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The Isolation and Packaging of Fission Products at Hanford

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THE ISOLATION AND PACKAGING OF FISSION PRODUCTS
AT HANFORD

This document consists of
18 pages, No. 10 of
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INTRODUCTION

The fission of uranium for the production of power or plutonium gives rise to a byproduct new to industry, the fission products. The utilization of these materials has not yet been fully developed, partially because of the high cost of the limited quantities available and because of an uncertainty in the availability and cost of such materials in large quantities. For example, the previously quoted purchase price of \$10.00/curie (\$2500/γ watt) of cesium must compete with radiocobalt at \$2.00 to \$14.00 per curie (about \$150/γ watt to \$1000/γ watt) depending upon the specific activity, or about \$100/watt from x-ray machines. Further price reductions may be expected in all fields. Packaged radiocesium is a potential source of gamma radiation for radiotherapy, radiography, chemical catalysis, or food sterilization; packaged cerium or strontium might be used as a source of heat or intense beta activity for specialized applications.

The removal of cesium and strontium from separations wastes at Hanford is also of potential value in that it simplifies the ultimate disposal of these chemical wastes. Not only is the time of self-boiling minimized, but subsequent scavenging operations need be less efficient to produce a solution suitable for disposal to the soil.

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Research and development work on the removal of specific fission products from aqueous wastes has been in progress at the Hanford Atomic Products Operation for several years. Initially, the primary incentive lay in the safe and economic disposal of these wastes. Scavenging techniques were developed which permitted the precipitation of the long-lived and biologically hazardous fission products cesium and strontium and the subsequent discharge of the supernates to the soil. Recently, interest has increased in the recovery of specific fission products for use in industry. Accordingly, research and development efforts have been expanded to include the search for economic processes for the isolation of specific fission products from Hanford wastes. The processes and techniques thus far developed are logical outgrowths of the scavenging processes currently being used in the disposal of Hanford wastes.

On May 1, 1956, the Hanford Operations Office directed a letter of inquiry to the General Electric Company requesting an appraisal of the feasibility of isolating and packaging radiocesium from Hanford wastes. In accordance with this request, the Engineering Department conducted a brief survey to determine the process, engineering, and economic feasibility of recovering specific fission products from Hanford waste solutions. This document presents the combined efforts of personnel from Chemical Research and Chemical Development (Separations Technology Section), Process Engineering (Design Section), and Project Engineering and Project Auxiliaries (Project Section). Since the processes and equipment postulated in this study are not completely developed, all estimates of construction and operating costs and timing must be regarded as preliminary.

SUMMARY

Research and development work in A.E.C. laboratories has evolved precipitation processes by which cesium, cerium, and strontium may be isolated from Hanford wastes, and relatively little development is apparently required to make the isolation and packaging of these materials practicable. The processes could be utilized to recover the fission products from Purex wastes in the 221-B or 221-T canyon, now idle because the obsolete bismuth phosphate process has been abandoned. The packaged fission product, packaged in small, double-walled, stainless steel cylinders in a form stable to both heat and irradiation, could be shipped about 150 days after pile discharge. Typically, 500 gamma curies of cesium might be packaged per can, and the cans might be shipped in lots of nine in a returnable 500-lb. lead cask. Larger or smaller shipments might be made on demand.

Additional chemical and mechanical development work would be required before this operation could be placed on a sound production basis. The chemical processing operations require further laboratory study and should be demonstrated in large-scale equipment. The calcining and packaging equipment must be developed and its operability established. This development work could be accomplished concurrent with the necessary modifications to the production facilities. It is estimated that about 18 months and \$250,000 of development effort would be required.

