SOLVENT EXTRACTION PROCESS
FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.		$ 1,657
Treated Water at 12 cents/M. gal		285
Steam at 60 cents/M. lb		24,132
Power and Lighting at 1 cent/kwh		33,955
Plant Air at $1/M.C.F.		2,640
TOTAL ESTIMATE FOR UTILITIES	$ 37,601	$ 62,669

TABLE NO. 59

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES
GROSS FISSION PRODUCTS PROCESS
FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.	$	$ 2,345
Treated Water at 12 cents/M. gal		435
Steam at 60 cents/M. lb		20,806
Power and Lighting at 1 cent/kwh		15,761
Plant Air at $1/M.C.F.		1,650
TOTAL ESTIMATE FOR UTILITIES	$ 24,598	$ 40,997

TABLE NO. 60

SUMMARY OF ESTIMATED ANNUAL COSTS OF UTILITIES
OXIDE LEACHING PROCESS
FOR OPERATION AT

Type of Service	25% of Design Capacity Dollars/Year	100% of Design Capacity Dollars/Year
Process Cooling Water at 12 cents/M.C.F.		$ 2,345
Treated Water at 12 cents/M. Gal		435
Steam at 60 cents/M. lb		24,607
Power and Lighting at 1 cent/kwh		24,790
Plant Air at $1/M.C.F.		1,650
TOTAL ESTIMATE FOR UTILITIES	$ 32,296	$ 53,827

TABLE NO. 61

ESTIMATE OF PAYROLL COSTS
CO-PRECIPITATION PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$ 15,000	1	$ 15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chemist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operators	5	30,000	9	54,000
4,500	Helpers	5	22,500	9	40,500
	Total Operations		89,000		131,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	34	$211,500	52	$296,500

TABLE NO. 62

ESTIMATE OF PAYROLL COSTS
CO-CRYSTALLIZATION PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$15,000	1	$15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chemist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operators	9	54,000	13	78,000
4,500	Helpers	9	40,500	13	58,500
	Total Operations		131,000		173,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	42	$253,500	60	$338,500

TABLE NO. 63

ESTIMATE OF PAYROLL COSTS
ION EXCHANGE PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$15,000	1	$15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chemist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operations	5	30,000	9	54,000
4,500	Helpers	5	22,500	9	40,500
	Total Operations		89,000		131,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	34	$211,500	52	$296,500

TABLE NO. 64

ESTIMATE OF PAYROLL COSTS SOLVENT EXTRACTION PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$15,000	1	$15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chamist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operators	5	30,000	9	54,000
4,500	Helpers	5	22,500	9	40,500
	Total Operators		89,000		131,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	34	$211,500	52	$296,500

TABLE NO. 65

ESTIMATE OF PAYROLL COSTS
GROSS FISSION PRODUCT PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$15,000	1	$15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chemist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operators	5	30,000	9	54,000
4,500	Helpers	5	22,500	9	40,500
	Total Operations		89,000		131,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	34	$211,500	52	$296,500

TABLE NO. 66

ESTIMATE OF PAYROLL COSTS
OXIDE LEACHING PROCESS

SALARY OR WAGE	JOB CLASSIFICATION	NO.	AT 25% DESIGN CAPACITY	NO.	AT 100% DESIGN CAPACITY
	Plant Office				
$15,000	Plant Manager	1	$15,000	1	$15,000
12,000	Assistant Manager	1	12,000	1	12,000
4,000	Secretary	1	4,000	1	4,000
3,500	File Clerk	-	-	1	3,500
	Total Plant Office		31,000		34,500
	Technical Staff				
8,500	Plant Engineer	1	8,500	1	8,500
5,500	Health Physicist	1	5,500	1	5,500
5,500	Statistician	-	-	1	5,500
3,500	Stenographer	-	-	1	3,500
4,500	Shipping Clerk	1	4,500	1	4,500
	Total Technical Staff		18,500		27,500
	Laboratories				
8,500	Chief Chemist	1	8,500	1	8,500
6,000	Assistant Chief Chemist	-	-	1	6,000
7,000	Radiation Source Physicist	1	7,000	1	7,000
5,500	Shift Chemists	4	22,000	4	22,000
4,000	Clerical	-	-	1	4,000
	Total Laboratories		37,500		47,500
	Operation				
8,500	Superintendent	1	8,500	1	8,500
7,000	Shift Supervisors	4	28,000	4	28,000
6,000	Operators	5	30,000	9	54,000
4,500	Helpers	5	22,500	9	40,500
	Total Operations		89,000		131,000
	Maintenance				
6,500	Instrument Supervisor	1	6,500	1	6,500
6,500	Mechanical Supervisor	1	6,500	1	6,500
4,500	Instrument Technicians	2	9,000	2	9,000
4,500	Mechanics	2	9,000	2	9,000
4,000	Mechanic Helpers	-	-	2	8,000
4,500	Pipe Fitters	1	4,500	2	9,000
4,000	Pipe Fitter Helpers	-	-	2	8,000
	Total Maintenance		35,500		56,000
	TOTALS FOR PROCESSING PLANT	34	$211,500	52	$296,500

TABLE NO. 67

SUMMARY OF ESTIMATED PERSONNEL COSTS-CO-PRECIPITATION PROCESS

PROCESSING PLANT	OPERATION AT 25% NORMAL CAPACITY		OPERATION AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	15	89,000	23	131,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		211,500		296,500
Allowance for Social Security		5,250		7,430
Workmen's Compensation		5,250		7,430
Insurance		4,230		5,940
Other Indirect Costs		6,330		8,920
Total Payroll Estimate	34	232,560	52	326,220
Average Per Person		6,840		6,273
Difference Between Operation at 25% and 100% Capacity			18	93,660

TABLE NO. 68

SUMMARY OF ESTIMATED PERSONNEL COSTS CO-CRYSTALLIZATION PROCESS

PROCESSING PLANT	OPERATION AT 25% NORMAL CAPACITY		OPERATION AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	23	131,000	31	173,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		253,500		338,500
Allowance for Social Security		6,330		8,460
Workmen's Compensation		6,330		8,460
Insurance		5,060		6,770
Other Indirect Costs		7,600		10,200
Total Payroll Estimate	42	278,820	60	372,390
Average Per Person		6,639		6,207
Difference Between Operation at 25% and 100% Capacity			18	93,570

TABLE NO. 69

SUMMARY OF ESTIMATED PERSONNEL COSTS-ION EXCHANGE PROCESS

PROCESSING PLANT	OPERATION AT 25% NORMAL CAPACITY		OPERATION AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	15	89,000	23	131,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		211,500		296,500
Allowance for Social Security		5,250		7,430
Workmen's Compensation		5,250		7,430
Insurance		4,230		5,940
Other Indirect Costs		6,330		8,920
Total Payroll Estimate	34	232,560	52	326,220
Average Per Person		6,840		6,273
Difference Between Operation at 25% and 100% Capacity			18	93,660

