NUCLEAR FUEL COPROCESSING PLANT

FLOWSHEET AND RADIOACTIVE WASTE SOURCES

by

Sayde Hamid Mortazavi

A Thesis Submitted to the Faculty of the

DEPARTMENT OF NUCLEAR AND ENERGY ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 8 1

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: S. Hamid Mortazavi

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. G. Post
Professor of Nuclear
and Energy Engineering

18 March 1981
Date

ACKNOWLEDGMENTS

The author would like to acknowledge the guidance of his Thesis Director, Dr. Roy G. Post.

The author would also express his gratitude to Dr. Reiner Papp for his unlimited help and guidance during this study.

Some parts of this document were performed at The University of Arizona under a contract with Los Alamos Scientific Laboratory, New Mexico.

To My Parents

and

My Wife

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

In this flow sheet the separation of plutonium and uranium is almost complete, comparable to the traditional Purex flow sheet. The plutonium product stream is finally diluted with uranium before it leaves the heavily shielded, inaccessible area. The most important difference is brought about by the omission of a second and third plutonium purification cycle, leading to some savings in the production of low activity radioactive waste.

CHAPTER 1

INTRODUCTION

1.1 Proliferation and Nuclear Cycle

The United States and all other nuclear weapon states as well as non-weapon states are deeply concerned with the risks of nuclear weapons proliferation. Concepts for development of civilian nuclear power with integrated controls for non-proliferation of military nuclear weapons have been studied ever since the Baruch plan was first proposed in 1946. The goal is to reduce the risks of weapons proliferation while maintaining the option of nuclear power as a significant source of energy. The international agreements developed to this date, such as the treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the 1977 "London Agreement" among 15 nuclear supplier nations, represent outstanding examples of international cooperation. The recognized need for such cooperation has led to the establishment of the International Atomic Energy Agency (IAEA) as a key organization for prevention of nuclear material diversion.

Additional measures are under investigation to reduce even further the risk of potential diversion of nuclear fuel cycle material to illicit nuclear devices, such as the United States Non-proliferation Alternative System Assessment Program (NASAP) and the IAEA international Nuclear Fuel Cycle Evaluation (INFCE).

In most decision-making situations, there are competing factors that are of such nature that all interests cannot be fully satisfied. In deciding the question of plutonium utilization, the primary factors in competition are the need to meet the expanding world energy demand versus the potential of increasing the risk of nuclear weapons proliferation.

The risk associated with plutonium has led the U.S. to conclude that utilization of plutonium should be deferred pending further evaluation. The U.S. support of the deferral option, however, has been incorrectly interpreted by many as a desire to foreclose the use of plutonium and the breeder option permanently. The actual U.S. position is more accurately articulated by Joseph Nye, who stated, "President Carter's April 7 (1977) statement did not prejudge the question whether some form of reprocessing would be necessary if we enter a breeder economy . . . In short, the President opposed the premature entry into plutonium economy" (Nye 1977). In spite of such policy statements and recommitment to guarantee enrichment services and fuel supply, the U.S. position of deferring the use of plutonium has frequently been viewed as a denial strategy by those nations not having abundant fossil fuel or uranium. The result is that a conflict of motives and interests exists, with the position of each nation being dictated by its own specific needs and the relative importance it places on the two competing factors of energy supply and proliferation risk.

1.2 Diversion Control Methods

The promulgation of a modified national energy program during the past years drastically changed the planning for completing the fuel cycle associated with commercial light water reactors (LWR). Proliferation of fissile material became the main issue of the new nuclear energy policy. Basic considerations of any detailed nuclear fission system reveal that each will carry within itself a certain potential for proliferation with sufficient technical ingenuity available to the operator and owner of the system. The question of the resistance to proliferation are related to the technological requirements for achieving the isolation of sufficient quantities and purity of fissionable materials to permit the fabrication of a device critical with fast neutrons.

The risk of diversion can be minimized by a variety of control methods. These methods can be classified as safeguard regulations, institutional controls and technical controls.

(1) Safeguard Regulations; These safeguard techniques include concepts of both material control and physical protection and are rigidly enforced through federal or international regulations and compliance inspections. The major elements of material control are material accounting, indepth measurements and timely inventories. Physical security measures include protection from intrusion, restricted access, continual surveillance.

(2) Institutional Controls; These include measures which utilize economic, political or societal factors to affect the ability or motivation

of a subnational or a nation group to achieve a nuclear capability. Example of such controls are the NPT and various contractual arrangements between nuclear supplier and user nation.

One of the most promising institutional type controls appears to be the use of a multi-national fuel services center where, by mutual agreement, nations could have fuel services performed in secure facility with no individual nation in position to use the facility for proliferation purposes.

(3) Technical Controls; These are measures applied to reactors and the basic fuel cycle that would inherently provide an increased margin of diversion protection. For maximum usefulness, these techniques should require a minimum of supplementary administrative controls. The following criteria may assure adequate proliferation resistance to uranium-plutonium fuel cycles:

- Spiking. This means that the fabricated fuel for reload to the reactor could be spiked by adding fission products or other isotopes such as CO^{60} emitting sufficient quantities of high energy gamma rays. This fuel then would present a significant problem in terms of radiation hazard to provide adequate protection against proliferation (EPRI 310 1975).
- Denaturing. The fissionable isotope would be diluted with a nonfissionable isotope of the same element and thus require isotope separation for the fissionable isotope to be concentrated enough to be used in a fast critical assembly.

Plutonium cannot be denatured because nonfissionable isotopes of this element is not abundant.

- Coprocessing and Partial Decontamination.

  The coprocessing concept is a fuel cycle option in which the recovery of fissile material from irradiated fuel is performed without producing a purified plutonium product. Obtaining weapons grade material then requires diversion of large quantities of material and subsequent chemical separation. The proliferation resistance can be further increased by incomplete separation of intensely radioactive fission products, leading to a situation similar to spiking.

1.3 Coprocessing as an Option

Coprocessing is conceived as a method to control proliferation by maintaining the plutonium with the uranium at all times. The chemical operations would be carried out in a secure area, and the only materials leaving the secure area would be the product stream uranium and plutonium in a mixed oxide form.

The proliferation resistance of this cycle can be breached by the expedient of chemically separating the uranium and plutonium if it can be obtained outside the secure area. There is the possibility of increasing the proliferation resistance of this material by retaining some of the fission products. If the plant is operated with high levels of fission products in the product stream, less decontamination is needed, and, in addition, it is possible to keep the transplutonium

actinides with the plutonium stream rather than allowing them to leave with the fission products and terminate in the high-level waste. Retention of these transplutonium actinides in the product stream provides an easy means for recycling and burning them in the reactor. The neutron physics has already been established for both the LWRs and LMFBRs (Patrasharn 1980). The big benefit is the reduction in the long-term hazard of the high level wastes. The chemical process necessary to accomplish these partitionings has not yet been fully demonstrated. Operation of this fuel cycle requires incomplete separation of the actinide and the fission product from uranium and plutonium in the first column of purex system and also the uranium and plutonium in the partition column. Thus, uranium would be present in controlled macroscopic concentrations in both exit streams. The operation of the partition column to provide two product streams, each with a specific composition, is very difficult. Since the concentration changes are geometric at each stage, the slightest change in flow ratios could result in major changes in the composition of the joint stream. It is operationally more desirable to operate the column as a fairly complete partition column so that the streams leaving the column would be a relatively pure plutonium and uranium stream, respectively, with the plutonium stream diluted with part of the uranium stream later in a mix tank within the secure area. This mode of operation would permit much more reliable process control than to try to operate the column in a way which would provide a particular ratio of uranium to plutonium in the streams leaving that column. The decontamination which is required

for plutonium stream would be reduced from about 10^7, as achieved in the Purex system, down to about 10^3 which would leave a significant level of radioactivity in the uranium and plutonium product stream. Therefore, the usual solvent extraction flow sheet can be followed; the differences would be elimination of second and third plutonium purification cycles and incomplete operation of the first solvent extraction column.

The least developed equipment for coprocessing of nuclear fuel in the co-conversion process is that associated with the evaporation and solidification of the final product of plutonium streams. Reasonable means for maintenance must be assured. The conversion of uranium and plutonium nitrate to the mixed oxide will be by direct solidification from solutions of proper U/Pu ratios.

The efforts were directed toward the evaluation of the LWR fuel cycle based on the coprocessing of uranium and plutonium in order to assess the non-high level solid wastes, gaseous and liquid effluents. The LWR selected generated 72PJ of thermal energy per year which corresponds to an installed electrical capacity of 1000 MWe, a load factor of 0.8 and a thermal efficiency of 33%. Based on a burnup of 33000 MWd per Mg of heavy metal the annual replacement requirement amounts to 27 Mg of heavy metal. The mass balance for the fuel cycle under consideration is represented in Appendix A. Since the fuel after coprocessing is depleted in fissile material, additional U-235 must be added to bring the reactivity level up to reactor fuel specifications. For

this purpose, 20% enriched uranium, which constitutes the upper limit of nonstrategic enrichment in U-235, has been added.

The plutonium recycling reactor under consideration has an annual discharge of approximately 15.5 kg of plutonium per Mg of heavy metal, 63% of which are fissile material. The residual uranium-235 content of the spent fuel amounts to 0.8% (Papp 1977). The fissile plutonium in association with the non-fissile plutonium isotopes normally generated in reactor produced plutonium has less reactivity value than uranium-235, hence, for each atom of U-235 displaced approximately 1.25 fissile atoms of plutonium must be added (Pueshl 1977).

As major portions of the fuel cycle under consideration are similar in waste generation to those available in the literature for other fuel cycles many data could be obtained from the literature. But for coprocessing itself no data could be found in the current literature, so that additional assumptions on that step in the fuel cycle were necessary.

CHAPTER 2

THE COPROCESSING FLOW SHEET

Coprocessing is defined as a scheme in which plutonium is never available in a separate stream, the main products being a mixture of plutonium and uranium suitable for feed to a fuel fabrication facility, and uranium as a separate by-product. Coprocessing does not entail large changes in most of the conceptual solvent extraction flow sheet of the basic Purex process. Quite often the coprocessing flow sheet eliminates the scrub section of the uranium-plutonium partition column, which assures that a significant amount of uranium will follow the plutonium into the aqueous stream.

A slightly different version was chosen in this study: As the operation of a partition column to provide two product streams, each with a specific composition, is very difficult, it is operationally more desirable to operate the column as a fairly complete partition column so that the streams leaving the column would be a relatively pure plutonium and uranium stream, respectively. This mode of operation would permit much more reliable process control than to try to operate the column in a way which would provide a particular ratio of uranium to plutonium in the streams leaving the column. Uranium would be added to the plutonium stream after solvent extraction but before final concentration and calcination.

The overall process which is used as a basis for the model flow sheet contains the following main components.

1) Fuel receiving and storage.
2) Shearing and dissolution of irradiated fuel, feed preparation, tritium removal.
3) Gross decontamination and recovery of plutonium and uranium.
4) Partitioning of uranium and plutonium.
5) Final decontamination and recovery of uranium in two cycles.
6) Solvent recovery.
7) Nitric acid recovery (including waste concentration and disposal).
8) The vessel off-gas (VOG) and dissolver off-gas (DOG) system.

Figure 2.1 shows the complete LWR spent fuel reprocessing flow sheet including all steps required to recover the fuel and bring it to reactor fuel specifications (UF_6 production, uranium/plutonium conversion). This diagram is a schematic representation of all sources of waste, routes the waste takes, and waste treatment facilities.

