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B-PLANT FISSION PRODUCT FLOWSHEETS - PART II

By

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Advance Process Development
Research and Engineering Operation
Chemical Processing Department

September 29, 1961

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By Authority of D. S. Lewis
CG-PR-2, 1-28-94

By J. E. Savely 2-14-94
Verified By Jerry M. Kelly 2-24-94

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

Work performed under Contract #AT(45-1)-1350
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B-PLANT FISSION PRODUCT FLOWSHEETS - PART IIINTRODUCTION

The technical bases for Phase I of the Fission Product Program have previously been presented (Ref. 1) for Phase I design. This report represents its sequel for Phase II of the program.

Phase I provides the means of segregating, concentrating, and aging crude fission product fractions with market value. Phase II is to provide the means for single-line purification and packaging of megacurie quantities of fission products (principally strontium-90).

The technical bases for Phase II project scoping studies are presented herein in the form of process flowsheets and tabulated data. Equipment needs are also described. Conceptual processes and flow diagrams for Phase III are presented for the Waste Management Program and the Fission Product Program.

SUMMARY

Design flowsheets for purification and packaging of Sr-90 are presented in Figures 1 through 3. Product specifications are also included in Tables I and II. Purification of Sr-90 is to be done at the Hot Semiworks using a one-cycle solvent extraction process. The product solution will then be trucked to the B-Plant Facility, loaded in, and packaged. The packaging operation is a batch process consisting of a precipitation, filtration, and calcination step. The final calcine is stable strontium oxide enclosed in a welded container for shipment. The packaging unit is suitable for other fission products with market potential (i.e., promethium-147, cerium-144, and cesium-137). Product handling auxiliaries and equipment needs are described where appropriate.

Conceptual flowsheets for a Phase III waste extraction process are presented in Figures 4 through 6, and fission product purification processes and equipment needs are discussed. The waste extraction process is a Waste Management function with the objective of efficient removal of long-lived fission products (Sr-90, Cs-137, and rare earths) from high-level wastes to permit low-volume waste packaging for final storage. The process includes: selective precipitations for Cs-137 removal, and solvent extraction removal of Sr-90 and rare earths. The fission products thus removed are packaged for final storage or may be used as feed for fission product purification and packaging for the Fission Product Program.

DECLASSIFIEDHISTORY AND STATUS

Currently Phase I construction activities at B-Plant are in progress; construction should be completed by October, 1962. Phase I of the Fission Product Program is to provide the means for the recovery, concentration and aging of fission products with market potential (i.e., Sr-90, Ce-144 and Pm-147) from the Purex formaldehyde-treated high-level waste (FTW). The design basis for this phase was based on precipitation processes.

The supernate from Purex neutralized high-level waste is a good source for Cs-137 and technetium-99. The Cs-137 recovery method presently used should provide market demands for several years. It consists of loading Cs-137 on a Decalso*-filled shipping cask directly from aged supernate waste, and provides customers with an unrefined product that can be processed further. Technetium-99 recovery has not been attempted since sufficient pure quantities are available from other AEC sites to meet initial market demands.

Phases I and II therefore have a tentative objective of processing FTW for fission products not available from aged supernate.

Phase II, as previously conceived, was to provide the means of purifying and packaging fission products using precipitation processes and ion exchange for final purification of Sr-90, or limited quantities of Pm-147. The processing rate for Sr-90 was to be capable of handling the Purex output of FTW assuming a single-line production facility (i.e., Sr-90). Since these early plans were made, a request by the AEC for about one megacurie of purified Sr-90 has resulted in the activation of the 244-CR Vault and the Hot Semiworks (a joint venture by the Chemical Processing Department and the Hanford Laboratories Operation under Projects CGC-909 and CGH-907). This was to provide interim aging, storage and purification capacity for Sr-90 in conjunction with recovery operations at the Purex Facility. During construction activities at the Hot Semiworks, the High-Level Radiochemical Facility was used to purify Sr-90 for the immediate needs of the program. The Sr-90 is being used for demonstrational prototype power generators (SNAP programs).

The successful use of a solvent extraction purification process at the Hot Semiworks has resulted in new technology with an impact on the means of achieving long-range objectives of both the Waste Management and Fission Product Programs. As a consequence, studies are now directed toward integrating the two programs, using a flexible solvent extraction system for efficient removal of fission products from FTW, and also for segregation and purification of fission products with market value.

The greater inherent efficiencies of solvent extraction (versus precipitation) lead to the belief that efficient removal of long-lived fission products from FTW will allow disposal of the remaining waste (after an interim

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5-year cooling period) with coating removal and solvent wash wastes via the in-tank solidification route. This concept (waste extraction) has both economic and technological incentives over previous bulk-calcination methods proposed for high-level waste disposal, and would result in an integrated Fission Product and Waste Management Program. The fission products thus removed would be available as feed stock for the Fission Product Program, or could be disposed of as high-level waste of much less volume than otherwise possible. Fewer operational and engineering problems are anticipated with this approach than with the previous concept of large-scale calcination of high-level waste at full Purex output capacities.