TABLE NO. 70

SUMMARY OF ESTIMATED PERSONNEL COSTS-SOLVENT EXTRACTION PROCESS

PROCESSING PLANT	OPERATION AT 25% NORMAL CAPACITY		OPERATION AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	15	89,000	23	131,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		211,500		296,500
Allowance for Social Security		5,250		7,430
Workmen's Compensation		5,250		7,430
Insurance		4,230		5,940
Other Indirect Costs		6,330		8,920
Total Payroll Estimate	34	232,560	52	326,220
Average Per Person		6,840		6,273
Difference Between Operation at 25% and 100% Capacity			18	93,660

TABLE NO. 71

SUMMARY OF ESTIMATED PERSONNEL COSTS-GROSS FISSION PRODUCT PROCESS

PROCESSING PLANT	OPERATION AT 25% NORMAL CAPACITY		OPERATION AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	15	89,000	23	131,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		211,500		296,500
Allowance for Social Security		5,250		7,430
Workmen's Compensation		5,250		7,430
Insurance		4,230		5,940
Other Indirect Costs		6,330		8,920
Total Payroll Estimate	34	232,560	52	326,220
Average Per Person		6,840		6,273
Difference Between Operation at 25% and 100% Capacity			18	93,660

TABLE NO. 72

SUMMARY OF ESTIMATED PERSONNEL COSTS-OXIDE LEACHING PROCESS

PROCESSING PLANT	OPERATIONS AT 25% NORMAL CAPACITY		OPERATIONS AT DESIGN CAPACITY OF PLANT	
Department	No. of Persons	$/Year	No. of Persons	$/Year
Plant Office	3	31,000	4	34,500
Technical Staff	3	18,500	5	27,500
Laboratories	6	37,500	8	47,500
Operations	15	89,000	23	131,000
Maintenance Personnel	7	35,500	12	56,000
Total Direct		211,500		296,500
Allowance for Social Security		5,250		7,430
Workmen's Compensation		5,250		7,430
Insurance		4,230		5,940
Other Indirect Costs		6,330		8,920
Total Payroll Estimate	34	232,560	52	326,220
Average Per Person		6,840		6,273
Difference Between Operation at 25% and 100% Capacity			18	93,660

TABLE NO. 73

CO-PRECIPITATION PROCESS
MATERIALS FOR PROCESSING

	ANNUAL CONSUMPTION			
MATERIAL	AT 25% DESIGN CAPACITY		AT 100% DESIGN CAPACITY	
	lb.	Dollars	lb.	Dollars
Process Use				
Nitric Acid	625	$ 481	2,500	$ 1,925
Sodium Hydroxide	193,750	10,462	775,000	41,850
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	650	1,950	2,600	7,800
Sodium Chloride	900	45	360	180
Hydrochloric Acid	625	450	2,500	1,800
Welding Rod	930	2,325	3,720	9,300
Sodium Ferrocyanide	1,275	306	5,100	1,224
Nickel Sulfate	2,600	962	10,400	3,848
Subtotals for Process Use		60,503		240,515
Decontamination Use				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,000
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$ 85,403		$ 290,315

TABLE NO. 74

CO-CRYSTALLIZATION PROCESS
MATERIALS FOR PROCESSING

	ANNUAL CONSUMPTION			
MATERIAL	AT 25% DESIGN CAPACITY		AT 100% DESIGN CAPACITY	
	lb.	Dollars	lb.	Dollars
Process Use				
Nitric Acid	900	$ 693	3,600	$ 2,772
Sulfuric Acid	5,800	145	23,200	580
Sodium Hydroxide	193,750	10,462.50	775,000	41,850
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	650	1,950	2,600	7,800
Sodium Chloride	150	7.50	600	30
Ammonia	2,025	911	8,100	3,645
Hydrochloric Acid	900	648	3,600	2,592
Sodium Carbonate	4,500	90	18,000	360
Aluminum Sulfate	6,250	937	25,000	3,748
Welding Rod	930	2,325	3,720	9,300
Subtotals for Process Use		61,690		245,265
Decontamination Use				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,800
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$ 86,590		$ 295,065

TABLE NO. 75

CO-CRYSTALLIZATION PROCESS
MATERIALS FOR PROCESSING

MATERIAL	ANNUAL CONSUMPTION AT 25% DESIGN CAPACITY lb.	ANNUAL CONSUMPTION AT 25% DESIGN CAPACITY Dollars	ANNUAL CONSUMPTION AT 100% DESIGN CAPACITY lb.	ANNUAL CONSUMPTION AT 100% DESIGN CAPACITY Dollars
Process Use				
Nitric Acid	40,750	$ 6,112	163,000	$ 24,450
Sodium Hydroxide	1,912,500	103,275	7,650,000*	413,000
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	1,000	3,000	3,000	9,000
Sodium Chloride	900	45	3,600	180
Ammonia	200	9	800	36
Hydrochloric Acid	625	450	2,500	1,800
Sodium Carbonate	39,750	795	158,000	3,180
Welding Rod	930	2,325	3,720	9,300
Ammonium Carbonate	3,000	48	12,000	192
Carbon Dioxide	600	138	2,400	552
Subtotals for Process Use		159,719		634,278
Decontamination Use				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,800
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$184,619		$ 684,078

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*Could store in hot cell for two months before exhausting capacity.

TABLE NO. 76

SOLVENT EXTRACTION PROCESS
MATERIALS FOR PROCESSING

	ANNUAL CONSUMPTION			
MATERIAL	AT 25% DESIGN CAPACITY		AT 100% DESIGN CAPACITY	
	lb.	Dollars	lb.	Dollars
Process Use				
Nitric Acid, Tech.	15,500	$ 2,325	62,000	$ 9,300
Nitric Acid, ACS	625	481.25	2,500	1,925
Methylisobutylketone	79,125	12,660	316,500	50,640
Thenoyltrifluoroacetone	82	2.870	328	11,480
Sodium Hydroxide	193,750	10,462.50	775,000	41,850
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	650	1,950	2,600	7,800
Sodium Chloride	150	7.50	600	30
Hydrochloric Acid ACS	625	450	2,500	1,800
Welding Rod	930	2,325	3,720	9,300
Subtotals for Process Use		77,053.25		306,713
Decontamination Use.				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,800
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$ 101,953		$ 356,513