Figure 2.2 shows the solvent extraction cycle with its acid wash system. The first compound column (1A) is a continuous centrifugal contractor, used to minimize the exposure of the solvent to degrading radiation. The 1A', 1B and 1C column are Mixer/Settlers. The 1A' compound column provides additional decontamination under conditions which favor the scrubbing of Zr, Nb, and Ru compounds. The partitioning of uranium and plutonium occurs in the 1B compound column. Only

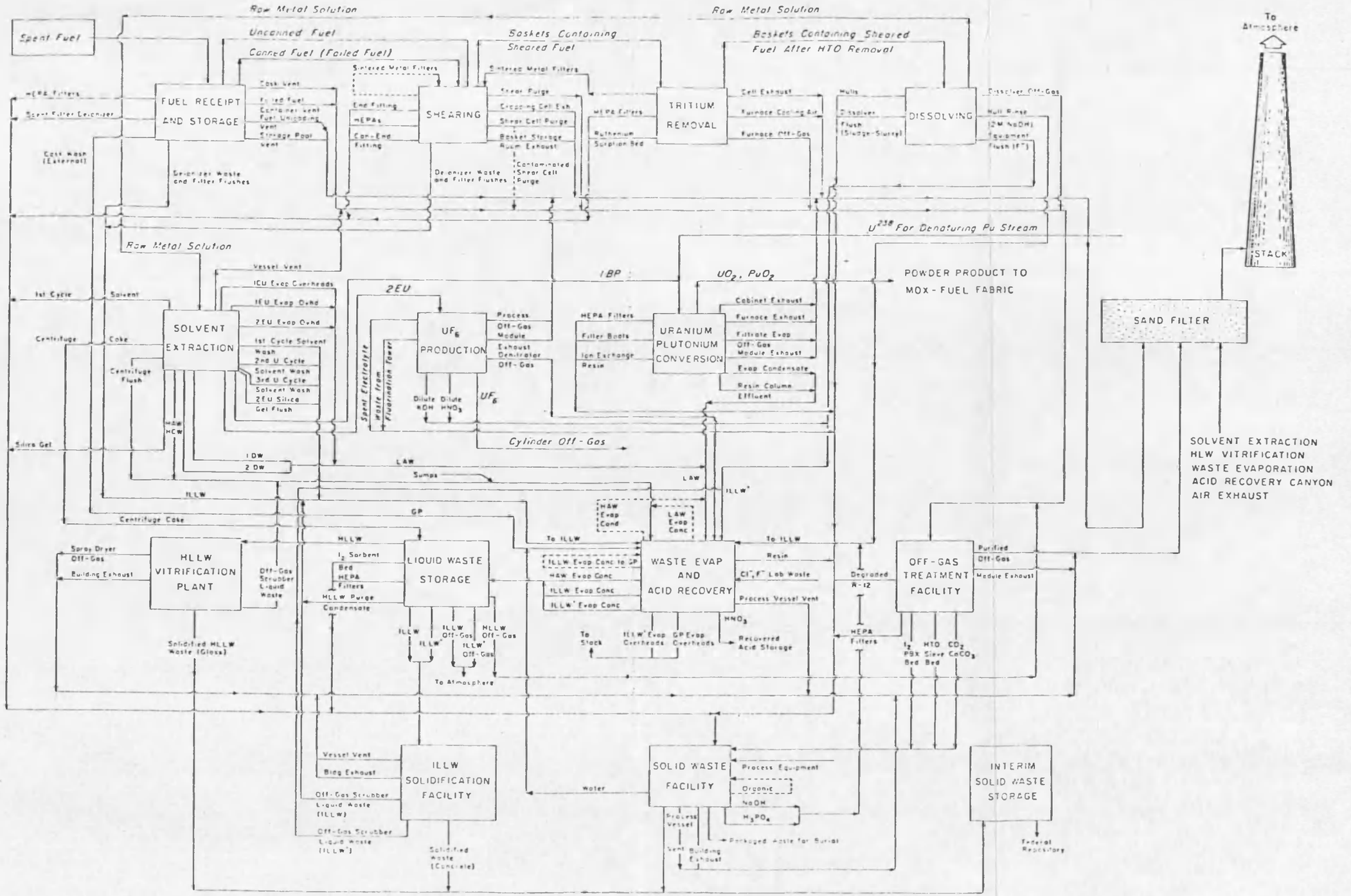


Fig. 2.1 Conceptual LWR Spent Fuel Co-Processing Flowsheet

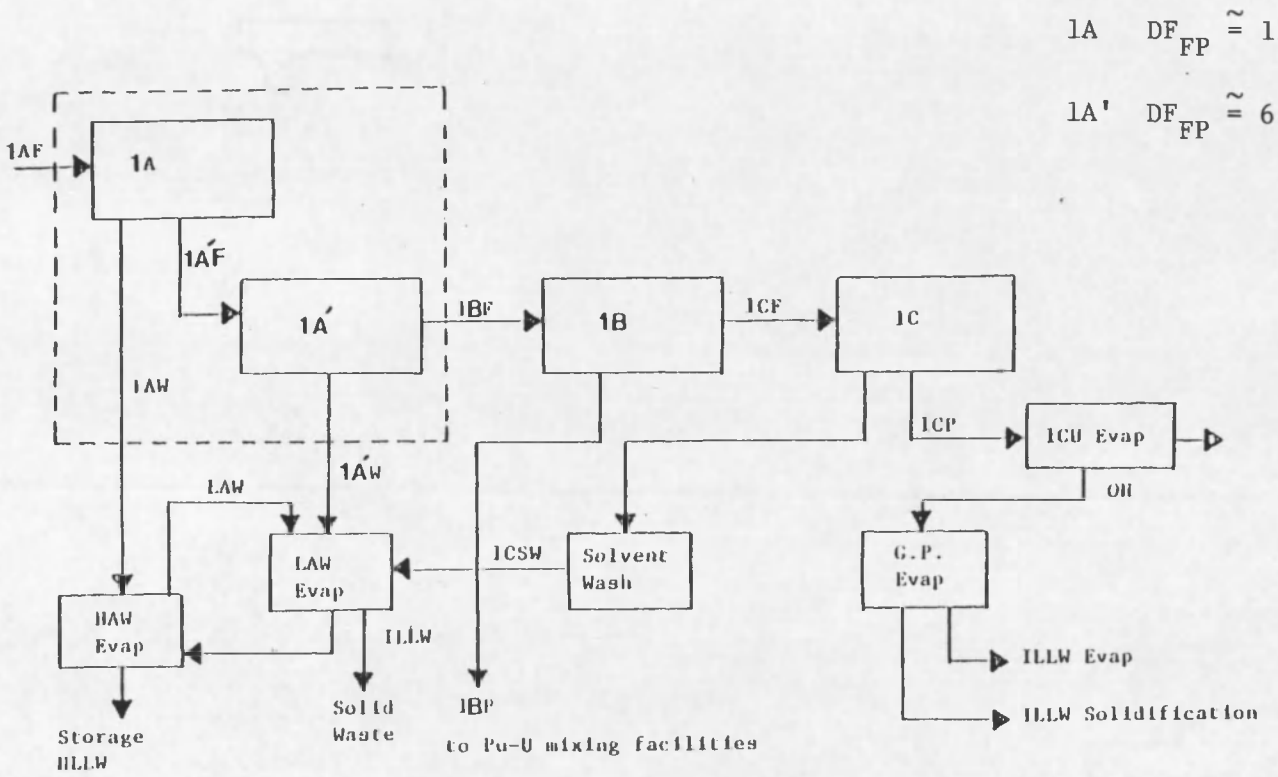


Fig. 2.2 First Solvent Extraction Cycle with its Acid Recovery System for LWR and LMFBR. -- Coprocessing.

traces of uranium remain with the plutonium in the 1BP product stream (approximately 0.1% uranium in case of LWR fuel, 3% for the LMFBR). The 1C acts as a scrubber for further decontamination of the uranium stream 1CF. Since the plutonium is purified only once in the codecontamination cycle consisting of 1A and 1A'--in contrast to the usual three decontamination cycles--less solvent is used, which leads to a reduced amount of low active waste due to solvent clean-up operations. The decontamination factor for the plutonium amounts to only 10^3 and the plutonium stream is later mixed with uranium makeup. The final product of the coprocessing step has a Pu/U ratio lying in the range 11 to 25%, respectively. The Tables 2.1 and 2.2 give an insight into the streams within the solvent extraction cycle. After having gone through the sections 1A and 1A', where the bulk of the fission products is removed, the uranium is extracted back into the aqueous phase in the 1C column. Table 2.1 demonstrates that most of the fission products and americium/curium follow the plutonium product stream 1BF (Benedict and Pigford 1957, pp. 279-285). The 1CU uranium stream is further decontaminated by two more cycles, which are shown in Fig. 2.3. The total decontamination factor for uranium eventually reaches 10^7, the requirement for feed to the isotope enriching plants.

The scrubbing sections 1C, 1E, and 2E generate waste which is directed to ILLW (intermediate level liquid waste) evaporators; the solvent from these three scrubbing sections goes through the solvent cleaning systems 1CSW, 1ESW, and 2ESW, respectively. LAW (low active waste) is generated in the 1A' column of the first cycle and in the extraction columns 1D and 2D of the uranium purification system.

Table 2.1. First Extraction Cycle and Associated Acid and Organic Recovery System (LWR Fuel).*

		1AF	1AW	1AW	1BF	1BP	1CU
Flow Rate, ℓ/h		1394	2178	419	5200	638	1122
U-238, g/h		398×10^3	26.7	26.7	398×10^3	3.9	393×10^3
Pu-239, g/h		3.7×10^3	1.86	~1.8	3.7×10^3	3.7×10^3	1.5
Fiss. Pr., G/h		12×10^3	11.9×10^3	68.	12.	10.8	1.2
Np, g/h		238.	235.	1.9	.36	.2	.02
Ru, Ci/h		1.1×10^5	1.1×10^5	103	11.4	7.6	2.5
Zr-Nb, Ci/h		3.65×10^4	3.64×10^4	327	36.4	32.55	3.3
HNO_3, mole/ℓ		2.5	2.45	2.08	.077	.67	.22
TBP, %		-	-	-	-	-	-
Actinides, g/h	Am	85.83	85.74	-	-	.09	-
	Cm	17.29	17.27	-	-	.02	-

*Based on 10 MgHM/day
Burnup of 33,000 MWd/Mg
Cooling time 160 days

Table 2.2 First Extraction Cycle and Associated Acid and Organic Recovery System (for LMFBR Fuel).*

	1AF	1AW	1A'W	1BF	1BP	1CU
Flow Rate, ℓ/hr	3082	3846	4892	5946	7560	3894
Uranium, g/hr	385.5×10^3	<192	<192	385.11×10^3	716.75	384.4×10^3
Pu-239, g/hr	24.4×10^3	<12.2	<12.2	24.38×10^3	24.37×10^3	9.88
Fiss. Pr., Ci/hr	2.14×10^6	2.126×10^6	12.11×10^3	2.163×10^3	2160.74	.876
Acid HNO_3, Mole/ℓ	3.2	3.34	-	3.09	2.86	.035
Ru-106, Ci/hr	412875	410123	2335.4	417.04	325.58	91.45
g/hr	123.34	122.518	.698	.125	.098	.027
Ce-144, Ci/hr	33708.33	33483.6	190.6	34.049	27.85	6.19
g/hr	10.56	10.49	.06	.011	.009	-
Am-241, g/hr	361.26	358.5	2.043	.365	.365	-
Am-243, g/hr	135.01	134.11	.764	.136	.136	-
Cm-244, g/hr	4.81	4.78	.027	.005	.005	-
Cm-244, g/hr	9.9	9.834	.056	.01	.01	-

*Based on 10 MgHM/day
Burnup of 40,800 MWd/Mg (Core and blankets mixed proportionally)
Cooling time 200 days

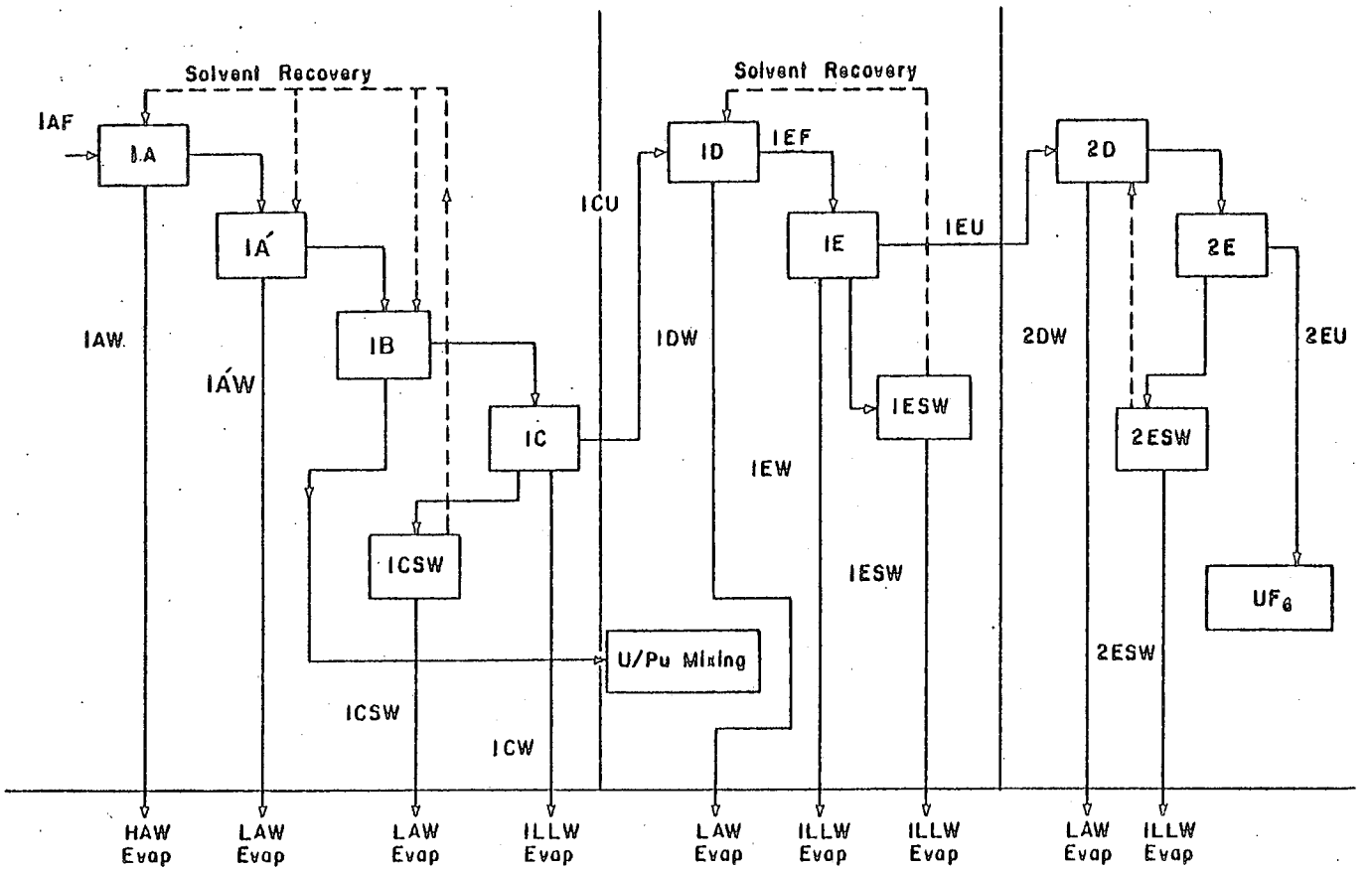


Fig. 2.3 COPRO Solvent Extraction Block Flow Diagram (LWR).