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Relatively little construction work appears to be required to adapt the 221-B facilities for the precipitation portions of the process. Waste transfer facilities can likewise be easily modified to meet the postulated needs. The time and cost of the over-all project are believed to be primarily controlled by the fabrication of the calcining and packaging units. The cesium packaging unit could be built and tested as a prototype, then installed as a production unit. Subsequent units could then be constructed and installed in the partially operating plant six to twelve months later. Preliminary estimates of construction time and cost, together with potential operating rates and costs are tabulated below:

PRELIMINARY ESTIMATES OF PRODUCTION POTENTIAL AND COSTS

	<u>Products Packaged</u>		
	<u>Cesium</u>	<u>Cesium, Cerium</u>	<u>Cesium, Cerium, Strontium</u>
Construction time, months after approved project proposal	18	24-30	24-30
Construction cost	\$ 750,000	\$1,350,000	\$1,900,000
Annual Operating cost ⁽¹⁾	\$1,800,000	\$2,200,000	\$2,400,000
Production potential, ⁽²⁾ beta megacuries per year			
30-year cesium-137	10-15	10-15	10-15
282-day cerium-praseodymium-144		470-700	470-700
25-year strontium-yttrium-90			25-38

(1) At rate of one megacurie cesium per year. Operating costs would be increased about 30% when producing 10 megacuries cesium per year.

(2) Assumes current Purex flowsheet. Continuous dissolution techniques might decrease production potentials sharply.

The unit cost of producing these materials would be sharply dependent on the production rate. Based on the preliminary estimates of construction and operating costs, typical unit costs of packaging the fission products were computed and are tabulated below. These unit costs are necessarily uncertain, but are believed to be within a factor of two of obtainable values.

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PRELIMINARY UNIT COSTS FOR PACKAGED FISSION PRODUCTS

Product	Production Rate, $\frac{\text{g}}{\text{Megacuries/Yr.}}$	Unit Cost Dollars Per Curie, FOB Hanford ⁽¹⁾	
		Operating Cost Only	Including Amortization ⁽²⁾
I. If only cesium is packaged			
Cesium	1	1.80	2.78
	10	0.23	0.33
II. If cesium and cerium are packaged			
Cesium	1	1.08	1.63
	10	0.16	0.21
Cerium-praseodymium-144	47	0.023	0.035
	470	0.0034	0.0045
III. If cesium, cerium, and strontium are packaged			
Cesium	1	0.81	1.21
	10	0.13	0.17
Cerium-praseodymium-144	47	0.017	0.026
	470	0.0027	0.0036
Strontium-yttrium-90	2.5	0.32	0.48
	25	0.052	0.068

(1) Assumes a shipment of nine cylinders of product in a returnable 500-pound cask. Each cylinder is assumed to contain about 500 curies of cesium, 250,000 curies of cerium, or 1250 curies of 25-year strontium-90.

(2) Assumes that the present book value of B Plant plus conversion expenses are amortized over five years.

Some alternate proposals were considered briefly but discarded as not being competitive. The Hot Semiworks is intrinsically a low-capacity solvent extraction facility, while the available processes for fission product isolation are predominantly based on precipitation. A new facility to duplicate the production rates and processes postulated above would require the duplication of most of the B Plant facilities at a guestimated cost of \$40,000,000 to \$60,000,000.

The removal of 90-95% of the cesium and strontium from the Purex wastes would decrease the cost of their subsequent disposal. By current flowsheets and operating technology, the self-concentrated Purex wastes may be predicted to self-boil for seven to one hundred years, depending on the processing history of the irradiated fuel from which it was produced. The removal of the cesium and strontium would reduce this time of boiling to the order of two to five years. At this time, scavenging operations need be a factor of 10 to 20 less

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effective to produce a solution suitable for disposal to the soil. It is probable that an operating schedule could be followed whereby each waste tank could be repetitively filled, scavenged, and emptied several times, thereby extending the useful life of a tank farm by many factors. The indefinite containment of the biologically hazardous cesium and strontium is also made more certain by the packaging operation.