TABLE NO. 77

GROSS FISSION PRODUCT PROCESS
MATERIALS FOR PROCESSING

	ANNUAL CONSUMPTION			
MATERIAL	AT 25% DESIGN CAPACITY		AT 100% DESIGN CAPACITY	
	lb.	Dollars	lb.	Dollars
Process Use				
Nitric Acid	625	$ 481	2,500	$ 1,925
Sodium Hydroxide	19,000	1,026	76,000	4,104
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	650	1,950	2,600	7,800
Sodium Chloride	900	45	3,600	180
Hydrochloric Acid	625	450	2,500	1,800
Welding Rod	930	2,325	3,720	9,300
Subtotals for Process Use		49,799		197,697
Decontamination Use.				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,800
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$ 74,699		$ 247,497

TABLE NO. 78

OXIDE LEACHING PROCESS
MATERIALS FOR PROCESSING

MATERIAL	ANNUAL CONSUMPTION			
	AT 25% DESIGN CAPACITY		AT 100% DESIGN CAPACITY	
	lb.	Dollars	lb.	Dollars
Process Use				
Nitric Acid, ACS	625	$ 481	2,500	$ 1,925
Sodium Hydroxide	19,000	1,026	76,000	4,104
Argon	5,800 SCF	522	23,200 SCF	2,088
Sand	500	500	500	500
Product Containers	13,000	26,000	52,000	104,000
Waste Containers	16,500	16,500	66,000	66,000
Resin	650	1,950	2,600	7,800
Sodium Chloride	900	45	3,600	180
Hydrochloric Acid, ACS	625	450	2,500	1,800
Welding Rod	930	2,325	3,720	9,300
Subtotals for Process Use		49,799		197,697
Decontamination Use				
Nitric Acid	50,000	7,500	100,000	15,000
Citric Acid	45,000	14,400	90,000	28,800
Detergents	10,000	3,000	20,000	6,000
Subtotals for Decontamination Use		24,900		49,800
Totals		$ 74,699		$ 247,497

TABLE NO. 79

SUMMARY TABLE OF ESTIMATED UNIT OPERATING COSTS FOR ALL PROCESSES

UNIT COSTS - CESIUM-137*

	PRODUCTION INDEX			
PROCESS	25 $/gamma curie	50 $/gamma curie	75 $/gamma curie	100 $/gamma curie
Co-Precipitation Process	0.30	0.18	0.14	0.12
Co-Crystallization Process	0.35	0.20	0.15	0.13
Ion Exchange Process	0.35	0.22	0.18	0.15
Solvent Extraction Process	0.37	0.21	0.16	0.14
Gross Fission Product Process	0.29	0.17	0.13	0.11
Oxide Leaching Process	0.30	0.17	0.13	0.11

UNIT COSTS - STRONTIUM-90**

Co-Precipitation Process	0.20	0.12	0.09	0.08
Co-Crystallization Process	0.24	0.14	0.10	0.09
Solvent Extraction Process	0.25	0.14	0.11	0.09
Oxide Leaching	0.20	0.12	0.09	0.07

*Production Index 100 equals 10,000,000 gamma curies per year of cesium.