CHAPTER 3

COPROCESSING TECHNICAL DESCRIPTION

3.1 Assumptions and Computation Method

This study is based on a flow sheet as presented in Fig. 2.1. All essential steps of spent fuel treatment are contained there. The technical description of coprocessing assumes that the uranium-plutonium cycle is the reference LWR fuel cycle. The coprocessing plant has a capacity of 3000 MTHM - fuel per year at a load factor of .82, this is equivalent to 10 MTHM to the processing plant per day. The model is based on coprocessing of BWR, PWR and LWR reference fuel, the latter having a representative mixture of BWR and PWR. Table 3.1.1 shows some characteristics of these fuels. This table serves as the input to the burnup calculation for which code ORIGEN (Bell 1973) was employed, the output of which is the basis for the calculation done on this model. Numerical values for the head-end of the coprocessing plant were done by aid of program COPRO (Appendix B) and the flow values of solvent extraction cycles were calculated using code SX (Appendix C).

3.2 Fuel Receipt and Storage

The coprocessing plant receives discharged fuel from the power reactor. This irradiated fuel is packaged in large, rugged containers, frequently with liquid coolant. A certain portion of the fuel elements may be found to be defective and releasing part of their radioactivity

Table 3.1.1 Fuel Characteristics

	PWR[1]	BWR[2]	"Reference" LWR[3]
Overall Assembly Length, m	4.059	4.470	---
Cross Section, cm	21.4 x 21.4	13.9 x 13.9	---
Fuel Element Length, m	3.851	4.064	---
Active Fuel Height, m	3.658	3.759	3.70
Fuel Element OD, cm	0.950	1.252	1.16
Fuel Element Array	17 x 17	8 x 8	121
Assembly Total Weight, kg	668.6	279	454.32
Uranium/Assembly, kg	461.4	188.7	311.4
MO_2/Assembly, kg	523.4	214.1	353.28
Zircaloy/Assembly, kg	129.7	56.7	89.55
Hardware/Assembly, kg	15.5	8.2	11.485
Total metal/Assembly, kg	145.2	64.9	101.03

1 - (Westinghouse, 1975)
2 - (General Electric)
3 - (ERDA 76-43, 1976)

to the coolant. At shipment, the irradiated fuel will have been "cooled" about 160 days, on the average. The total radioactivity in the fuel will be approximately 4.34×10^6 curies per metric ton of irradiated fuel. After this cooling period, the containers are to be shipped to the reprocessing plant. At shipment, a maximum of 1% of the fuel rods is assumed to be damaged, with the consequences that fission products are released from the rod void spaces into the shipping cask coolant. Based on experiments the concentration of radioactivity in the cask water should range from 10^{-4} to 10^{-2} $\mu Ci/cm^3$ (Wash-1238 1975, pp. 29-81). Table 3.2.1 illustrates maximum activity in void space. For high burnup fuel, a level of 1 $\mu Ci/cm^3$ has been estimated; beside fission products, it may include a mixture of corrosion and activation products. The total activity in the coolant is based on approximately 1 m^3 and 0.1 m^3 coolant for rail and truck transportation, respectively, giving amounts of 1 Ci and 0.1 Ci. Assuming that each rail cask contains 3.2 Mg of irradiated fuel and a truck cask 0.5 Mg, 4.2 m^3 of contaminated water will be generated per day (based on a fuel reprocessing capacity of 10 Mg per day and a fuel shipment of 1/3 by truck 2/3 by rail). If the cask coolant is contaminated above .02 $\mu Ci/m^3$ (NUREG 0009 1976, p. 5-2), the cask water is pumped to a waste treatment system, where it will contribute to ILLW (intermediate level liquid waste) and general purpose evaporator flow with radioisotopes showing up in spent resins, filter sludges, and evaporator slurry.

Table 3.2.1 Irradiated Fuel Rod Void Space Activity. -- (Burnup 33000 Mwd/Mg)

Nuclide	Total Inventory Ci/Mg 150 days Cooling	Percent in Void Space of Fuel Rods	Activity in Void Spaces Ci/Mg
Kr-85	1.12×10^{4}	30	3.36×10^{3}
Xe-131m	1.78	2	3.56×10^{-2}
I-129	3.74×10^{-2}	30	1.12×10^{-2}
I-131	.923	2	1.85×10^{-2}
H-3	691	1	6.91
Other F.P.	4.19×10^{6}	0.01	4.49×10^{2}
Actinides	1.26×10^{5}	None	None

For a 3000 MgHM fuel coprocessing plant, the fuel receipt and storage building contains two systems of five interconnected pools of water with a total fuel capacity of 800 MgHM. Two of the pools are cask unloading pools, each of which holds approximately 871 m^3 of water. The fuel assemblies are moved from the casks in portable storage canisters into these pools, then to the fuel storage pool (2044 m^3 of water). In the fuel transfer pool, the fuel assemblies are prepared for shear and dissolver. A fifth pool, the failed-fuel pool, is provided for fuel assemblies which leak or are damaged. The capacity of these two pools together is 1079 m^3. Based on available literature, the activity in the storage pool water is primarily due to cesium-137 and 134. Data from storage pool operations have validated this assumption; the total volumetric activity of the pool water is about 5×10^{-2} $\mu Ci/m^3$ (NUREG 0009 1976, p. 5-5).

The liquid radioactive waste in the fuel receiving and storage station is divided into two main categories: low level ($<.02$ $\mu Ci/cm^3$) and high level ($>.02$ $\mu Ci/cm^3$).

- The high level tank will receive waste from the cask cooldown system, cask cooldown filter system back flush, regeneration liquids of ion exchanger columns, and pool cooling system backflush. The approximate concentration in the high level tank is 60 $\mu Ci/cm^3$ consisting mainly of fission products.
- The low level tank will receive regeneration waste from pool cleanup operations at a maximum of 9 μCi Cs-137/cm^3. These

wastes are routed to the waste evaporation and solidification system.

- The pool cleanup system consists of filtration and demineralization wastes of the pool water. The regeneration solutions from this system drain to the low level tank. This system has a Cs-137 load of 4 Ci/day.
- Off-gas system. A sintered metal filter in the cask cooldown system will provide rough filtration of gases released during venting and cooling down. There are usually two HEPA filters in the off-gas stream to collect particulate activity and a silver zeolite column to absorb iodine. If the radioactive load causes the dose rate to exceed 10 mrem/h at 1 ft, the units will be replaced. In Table 3.2.2, the isotropic composition of the fuel receiving and storage waste is given: In Table 3.2.3 the main constituents of the waste from this part of the fuel cycle are given.

3.3 Shearing, Tritium Removal, Dissolving

In the shearing area, fuel assemblies are cut into small sections of approximately 2 cm in order to increase the UO_2 area for dissolving. To prevent fires from zirconium fines produced by the shearing operation, an inert gas purge system is provided. Waste from the shearing station comprises end fittings from fuel elements, HEPA filters from the shear purge, approximately 2.27 m^3 of filter deionizer for a 10 mg/day operation, and argon from the purge system contaminated with traces of krypton, xenon, and iodine.

Table 3.2.2 Radioactive Content of Waste Generated in Fuel Recovering and Storage Station. -- Inventory 800 Mg, Burnup 33000 MGW/Mg, 160 Days Cooling, 2% Failed Fuel.

Nuclide	Curie/Year	Pathway
H-3	415	Air/Water
Kr-85	1.98×10^{5}	Air
I-129	673.	Air/Water
I-131	1.11	Air/Water
All Other β-γ	.02	Water
All α	2×10^{-7}	Water

Table 3.2.3 Waste from Fuel Receipt and Storage

Waste Form	Waste Type	Quantity (m^3/yr)
HEPA Filters	Combustible β-γ	.85
Spent Resins	Combustible β-γ	1.2
Cask Wash (ext.)	LLW to General Purpose Evap.	1419
Demineralizer Waste and Filter Flushes	ILLW to Waste Evapor. (5% NaOH, 5% HNO_3)	4315
Cask Vent, Failed Fuel Container Vent	Off-Gas (Helium)	934
Fuel Unloading Vent and Storage Pool Vent	Stack (Air)	1.7×10^{9}

Tritium Removal: Voloxidation as a tritium removal process has not yet been demonstrated, but it is close to demonstration (DPST-LWR-77-1-1, DPST-LWR-76-4-1 1977) and was therefore included in the model. This process releases tritium as the oxide and some of the noble gases and other volatile fission products from the sheared oxide fuel by heating and oxidizing it in air. (About 10% of Kr 85 is released to DOG at this stage of process.) UO_2 oxidation starts at 450°C, and cooling of the voloxidizer is provided by excess air. The cooling air is routed through HEPA filters, while the off-gas containing tritium and other gaseous fission products goes through ruthenium adsorbers and a set of sintered metal filters and HEPA filters. This off-gas treatment is the major factor in controlling the amount of tritium being released. Since the tritium is in the form of tritiated water, its removal by adsorption on Zeolite is quite efficient. The overall tritium removal efficiency in coprocessing plant was estimated to be 99% at this stage.

The recovery of ruthenium by the Ru-sorber occurs at a rate of 10g/Mg of fuel which corresponds to 2% of the total Ru inventory. A decontamination factor across Ru-sorber was assumed to be 10^8. Solid wastes in the form of HEPA filters and Ru-sorbers are sent to the solid waste facility. Based on available information, two HEPA filters per month are needed for that process (Wash 1322 1972). The radioactive load on the ruthenium amounts to 12,000 Ci of ruthenium per Mg of fuel; the apportioned volume of sorber is 10 ℓ/day.

Dissolver: The spent fuel is dissolved in nitric acid. Most of the volatile fission products such as iodines and much of the noble

gases are removed by the off-gas treatment system. Zircaloy hulls remain undissolved and are rinsed with nitric acid in order to remove traces of uranium and plutonium attached to the hulls; after final rinsing with NaOH, the hulls are transferred to fixation and final disposal. They are part of the high-level waste. In order to keep accumulation of insoluble solids--such as Zircaloy fragments, undissolved fuel, and insoluble fission products as low as possible, flushing of the dissolver is applied, which results in the formation of dissolver sludge. The sludge is routed to the solid waste facility. The hull rinse is treated in the waste evaporator and acid recovery system.

Approximately 87% of the krypton is sent to the off-gas treatment system (DOG), where krypton can be retained with an efficiency of approximately 90%, according to the current status of low temperature techniques, the KALC (Krypton Adsorption Liquid Carbon dioxide)(Notz 1973, p. 318). Dissolver flush and hull rinse amount to approximately 630 ℓ per Mg of fuel and contain up to 3 kg Zircaloy, 26 kg NaOH, and 0.3 kg fission products, and less than .2 kg of plutonium. They end up on the waste evaporator and acid recovery and then the solid waste facility. Table 3.3.1, the Isotopic Composition of different streams of the shearing, Tritium Removal and Dissolver processes are shown.

Table 3.3.1 Wastes and Product of Shearing and Tritium Removal and Dissolver. -- HLW, LAW and LLW Fuel Coprocessing Case (input in gram).