DISCUSSION

A number of processes have been developed in laboratories throughout the world for the isolation of specific fission products from irradiated uranium. While these processes have included adsorption on inorganic materials, ion exchange using organic resins, precipitation, crystallization, and solvent extraction, only the precipitation processes are believed to be sufficiently well developed to serve a production facility at this time. This situation is perhaps fortuitous since the Hanford Atomic Products Operation has two operable precipitation plants which are available for other use because the bismuth phosphate process is now obsolete. The chemical and engineering bases underlying the proposed method of isolating and packaging specific fission products at Hanford are described below.

Production Potential

The production capabilities of a fission product packaging facility at Hanford are limited by the irradiation levels of the piles, the compatibility of the isolation processes with the chemical composition of the aqueous separations wastes (defined by both the fuel element composition and the separations process used), and the processing capacity of the isolation and packaging facilities provided.

For purposes of estimating production potential, the concentrated solvent extraction wastes from the Purex process were chosen as being most compatible with fission product isolation in available facilities, and the precipitation and liquid-solid-separation capabilities of the 221-B or T equipment were found to be adequate to process the entire Purex waste effluent. The capacity of the 221-B facilities to process these wastes depends, to a large extent, on a low concentration of metallic ions in the wastes. If, for example, other processing commitments required continuous dissolution techniques in the Purex Plant, the processing capacity of 221-B facilities for the recovery of cesium might be reduced on the order of 40-fold because of the bulk of the aluminum present. This reduction could probably be partially offset by diverting additional precipitation equipment to the removal of iron and aluminum at the expense of cerium and strontium packaging, or by using settling tanks for the separation of most of the iron and aluminum precipitate. Since the plutonium production commitments for the Purex Plant cannot be forecast with certainty, it is assumed that, by Fiscal Year 1959, the Purex Plant will be processing 500 to 800 tons of uranium per month, the metal having been irradiated to 600 MWD/T. Assuming an irradiation rate of 7.5 MW/T, a 90% fission product recovery by the processes outlined below, and a 150-day time lag between pile discharge and product delivery, the production potential and characteristics of the packaged fission products would be as follows:

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POTENTIAL PRODUCTION OF ISOTOPES AT HANFORD

<u>Isotope</u>	<u>Half-Life</u>	<u>β Megacuries/Yr.</u>	<u>β Watts/ β Curie</u>	<u>β Curies/ Gram*</u>
Cesium				
Cs-Ba-137	30 y.	10-15	0.00136	10
Cerium				
Ce-141	32.5 d.	45-70	0.00118	50
Ce-Pr-144	282 d.	480-720	0.00377	600
Strontium				
Sr-89	53 d.	125-185	0.00344	60
Sr-Y-90	~25 y.	26-39	0.00333	10

*) Estimated on the basis of total weight of solids packaged.

The cesium product would be packaged as a mixture of zinc and cesium chlorides and iron oxide, with cesium constituting about half of the mass. The radio-chemical purity would be high, probably of the order of 98% or greater. The cerium product would be packaged as the oxide and would also be relatively pure as a radio-chemical, but might contain some rare-earths. The strontium product would be packaged as the oxide or chloride, and would contain iron as a metallic diluent. Other fission products would also be present. The cesium product should be well suited for radiotherapy or radiography, but the use of these products for purposes other than gamma irradiation or heat should be carefully evaluated prior to trial. The cesium-barium-137 averages about 0.92 gamma curie per beta curie.

It is recognized that a large quantity of cesium is currently stored in the wastes from the bismuth phosphate and Redox processes. The recovery of this material is not judged to be economic, however, so long as the market demand can be met by processing current Purex wastes. The aluminum in the Redox wastes would place a serious limitation on the processing capacity of the precipitation equipment, and the phosphate ion in the metal recovery wastes would cause an unknown process complication. Should other factors establish the desirability of recovering fission products from these wastes, the necessary flowsheet and/or equipment modifications can doubtless be made and the waste removal equipment be utilized to make the operation possible.