The capacity of the Hot Semiworks for purifying Sr-90 (sufficient to meet market forecasts until Phase III) has prompted the use of this facility by the Chemical Processing Department to meet the primary purification objective of Phase II (i.e., Sr-90 purification). This will allow time for further study, the development of an integrated Fission Product and Waste Management Program, and reduce early capital commitments to the Fission Product Program.

The large pilot plant production capacity of the Hot Semiworks will also provide valuable experience and training for personnel.

PROCESS AND DESIGN BASES

Processing functions and operations for Phase II assume the availability of segregated, concentrated, and aged fission product crude fractions. These fractions are to be produced from FTW by the Purex and B-Plant complex using precipitation processes which are:

- (1) lead sulfate carrier precipitation of strontium with rare earths,
- (2) caustic-carbonate metathesis and dissolution of the precipitate,
- (3) oxalate precipitation of rare earths from the resulting strontium solution,
- (4) peroxyacetate precipitation of cerium from rare earths.

Availability of cross-country waste lines will dictate the disposition of anticipated excess quantities of the cerium fraction produced by these processes during Phases I and II.

The principal product of interest will be Sr-90. Continuous recovery of a Sr-90 crude fraction will be provided for during Phase I and II operation, with megacurie purification capability provided by the Hot Semiworks operation.

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Ten megacuries of Pm-147 and associated rare earths are scheduled for aging and storage as a Pm-147 - rare earth fraction. This will be available for Phase II operations (Ref. 2) if Pm-147 demand arises.

Megacurie quantities of Ce-144 will be available on demand for processing into a pure product form. From Purex aged supernate waste, megacurie quantities of Cs-137 can be made available on a campaign basis.

Capability should be provided for packaging each of the fission products described above with major emphasis on Sr-90 production.

Improved ventilation and containment control in the B Facility will be necessary before fission product packaging operations can be conducted on a megacurie scale.

DESIGN FLOWSHEETS AND EQUIPMENT NEEDS

The objective of single-line purification and packaging of fission products can be met by extension of the current Hot Semiworks operation, and the addition of a packaging unit with product handling auxiliaries in B-Plant Facility. Scope design flowsheets and equipment needs for accomplishing Phase II objectives are described below.

Hot Semiworks - Strontium Purification

The Hot Semiworks is to process an aged Sr-90 crude fraction and produce a Sr-90 nitric acid solution with the compositions shown in Table I. The compositions are tentatively based on SNAP program requirements.

Figures 1 and 2 show the process flowsheet for purification of Sr-90. Using a solvent of 0.4 M di-2-ethyl hexyl phosphoric acid (D2EHFA) dissolved in 0.2 M TBP and kerosene diluent, strontium is extracted and recovered from the crude in a one-cycle operation consisting of an extraction column, followed by a stripping column. Process interference from bulk impurities of iron and lead in the feed is prevented by use of the complexing agent diethylenetriamine-penta acetic acid (DTPA). The extraction occurs at favorable pH conditions. However, since the process is sensitive to pH variations and since the extraction process itself tends to vary the pH, the operation is conducted using highly buffered aqueous streams. Process pH control has been very good in Hot Semiworks equipment using buffered streams with full-level Purex Sr-90 fission product crude.

Strontium - calcium separation is made in the stripping column by selectively stripping the strontium with citric acid of appropriate

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buffer strength. The citrates in the product solution must be allowed time to decompose (to carbon dioxide) by radiolysis. The radiolysis product (strontium carbonate) may then be dissolved in nitric acid. Citrates have approximately a one-hour half-life at a 900-watt-hr/liter dose rate.

The solvent stream has been exposed to radiation greater than 10^9 R with no adverse process effects observed to date. Solvent clean-up is effected by a nitric and oxalic acid batch contact, followed by an EDTA (ethylenediaminetetra acetic acid) and sodium carbonate column scrub. Periodic replenishment of the D2EHPA is required due to radiolysis losses.

Although flowsheet throughput capacities are greater than the current Purex output, the Hot Semiworks capacity is limited by the uncertain and variable operating efficiencies associated with contact-maintained facilities. All things considered, the Hot Semiworks capability during Phase II will allow meeting forecast Sr-90 market demands.

The limited product storage capacity of the Hot Semiworks requires that additional tankage be supplied to accumulate product during campaign operations without interfering with the continuity of processing.