FUEL POOL CAPACITY 800MTHM STEADY STATE FLOW OF MATERIAL 10.00MTHM/DAY BURNUP 33000.000MWD
COOLING TIME 160DAY,

ALL VALUES OF THIS TABLE IS IN UNITS OF GRAM/M**3 OF FLOW OF MATERIAL PER DAY

ISOTPE	SHEARING					DISSOLVER[3]		DOG[2]	H-3 REMOVAL[1]	
	STAINLESS STEEL	INCONAL 718	ZIRCALOY TWO	ZIRCALOY FOUR	HALL	RINSE	FLUSH		OFF GAS	FEED TO SX[4]
STRUCTRAL**********										
H 3	0.	0.	0.	0.	1.59E-07	5.85E-11	5.95E-09	0.	0.	0.
HE 4	0.	0.	0.	0.	2.36E+00	8.68E-04	8.84E-02	0.	0.	0.
C 14	0.	0.	0.	0.	0.	0.	0.	4.56E-14	0.	0.
AL 27	0.	1.08E+03	0.	0.	0.	0.	0.	0.	0.	0.
P 32	1.96E-15	0.	0.	0.	0.	0.	0.	0.	0.	0.
S 32	6.95E-11	2.74E-12	0.	0.	0.	0.	0.	0.	0.	0.
S 35	7.88E-23	3.11E-24	0.	0.	0.	0.	0.	0.	0.	0.
TI 48	1.31E+03	0.	0.	0.	0.	0.	0.	0.	0.	0.
CR 50	1.83E+03	5.03E+02	0.	5.80E+00	1.13E+05	4.14E+01	4.21E+03	0.	0.	0.
CR 53	2.22E+04	6.11E+03	0.	7.15E+01	1.37E+06	5.03E+02	5.13E+04	0.	0.	0.
MN 54	2.16E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
MN 55	1.78E+03	0.	0.	0.	0.	0.	0.	0.	0.	0.
FE 54	1.96E+03	1.42E+02	0.	3.26E+00	6.02E+04	2.22E+01	2.26E+03	0.	0.	0.
FE 55	6.43E+00	4.64E-01	0.	1.07E-02	1.97E+02	7.25E-02	7.38E+00	0.	0.	0.
FE 56	3.08E+04	2.22E+03	0.	5.10E+01	9.44E+05	3.47E+02	3.53E+04	0.	0.	0.
FE 59	3.57E-03	2.58E-04	0.	5.91E-06	1.09E-01	4.02E-05	4.10E-03	0.	0.	0.
CO 58	0.	2.14E-01	0.	0.	0.	0.	0.	0.	0.	0.
CO 59	0.	4.83E+02	0.	0.	0.	0.	0.	0.	0.	0.
CO 60	0.	5.15E+01	0.	0.	0.	0.	0.	0.	0.	0.
NI 59	1.94E+02	3.14E+02	0.	0.	0.	0.	0.	0.	0.	0.
NI 63	3.48E+01	5.64E+01	0.	0.	0.	0.	0.	0.	0.	0.
CU 65	0.	2.74E+02	0.	0.	0.	0.	0.	0.	0.	0.
ZN 64	0.	0.	0.	0.	1.67E-02	6.14E-06	6.25E-04	0.	0.	0.
ZN 65	0.	0.	0.	0.	2.89E-06	1.06E-09	1.08E-07	0.	0.	0.
ZN 66	0.	0.	0.	0.	8.88E-02	3.27E-05	3.33E-03	0.	0.	0.
ZR 90	0.	0.	0.	6.40E+04	1.20E+09	4.42E+05	4.50E+07	0.	0.	0.
ZR 91	0.	0.	0.	1.38E+04	2.59E+08	9.53E+04	9.70E+06	0.	0.	0.
ZR 92	0.	0.	0.	2.14E+04	4.02E+08	1.48E+05	1.50E+07	0.	0.	0.
ZR 93	0.	0.	0.	2.02E+01	3.78E+05	1.39E+02	1.42E+04	0.	0.	0.
ZR 94	0.	0.	0.	2.16E+04	4.05E+08	1.49E+05	1.52E+07	0.	0.	0.
ZR 95	0.	0.	0.	1.24E-01	2.33E+03	8.56E-01	8.71E+01	0.	0.	0.
ZR 96	0.	0.	0.	3.40E+03	6.53E+07	2.40E+04	2.45E+06	0.	0.	0.
NB 95	0.	2.48E+00	0.	0.	0.	0.	0.	0.	0.	0.
MO 94	0.	5.00E+02	0.	0.	0.	0.	0.	0.	0.	0.
MO 95	0.	9.06E+02	0.	0.	0.	0.	0.	0.	0.	0.
MO 96	0.	2.47E+00	0.	0.	0.	0.	0.	0.	0.	0.
RU101	0.	0.	0.	0.	2.44E+01	8.97E-03	9.14E-01	0.	0.	0.
SN125	0.	0.	0.	1.23E-10	2.30E-06	8.46E-10	8.61E-08	0.	0.	0.

Table 3.3.1 -- Continued

FUEL POOL CAPACITY 800MTHM STEADY STATE FLOW OF MATERIAL 10.00MTHM/DAY BURNUP 33000.000MWD
COOLING TIME 160DAY,

ALL VALUES OF THIS TABLE IS IN UNITS OF GRAM/M**3 OF FLOW OF MATERIAL PER DAY

ISOTPE	STAINLESS STEEL	SHEARING INCONAL 718	ZIRCALOY TWO	ZIRCALOY FOUR	HULL	DISSOLVER RINSE	DISSOLVER FLUSH	DOG	H-3 REMOVAL OFF GAS	FEED TO SX
HEAVY ELEMENTS**********										
HE 4	0.	0.	0.	0.	0.	1.11E-04	0.	6.74E-11	0.	1.08E-01
RN220	0.	0.	0.	0.	0.	8.22E-16	0.	5.01E-22	0.	8.03E-13
RN222	0.	0.	0.	0.	0.	4.29E-17	0.	2.62E-23	0.	4.19E-14
RA224	0.	0.	0.	0.	0.	4.72E-12	0.	2.88E-18	0.	4.61E-09
RA225	0.	0.	0.	0.	0.	2.94E-16	0.	1.79E-22	0.	2.87E-13
RA226	0.	0.	0.	0.	0.	6.67E-12	0.	4.07E-18	0.	6.52E-09
U232	0.	0.	0.	0.	0.	1.15E-07	0.	7.02E-14	0.	1.13E-04
U233	0.	0.	0.	0.	0.	1.61E-06	0.	9.80E-13	0.	1.57E-03
U234	0.	0.	0.	0.	0.	4.03E-02	0.	2.46E-08	0.	3.94E+01
U235	0.	0.	0.	0.	0.	2.64E+00	0.	1.61E-06	0.	2.57E+03
U236	0.	0.	0.	0.	0.	1.50E+00	0.	9.16E-07	0.	1.47E+03
U238	0.	0.	0.	0.	0.	3.11E+02	0.	1.90E-04	0.	3.04E+05
NP236	0.	0.	0.	0.	0.	4.56E-62	0.	2.78E-68	0.	4.45E-59
NP237	0.	0.	0.	0.	0.	1.59E-01	0.	9.70E-08	0.	1.55E+02
NP238	0.	0.	0.	0.	0.	5.85E-27	0.	3.56E-33	0.	5.71E-24
NP239	0.	0.	0.	0.	0.	2.58E-08	0.	1.57E-14	0.	2.52E-05
PU236	0.	0.	0.	0.	0.	3.92E-07	0.	1.19E-13	0.	1.91E-04
PU238	0.	0.	0.	0.	0.	1.10E-01	0.	3.36E-08	0.	5.39E+01
PU239	0.	0.	0.	0.	0.	3.48E+00	0.	1.06E-06	0.	1.70E+03
PU240	0.	0.	0.	0.	0.	1.43E+00	0.	4.37E-07	0.	7.00E+02
PU241	0.	0.	0.	0.	0.	6.67E-01	0.	2.03E-07	0.	3.26E+02
PU242	0.	0.	0.	0.	0.	2.34E-01	0.	7.12E-08	0.	1.14E+02
AM241	0.	0.	0.	0.	0.	1.53E-02	0.	9.33E-09	0.	1.49E+01
AM242	0.	0.	0.	0.	0.	3.73E-09	0.	2.27E-15	0.	3.64E-06
AM243	0.	0.	0.	0.	0.	3.12E-02	0.	1.90E-08	0.	3.04E+01
AM244	0.	0.	0.	0.	0.	6.27E-29	0.	3.82E-35	0.	6.13E-26
AM245	0.	0.	0.	0.	0.	2.02E-18	0.	1.23E-24	0.	1.97E-15
CM242	0.	0.	0.	0.	0.	1.70E-03	0.	1.03E-09	0.	1.66E+00
CM243	0.	0.	0.	0.	0.	2.64E-05	0.	1.61E-11	0.	2.58E-02
CM244	0.	0.	0.	0.	0.	9.81E-03	0.	5.98E-09	0.	9.58E+00

Table 3.3.1 -- Continued

FUEL POOL CAPACITY 800MTHM STEADY STATE FLOW OF MATERIAL 10.00MTHM/DAY BURNUP 33000.000MWD
COOLING TIME 160DAY,

ALL VALUES OF THIS TABLE IS IN UNITS OF GRAM/M**3 OF FLOW OF MATERIAL PER DAY

ISOTPE	STAINLESS STEEL	SHEARING INCONAL 718	ZIRCALOY TWO	ZIRCALOY FOUR	HULL	RINSE	DISSOLVER FLUSH	DOG	H-3 REMOVAL OFF GAS	FEED TO SX
FISSION PRODUCT**********										
H 3	0.	0.	0.	0.	0.	0.	0.	0.	1.25E-04	2.30E 04
KR 84	0.	0.	0.	0.	0.	0.	0.	3.95E-02	1.47E-04	8.90E-14
KR 85	0.	0.	0.	0.	0.	0.	0.	9.93E-03	3.69E-05	2.24E-14
KR 86	0.	0.	0.	0.	0.	0.	0.	6.81E-02	2.53E-04	1.53E-13
ZR 90	0.	0.	0.	0.	0.	9.25E-03	0.	5.64E-09	0.	9.03E100
ZR 91	0.	0.	0.	0.	0.	2.00E-01	0.	1.22E-07	0.	1.95E102
ZR 92	0.	0.	0.	0.	0.	2.19E-01	0.	1.34E-07	0.	2.14E102
ZR 93	0.	0.	0.	0.	0.	2.43E-01	0.	1.48E-07	0.	2.37E102
ZR 94	0.	0.	0.	0.	0.	2.61E-01	0.	1.59E 07	0.	2.55E102
ZR 95	0.	0.	0.	0.	0.	3.90E-03	0.	2.37E-09	0.	3.81E100
ZR 96	0.	0.	0.	0.	0.	2.75E-01	0.	1.67E-07	0.	2.68E102
NB 95	0.	0.	0.	0.	0.	3.96E-03	0.	2.42E-09	0.	3.87E100
RU101	0.	0.	0.	0.	0.	2.57E-01	0.	1.56E-07	2.84E 01	1.99E102
RU103	0.	0.	0.	0.	0.	7.63E-04	0.	4.65E-10	8.44E-04	5.91E-01
RU104	0.	0.	0.	0.	0.	1.80E-01	0.	1.10E-07	1.99E-01	1.39E102
RU106	0.	0.	0.	0.	0.	4.26E-02	0.	2.60E-08	4.71E-02	3.30E101
RH103	0.	0.	0.	0.	0.	1.26E-01	0.	7.71E-08	0.	1.24E102
RH103M	0.	0.	0.	0.	0.	7.63E-07	0.	4.65E-13	0.	7.45E-04
RH106	0.	0.	0.	0.	0.	3.73E-08	0.	2.27E-14	0.	3.64E 05
AG110	0.	0.	0.	0.	0.	2.42E-11	0.	1.48E-17	0.	2.37E 08
CD133	0.	0.	0.	0.	0.	7.36E-05	0.	4.49E-11	0.	7.19E 02
SN125	0.	0.	0.	0.	0.	3.02E 10	0.	1.84E-16	0.	2.95E-07
SN126	0.	0.	0.	0.	0.	6.34E-03	0.	3.86E-09	0.	6.19E100
I129	0.	0.	0.	0.	0.	0.	0.	7.94E-02	1.94E 03	2.85E-13
I131	0.	0.	0.	0.	0.	0.	0.	2.62E-09	6.40E-11	9.40E-21
I132	0.	0.	0.	0.	0.	0.	0.	6.15E-20	1.50E 21	2.21E-31
XE133M	0.	0.	0.	0.	0.	0.	0.	2.53E-26	8.95E-29	7.02E-38
XE133	0.	0.	0.	0.	0.	0.	0.	2.70E-12	9.57E-15	7.50E-24
XE136	0.	0.	0.	0.	0.	7.63E-01	0.	4.65E-07	0.	7.45E103
CS133	0.	0.	0.	0.	0.	3.34E-01	0.	2.03E-07	0.	3.26E102
CS134	0.	0.	0.	0.	0.	5.38E-02	0.	3.28E-08	0.	5.26E101
CS135	0.	0.	0.	0.	0.	1.07E-01	0.	6.52E-08	0.	1.05E102
CS137	0.	0.	0.	0.	0.	4.06E-01	0.	2.48E-07	0.	3.97E102
CE141	0.	0.	0.	0.	0.	5.25E-04	0.	3.20E-10	0.	5.13E 01
CE144	0.	0.	0.	0.	0.	7.79E-02	0.	4.75E-08	0.	7.61E101

Table 3.3.1 -- Continued

**********	
1-TRITIUM REMOVAL,CELL VENTILATION AIR TO SAND FILTER	5.66E+06M**3/DAY
TRITIUM REMOVAL FURENACE COOLING AIR TO SAND FILTER (11 DEGREES C TEMP. RISE)	5.66E+03M**3/DAY
SHEARING CELL PURGE, ARGON WITH TRACE OF KR,XE,I AND H	1.70E+03M**3/DAY
TRITIUM REMOVAL OFF GAS (FURENACE PURGE)	5.66E+03M**3/DAY
2-DISSOLVER OFF GAS (DOG).	2.83E+04M**3/DAY
SHEARING FILTER DEIONIZER REGEN (ILLW) 5 0/0 NAOH AND 5 0/0 HNO	2.27E+00M**3/DAY
3-HALL RINSE , (NAOH ,NANO3 AND H20)	3.03E+00M**3/DAY
DISSOLVER RINSE (NITRIC ACID)	3.03E+00M**3/DAY
DISSOLVER FLUSH (NAOH AND H20)	3.03E-01M**3/DAY
4-RAW METAL SOL'N TO SOLVENT EXTRACTION (HNO3 AND NH4OH)	3.10E+01M**3/DAY

3.4 Solvent Extraction

In addition to the more general description of the coprocessing flow sheet in Chapter 2, the approach to a quantitative assessment of streams and nuclide distribution is going to be discussed in this section.