The use of other facilities is not economically competitive with the use of B or T plant. The Hot Semiworks has insufficient floor area to house the required equipment, and currently contains equipment not suited to the processes currently available. The major revisions required would cost many times the estimated revision costs of B or T plant. The construction of an entirely new plant to utilize the available processes at the potential production rates would require the duplication of a large portion of the B plant facilities. Such a plant would probably cost forty to sixty million dollars.

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Chemical Processes

The processes believed to be most adaptable for isolating cesium, cerium, and strontium at Hanford are based on the precipitation technology developed in A.E.C. laboratories. The precipitation and purification of cerium is based on development work at the Oak Ridge National Laboratory and other sites. The carrier-precipitation of strontium is based on development work at many sites, and includes no unique technology. The precipitation of cesium as the zinc cesium ferrocyanide is based on laboratory work at H.A.P.O. and is now believed to be ready for large scale development work.

The concentrated aqueous waste from the Purex process is essentially a nitric acid solution of the fission products, including small amounts of aluminum, uranium, plutonium, iron, corrosion products, and sometimes sodium. The proposed process for the recovery of specific fission products from this complex solution eliminates the undesired contaminants by precipitation (except uranium, which stays in the supernate) and then precipitates the desired materials as relatively pure compounds. The process is outlined in Figure 1, which presents the process steps and the equipment pieces proposed for this use. The chemical flowsheet is still being developed and is, therefore, incomplete in many respects.

As outlined in Figure 1, partially neutralized IWW is routed from the Purex Plant via existing underground lines through a cooled 50,000-gallon surge and pump tank (244-CR-011) in the C Tank Farm to the 221-B Building.

The precipitation and removal of iron and corrosion products from the solution by pH adjustment in Section 6 and centrifugation in Sections 7 and 8 removes most of the ruthenium and zirconium-niobium activities. The precipitation can be effected by dilute ammonia gas or by the hydrolysis of urea. Laboratory tests have shown that either method produces a granular precipitate of hydrated ferric oxide which can be centrifuged from the supernate solution. This precipitate could be calcined and packaged if a market for such a heterogeneous radiation source were developed, although the present flowsheet returns this material to waste storage via Section 9. This process step is the capacity-limiting one, production being limited by the quantities of iron and/or aluminum removed at this point.

Following the separation of the bulk of the objectionable contaminants in Sections 7 and 8, the strontium, cerium, rare earths, and the remainder of the iron and uranium are precipitated by pH adjustment and centrifuged in Section 10.

The supernate from this precipitation is then treated to precipitate $\text{ZnCs}_2\text{Fe}(\text{CN})_6$ in Section 17. This precipitate is filtered and calcined in a gaseous atmosphere containing either chlorine or HCl gas to produce a mixture of the solids zinc chloride, cesium chloride, and iron oxide. This product material is a free-flowing powder which is not appreciably deliquescent. The calcining and packaging operation is conducted in new equipment in Section 20.

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The precipitate centrifuged in Section 10 is dissolved in nitric acid, and cerium oxalate is precipitated in Section 12, the uranium remaining with the supernate. The precipitate is centrifuged, dissolved and oxidized with bromate, and reprecipitated as ceric phosphate in Section 13. This precipitate is centrifuged, metathesized to the hydroxide, and reprecipitated as the oxalate in Section 14. The cerous oxalate is filtered, calcined to the oxide, and packaged in Section 11.

Treatment of the supernate solution from Section 13 with ammonia and sodium carbonate reprecipitates strontium in Section 18, the uranium again remaining with the supernate. The precipitate may be treated with a halogen acid or simply filtered and calcined to produce an impure strontium product containing macro amounts of iron. This product is packaged in Section 20.

The waste solutions produced in B Plant operations are accumulated in Section 9 (some via 15) and are returned to the Purex Waste Tank Farm via existing underground lines and a pump tank in C Farm.

The preferred physical and chemical form of the fission products for packaging is currently believed to be a free-flowing, dry powder of chemical compounds whose constituents have a high recombining potential. Assuming the elements are packaged as the oxide or the chloride, any gases produced by irradiation-induced decomposition should recombine readily, thereby establishing an equilibrium at a low pressure. The absence of water also assures a minimum of pressure which might arise from its vapor pressure at high temperatures or its decomposition by irradiation.