**Production Index 100 equals 15,200,000 beta curies Strontium-90 per year.

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

CO - PRECIPITATION PROCESS

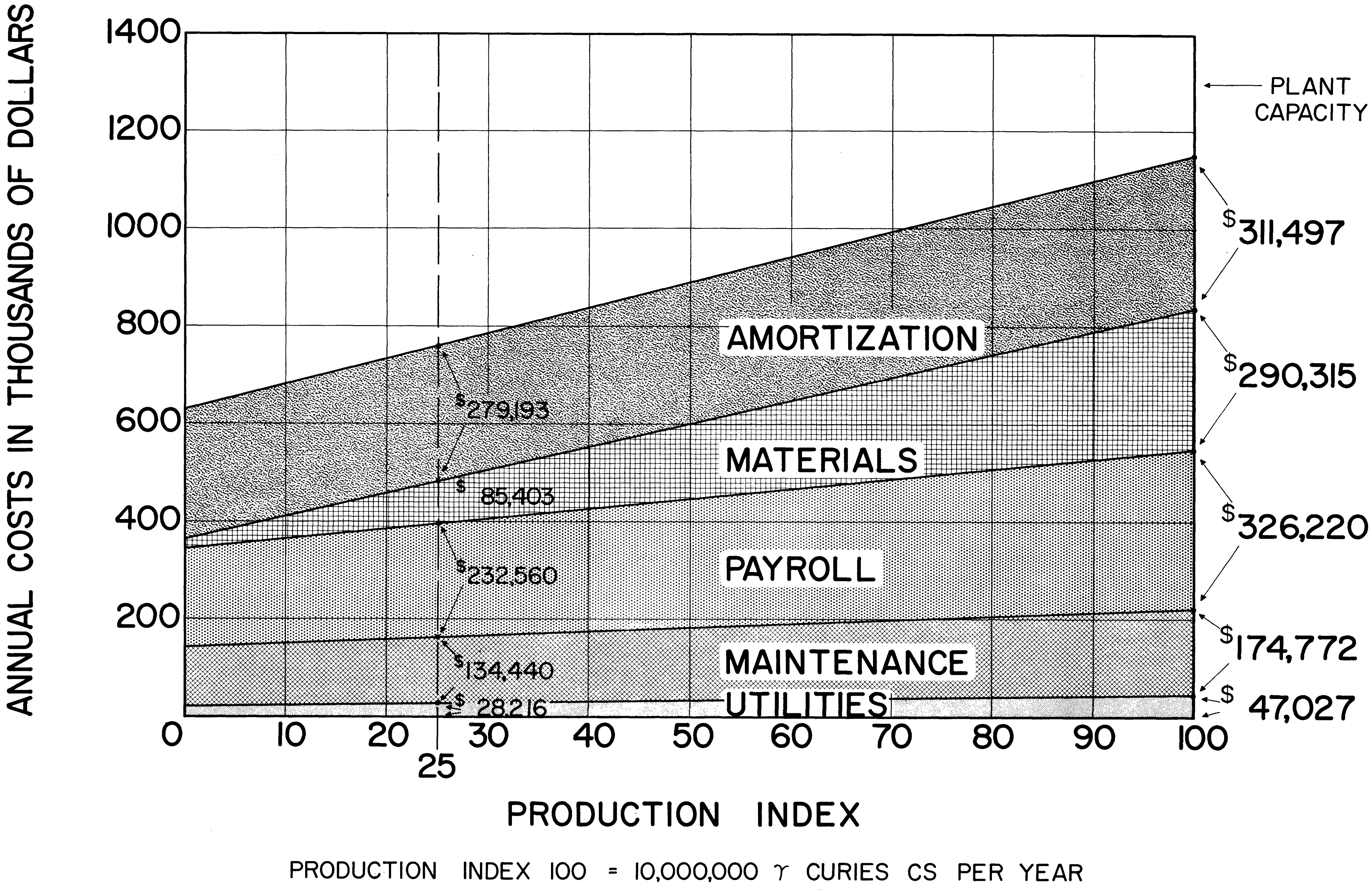
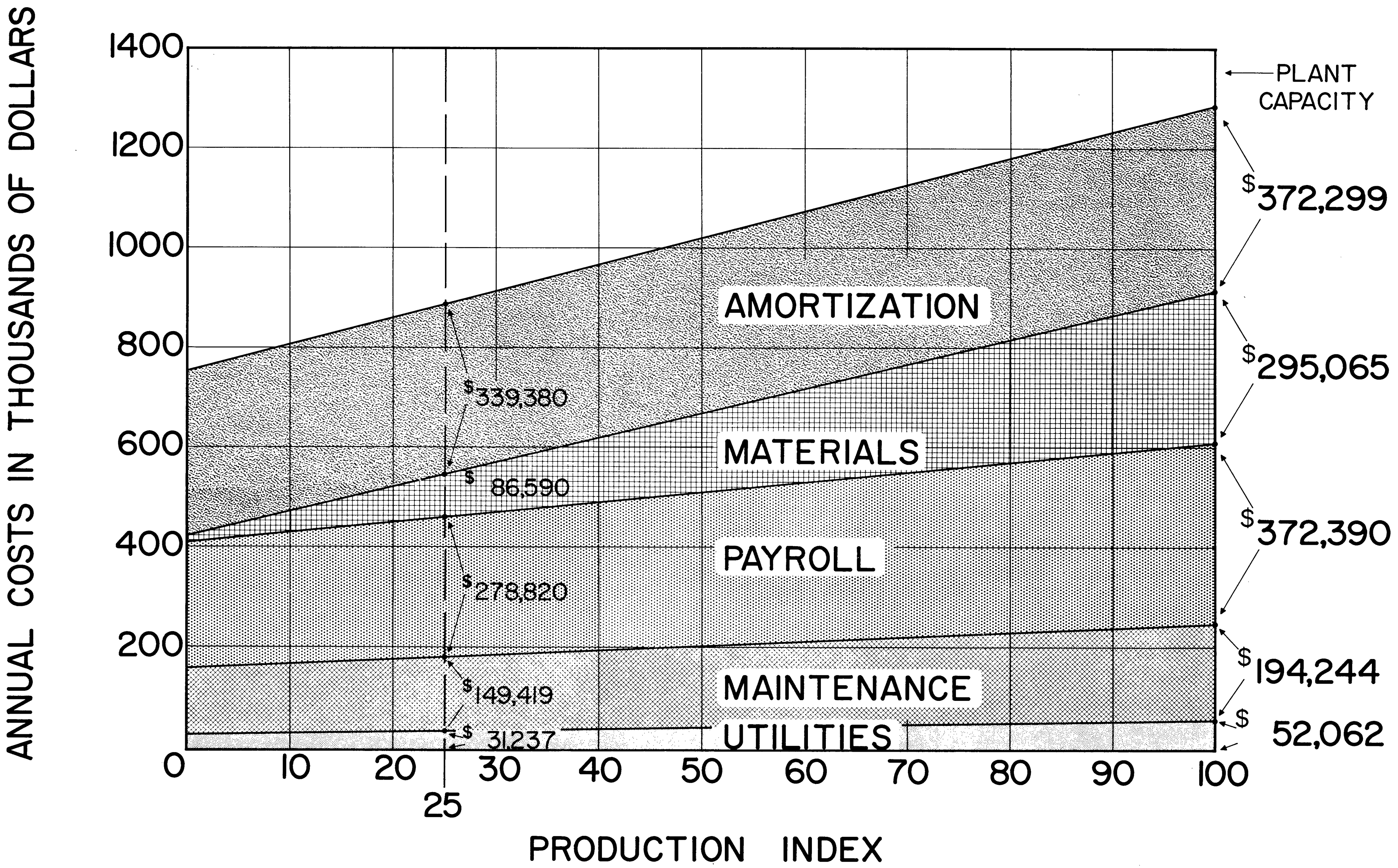


Figure 16.