Coprocessing proposed in this study uses the basic Purex solvent extraction technology. The process utilizes a number of simple and compound columns (the compound column is composed of scrubbing and extraction sections and it is center fed). In the flow sheet (Fig. 2.3) the codecontamination of the Raw Metal Solution (RMS) coming from feed clarification is done by 1A and 1A' compound columns, with combined decontamination factor of about 10^3. The 1A column removes the bulk fission product and 1A' contactor provides an additional decontamination under conditions which favor the scrubbing of Zr, Nb, and Ru compound.

The uranium-plutonium separation is performed in the partitioning column by adding reductant such as ferrous ion to the feed of this contactor. The valence state of plutonium is changed to non-extractable form pu (III).

$$Pu^{4+} + Fe^{2+} + NH_2SO_3^- \rightleftharpoons Pu^{3+} + Fe^{3+}\ NH_3SO_3^-$$

The sulfamate acts as a nitrite suppressor (Cleveland 1979, p. 463). The uranium bearing stream (1CF) overflows the 1B column and flows into the bottom of scrubbing column 1C. The product-free solvent (1CW) is route to the solvent recovery. The aqueous effluent (1CP) is steam-stripped of residual organic phase, and concentrated in the ICU concentrator to meet the final uranium cycles feed specifications.

The second and third uranium purification cycles (Fig. 2.3) have a total decontamination factor of 10^4, changes in the decontamination of the product streams are brought about through variations of flows in the columns 1A and 1A' only. As the decontamination factors in these contractor increases, the waste streams 1AW and 1A'W are growing accordingly, the latter giving rise to solid non high-level waste in the waste evaporation facility.

As mentioned in Chapter 2, the plutonium is purified only once in the codecontamination cycle (1A, 1A') leading to savings in the amount of low active waste, such as spent solvent, resins, etc. It is the purification of the plutonium in a second and third cycle, not present in the coprocessing flow sheet, that constitutes the main difference in waste production compared to a standard Purex system. Table 3.4.1 shows the streams in the second and third Pu purification cycle; the savings due to omission of these two cycles amount to approximately 3500 ℓ of 1AW per hour.

It should be remembered that in both cases (standard reprocessing and coprocessing) the final products or uranium and plutonium are evaporated before being sent to the UF_6 production and Pu conversion plants, respectively. The values in Table 3.3.2 are those before evaporation.

The ratio Pu/U in Table 3.4.2 is 1000 for the plutonium stream; this ratio is changed to an approximate value of 10 prior to conversion by adding U-238 from the head end of the fuel cycle. This blending occurs with a concentrated natural uranium nitrate solution to produce

Table 3.4.1 Waste from Second and Third Pu Purification Cycles. -- (Reprocessing); Pu Product to Pu Conversion

	Second Pu Cycle LAW Evap. (HLLW)	Third Pu Cycle* LAW (HLLS)
Flow, ℓ/h	1484	2126
Uranium, g/h	6.8×10^{-4}	4.2×10^{-3}
Plutonium, g/h	.38	<.1%
Zr/Nb, Ci/h	32.7	-
Ru, Ci/h	7.6	-
F.P., g/h	12.6	105

Product Pu from Reprocessing Plant to Pu Conversion

Flow, ℓ/h	75.3
U, g/h	3.8
Pu, kg/h	3.7
FP, g/h	4.4×10^{-6}
Ar, Nb, Ru, Ci/ℓ	3.1×10^{-3}
HNO_3, mole/h	2.96

*Like the second cycle, the third cycle comprises three streams leaving the two contactors. One of these streams consists of evaporator condensate, which concentrates the Pu stream for Pu conversion (≈454 ℓ/h).

Table 3.4.2 Product Streams from Solvent Extraction. -- See Fig. 2.3, LWR Coprocessing before final concentration.

	Plutonium (1BP)	Uranium (2EU)
Flowrate, ℓ/h	638	6244
Uranium, g/h	3.96	386.5×10^{3}
Plutonium, g/h	3.7×10^{3}	8.7×10^{-8}
FP, g/h	10.8	7.49×10^{-3}
Np, g/h	.2	6.6×10^{-3}
Ruthenium, Ci/h	7.66	2.75×10^{-3}
Zr-Nb, Ci/h	32.6	6×10^{-3}
α Emitters, Ci/h	-	5.22
Am, Cm	<1% feed	
HNO_3, mole/ℓ	.67	0.032

a "master-mix". Feed batches to coconversion are sufficiently large to permit a two weeks operation of each coconversion line on a solution having uniform plutonium isotopic composition.

Flow ratios for columns in solvent extraction were calculated by aid of code SX (Appendix C). The code uses extension to the Kremser-Brown equation (Smith 1963, p. 257). This equation is applicable to the problem if the following assumptions are made;

- The equilibrium and operating curves for the column are linear
- The output flows of each stage of a column are at chemical equilibrium
- Steady state conditions are reached

The computer program is able to calculate all flows for a given number of extraction and scrubbing stages (calculation of solvent extraction is based on the assumption of discrete stages, preferentially when the separation is done in stage-wise equipment such as mixer-settlers). The average distribution coefficient for isotopic species in input to the calculation, i.e., which is constant throughout a column.

3.5 Waste Treatment Systems

To describe the system properly, the different types of waste should be defined at this point:

- High level liquid waste HLLW). This waste is composed of two classes within itself: High Active Waste (HAW) which is produced by the 1A column of the first solvent extraction cycle; it contains ~ 99% of all fission products. Low Active Waste (LAW) is produced primarily by the 1A' column and in the

plutonium evaporator overhead. Generally, LLW is produced by all plutonium purification cycles; these are eliminated in the coprocessing plant. LAW contains about 1% of the fission products.

- Intermediate level liquid waste (ILLW). This type of waste is generated by aqueous solvent extraction washes from the purification of uranium and contains lower concentrations of fission products than LAW. This waste does not contain appreciable amounts of uranium and/or plutonium.
- Low level liquid waste (LLLW). These are condensates of ILLW evaporators. LLLW are monitored and may need some treatment before being released to the environment.

Waste Evaporation and Acid Recovery (Docket 50-332-57 1974)

This system accepts HLLW and ILLW from solvent extraction and other parts of the coprocessing plant. The main function of this system is to reduce the storage requirements for such waste. After HLLW and ILLW are evaporated, the condensates from this evaporation are further processed to recover nitric acid and water for reuse in the plant. The results of the acid recovery processes, condensate, and overhead are channeled to proper storage areas prior to solidification. Figure 3.5.1 shows a simplified version of waste evaporation and acid recovery. As stated above, HLLW is broken down into HAW and LAW and is guided to HAW and LAW evaporators, respectively. Each of these evaporators is composed of two stages: in the case of the LAW evaporator, the concentrate from the first stage is passed through an agitated anion-exchange

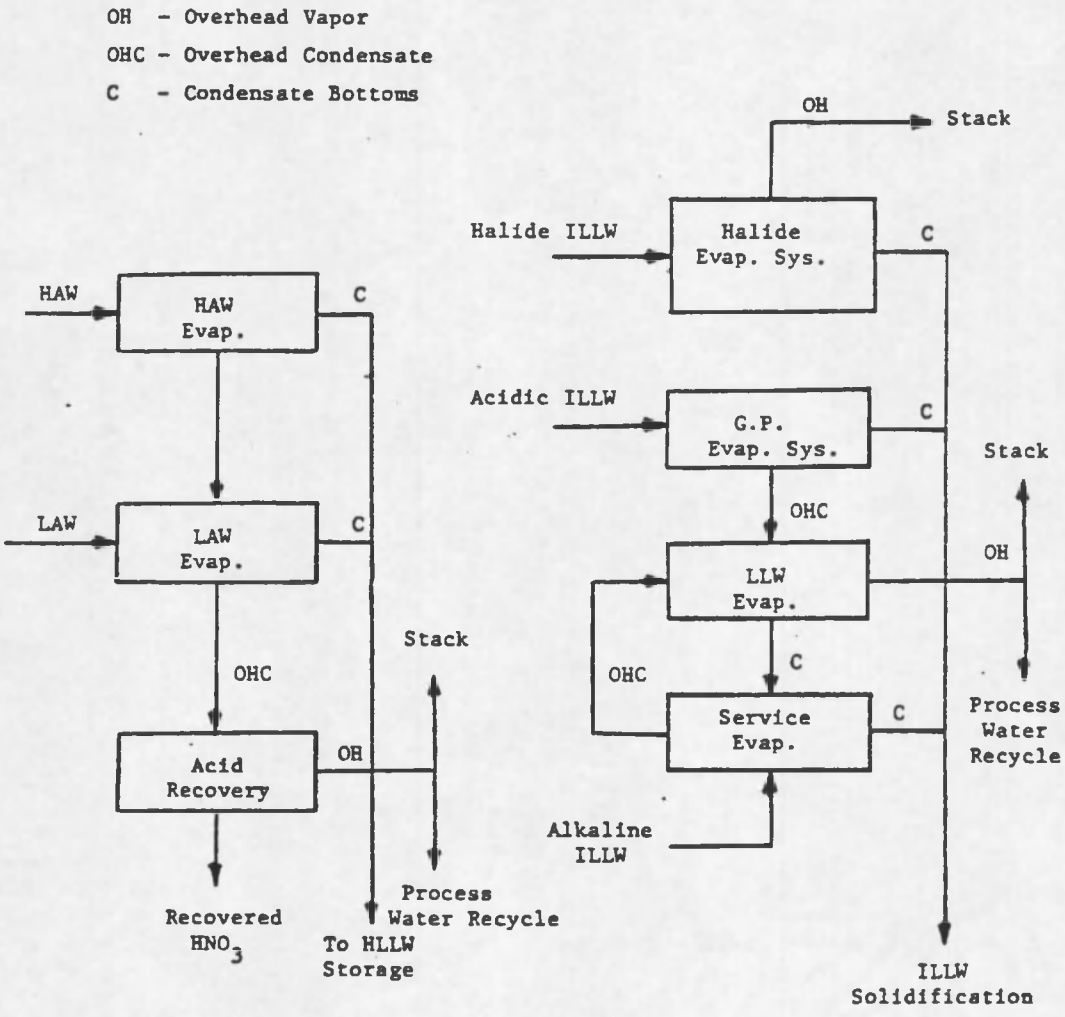


Fig. 3.5.1 Waste Evaporation and Acid Recovery Block Diagram.

column to recover plutonium. The acidic concentrate bottoms from the first stage of the HAW evaporator; feed clarification slurry, solids, and anion-exchange column products are then sent to the HLLW tanks. The operation in both systems, HAW and LAW, is carried out by adding a solution of sugar to suppress ruthenium oxidation, and volatilization. The overhead, from the second HAW stage and the first stage of the LAW evaporator, is sent to the second stage of the LAW evaporator; from there, the overhead is routed to the acid recovery unit. The product of this last stage is nitric acid to be used in the plant and water, some of which is evaporated through the off-gas system. The overhead of the second stage LAW evaporator consists of about 269 m^3 per day (based on the processing of 10 MgHM per day) which contains 13.2 w/o nitric acid. In the acid recovery, this is separated into 57 m^3 of 50% HNO_3 to be recycled and 212 m^3 of water, containing approximately 0.05% HNO_3. All the products of the acid recovery system have low level activity. This facility is also used for the UF_6 acidic waste.

Depending upon its origin (acidic, alkaline, halide), ILLW is routed to one of three evaporator systems:

- The general purpose (G.P.) evaporator concentrates ILLW, generated by the uranium evaporator condensates in SX (solvent extraction) and the solvent wash wastes from the uranium cycles, plus the external cask wash and some water from solid waste facilities and UF_6. These wastes are acidic, and their total volume amounts to approximately 300 m^3/day (see Table 3.5.1). The overhead of this evaporator is then sent to the LLW

Table 3.5.1. Wastes from Uranium Purification Cycles. -- For LWR Fuel.

	Codecontamination Cycle		Second U Cycle			Third U Cycle	
	1CW (ILLW)	1CSW* (LAW)	1DW (LAW)	1EW (ILLW)	1ESW (ILLW)	2DW (LAW)	2ESW (ILLW)
Flow, ℓ/h	7063	125	2109	5360	84	2107.	84
Uranium, g/h	35.3	38.7	40.0	39.7	39.5	40.	39.5
Plutonium, g/h	1.4×10^{-4}	.36	1.39	0	.02	5.9×10^{-4}	0
Zr/Nb, Ci/h	2.8×10^{-4}	.36	3.16	1.4×10^{-2}	1.6×10^{-2}	1.4×10^{-4}	7.3×10^{-4}
Ru, Ci/h	2.1×10^{-3}	1.24		2.3×10^{-4}	4.2×10^{-2}	6.32	.14
FP, g/h	1.06×10^{-4}	7.77	1.2	1.7×10^{-3}	1.9×10^{-2}	-	.08
NF-239, g/h	1.8×10^{-4}	.22	2×10^{-2}	$3.\times10^{-7}$	3.2×10^{-2}	2.7×10^{-3}	1.4×10^{-5}
HNO_3, mole/h	-	-		-	-	2.33	-

*Treatment of LAW leads to 54 ℓ/h solid waste.

evaporator. In the G.P. evaporator, the activity at the inlet amounts to 128.4 μCi/kg, while the overhead condensate leaving this unit has only 1.7×10^{-3} μCi/kg (and is routed back to the LLW processor) and consists of approximately 450 Mg of liquid per day.