Process Equipment

The precipitation steps outlined above are ideally suited to the precipitation and centrifugation equipment available in the bismuth phosphate facilities in 221-B and 221-T. The use of 221-B is proposed because it is more easily integrated with the operation of the Purex Plant. The transfer of the Purex chemical wastes to and from the 221-B facility can be effected by using existing underground transfer lines in conjunction with pumping stations no longer required by the Metal Recovery operations. As evaluated against current technology, few changes appear to be required to permit the operation of the precipitation and solid-separation steps in the existing facilities, and nearly all of the 221-B facilities would be required to isolate and package cesium, strontium, and cerium.

The drying and conversion of the precipitates to the chemical and physical forms desired for packaging requires the development and construction of new and unique equipment. The unit operations required for the filtration and calcining operations are quite similar to those being developed for the continuous Task I and Task II operations of the 234-5 facility, and it is believed that much of the technology so developed can be utilized in the postulated project. The packaging operation is similar in many respects to the loading of shells, and industrial technology should be applicable. New and unique problems are anticipated, however, and the prototyping of the first calcining and packaging facility is believed mandatory. A substantial portion of this prototype might be installed as a part of the first production facility.

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The development and demonstration of the prototype of this packaging unit is estimated to require 18 months of effort and the expenditure of about \$150,000. The demonstration in large-scale equipment of the precipitation and solids-separation steps could be accomplished in 224-B equipment at an estimated expenditure of \$100,000 labor and materials. This work could be accomplished concurrently with the construction and prototyping outlined above.

Packaging and Shipment

For purposes of this report, it is assumed that the fission products would be produced and canned as dry solids in stainless steel cylinders. As currently postulated, this operation would be conducted in equipment similar to that pictured in Figure 2. Remote mechanical equipment would be utilized for the calcining and packaging operations, with the operator viewing the apparatus through lead-glass or zinc-bromide windows and controlling the operations with pneumatic or hydraulic actuators. A laboratory-type manipulator would be provided to assist in the operation and maintenance of the facility. The entire assembly would be located in a canyon cell so that the canyon crane would be available to assist in maintenance operations and to handle the shipping containers.

The product solution would be filtered, calcined, and sometimes converted to the chloride in small-scale continuous equipment. The powder would be poured into a cylinder constructed of standard 5/8-in. diameter, 24 gauge stainless steel tubing. After compacting and capping the material, the excess tubing would be cut off and the cap welded into place. The capped cylinder would be soaked and washed to remove external contamination. The washed cylinder would then be baked at high temperature (say, 400-500°C.) to dry the tube and to establish the integrity of the can. This cylinder would then be inserted into a second cylinder constructed of standard 3/4-in. diameter, 24 gauge stainless steel, and a cap welded in place. The cylinder thus prepared for shipment is postulated to be of any desired length greater than four to six inches.

The cylinders could be shipped in casks containing at least three inches of lead on all sides. A cask designed to carry nine such cylinders is estimated to weigh about 500 pounds. Larger or smaller shipments could be made on demand, but the shipping costs in all cases would be governed by the weight of the cask. Obviously, the shipping cost per unit of product is minimized by large shipments. For example, a cask for shipping one cylinder would probably weigh about 250 to 300 pounds, while one for shipping 18 would probably weigh about 750 pounds.

Construction Costs and Scheduling

Utilizing the above concepts of chemical flowsheet and equipment, the time and cost of adapting 221-B to this use was estimated by Engineering personnel. These estimates are necessarily rough since they are based on technical and engineering assumptions which are not completely demonstrated. Both time and cost estimates are believed to be approximately correct.