B-Plant Strontium Packaging

Packaging operations and equipment are currently being developed assuming heavy-duty master-slave manipulators and viewing windows will be used to perform the mechanical handling operations required for packaging. Experiences in the High-Level Radiochemical Facility and at other AEC sites indicate this approach is desirable at the scale of operation contemplated (approximately 1 kilogram of strontium oxide per day).

Processing requirements and product compositions for the packaging operation are shown in Figure 3 and Table II. The process steps are simple and have been tested in development laboratories on a "cold" engineering scale. Strontium nitrate solution is neutralized and then hydrogen peroxide is added to precipitate strontium peroxide as a filterable intermediate. The precipitate is filtered and washed in the precipitator vessel and then slurried through a filter container where it is retained in an annulus as strontium peroxide cake. The wash operation is required to remove macro quantities of sodium and other soluble impurities. A drying operation follows, and finally, the cake is baked in situ at 650 °C for one hour. This converts the peroxide and any hydroxide present to the oxide, driving off the excess oxygen. Helium is used to improve

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heat transfer during the operation and for leak detection upon sealing the containers for shipment. The oxide product is stable to radiation, and pressurization of containers is not expected. The containers have two major seals. The first is a high-integrity mechanical seal, and the final one is a welded closure. Welds will be leak-checked, and the container exterior will be decontaminated to allow cross-country shipment.

B-Plant - Product Handling Auxiliaries

Product handling auxiliaries are required to transfer the Hot Semiworks Sr-90 product solution and load it into the packaging operation at B-Plant. A shielded tank truck for transport and a load-in and load-out station at B-Plant are therefore required. In addition, the station should be capable of handling slurried products for filter cask loading or unloading.

New shielded casks will be required for shipping packaged fission products. These are envisioned as large blocks of steel with holes suitable for holding several shipping containers while affording shielding, ease of heat transfer, and secondary containment. The casks should be designed for shipping a variety of fission products of stable form. Tentatively, the container capable of holding 30,000 curies of Sr-90 is 4.5 inches in diameter by 24 inches long and constructed of Schedule 80 stainless steel. This cask-container concept is preferred versus our current method in order to meet safety goals for shipping fission products. A small facility will be necessary to handle and load the new casks with the packaged fission product containers.

Waste would be disposed to the B or A Tank Farm, depending on the availability of cross-country waste lines.

OTHER PRODUCT POTENTIALS

The uncertainty of the fission product market for any one product requires that capability be provided for packaging a variety of fission products. Processes for purifying Sr-90, Ce-144, Pm-147, Cs-137 and Tc-99 have been demonstrated or are currently in a demonstrational state of development. A "universal" packaging unit is also being developed with the aim of using similar services and processes. Potential product forms, other than Sr-90 oxide, for Phase II are: (1) Ce-144 oxide, (2) Pm-147 with associated rare earths as oxides, and (3) Cs-137 as a mineral or salt. Tentative processes for packaging these products are shown in Figure 3.

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A flexible station at B-Plant for handling both slurried products and solutions will allow strontium carbonate and rare earth (RE) or cerium-double sulfate products to be loaded out and shipped via slurry filter casks. The process leading to a cerium-double sulfate product is currently being tested in plant equipment in the Purex Facility. It consists of separating cerium from a cerium-rare earth solution by the peroxyacetate precipitation of cerium (Ref. 3). After this separation, the cake is dissolved with nitric acid, and the solution is transferred to a product load-out precipitator vessel. Sodium sulfate is added, and a cerium-double sulfate precipitate is formed which is then loaded into a slurry filter cask. One cerium filter cask (HAPO-I) is available for this purpose. Procedures for loading will be similar to those used for strontium carbonate product shipments at the Hot Semiworks. A soluble metal (copper) should be mixed with the cerium-double sulfate product to ease the removal of cake from the cask by customers. Megacurie quantities of Ce-144 can be produced by this means. A crude rare earth mixture containing about 6 percent Pm-147 can be handled similarly by starting with the centrifuged supernate from the peroxyacetate precipitation step. Similar capability is available at the Purex Facility; however, processing at Purex would interfere with Sr-90 recovery activities.

Cesium-137 can be recovered on demand from aged Purex supernate. However, additional cross-country waste lines and equipment would be required to incorporate Cs-137 recovery into B-Plant for Phase II. Should megacurie quantities be required, interruption of Sr-90 recovery would permit Phase I and II equipment to be used for Cs-137 recovery.