- The service evaporator concentrates ILLW wastes which are alkaline in nature. Typical waste streams include decontamination solutions, laundry wastes, wastes from all building floor drains not located in a high radiation area, and fuel storage pool wastes. The volume of these waste streams varies, depending upon the activities in the plant, but the amount of waste can be estimated to be 270 Mg/day with activities of 24.8 mCi/kg (approximately 3 Mg/day of which are contributed by the MOX fabrication). The mass reduction factor for this evaporator is 0.993, the output to the LLW evaporator has a specific activity of 25.3 μCi/kg.
- The halide waste evaporator concentrates waste streams containing some quantities of chlorides or fluoride. Such wastes include laboratory waste, raffinate from the Plutonium Ion exchanger recovery column in the Pu conversion process. The waste stream to the evaporator has an activity of 2.7×10^{-2} Ci/kg and the mass is reduced by 9.7%.

LLW Evaporator

Overheads from the general purpose and service evaporators are combined to produce an LLLW waste stream which is routed to the

low level waste (LLW) evaporator for further concentration. The concentrated bottom of the LLW evaporator is recycled to the service evaporator, and the overheads are either condensed and reused as process water or vaporized and discharged to the atmosphere.

The total condensed bottoms from the G.P., Service, and halide waste evaporators are directed as indicated in Fig. 3.5.1 and quantified in Table 3.5.2 to the ILLW solidification.

3.6 UF_6 Production

In this section of the model, the $UO_2(NO_3)_2$ originating in the solvent extraction purification cycles is converted to UF_6, which is shipped to the uranium enrichment facility. The UF_6 facility receives purified uranium nitrate solution from solvent extraction (Table 3.4.2) in an accountability tank where it is weighed, sampled, and transferred to storage tanks. Then the uranylnitrate solution (61.8 g U/ℓ) is concentrated in an evaporator to approximately 1089 g U/ℓ, becoming UNH.

Uranium conversion is based on a demonstrated four-step process (ORNL/NUREG/TM-37 1977).

The denitration process is based on thermal decomposition of uranyl nitrate hexahydrate to uranium trioxide by the following series of reactions:

$$UO_2(NO_3) \cdot 6H_2O \longrightarrow UO_2(NO_3)_2 + 6H_2O$$

$$HO_2(NO_3)_2 \longrightarrow UO_3 + N_2O_4 + \tfrac{1}{2}O_2$$

Table 3.5.2 Concentrated Bottoms Form G.P., Service, and Halide Evaporators to ILLW Solidification

	G.P.	Service	Halide
Mass, Mg/day	1.045	1.807	1.1
Activity, Ci/kg	51×10^{-3}	$25. \times 10^{-3}$	27×10^{-3}
Pu, g/day	6.75×10^{-3}	-	7.97
U, g/day	-	-	29.94
F.P. Activity, Ci/Kg	$50. \times 10^{-3}$	25×10^{-3}	27×10^{-3}
Actinides, Ci/Kg	$.095 \times 10^{-3}$	$.0824 \times 10^{-3}$	-

The temperature at which these reactions take place are generally between 300°C to 400°C.

Then, uranium dioxide is prepared by reduction of UO_3 with hydrogen, utilizing the fluidized bed reactor technique developed at Oak Ridge. The reaction is presented by the equation:

$$UO_3 + H_2 \longrightarrow UO_2 + H_2O$$

Heat is applied to the reactor at the beginning of a cycle to increase its temperature from abiant to a value in range of 540°C to 620°C. Once the reaction has been initiated, heat must be removed from system because of the exthermic nature of the reaction. Careful control of the temperature is essential at this stage of the process.

In the next step uranium tetrafluoride is prepared by reaction of HF with UO_2 at temperatures of 350°C to 600°C according to the equation:

$$UO_2 + 4HF \longrightarrow UF_4 + 2H_2O$$

The reaction is highly exothermic. The product of this stage is 93% UF_4 ("green salt") with 5% UO_2 and 2% UO_2F_2. The model plant uses a fluidized bed fluorinator as reference method with CaF_2 as dilutent to control the highly exothermic reaction.

$$UF_4 + F_2 \longrightarrow UF_6$$

Excellent conversion of UF_4 to UF_6 can be obtained when operating in the temperature range of 425°C to 565°C. The reaction

rate is extremely fast under these conditions and increases rapidly with the temperature. Such a condition can place a heavy load on the reactor. Hence, CaF_2 is used in the bed as heat exchange medium and to dilute the UF_4. Periodic removal of the fluorinator bed material is needed to control the buildup of plutonium and fission products in the system. Filtered UF_6 product is then passed through two cold-traps which are in series in order to remove impurities in UF_6. This is done by first freezing to get the impurities out and finally be heating the cold-traps to vent the UF_6 liquids. The product usually has less than 0.5 w/o HF. Table 3.6.1 shows some of the waste generated by the UF_6 facility. The off-gas is treated by going through a scrubber after leaving the cold-trap to prevent release of F_2 and HF to the atmosphere. The scrubber is followed by an absorber and filter. A solution of KOH is used to purify the off-gas. K_2UO_4 is part of the recovered solid waste and is drummed for storage.

3.7 Coconversion of Plutonium and Uranium

The coconversion of plutonium and uranium is a critical step in the coprocessing flow sheet of LWR fuel. The process of coconversion of plutonium and uranium nitrate solutions to mixed power is under investigation by the General Electric and DuPont Companies. The process is dubbed "coprecal" (CONF-780304 1978 pp. VII-15; - VII-16), which is a short form of coprecipitation-calcination. It is done by first adding ammonium hydroxide to concentrated plutonium-uranium nitrate solution to produce divided slurry of ammonium diuranate and plutonium hydroxide. Next, both slurries are introduced to an elutriative fluid bed unit

Table 3.6.1. Waste in UF_6 Production Normalized to 10 MTHM.

Liquid Waste	
Water from Concentration and Other Processes to G.P. Evap. (78 kg HNO_3/day)	146.57 Mg/day
Acid from Acid Recovery from Calcination	28.7 m^3/day (.18 mole HNO_3)
Solids	
Spent Electrolyte	1814 kg/day
Fluorination Tower Waste (CaF_2 + Ash)	152.4 kg/day (contains Pu and F.P.)
Solid K_2UO_4 Mud from Cold Trap	43.54 kg/day
Solid KOH + CaF_2 from Cold Trap	1251.91 kg/day (2.61 ^{w}/o KOH)

until they are calcined to UO_3-PuO_2. Then it is further reduced by mixing 6% hydrogen in nitrogen at high temperature to produce UO_2-PuO_2. The powder is treated with hot carbon dioxide gas to stabilize the powder, so that reoxidation is inhibited when contacted with air.

The 1BP stream (Fig. 2.1, Table 3.4.2) containing uranium, plutonium and traces of fission products, carries approximately 89 kg of plutonium and 0.1 kg of uranium per day with a flow rate of approximately 15.3 m^3/day. This flow is concentrated by a factor of about 8 in a final evaporation. So the 1BP stream feeding into a coconversion facility has a flow rate of 2.1 m^3/day or 42.7 mgHM/Cm^3. In a next step, some of the uranium from the UF_6 facility is mexed with this stream to bring the concentration of heavy metal up to 400 mg/m^3. This can be done in two ways:

1) Wet mixing: Concentrated uranium nitrate from the UF_6 facility is mixed with the 1BP stream.
2) Dry mixing: UO_2 from the reductor is mixed with Puo_2, Pu_2 which has been denatured with natural uranium to a Pu/U ratio of 1/9.

The first alternative is more practical at this time. After bringing the concentration of 400 mgHM/m^3 of solution, a certain quantity of natural uranium solution (from the head end of the fuel cycle) is added to produce a "master mix" containing 10% plutonium in the U-Pu product (Fig. 3.7.1 shows a schematic of this facility).

The feed to coconversion is provided in a sufficiently large batch so that the feed solution is uniform in isotopic composition.

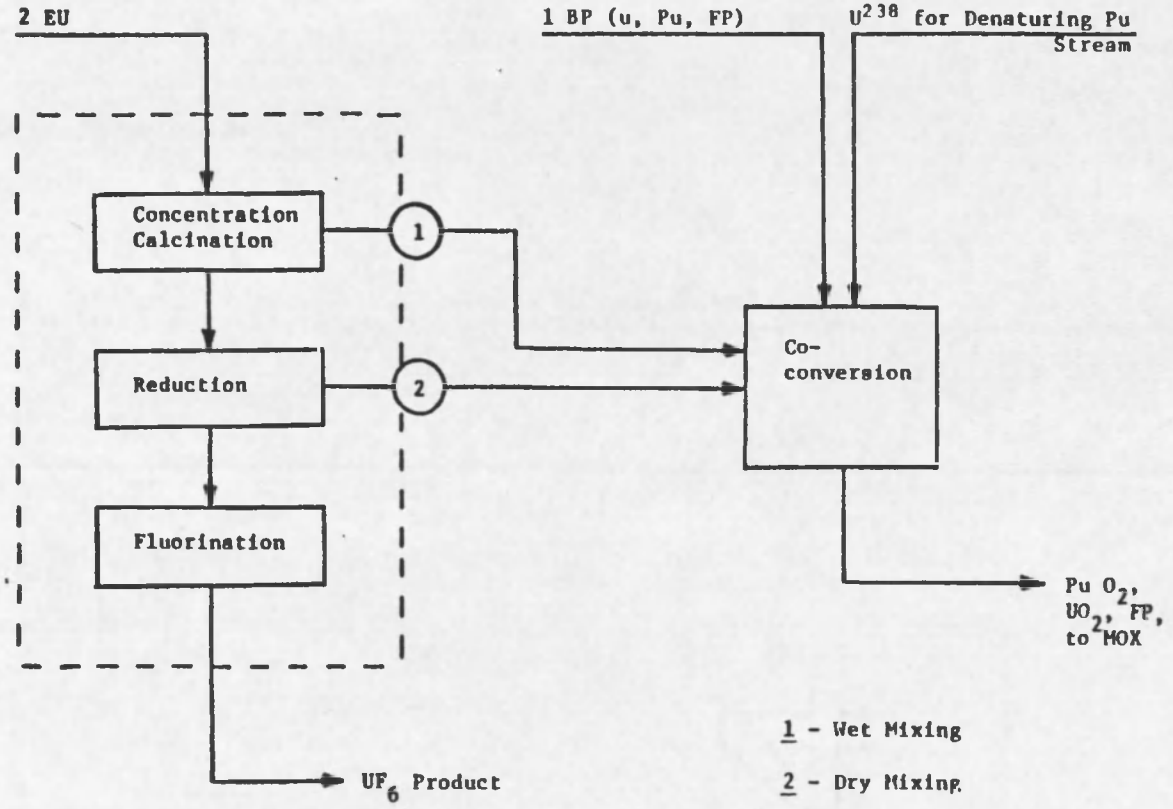


Fig. 3.7.1 Coconversion Facility.

The product of the conversion is then sent to the MOX fuel fabrication. All processes in this facility are done in caves. The final product consists of approximately 1 Mg of PuO_2-UO_2 per day with an activity of 2.146 KCi. The acidic and aqueous waste of this process can be recycled; solid waste consists of spent filters and resins. As the facilities are not yet developed fully, assumptions about waste quantities have to be made.

3.8 Off-Gas Treatment

The atmospheric releases of radioactive radioisotopes from a fuel processing plant are greatly reduced by the use of effluent treatment systems. Figure 3.8.1 shows the block diagram for the vessel off-gas (VOG) and dissolver off-gas (DOG) systems (ORNL/NUREG/TM-6 1977).

The present off-gas systems include voloxidation and trapping for tritium (or HTO) removal, fluorocarbon absorption of Kr-85 and C-14 (as CO_2) (the process is called KALC: Krypton Absorption in Liquid Carbon dioxide), volatilization of I-129 and I-131 from dissolver solutions followed by sorption in a scrubber system, filtration of particulates by HEPA filters, and Ru by silicagel beds. This system is designed to meet all existing NRC requirements.