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As summarized in Table I, the estimated cost of converting Hanford facilities for the packaging of cesium only is \$750,000. Over 75% of this estimated cost is assigned to the fabrication and installation of the calcining and packaging facility, the balance reflecting the small number of piping and equipment changes believed to be required to utilize the precipitation equipment in 221-B. The fabrication of the specialized equipment is assumed to be by off-site vendor (except for the prototyping of the cesium packaging unit), and the piping modifications and equipment installation are assumed to be performed by Minor Construction.

In Table II, the estimated construction cost for the packaging of cesium, strontium, and cerium is summarized. The increased cost accompanying the increased scope is largely due to the additional calcining and packaging units required. In view of this fact, a separate estimate was not prepared for the case of packaging only two products, the construction cost for this case lying midway between the two estimates presented.

As indicated in Table III, the modifications of the plant facilities, excepting the calcining and packaging facilities, could probably be accomplished in 17 months after approval of the project proposal. The fabrication and testing of the first calcining and packaging facility is estimated to require 18 months of development effort, including installation and testing in the production plant. The off-site fabrication of subsequent units could be started about six to twelve months after the project proposal was authorized, and these units could then be made ready for use about one year after the first unit. The installation of the later packaging units could be accomplished while the cesium packaging operation is in progress.

Operating Costs

The cost of operating the modified 221-B facility was estimated by comparing the labor, materials, and services estimated to be required with those required for the operation of the bismuth phosphate process. Details of this estimate are presented in Table IV. The \$2,400,000 annual cost of operating the complete facility includes labor, materials and services, plus plant protection and general administration costs. For packaging cesium only, the comparable annual cost of \$1,800,000 is estimated, while packaging cerium also would increase these costs to about \$2,200,000. These expenditures would be virtually independent of the operating rate, although small economies could doubtless be made at low production. Two items of operating cost vary directly with operating rate, the direct materials and the cost of providing shipping containers. These items, however, constitute only a minor portion of the total operating expenses. The unit operating costs of packaging these products are, therefore, sharply dependent on the operating rate. For purposes of this report, the total operating costs were assumed to be shared equally by each of the products assumed to be packaged. The unit operating costs calculated on these bases are presented in Table V.

To obtain an indication of the total costs including plant amortization, the present book value of \$4,157,318 of the B Plant facilities was added to the estimated project costs, and the sum amortized over five years. Unit costs were computed including this amortization and are included in Table V.

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Manpower Requirements

The operation of the 221-B facilities for the packaging of cesium only or the cesium, cerium, strontium products would require about 55 or 75 operational personnel, respectively, plus supporting service personnel. The operation of the metal recovery facilities currently requires 115 operational personnel, and current plans indicate that this labor pool will be available for reassignment about July, 1957.

Effect on Waste Storage

The removal of the long-lived isotopes of cesium and strontium from the aqueous wastes to be stored would simplify appreciably some of the problems of containing these wastes. The application of current and planned flowsheets to the processing of increased tonnages of irradiated fuel through the Purex facility would result in aqueous wastes that might boil from seven to as much as one hundred years. During this time, close operating attention would be required to insure absolute confinement of the biologically hazardous materials. The removal of the cesium and strontium would reduce the time the tank contents might be expected to boil to the order of 2 to 5 years after the tank is filled. This change reduces the corrosion of the tank and places a practical limit on the length of time the tank would require close operating attention. The packaging of the cesium and strontium would also increase the certainty of their indefinite confinement, thereby minimizing the biological hazards of their existence.

The removal of the long-lived cesium and strontium would also pave the way for an appreciable reduction in waste disposal costs. After the bulk of the cesium and strontium is removed, the aqueous waste could be stored for a short period (2 to 5 years), and the remaining cesium and strontium precipitated by current scavenging techniques. The residual non-boiling wastes could then be discharged to the soil. By this procedure storage tanks could be re-used several times. At a processing rate of five hundred tons uranium per month, the reduction in waste storage costs could run as high as \$250,000 per year.