Cesium can be loaded on mineral exchangers to concentrations greater than those attained for recent shipments by using a precipitation-purification process. Loadings as high as 25,000 curies of Cs-137 per gallon of Decalso (Ref. 4) are possible from pure cesium solutions. Such high loadings represent a promising final product form. Presently, full-level laboratory tests are being made to recover cesium suitable for high Decalso loading. The process consists of precipitating cesium as the nickel ferrocyanide (Ref. 4) from supernates. The precipitate is then metathesized with silver or cuprous carbonate which solubilizes the cesium. The resulting solution is sufficiently pure (sodium/cesium ratios of about 1.0 have been obtained in tracer tests) that loadings greater than 10,000 curies Cs-137 per gallon of Decalso are possible. The interrelationship between Cs-137 removal from supernate (a Waste Management objective) and Cs-137 recovery for the Fission Product Program will be presented in a forthcoming report.

Limited quantities of Tc-99 can be recovered from Purex supernate waste, either before or after Cs-137 removal, by contact of the supernate with an anion exchange medium (Ref. 5). This method is still in an early state of development but shows promise.

DECLASSIFIEDCONCEPTUAL FLOWSHEETS - PHASE III

The objectives of the Waste Management Program and the Fission Product Program as presently set are identical in many respects. Processing requirements, equipment needs, and operations are similar. However, the end result desired is different in each program (i.e., high-integrity containment for final waste disposal vs high-integrity containment for fission product marketing).

Waste Management Program

Conceptual process flow diagrams for Phase III are shown in Figures 4, 5, and 6. The purpose of the waste extraction concept is to efficiently remove long-lived fission products and rare earths from Purex FTW and neutralized high-level waste supernate. The following steps are required on FTW:

- (1) clarification and leach;
- (2) cesium removal by selective precipitation;
- (3) strontium and rare earth extraction and segregation.

The isolated fission product streams resulting from processing FTW may be calcined for Waste Management as a blend or as segregated fractions, or processed further for fission product packaging. The bulk salt waste from processing FTW would be held in tanks for boiling waste storage on an interim basis for short-lived isotope decay (Y-91, ZrNb-95, Ru-106, and possibly Ce-144 and rare earths) and then solidified with coating waste as a salt cake in available tanks for non-boiling waste storage.

Clarification and cake leach of FTW is required (Refs. 6 and 7) to remove small quantities of Cs-137, Sr-90, and rare earths in the solids. The wash and the leach liquor are blended with the clarified FTW. Cesium is then removed by using phosphotungstic acid as a precipitant. The precipitate ($\text{Cs}_3\text{PW}_{12}\text{O}_{40} \cdot \text{XH}_2\text{O}$) is highly selective, with greater than 99 percent removal of cesium from synthetic IWW having been obtained in tracer laboratory tests (Ref. 8). The cesium is dissolved with dilute caustic or ammonia, stored for fission product recovery or calcined into a glass along with the strontium fraction obtained subsequently from the solvent extraction process.

Strontium and rare earths are extracted from clear, cesium-free FTW by D2EHPA solvent described previously. The strontium and rare earths can be selectively stripped into mixed or segregated fractions (strontium with rare earths, or strontium and rare earths). Figure 5 shows one possibility where separate strontium and rare earth fractions are obtained.

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Solvent extraction equipment would require five of the B-Plant cells. The extraction columns would be a continuous cascade requiring full cell height. Column diameters of 8 to 10 inches and 8 to 6 inches for extraction and stripping columns, respectively, would be required. Column sizes are based on a two-fold greater capacity than the Purex output of FTW. The three fractions (cesium, strontium, rare earths) from the waste extraction process constitute fission product crudes. They can be blended and calcined for final disposal or stored for fission product purification and packaging. The processing possibilities are numerous and the system is flexible.

In a parallel system using precipitation equipment, Purex supernate can be processed simultaneously with FTW processing. Using a nickel ferrocyanide precipitation on Purex supernate waste, greater than 99 percent of the cesium in supernate can be removed (Ref. 4). Cesium is recovered from the precipitate using a silver carbonate metathesis. This cesium would be suitable feed for the Fission Product Program, or could be disposed of by blending with the fission product crudes from the waste extraction process.

Fission Product Program

In Phase III, fission product processing is concerned only with the purification and packaging of the crude fractions produced by the waste extraction process. Strontium-90 purification would be done using the same solvent extraction equipment that is used for waste extraction processing, but at a 30-fold greater capacity than the Sr-90 output from the Purex Facility. A flowsheet similar to Figure 1 would be used.

Cerium can be separated from promethium and the other rare earths by three different processes:

- (1) peroxyacetate precipitation - recently tested in Purex;
- (2) batch solvent extraction using solvent recovery equipment - recently demonstrated in the Hot Semiworks;
- (3) continuous solvent extraction using the waste extraction columns (but at 10- to 20-fold greater capacity than the Ce-144 output from the Purex Facility).

The latter process has been demonstrated in the laboratory (Ref. 9). In this process, separation factors between promethium and cerium (Ce^{+3}) of 5 to 8 have been obtained without the use of strong oxidants.