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

CO - CRYSTALLIZATION PROCESS



PRODUCTION INDEX 100 = 10,000,000 γ CURIES CS PER YEAR

Figure 17

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

ION EXCHANGE PROCESS

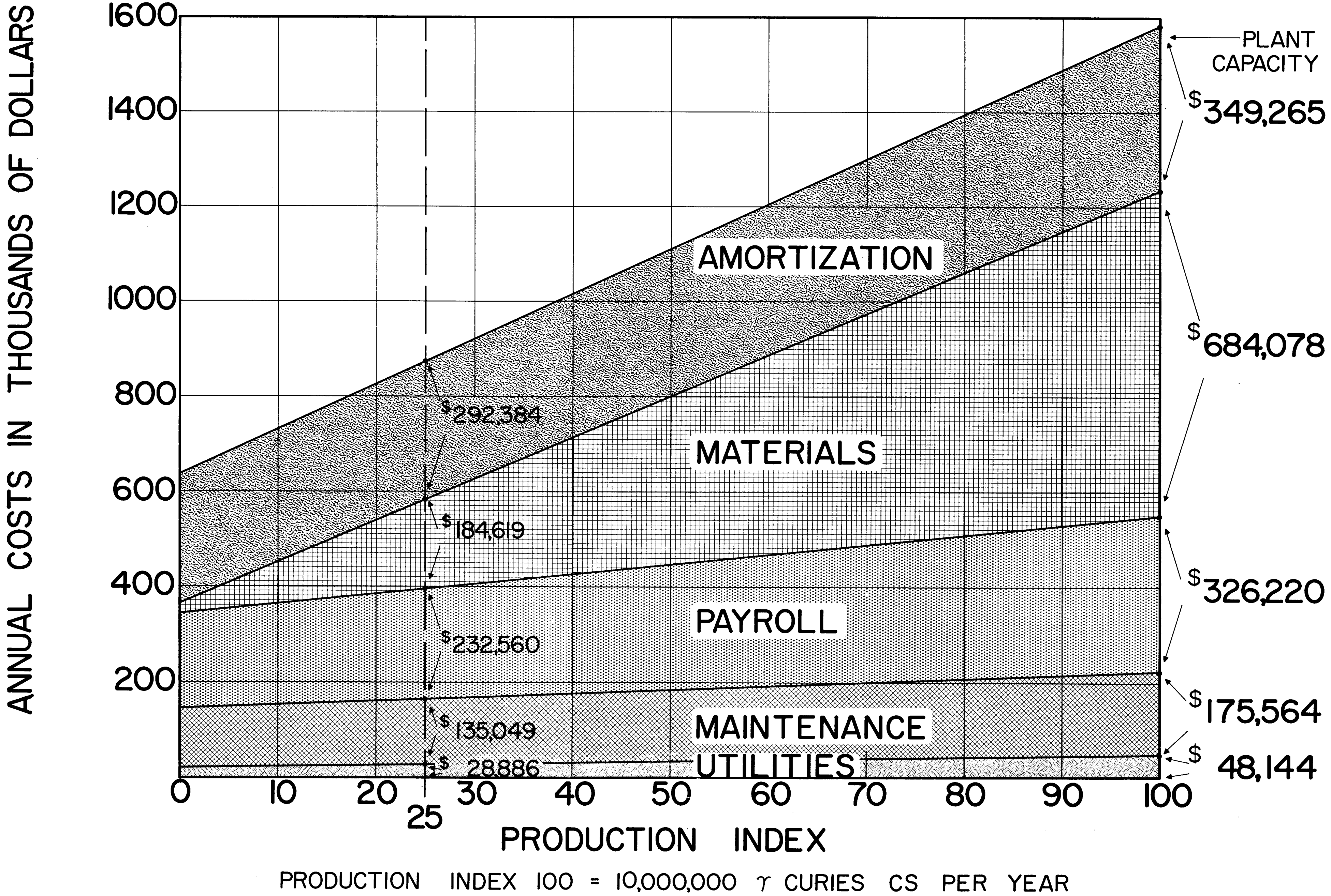
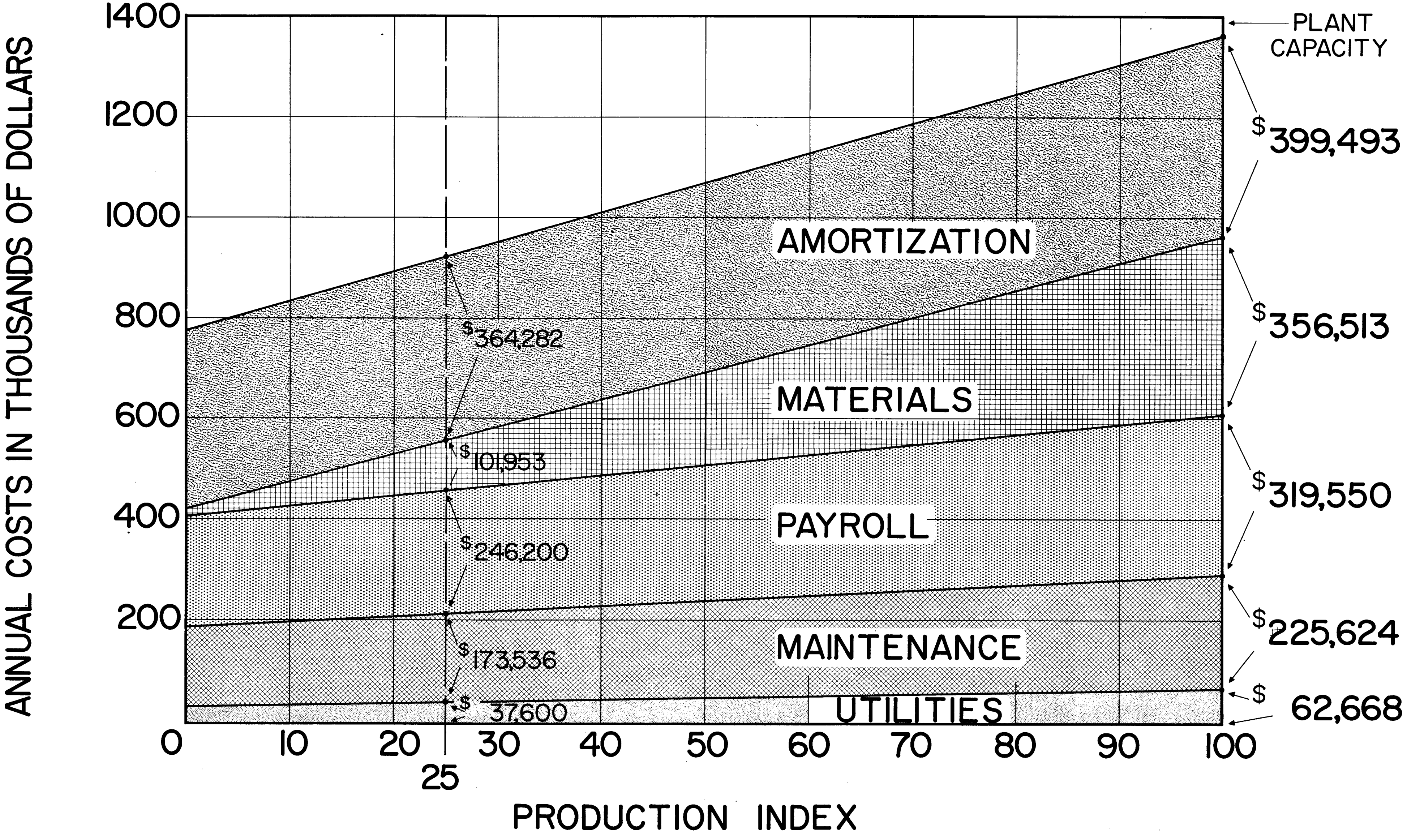