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TABLE I

ESTIMATE OF CONSTRUCTION COST
ISOLATION AND PACKAGING OF FISSION PRODUCTS-CESIUM ONLY

<u>Description</u>	<u>Amount</u>
Temporary Construction	\$ 5,000
Area Preparation	3,200
Architectural & Structural	185,000
Trench Piping and Jumpers	71,800
Processing Equipment	30,000
Packaging Equipment	40,000
Controls	13,000
Instrumentation	10,000
Sub-Total Direct Constr. Cost	\$ 358,000
Other Directs	44,200
Payroll Burden	4,800
Sub-Total	\$ 407,000
Indirect Cost	13,500
Fee	2,500
Constr. Engr.	16,000
Sub-Total	\$ 439,000
Start-Up	26,000
Contingency	200,000
Sub-Total	\$ 665,000
G.E. Overhead	35,000
Total Constr. Cost	\$ 700,000
Design	50,000
Total Project Cost	\$ 750,000

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TABLE II

ESTIMATE OF CONSTRUCTION COST
ISOLATION AND PACKAGING OF FISSION PRODUCTS-CESIUM, CERIUM, AND STRONTIUM

<u>Description</u>	<u>Amount</u>
Temporary Construction	\$ 5,000
Area Preparation	3,200
Architectural & Structural	555,000
Trench Piping & Jumpers	100,000
Processing Equipment	90,000
Packaging Equipment	120,000
Controls	39,000
Instrumentation	<u>30,000</u>
Sub-Total Direct Constr. Costs	\$ 942,200
Other Directs	107,000
Payroll Burden	<u>11,800</u>
Sub-Total	\$ 1,061,000
Indirect Cost	33,000
Fee	6,000
Constr. Engr.	<u>43,000</u>
Sub-Total	\$ 1,143,000
Start-Up	30,000
Contingency	580,000
Sub-Total	\$ 1,753,000
G.E. Overhead	<u>85,000</u>
Total Constr. Cost	\$ 1,838,000
Design	<u>62,000</u>
Total Project Cost	\$ 1,900,000

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TABLE III

ESTIMATED WORK SCHEDULE
ISOLATION AND PACKAGING OF FISSION PRODUCTS

Breakdown	Revisions Exclusive of Calcining and Packaging Unit Time from Project Approval, Months				
	Design	Procurement		Field Progress	
		Start	Delivery	Start	Complete
Jumpers	4	2.5	12	12	16
Cold Work Incl. scales, piping, pH meters, instruments	5	2	14	7	17

Breakdown	Fabrication and Installation of Packaging Unit Time from Design Completion (Say 6-12 Months After Authorization)			
	Procurement		Field Progress	
	Start	Delivery	Start	Complete
Arch. and Struct. 3 Doors into 3 Cells Mod. Cells - Partition Walls Manipulators	0	12	3	16
Ventilation	0	10	10	13
Electrical	0	9	5	18
Instruments	0	15	10	18
Piping	0	10	5	18
Fluorinator, Calciner & Filter Unit	0	14	14	18
Packaging Station	0	14	14	18
Washing, Baking & Heat Test	0	14	14	18
Tubing for Containers	0	10	10	12
Shipping Casks	0	8	8	9

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TABLE IV

ESTIMATE OF ANNUAL OPERATING COSTS
ISOLATION AND PACKAGING OF FISSION PRODUCTS IN 221-B

Item	Thousands of Dollars	
	Cesium Only	Cesium, Cerium, Strontium
Direct Labor	225	325
Indirect Labor	100	125
Cont. of Service	30	40
Area Bus	15	18
Laundry	18	25
Shop, Office Supp.	35	40
R.M.U.	65	80
Proj. & Pers. Devel.	15	20
Mfg. General	25	40
Process & Plant Serv.	90	130
Process Air & Vent.	15	15
Rent, Light, Heat	60	70
Maintenance	400	500
Electricity	10	10
Water, Steam	85	100
Analytical	150	200
HW Railroad	15	20
Sub-Total	1353	1758