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Cerium from these separations can be packaged as a pure product. However, promethium and associated rare earths require further purification, e.g., by the chromatographic ion exchange process under development in the Hanford Laboratories (Ref. 10). From six to eight large ion exchange columns would be required to process Pm-147 at full Purex output capabilities. A Pm-147 purification feed free of Ce-144 and europium-154 would reduce shielding requirements for final purification. This is within the capability of the D2EHPA solvent extraction process.

Promethium and cerium packaging operations will be similar to strontium packaging as shown in Figure 3. However, oxalate intermediates will be required to obtain oxide products. Packaging containers previously described for Sr-90 will be usable (slightly modified) for cerium and promethium with container capacities of 30,000 curies for Ce-144 and up to 400,000 curies for Pm-147.

Cesium products of potential interest include a cesium mineral glass and cesium salt (chloride or sulfate). The cesium carbonate product from the supernate treatment process (nickel ferrocyanide and silver metathesis) may be sufficiently pure to give a specific activity (one-fifth to one-half of the maximum) that is acceptable without further purification. With further purification, either product can be made pure and loaded into the standard packaging container with potential Cs-137 batch sizes of 15,000 to 40,000 curies. The desired specific activity for cesium products will determine if additional purification is needed.

The processing alternatives available for both the Waste Management and Fission Product Programs require a thorough economic, technical, and facilities study before the preferred path for developing Phase III is chosen. Currently alternates are being studied.

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TABLE I

HOT SEMIWORKS STRONTIUM-90 PURIFIED PRODUCT COMPOSITION

<u>Activity Ratios Required curies/curie</u>	<u>Salt Concentration, M</u>	
Ce-144/Sr-90 $\leq 3 \times 10^{-3}$	Na ⁺	0.22
Ru-106/Sr-90 $\leq 6 \times 10^{-4}$	Sr ⁺⁺ (a)	0.085
ZrNb-95/Sr-90 $\leq 8 \times 10^{-4}$	Other Cations ^(b)	0.028
Y-91/Sr-90 ≤ 0.04	HNO ₃	0.3
Sr-89/Sr-90 ≤ 1	Citrate ³	≤ 0.001

(a) Assuming 53% of total Sr is isotopic Sr-90.

(b) Primarily calcium, barium and iron. Excludes sodium contamination.

TABLE II

B-PLANT STRONTIUM-90 PACKAGED PRODUCT COMPOSITION

<u>Activity Ratios Required curies/curie</u>	<u>Cation Percent by Weight</u>		<u>Watts Per Container Batch^(c)</u>	
Ce-144/Sr-90 $\leq 3 \times 10^{-3}$	Sr-90	40	Sr-90	198.0
Ru-106/Sr-90 $\leq 6 \times 10^{-4}$	Sr(total)	75	Sr-89	8.4
ZrNb-95/Sr-90 $\leq 8 \times 10^{-4}$	Others ^(d)	25	Other	20.4
Y-91/Sr-90 ≤ 0.04			Total	226.8
Sr-89/Sr-90 ≤ 0.1				

(c) Assumes 30,000 curies Sr-90 per batch.

(d) Primarily calcium, barium and iron. Excludes sodium contamination.

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TABLE IIINOTES FOR FIGURES 1 THROUGH 6

1. Fission product concentrations and heat generation rates are based on uranium irradiated to 600 MWD/T at 7.5 MW/T. "Cooled" time is 100 days for Figures 3 through 6 only. "Cooled" times for Figures 1 through 3 are as required to obtain isotopic ratios quoted.
2. Batch sizes for Figures 3 through 6 represent the amount of material from Purex formaldehyde treated waste from 37 tons of uranium production. Batch sizes for Figures 1 through 3 were nominally chosen.
3. All fission product percentages are based on Purex formaldehyde treated waste as being 100 percent.
4. All volumes given in gallons except for Figures 1 through 3 which are in liters.
5. All temperatures are ambient unless otherwise noted.
6. Units for flow are gallons per minute (GPM) except Flowsheets 1 through 3 which are in liters per minute (LPM).
7. The trivalent rare earths (exclusive of cerium) are abbreviated TRE on flowsheets; rare earths including cerium are abbreviated RE.
8. All process water is "soft" water.