Figure 18

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

SOLVENT EXTRACTION PROCESS

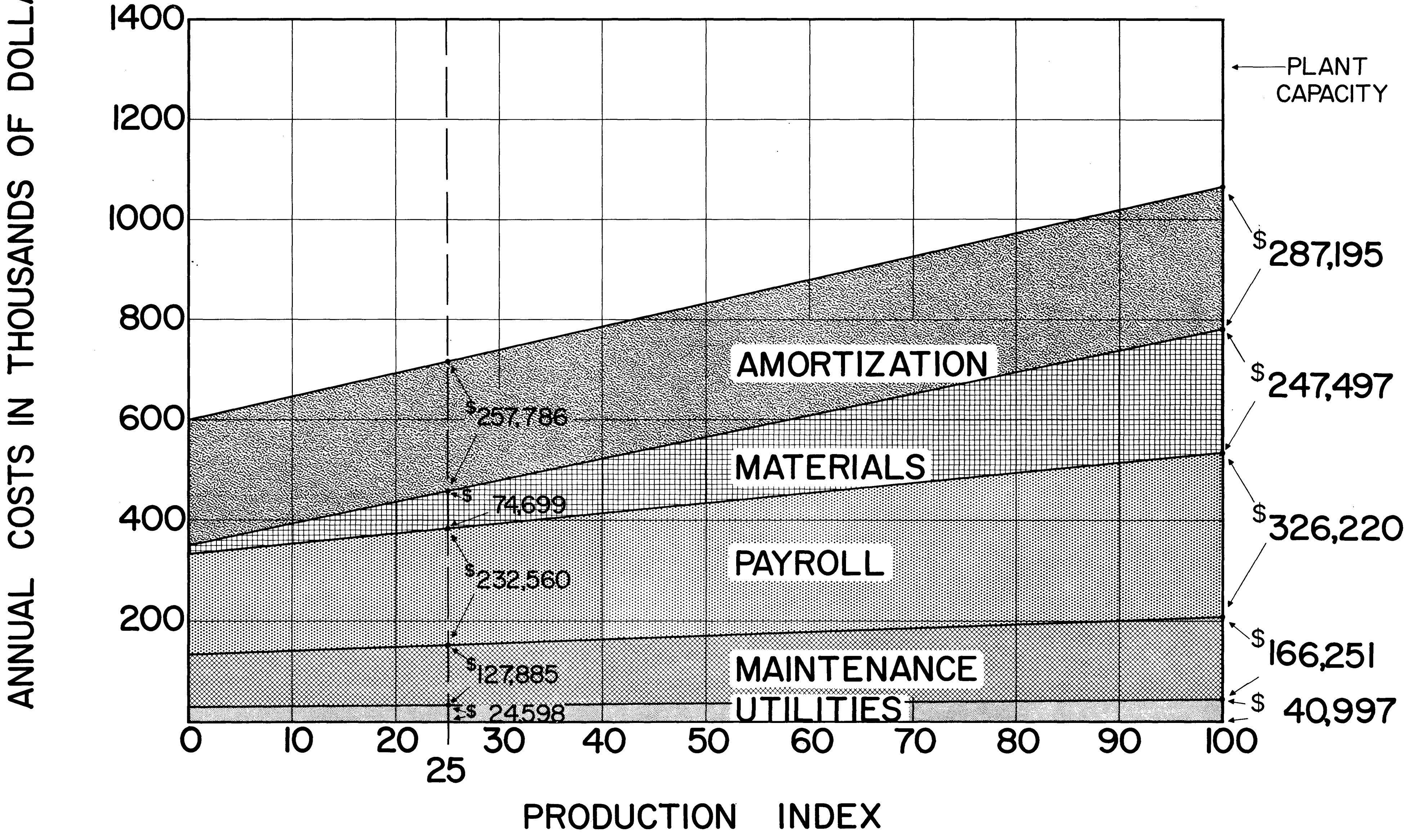


PRODUCTION INDEX 100 = 10,000,000 γ CURIES CS PER YEAR

Figure 19

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

GROSS FISSION PRODUCTS PROCESS



PRODUCTION INDEX 100 = 10,000,000 γ CURIES CS PER YEAR

Figure 20

ANNUAL COSTS OF PACKAGING FISSION PRODUCTS

OXIDE LEACHING

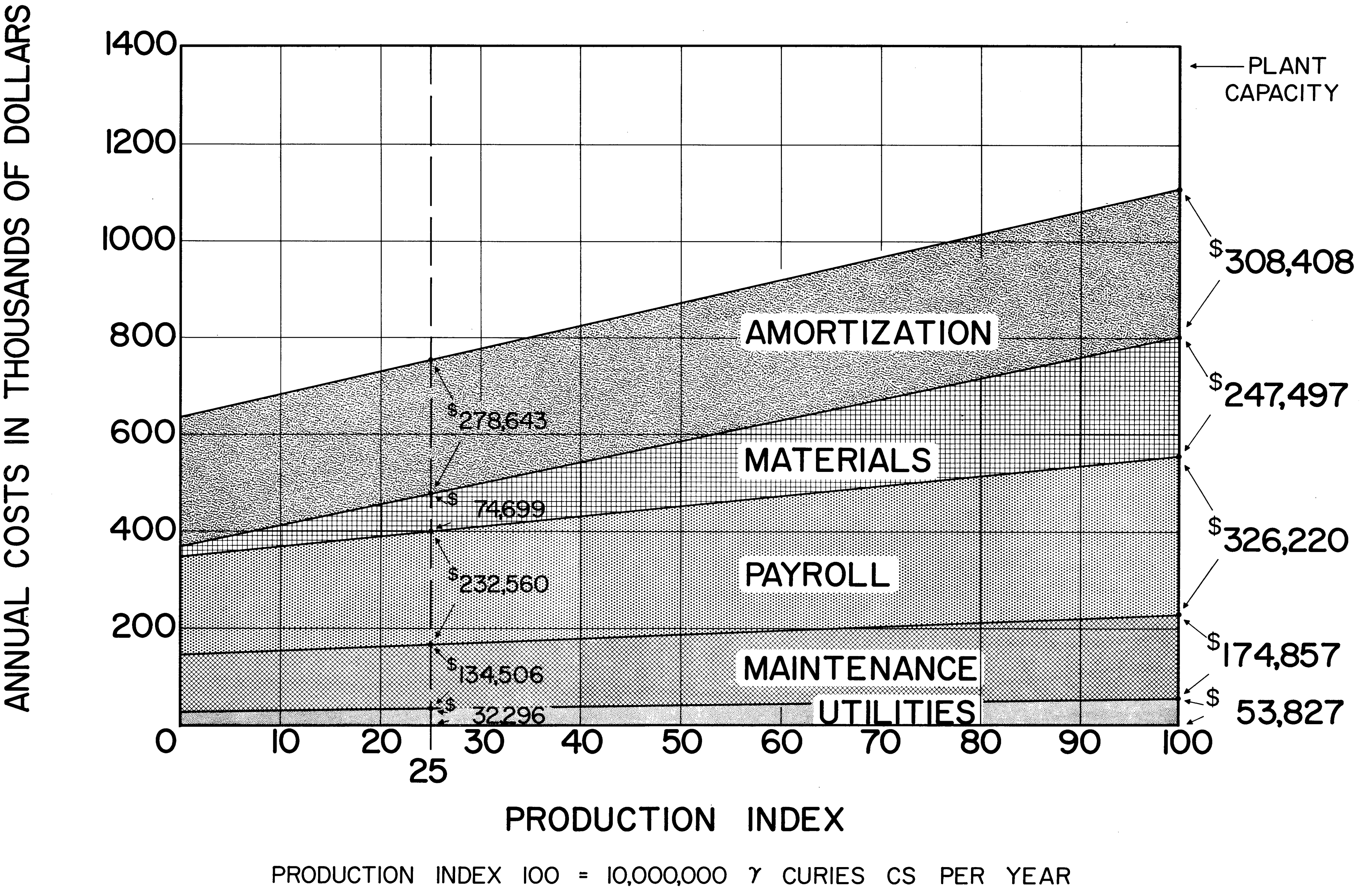
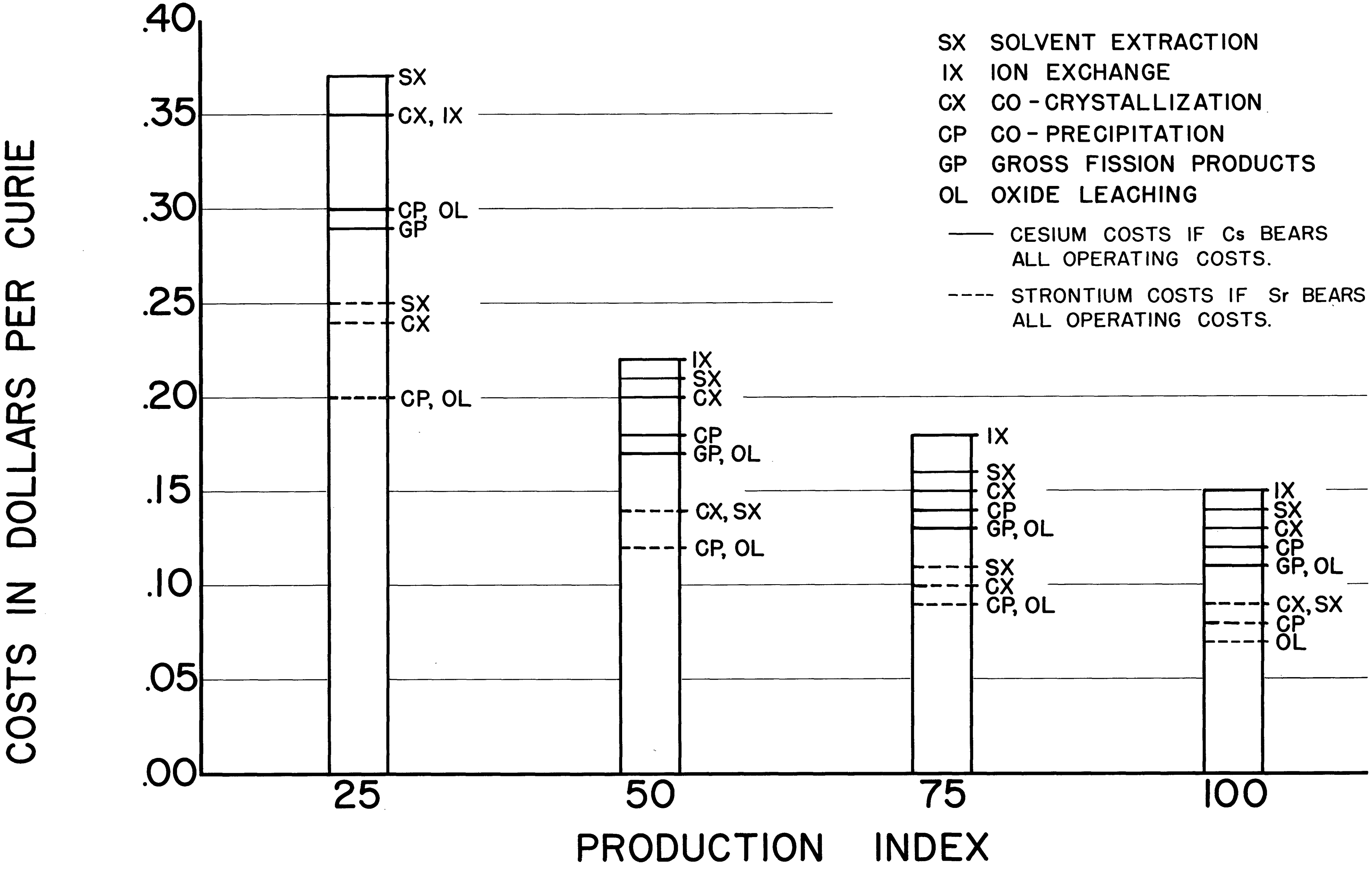


Figure 21

OPERATING COSTS PER CURIE OF CESIUM OR STRONTIUM



PRODUCTION INDEX 100 = 10,000,000 γ CURIES CS PER YEAR

PRODUCTION INDEX 100 = 1.52×10^7 β CURIES Sr^{90} PER YEAR

Figure 22

VIII. CONSIDERATION OF DEVELOPMENT PROGRAMS

A. General

It has been assumed in preparing the accompanying estimates of cost of the construction and operation of the several alternative fission product plants that a parallel program of chemical and engineering development and mechanical testing would be carried on in order to provide the detailed data required for production designs and economical operation. For the purpose of the estimates presented in this report, existing chemical processes and engineering methods of design have been employed where applicable. However, the processes to be conducted in the plant studied are not duplicated, apparently, in any existing facilities. The approach to this problem has been to use existing chemical processes where possible, and to adapt equipment currently being used to the extent required for the remote operation on a continuous basis. A part of the estimated costs of this chemical processing plant which is not included in the estimates heretofore presented is an expenditure for a development program required to achieve the objectives set forth. Development cannot be placed on a rigid time schedule, and no detailed development costs have been estimated as a part of this report.