When packaging at a rate of 1 megacurie cesium per year

Direct Materials ⁽¹⁾	9	11
Cylinders and Casks ⁽²⁾	50	150
General Overheads ⁽³⁾	390	495
Total annual operating costs	1802	2414

When packaging at a rate of 10 megacuries cesium per year

Direct Materials ⁽¹⁾	85	110
Cylinders and Casks ⁽²⁾	500	1500
General Overheads ⁽³⁾	410	520
Total annual operating costs	2348	3888

- (1) Assumes a chemical cost of \$15 per ton of 600 MWD fuel processed through this operation for cesium isolation only, and \$20 per ton processed for cesium, cerium, and strontium.
- (2) Assumes that 25 casks containing 4500 curies cesium each are required per megacurie of cesium production. Each cask is estimated to cost about \$4,000, and is good for 20 round trips. The shipment of cerium or strontium is assumed to require a similar number of casks, the curies of product per cylinder being adjusted as required to make this simplifying assumption.
- (3) Includes Plant Service, Plant Protection and Personnel, and General Administration Costs.

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TABLE V

ESTIMATED UNIT COST CALCULATIONS

Isotope Packaged	Mega-Curies Per Year	Annual Oper. Cost \$x10 ⁻³	Annual Chem. Cost \$x10 ⁻³	Annual Pack. Cost \$x10 ⁻³	General Overhead \$x10 ⁻³	Sub- Total \$x10 ⁻³	Unit Cost \$/Curie	Amort. ⁽¹⁾ \$x10 ⁻³	Total \$x10 ⁻³	Unit Cost \$/Curie
Cesium Only	1	1,353	9	50	390	1,802	1.80	981	2,783	2.78
	10	1,353	85	500	410	2,348	0.23	981	3,329	0.33
Cesium Plus Cerium										
Cs	1	800	5	50	226	1,081	1.08	551	1,632	1.63
	10	800	49	500	237	1,586	0.16	551	2,137	0.21
Ce	47	800	5	50	226	1,081	0.023	551	1,632	0.035
	470	800	49	500	237	1,586	0.0034	551	2,137	0.0045
Cesium, Cerium, and Strontium										
Cs	1	586	4	50	165	805	0.81	404	1,209	1.21
	10	586	37	500	173	1,296	0.13	404	1,700	0.17
Ce	47	586	4	50	165	805	0.017	404	1,209	0.026
	470	586	37	500	173	1,296	0.0027	404	1,700	0.0036
Sr	2.5	586	4	50	165	805	0.32	404	1,209	0.48
	25	586	37	500	173	1,296	0.052	404	1,700	0.068

(1) Book Value B Plant + Presently Installed Equipment = \$4,157,318

Estimated Cesium Conversion = \$750,000; Cs + Ce = \$1,350,000; Cs + Ce + Sr = \$1,900,000

Book and Conversion Costs Amortized over a 5 year period.

FIGURE I
FISSION PRODUCT FLOW SHEET
B PLANT

JUNE 22, 1956

CHEMICAL DEVELOPMENT
ENGINEERING DEPARTMENT
HANFORD ATOMIC PRODUCTS OPERATION

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HIGH-DENSITY GLASS SHIELDING

SCRUB TOWER

CALCINER

ROTARY FILTER

FILL INNER CAPSULE

INNER CAPSULE
DISPENSER

INERT GAS ARC
WELDER FOR
INNER CAPSULE

CUTTER

LATHE CHUCK

CAPSULE RECEIVER

CONTROL PANEL

HW-43835

Page 18

FIGURE II

CONCEPTUAL SKETCH

CALCINING AND PACKAGING UNIT
FISSION PRODUCT RECOVERY FACILITY

JUMPER NOZZLE (TYPICAL)

ATING TUBE REACTOR

CHEMICAL DEVELOPMENT SUB-SECTION
ENGINEERING DEPARTMENT
HANFORD ATOMIC PRODUCTS OPERATION
JUNE 22, 1956 R.W.W.

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