The majority of gaseous radionuclides is released in the head end of the fuel processing plant, which includes fuel shearing, tritium removal, and dissolver operations. Radioactive gases from H-3 removal are first passed through a silver zeolite bed to recover iodine. The effluents are combined with the argon shear purge (and the shear cell

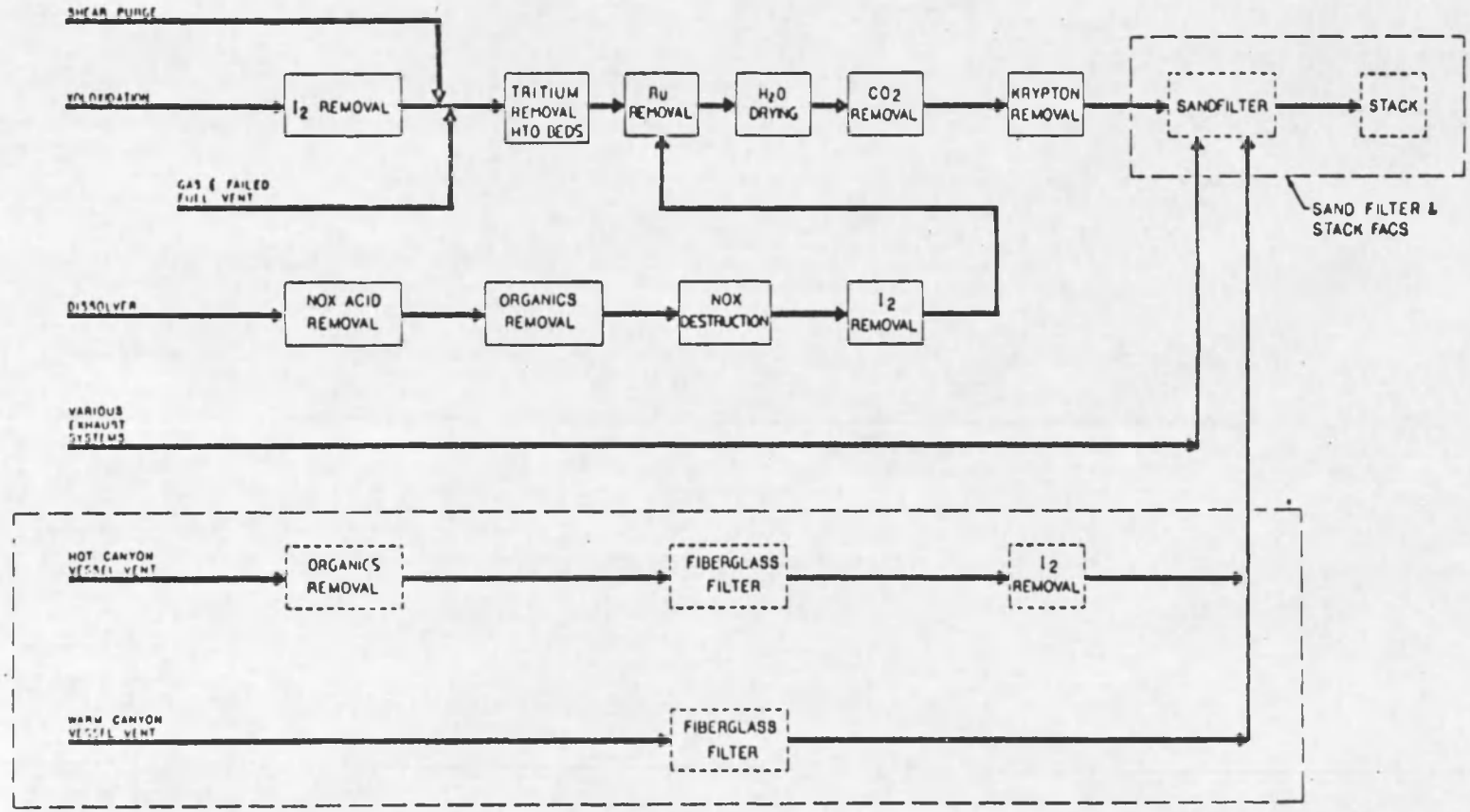


Fig. 3.8.1. Off Gas Treatment System.

purge, if contaminated) and passed through the tritium recovery system. H-3 is oxidized to HTO and absorbed on special zeolite beds (Yarbro 1974).

The off-gas from the dissolver is first passed through a stainless steel-wool ruthenium abosrption bed, then through NO_x recovery. After that, this flow is treated to remove TBP vapor and more of the iodine. This flow is combined with effluents from the HTO recovery system and is further purified from C-14 and Ru-103, 106. Finally, Kr-85 is recovered by a selective absorption process using R-12 (dichlorodifluoromethane).

Table 3.8.1 shows the flow rates and order of magnitude of activities of the off-gas system. The total discharge to sand filters is 1.56×10^6 m^3/hr. The sand filters are a final step in removal of particulates before the off-gas is discharged to the environment.

Sand filters are long-lived, have high efficiency of particulate retention, and high air permeability. To obtain these qualities, a flow velocity of about 2.5 to 3 cm/sec is suitable, leading to an efficiency of approximately 99.95%. After passing through sand filters, the flow is routed through a series of HEPA's and is finally released to the atmosphere at the top of a 200 ft stack. The activity of the stock air is listed in Table 3.8.2, based on data from various sources.

In a final Table 3.8.3, the solid waste generated by dissolver off-gas and vessel off-gas treatment is shown.

Table 3.8.1 Off-Gas Treatment Flows*

Stream	m^3/day	Gas Composition	Ci/m^3
Failed Fuel Vent	3.12	He,I,Kr,H^3	1.55
Purge Shear	1430	Argon,Kr,Xe,I,H	
Voloxidation Furnace Purge	4764	Air,HTO,Kr,I,Xe,Ru	1.2×10^{-3}
Dissolver Off-Gas	2.38×10^4	Air,NO_X,Kr,I,Xe,CO_2	
Vessel Vent Hot Canyon	3.43×10^5	Air,Solvent (TBP) F.P.	2.5×10^{-4}
HLLW Tank Off-Gas Warm Canyon and Vitrification	4.05×10^4	Air,F.P.	3.5×10^{-3}
Off-Gas-to-Sand Filter			
Various Exhaust Systems	7.13×10^6	Air, Impurities (NO_x,CO_2)	nil
Off-Gas Treated (Purified)	2.38×10^5	Air	nil
Off-Gas Treatment Bldg. Rent	21.76×10^3	Air	nil
Other Building Rents			
(ILLW, ILLW, Vessel, etc. Rent)	3.01×10^7	Air, (NO_x,CO_2)	nil

*Flow rate per 10 MTHM/day.

Table 3.8.2 Estimated Mainstack Gas Composition

Species	Concentration $\mu Ci/Dm^3$	Concentration ppm
NO_x	---	5
Kr-85	4.45×10^{-4}	---
	8×10^{-3}	8×10^{-3}
HTO, HT	1.75×10^{-5}	---
	3×10^{-5}	4×10^{-4}
I_2-129	4.45×10^{-11}	---
	3×10^{-12}	2×10^{-5}
Ru-106	4.45×10^{-8}	---
	1×10^{-9}	---
C-14	3.11×10^{-8}	---

Table 3.8.3 Waste Generation by DOG, VOG Treatment. -- Based on a fuel throughput of 10 Mg/day.

Facility	Quantity (ℓ/day)	Activity Ci/day
I Removal (Silver Exchanged Mordenite Beds)	7.4	~1.12 (I-129, 131)
HTO Sieve Bed	.08	772
Sorbent CO_2 as $CaCO_3$	40.	---
HEPA Filters	792.	4965 (TRU,α)
	736	10 (FP,β-γ)
Ru Adsorbers	10	6.8×10^{3}*
Sand Filter m^{3}** (Gravel and Sand)	39000	---

*This activity si calculated at 270 days after discharge of fuel from reactor.

**The lifetime of the sand filter is not known.

CHAPTER 4

FUEL CYCLE IMPACT

4.1 Operational Impacts

Should the coprocessing with partial decontamination option be adopted, various steps in the fuel cycle will be effected in a variety of ways. But, coprocessing, by itself creates relatively minor changes in the traditional fuel reprocessing in way of plant design, equipment, or operational constraints. This fact is its basic and most important advantage of a coprocessing strategy. In the case of reactors and fuel fabrication, coprocessing with partial decontamination will introduce some impact over that previously projected for mixed-oxide fuel cycle.

In reprocessing facilities, only a few pieces of equipment will be directly affected. Major changes as mentioned in the Chapter 3 will be in the solvent extraction's first cycle 1A and 1B contactors and the coconversion facilities, however, in order to ensure that the equipment, and flow sheet of facility are not modified to produce a pure plutonium stream, new operating and monitoring constraints could be imposed.

The basic designs required to achieve the conversion and partial separations dictated by coprocessing are not expected to be much different from the conventional reprocessing hardware. The technological challenge would be to design equipment that is temper-resistant and inherently limits the separation or mixing of uranium and plutonium,

to those concentrations specified by coprocessing concept. While it may be theoretically possible to design equipment to limit the product (CONF-780304 1978 pp. v-7 - v-9), it would be extremely difficult to do so practically.

The conversion step is the most heavily impacted portion of the fuel cycle because of the large increase in volume throughput. For comparison purposes in pure plutonium conversions plant servicing a 10 mg/day reprocessing a throughput volume of only about 60 kg/day of PuO_2 would be expected. The throughput volume increases to 1 mg/day of PuO_2 - UO_2 in case of coprocessing with partial decontamination. This increase in the throughput volume will increase the radiation level and the number of processing lines, which will result in higher operating risks. The operation of multiple lines will also increase maintenance requirements, sampling and analytical needs, and operating crew size in a manner far less efficient than normally assumed when scaling up a process for greater throughput. One advantage is a gain of reliability, because of multitrain process equipment.

4.2 Resource Impacts

Coprocessing has a negligible impact on the overall uranium and enrichment requirements when it is compared to previous plutonium LWR recycling concepts. However, coprocessing can play an important role in increasing the effective uranium and enrichment supply by helping to provide a plutonium utilization fuel cycle that is acceptable for use. If coprocessing can enable plutonium and uranium to be recycled to LWR's, the potential exists for reducing the uranium requirements by

about one-third and the enrichment requirements by about one-fourth. Of still more importance is the potential that coprocessing has for demonstrating commercial-scale plutonium processing such that there will be an existing technical base from which a viable breeder program can be launched. The breeder option represents one of the few demonstrated sources for meeting the energy needs of the 21st century and prudent energy planning should ensure that this option remains open. From the standpoint of global security and stability, the lack of adequate power may well be a greater risk than the risk that nations will use the fuel cycle as a source for nuclear weapons.

4.3 Advance Reactor Concepts

The coprocessing strategy for LWR uranium-plutonium fuel cycle appears practical and achievable. This is made possible by the fact that utility reactors are not significantly affected and the existing infrastructure needs not suffer major dislocation. The experiences with mixed oxide fuel implant minor changes in fuel rod composition within a fuel assembly (all-rod concept for PWR and island design for BWR), it is possible to utilize current reactors (Regional Nuclear Fuel Cycle Centers 1977 pp. 167-191).

Coprocessing appears to easily integrate into the more commonly proposed advanced reactor concepts (Williams 1978). One parameter that must be defined to enable coprocessing service a wide range of reactor concepts is the degree of proliferation risk associated with products containing upwards of 25-30% plutonium. Without such definition, the application of coprocessing to breeder fuels may be

jeopardized. It should be noted that while the majority of data in this report has assumed an LWR fuel cycle as the reference case, there have been no identified factors that prevent coprocessing from being successfully applied to a breeder fuel cycle or to mixed LWR and breeder cycles.

Undenatured (no U-238) thorium cycles could logically incorporate the coprocessing concepts by utilizing thorium as the chemical diluent for the fissile U-233. In general, with the presence of U-238 in the flow sheet, the recovery system will be required to handle a combination of not only thorium and uranium, but also the plutonium which is produced in the reactor form the fertile U-238. The plutonium could be coprocessed using portions of the U-238 present as diluent or it could be diluted with depleted uranium after having been recovered in purified form. The coprocessing plant's main stream would process the bulk thorium and uranium such that the U-233/U-238 mixture would be the proper proportion for recycle. The actual ratio of U-238 denaturant and thorium diluent to the U-233 fissile product will likely be determined by reactor physical considerations more than non-proliferation attributes (LA-7411-MS 1978).

CHAPTER 5

SUMMARY AND RECOMMENDATION

Coprocessing with partial decontamination is one alternative which can help to meet nonproliferation objectives in the nuclear fuel cycle. Its implementation requires change in only two steps of the nuclear fuel cycle, a relatively minor change in the reprocessing concept, and a substantial development effort in the field of coconversion of uranium and plutonium solutions. It is one of the attractive features of the coprocessing option that an incremental reduction in diversion risk is gained at a relatively small increase in fuel cycle complexity. Basically, there are two coprocessing techniques: In one the partitioning of plutonium and uranium from irradiated fuel is performed without producing a pure plutonium stream. In this version plutonium is chemically diluted with uranium whose main constituent is fertile uranium-238 (Pobereskin 1977). A second approach, which served as a model for this study, uses the traditional Purex flow sheet but confines the plutonium product stream to heavily shielded, inaccessible areas of the plant until uranium diluent is added (DPST-AFCT-77-1-2).

An objective of this study was to estimate the non high level wastes generated in this modified reprocessing facility. This assessment is based on the amounts of waste encountered in the Purex process and related operations. Even though not too many detailed data are

available, this analysis was aided by the fact that the main steps in the reprocessing flow sheet are similar for both coprocessing and standard Purex. The most striking difference lies in the omission of a second and third plutonium purification cycle. All other processes are found in both reprocessing alternatives. In order to quantify the savings in waste production, equal waste categories should be compared; in terms of LAW production, comparison is based on one Mg of fuel processed:

Coprocessing:	54 ℓ/h of LAW stemming from codecontamination	
	422 ℓ/h of LAW from second and third uranium cycle	
Total:	476 ℓ/h	
Standard Purex:	476 ℓ/h	
	148	} Waste from 2nd and 3rd Pu Purification (Table 3.3.1)
	213	
Total:	837 ℓ/h	
Savings:	361 ℓ/h (≈58%)	

Besides these savings, there are also penalties which contribute especially to solid waste which cannot be quantified as easily as the liquid waste mentioned above. The product stream 1BP from solvent extraction to the U-Pu conversion is contaminated with FP's and actinides, which requires additional precaution in adding to the solid waste in the form of small equipment and HEPA filters.