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Feed Butt (1)	
NaOH	19 M
SpGr	1.53
Volume	50 L
Flow	Batch
Feed Butt (3)	
NaHc	4.5 M
SpGr	1.15
Volume	267 L
Flow	Batch

Feed Butt (2)	
Na5DTPA	1.05 M
SpGr	-
Volume	229 L
Flow	Batch
Feed Butt (4)	
Na ₂ SO ₄	3.7 x 10 ⁻² M
SpGr	1.0
Volume	54 L
Flow	Batch

HAS	
Citric Acid	0.6 M
Na5DTPA	0.2
NaOH	0.3
pH 3.0	
SpGr	1.14
Volume	176
Flow	6.25

B Plant Strontium Conc. Crude			
HNO ₃	0.86 M	Sr	75 %
Na	0.10	Ce	5
Fe	0.04	TRE	5
Pb	0.002	Y	10
Sr	0.0031	ZrNb	3
Ca	0.0055		
Ba	0.0005		
SpGr		1.03	
BTU/HR/Liter		2.1	
Volume		2000 L	
Flow		Batch	

Jet Dilutions
210 L

Solvent Extraction Feed (HAF)			
Na	1.28 M	Sr	75 %
Fe	0.029	Ce	5
Pb	0.0014	TRE	5
Sr	0.0022	Y	10
Ca	0.0039	ZrNb	3
Ba	0.0004		
NO ₃ ⁻	0.61		
SO ₄ ⁼	0.0007		
Acetate	0.428		
DTPA	0.086		
pH 4.7			
SpGr		1.07	
BTU/HR/Liter		1.5	
Volume		2810 L	
Flow (4 LPM)		100	

Na	
Sr	
Ca	
Ba	
SpGr	
BTU/HR/L	
Volume	
Flow	

From B-Plant
Via
244-CR Vault

HA

HAX	
Na-HD2EHPA	0.4 M
TBP	0.2
SpGr	0.84
Volume	703 L
Flow	25

From Solvent
Recovery

HAW			
Na	1.28 M	Sr	
NO ₃ ⁻	0.57	Ce	
Acetate	0.41	TRE	
DTPA	0.09	Y	
Citrate	0.004	ZrNb	
SpGr		1.03	
BTU/HR/Liter		0.7	
Volume		2986 L	
Flow		106.25	

To Waste Disposal

Recycle Alt.

0.6 M
0.2
0.3

1.14
176
6.25

HCX	
Citric Acid	1.0 M
SpGr	1.07
Volume	162 L
Flow	5.75

HCW			
HD2EHPA	0.4 M	Ce	< 0.5 %
TBP	0.2	TRE	< 0.5
Ca	0.016	Y	< 0.5
<hr/>			
SpGr	0.84		
Volume	703 L		
Flow	25		

To Solvent R.

HAP			
Na	0.022 M	Sr	> 70 %
Sr	0.0083	Ce	< 0.5
Ca	0.0147	TRE	< 0.5
Ba	0.0009	Y	< 0.5
<hr/>			
SpGr	0.85		
BTU/HR/Liter	3.2		
Volume	703		
Flow	25		

Product Clean Out	
HNO ₃	2 M
SpGr	1.19
Volume	45 L
Flow	Batch

Radiolysis Products	
CO ₂ - NO ₂ - H ₂	

HAW			
	1.28 M	Sr	< 5 %
	0.57	Ce	4.5 %
ate	0.41	TRE	4.5
A	0.09	Y	10
rate	0.004	ZrNb	3
<hr/>			
SpGr	1.03		
BTU/HR/Liter	0.7		
Volume	2986 L		
Flow	106.25		

To Waste Disposal

HCP Concentrator			
Na	0.095 M	Sr	> 70 %
Sr	0.036	Sr ^{89/90}	2.5
Ca	0.006		
Ba	0.004		
Citric	1.0		
<hr/>			
pH 2.3			
SpGr	1.07		
BTU/HR/Liter	13.2		
Volume	162 L		
Flow	Batch		

Condensate to
Waste Disposal
Volume 138 L

Product Store			
HNO ₃	0.3 M	Sr ^{89/90}	0.1 %
Na	0.22		
Sr	0.085	Sr ⁹⁰	≥ 70
Ca	0.015		
Ba	0.010		
Citrate	< 0.01		
<hr/>			
SpGr	1.01		
BTU/HR/Liter	31 -14		
Volume	69 L		
Flow	Batch		

Notes: See Table

FIGURE 1
Hot Semiworks Strontium Purification Flowsheet

Notes: See Table III

FIGURE 1

HCW	
HD2EHPA	0.4 M
TBP	0.2
<hr/>	
SpGr	0.84
Volume	703 L
Flow	25

Acid Wash	
HNO ₃	0.5 M
H ₂ C ₂ O ₄	0.5
<hr/>	
SpGr	1.03
Volume	1406 L
Flow	Batch

IOS	
Na ₂ CO ₃	0.25 M
Na ₄ EDTA	0.05
<hr/>	
SpGr	1.03
Volume	840 L
Flow	30

Solvent Acid Wash	
Time 1 hr. Temp. 25 °C	
Volume	2109 L
Flow	Batch

IOF	
HD2EHPA	0.4 M
TBP	0.2
<hr/>	
SpGr	0.84
Volume	703 L
Flow	25

IO	
----	--

HAX	
Na-HD2EHPA	0.
TBP	0.
<hr/>	
Volume	70
Flow	25

Acid Wash Waste	
HNO ₃	0.5 M
H ₂ C ₂ O ₄	0.5
<hr/>	
SpGr	1.03
Volume	1406 L
Flow	Batch