It is expected that some developmental work can be carried on in national laboratories as required. The amount of integrated effort and adequacy of data for industrial production design concepts, however, would be limited through requiring an effort of considerable magnitude by the concern contemplating an economical competitive processing unit. There is visualized a need for coordinated effort which is conducted in a single facility under the operation and control of the owner in the processing plant. Such an arrangement would not only permit the achievement of a given schedule of effort, but would permit closer coordination of work in various phases of development, with considerable savings in liaison and in possible duplication or omissions of effort. The construction of a single coordinated facility for development purposed would have the additional advantage of conducting training of operators and supervisory personnel at a time well in advance of that in which the main facilities were to be constructed. The development facility might be operated for a period of several months after development work has been completed in order to provide additional opportunities for the training of supervisory and operational personnel with a consequent saving in inspection and testing and various aspects of initial operation of work to be undertaken before the completion of construction of a separation plant. Such an arrangement should provide a considerable saving in start-up time and avoidance of duplication of expense between development and training programs.

Of the six processes selected for evaluation, evaporation of gross fission product solutions to a dry oxide powder gives greatest immediate promise. Development problems in this process are largely in equipment. This would include a reliable drying furnace suitable for remote operations with very low or zero maintenance requirements and equipment for handling and packaging the dried oxide powder.