IOW	
Na ₂ CO ₃	0.25 M
Na ₄ EDTA	0.05
<hr/>	
SpGr	1.03
Volume	840 L
Flow	30

Hot Semiwo:

FIGURE 2

Notes: See Table III

Neutralizer	
NaOH	19 M
SpGr	1.53
Volume	100 L
Flow	Batch

Waste Neutralization			
	7.0	M	Sr < 5 %
PO ₃	2.8		Ce 5
PO ₄	0.8		TRE 5
H ₃ PO ₂	1.3		Y 10
TPA	0.33		ZrNb 3
DTA	0.05		
SpGr	1.50		
Volume	900 L		
Flow	Batch

To
Waste Disposal
C-Farm

Waste Condensate	
PO	-
Gr	1.0
Volume	4536 L
Flow	Batch

To
Waste Disposal
Crib

Notes: See Table III

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Cs - Packaging Feed		Sr - Packaging Feed	
NaNO ₃	0.86 M	HNO ₃	0.3 M
Cs ¹³⁷	390 Curies/Liter	NaNO ₃	0.22
		Sr(NO ₃) ₂ (70 %)	0.085
		Ca(NO ₃) ₂	< 0.015
		Ba(NO ₃) ₂	< 0.010
β	> 44,000 curies	β	36,000 curies
pH	7 - 10		
SpGr	1.06	SpGr	1.01
BTU/HR/Liter	6.1	BTU/HR/Liter	14
Volume	113.5 L	Volume	57.6 L
Flow	Batch	Flow	Batch

Ce - Packaging Feed		TRE - Packaging Feed ⁺	
HNO ₃	4.00 M	Na	0.64 M
ZrNb (4 %)	0.0001	Sr	10 %
TRE (5 %)	0.0018	Ce	2
Ce (83 %)	0.0114	Pb	0.013
		TRE	75
β	> 33,000 curies	ZrNb	< 3
		β	72,700 curies
SpGr	1.13	SpGr	1.04
BTU/HR/Liter	135	BTU/HR/Liter	1.05
Volume	20.6 L	Volume	340 L
Flow	Batch	Flow	Batch +

Boil Off
As
Required

Sr - Precipitant (1)		TRE-Acid Ad
H ₂ O ₂	1.5 M	HNO ₃
SpGr	1.01	SpGr
Volume	10 L	Volume
pH Adjust. (2)		TRE - Preci
NaOH	1.55 M	H ₂ C ₂ O ₄
SpGr	1.06	SpGr
Volume	18.4 L	Volume
Cake Wash (3)		Cake Wash
H ₂ O	- M	HNO ₃
SpGr	1.00	SpGr
Volume	30 L	Volume
Slurry Water (4)		Slurry Solu
H ₂ O	-	H ₂ O
SpGr	1.0	SpGr
Volume	19 L	Volume

Cs - Filtrate		Sr - Filtrate	
NaNO ₃	0.73 M	NaNO ₃	0.22 M
Cs ¹³⁷	255 curies/liter	NaOH	0.08
		H ₂ O ₂	0.06
β	> 34,000 curies	SrO ₂ ·8H ₂ O	0.034
		Ca + BaO ₂	0.008
pH	10	β	3,000 curies
BTU/HR/Liter	3.3	BTU/HR/Liter	0.63
Volume	133.5 L	Volume	135 L
Flow	Batch	Flow	Batch

Ce - Filtrate		TRE - Filtrate	
HNO ₃	0.91 M	HNO ₃	1.42 M
H ₂ C ₂ O ₄	0.23	H ₂ C ₂ O ₄	0.35
ZrNb	4 %	Na	1.28
Ce	4 %	Acetate	0.42
TRE	1 %	Pb	0.026
β	> 700 curies	ZrNb 3 % TRE	5 %
		β	> 4,700 curies
BTU/HR/Liter	21	BTU/HR/Liter	0.10
Volume	90.2 L	Volume	169 L
Flow	Batch	Flow	Batch

Calcine
Off-Gas

O₂
CO₂
CO

Cs - Scavenge	
NaNO ₃	0.79 M
Cs ¹³⁷	390 curies/liter
DeCalso	15.8 gr/liter
Time 30 Min.	
pH 7 - 10	
Cs-DeCalso B.Den.	0.72 gr/cc
BTU/HR/Liter	5.6
Volume	123.5 L
Flow	Batch
Ce - Precipitation	
HNO ₃	2.0 M
H ₂ C ₂ O ₄	0.5
Ce ₂ (Ox) ₃ ·9H ₂ O	0.051
Time 1 hr.	
ppt Ce B.Den.	0.28 gr/cc
BTU/HR/Liter	67.5
Volume	41.2 L
Flow	Batch