Of the remaining processes, fractional precipitation-crystallization and chelation-solvent extraction are the only processes offering relatively pure products and a complete removal of long-lived activity from the gross fission products. For these reasons these processes deserve some preference. In the fractional precipitation-crystallization process, development should be devoted toward remote equipment to make solids-liquid separations that operate for long periods with minimum maintenance. In addition to this, the chemical flowsheet should be piloted to get better data on percent recovery and purity of product.

The chelation-solvent extraction fortunately has a large background of operating experience on remotely operated solvent extraction equipment to fall back on. However, the process itself loses appreciable quantities of chelating agent due to hydrolysis if pH's are maintained higher than 7.5. Development work should be done in finding a more stable chelating agent. Distribution ratios of strontium, barium, cesium and rubidium should be measured under more widely varying conditions. Such data would indicate how two closely chemically allied elements could be split into pure fractions by solvent extraction techniques. The process could be further "firmed-up" by additional measurements of distribution ratios of other elements present in gross fission products as well as those of the corrosion products likely to be present.

IX. CONCLUSIONS AND SUMMARY

A. General

The conclusions presented should be qualified to the extent that they are based upon the cost estimates presented, and upon certain assumptions of availability of fission products from existing processing plants which might be placed on a national defense site rather than drawing upon anticipated civilian power and fission products. The costs presented reflect the assumptions that most of the general facilities for plant operation will be provided by others and available to the separations plant on a unit cost basis

1. It is concluded from these studies that the cost of the plant, particularly in structures and general facilities required for the separation and packaging of fission products produced from fuels separations by others, is quite comparable in magnitude to the probable cost required for the construction of an entire fuels separation plant to treat irradiated fuel elements by an aqueous method. Under these conditions, the serious question has arisen as to the value of proceeding with the plans for a separate fission product packaging facility, although programs of development for fission product packaging appear to be promising as necessary adjuncts to civilian fuel processing plants and as sources of by-product revenue. It is believed that consideration should be given to the conduct of fuels separation operations so that several sources of revenue might be obtained from such a plant for a capital investment comparable with that required for a fission products separation plant. Sources of revenue from fuel processing would be those from the recovery of source and fissionable materials, thus permitting joint or by-product costing for the fission product operation.

2. The use of reactors for radiation sources would probably result in the lowest possible cost per equivalent curie of gamma radiation power. The construction of a reactor for this purpose is an open consideration and no recommendations are provided in this report.

B. Process Discussion

Six processes were considered for treatment of gross fission products, only two of these showing an ultimate capability of completely removing cesium and strontium from gross fission products in a highly pure state. These two processes are fractional precipitation-crystallization (here designated as the co-crystallization process) and chelation-solvent extraction.

Co-precipitation gives incomplete removal of strontium and cesium, while many other ions are carried down with the precipitate, resulting in an impure product.

Ion exchange processes are subject to radiation damage of the resin and problems in removal and disposal of the damaged resin by remote means. Some difficulties have been experienced in the past in eluting molybdenum and ruthenium from the resin. No runs have been made using ion exchange processes of gross fission products. In these studies, cesium was assumed to be the only product of the ion exchange process.

Evaporation of water and acids from gross fission product solutions has promise if immediate results are desired and the desired product is a mixture of gross fission products.

Leaching of soluble oxides from a dried mass of fission product oxides gives a solution mixture of cesium, strontium, barium, and other alkali metals present. Such solutions, having been freed of the great bulk of structural materials and other fission products, could be separated on a small scale, using other techniques. There is some question that leaching will give complete removal of cesium and strontium from the gross fission product oxides.

C. Unit Costs of Fission Products

Processes are considered in which cesium and strontium are to be separated individually from the remainder of the fission products and packaged as sources of radiation. The lowest costs of these materials to be anticipated, corresponding to capacity rates of operation of each plant studied, vary from $0.11 to 0.15 per gamma curie for cesium, and $0.07 to 0.09 per beta curie for strontium. All costs are charged against one or the other of these materials. The variation in costs mentioned here would be due to the selection of the least costly or most costly of the processes studied for the complete separation of either of these materials.

The unit cost estimates mentioned are for strontium and cesium. If gross fission products are packaged relatively soon, say ninety days after pile discharge of a reactor operating on a 42 day cycle, then the cost per gamma curie of the gross fission products would be much lower, say $.0009 per equivalent gamma curie based on activity at the end of processing. Gross fission products one year after such packaging would reflect the same costs of operation in higher per curie costs of about $0.005 per equivalent gamma curie because of radioactive decay. Thus the cost, per gamma curie, would be lower for the gross fission product packaging than for the production of the separated individual cesium and strontium materials. However, the gross fission sources are quite variable in activity with time. The gross fission product process is probably the simplest to develop and get into operation at an early date and the plant requirements for this process are probably quite similar to those required for modification to a more refined process, if this is desired at a later date.

D. Demand for Fission Product Sources of Radiation

Considerations for the pricing of the packaged gross fission products might take into account the possible costs of production of radiation by the separation of fission products produced by others. Given a decision as to which of these alternative methods might be pursued, consideration should probably be given to the competition from alternative sources of radiation, such as radium, cobalt-60, particle accelerator machines, and nuclear reactor operations available for civilian use. The sale of fission product sources of radiation would probably be free of much of this competition if the seller of such sources were able to provide megacurie or multi-megacurie sources in readily transportable form for use in development or pilot production studies in the industrial utilization of fission product radiation. If smaller scale operations were considered, then the competition from the above alternative sources of radiation would probably have to be taken into account in relative pricing policies. Favorable freight rate rulings on the transportation of shielded casks are required before the economical transportation for long distances of small quantities of highly active fission products can become an economically attractive proposition. If it were possible to obtain rulings such that the carriers would pay for the major share of the carrying of the dead weight of the cask itself, then such shipping restrictions might be minimized.

E. Savings in Storage

Each of the unit costs of the fission products summarized in Section C are assumed to carry the whole burden of cost of operation of the plant and this operation is further assumed to provide for the packaging of the undesired fission products and waste materials in dry form. Consequently, these waste materials are obtained in dry form, suitable for permanent storage for time schedules which would permit their ultimate disposal under simplified procedures. Investigations appear to be in order of the possible charge to the fission product processor for his raw material fission products and of the possible credits for his disposal of the waste fission products.

F. Timetables of Availability

It appears that if development work were instituted now, that the first production of fission products might be achieved by approximately thirty-eight months, assuming availability of gross fission products and suitable arrangements for land and other required facilities.

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