Notes: See Table III

+ Aged Feed

Reagent (1)	TRE-Acid Adjust.(1)	Ce - Precipitant (1)	Cs - Scavenger (1)
1.5 M	HNO ₃ 19 M	H ₂ C ₂ O ₄ 1.0 M	DeCalso 1950 gr.
1.01	SpGr 1.37	SpGr 1.04	100 (mesh) -
10 L	Volume 6.3 L	Volume 20.6 L	Volume 3 L
Reagent (2)	TRE - Precipitant(2)	Cake Wash (2)	Slurry Water (2)
1.55 M	H ₂ C ₂ O ₄ 1.0 M	H ₂ O -	H ₂ O -
1.06	SpGr 1.04	SpGr 1.0	SpGr 1.0
18.4 L	Volume 60 L	Volume 30 L	Volume 20 L
Reagent (3)	Cake Wash (3)	Slurry Solution (3)	Wash (3)
- M	HNO ₃ 6 M	H ₂ O - M	H ₂ O - M
1.00	SpGr 1.20	SpGr -	SpGr 1.0
30 L	Volume 30 L	Volume 19 L	Volume 10 L
Reagent (4)	Slurry Solution (4)		
-	H ₂ O -		
1.0	SpGr 1.0		
19 L	Volume 19 L

FIGURE 3

rt Gas
- As Needed

Cs - Product

Cs - DeCalso 2185 gr.
Volume 3000 cc
Bulk Cs¹³⁷ 10,000 curies
Watts 45

Sr - Product

SrO 475 grams
Bulk Sr⁹⁰ 30,000 curies
Bulk Sr⁸⁹ 3000 curies
Watts 230

TRE - Product

(TRE)₂O₃ 934 grams
Ce₂O₃ 12 grams
Bulk Pm¹⁴⁷ 59,200 curies
Bulk Ce¹⁴⁴ 8800 curies
Watts 100

Ce - Product

Ce₂O₃ 40 grams
(TRE)₂O₃ 6 grams
Bulk Ce¹⁴⁴ 32,000 curies
Bulk Pm¹⁴⁷ 300 curies
Watts 260

To
Container
Welding
and
Decontamination

(1) Cake Wash	
HNO_3	0.1 M
Temp.	60 °C
SpGr	1.00
Volume	200
Flow	Batch

(2) Cake Leach	
HNO_3	4 M
Temp.	60 °C
SpGr	1.13
Volume	80
Flow	Batch

(3) Cake Wash	
H_2O	-
Temp.	60 °C
SpGr	1.0
Volume	400
Flow	Batch

(4) Cake Removal	
NaOH	6 M
Temp.	60 °C
SpGr	1.22
Volume	150
Flow	Batch

Precipitate	
$\text{H}_3\text{PW}_{12}\text{O}_{40}$	
SpGr	
Volume	
Flow	

Purex Formaldehyde Treated Waste (FTW)			
HNO_3	0.50 M	Cs	100 %
Na	1.10	Sr	100
Fe	0.30	TRE	100
Al	0.14	Ce	100
Cr	0.03	Ru	100
Ni	0.02	ZrNb	100
SO_4	1.10	Solids	5
SpGr		1.18	
BTU/HR/Gal.		270	
Volume		1100	
Flow		10 GPM	

Centrifugation	

Precipitate	
HNO_3	0.45
Na	0.60
Fe	0.17
Al	0.08
Cr	0.02
Ni	0.01
SO_4	0.60
$\text{PW}_{12}\text{O}_{40}$	0.004
Time	
SpGr	
BTU/HR/Gal.	
Volume	
Flow	

ZrNb Fraction			
NaOH	6 M	ZrNb	50 %
		TRE	< 2
		Ce	< 2
		Y	< 2
		Sr	< 1
		Ru	5
SpGr		1.25	
BTU/HR/Gal.		510	
Volume		150	
Flow		Batch	

From Purex
Via
244-CR Vault

To Waste Disposal

FIGURE 4

B-Plant Conceptual Waste Extraction Flowsheet (Cesium Removal)

Notes: See Table III

FIGURE 5

B-Plant Conceptual Waste Extraction Flowsheet (Strontium and Rare Earth Extraction)

Notes: See Table III

FIGURE 6

B-Plant Conceptual Waste Extraction Flowsheet (Wa)

FIGURE 6

Action Flowsheet (Waste Handling and Packaging)

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PART II

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