The coprocessing flow sheet as it is presented in this document suggests the following conclusions:

- The inherently safe nuclear fuel cycle cannot be established. The safeguarding measures already in effect have reduced the risk to a relatively low level. A coprocessing measure will only result in an incremental reduction of such a risk.
- As an effective method of non-proliferation measures, any technical control should be supplemented with institutional controls.
- Coprocessing with partial decontamination can be a substantial deterrent to potential diverters who are members of a subnational group. The increases in mass of material that has to be diverted plus the activity of this material will reduce its attractiveness.
- The technology required for coprocessing is readily available, therefore the option coprocessing can be applied to nuclear fuel cycle in a short period of time.
- No major barrier have been identified which would prevent orderly implementation of the coprocessing and partial decontamination into LWR or breeder

fuel cycle. Implementation timing would largely be dependent on the lead time required for facility design and construction. Furthermore coprocessing with partial contamination does not aggravate existing sensitive nuclear issues such as waste disposal but on the contrary it would be a method to reduce high active waste (Patrashakorn 1980).

This document considered only LWR fuel cycle. In order to complete the perspective of nuclear fuel cycle, further studies in the following areas are recommended:

1) Reactor physic calculation concerning recycle of fission products.
2) Development of a general computer code for Pu-U, Th-U fuel coprocessing using the codes "COPRO" and "SX".

APPENDIX A

MASS BALANCE AND RADIOACTIVE PROCESS LOSSES FOR LWR COPROCESSING FUEL CYCLE

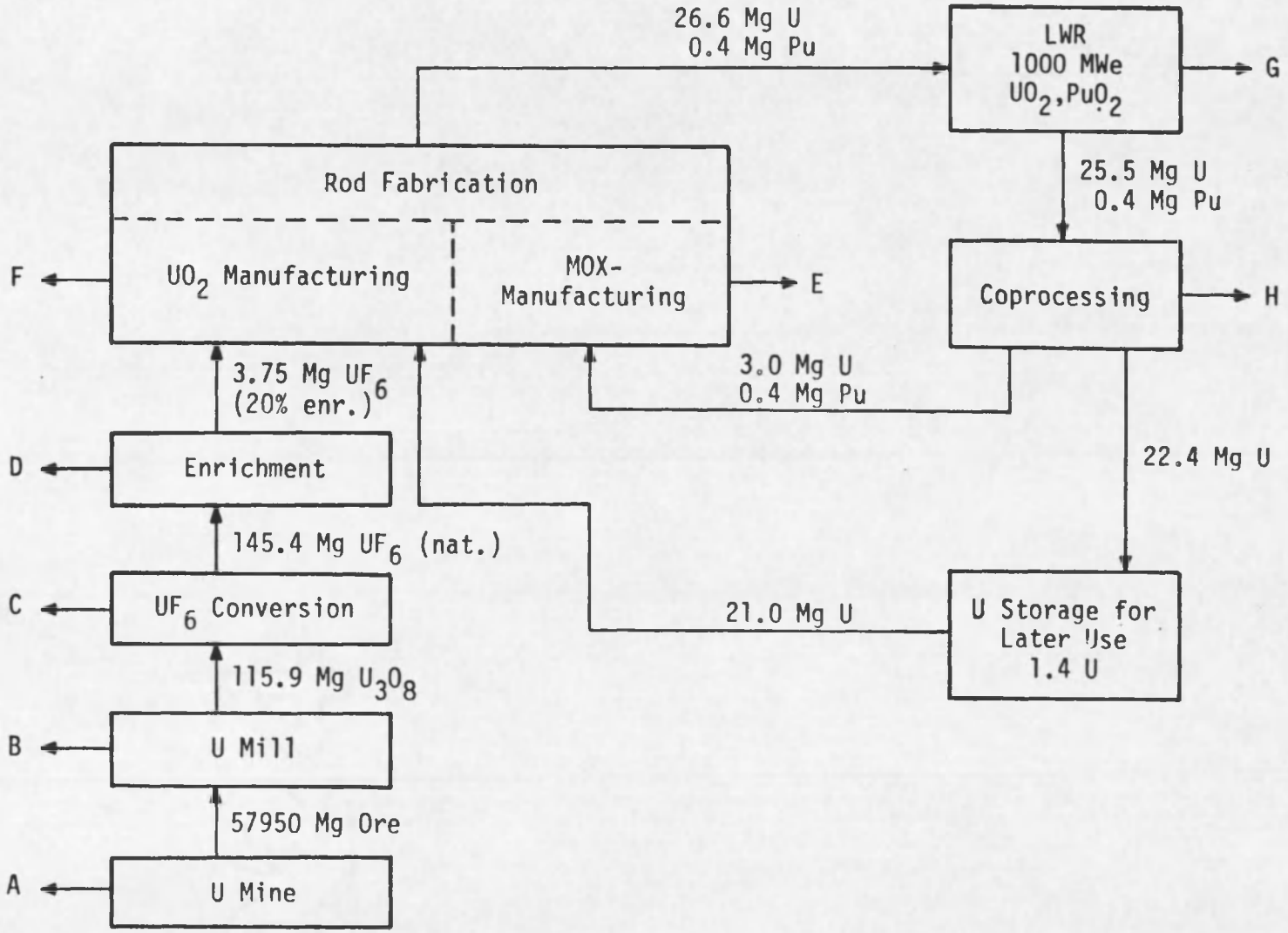


Fig. 1 Coprocessing Fuel Cycle with Process Indices for Table 1.

Table 1 Radioactive Process Losses and Effluents. -- A LWR cycle using coprocessing.

Index	Isotopes	State		Concentration	Mass	Radioactivity	
		Physical	Chemical	(μCi/ml)	(Mg)[b]	(Ci)	(Bq)
A U-Mining		Liquid			4.7 E 5 m^3		
	U-238		oxides	7.3 E-8	3.1 E-2	1.0 E-2	3.8 E 8
	U-235		oxides	1.1 E-9	2.3 E-4	4.9 E-4	1.8 E 7
	U-234		oxides	2.3 E-8	1.7 E-6	1.0 E-2	3.8 E 8
	Th-234		oxides	2.3 E-8	4.6 E-13	1.0 E-2	3.8 E 8
	Ra-226		oxides	2.3 E-8	1.0 E-8	1.0 E-2	3.8 E 8
	Other			1.7 E-7	5.5 E-7	7.8 E-2	2.9 E 9
		Gaseous					
	Rn-222		Rn	1.4 E-12	9.1 E-10	1.4 E 2	5.1 E 12
	Rn-222 daughters		NA	6.5 E-10	3.7 E-7	6.3 E 2	2.3 E 13
B U-Milling	U (tails)	Solid	oxides		5.9 E 4	1.6 E 4	5.7 E 14
	U daughters		oxides		(tails)		
	U (tails pond)	Liquid	oxides, ions	NA	3.8 E 4m^3[c]	Not Released	
	U daughters						
	U (natural)			5.2 E-7		NA	
	Th-230		Th(IV)	1.4 E-5		NA	
	Ra-226		Ra(II)	2.3 E-7		NA	

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity (Ci)	(Bq)
		Physical	Chemical				
		Gaseous					
	U-238		oxides	2.0 E-16	5.9 E-2	2.0 E-2	7.2 E 8
	U-235		oxides	9.1 E-18	4.2 E-4	9.1 E-4	3.4 E 7
	U-234		oxides	2.0 E-16	3.2 E-6	2.0 E-2	7.2 E 8
	Th-234		NA	1.0 E-16	4.2 E-13	9.8 E-3	3.6 E 8
	Pa-234m		NA	1.0 E-16	1.4 E-17	9.8 E-3	3.6 E 8
	Th-231		NA	9.1 E-18	1.7 E-15	9.1 E-4	3.4 E 7
	Pa-231		NA	9.1 E-18	1.7 E-3	9.1 E-4	3.4 E 7
	Th-230		NA	1.0 E-16	4.9 E-7	9.8 E-3	3.6 E 8
	Ra-226		NA	1.0 E-16	9.8 E-9	9.8 E-3	3.6 E 8
	Rn-222		Rn	4.5 E-13	2.9 E-10	4.4 E 1	1.6 E 12
	Po-218		NA	4.5 E-13	1.6 E-13	4.4 E 1	1.6 E 12
	Pb-214		NA	4.5 E-13	1.3 E-12	4.4 E 1	1.6 E 12
	Bi-214		NA	4.4 E-13	9.8 E-13	4.4 E 1	1.6 E 12
	Po-214		NA	4.5 E-13	1.4 E-19	4.4 E 1	1.6 E 12
	Other		NA	2.6 E-15	4.6 E-10	2.5 E-1	2.9 E 10

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity	
		Physical	Chemical			(Ci)	(Bq)
C		Solid					
UF_6 Conversion	U-238		oxides		1.4 E-1	4.8 E-2	1.8 E 9
	U-235		UF_6		3.9 E-3	2.0 E-3	7.4 E 7
	U-234		UF_4		7.7 E-6	4.8 E-2	1.8 E 9
	Th-230		ThO_2		5.2 E-4	1.0 E 1	3.9 E 11
	Ra-226		Ra(II)		1.0 E-7	1.0 E-1	3.9 E 9
	Other		--		--	1.1 E-1	3.9 E 9
		Liquid			2.4 E 4m[3c]		
	U-238		oxides	5.3 E-10	3.9 E-5	1.3 E-5	5.3 E 5
	U-235		$(NH_4)_2U_2O_7$	2.3 E-11	9.5 E-9	6.3 E-7	2.3 E 4
	U-234			5.2 E-10	2.3 E-9	1.4 E-5	5.3 E 5
	Th-234		Th(IV)	5.3 E-10	6.2 E-16	1.4 E-5	5.3 E 5
	Other		ions	4.6 E-9	7.4 E-10	1.2 E-4	4.6 E 6
		Gaseous					
	U-238		UO_2F_2	6.7 E-17	1.7 E-3	5.6 E-4	2.1 E 7
	U-235		oxides	3.0 E-18	6.9 E-5	2.6 E-5	9.5 E 5
	U-234			6.7 E-17	9.1 E-8	5.6 E-4	2.1 E 7
	Th-234		NA	6.7 E-17	2.5 E-8	5.6 E-4	2.1 E 7
	Pa-234m		NA	6.7 E-17	8.2 E-19	5.6 E-4	2.1 E 7

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass (Mg)[b]	Radioactivity	
		Physical	Chemical			(Ci)	(Bq)
	Th-231		NA	3.0 E-18	4.8 E-17	2.6 E-5	9.5 E 5
	Th-230		NA	1.3 E-19	5.7 E-11	1.1 E-6	4.2 E 4
	Ra-226		NA	1.3 E-19	1.1 E-12	1.1 E-6	4.2 E 4
	Rn-222		NA	1.3 E-19	7.4 E-18	1.1 E-6	4.2 E 4
	Po-218		NA	1.3 E-19	4.1 E-21	1.1 E-6	4.2 E 4
	Pb-214		NA	1.3 E-19	2.9 E-20	1.1 E-6	4.2 E 4
	Bi-214		NA	1.3 E-19	2.6 E-20	1.1 E-6	4.2 E 4
	Po-214		NA	1.3 E-19	3.5 E-27	1.1 E-6	4.2 E 4
	Bi-210		NA	9.2 E-20	6.2 E-18	7.7 E-7	2.9 E 4
	Pb-210		NA	9.2 E-20	1.0 E-14	7.7 E-7	2.9 E 4
	Po-210		NA	9.2 E-20	1.7 E-16	7.7 E-7	2.9 E 4
D Enrichment	U-238	Solid	UF_6		9.4 E-2	3.2 E-2	1.2 E 9
	U-236		UF_6		1.3 E-5	8.2 E-4	3.0 E 7
	U-235		UF_6		3.2 E-4	6.9 E-4	2.6 E 7
	U-234		UF_6		2.7 E-5	1.7 E-1	6.3 E 9
	Th-234		ThO_2		1.3 E-12	3.2 E-2	1.2 E 9
	Other				--	3.8 E-2	1.5 E 9

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity (Ci)	Radioactivity (Bq)
		Physical	Chemical				
		Liquid			4.0 E $4m^3$		
	U-238		UF_6,UO_2F_2	1.2 E-8	1.5 E-3	4.9 E-4	1.8 E 7
	U-236		UF_6,UO_2F_2	3.1 E-10	1.9 E-7	1.2 E-5	4.6 E 5
	U-235		UF_6,UO_2F_2	2.6 E-9	4.9 E-5	1.0 E-4	3.7 E 6
	U-234		UF_6,UO_2F_2	6.2 E-8	3.9 E-7	2.5 E-3	9.1 E 7
	Th-234		TH(IV)	1.2 E-8	2.2 E-14	4.9 E-4	1.8 E 7
	Other		charged atoms	7.1 E-9	--	2.8 E-4	1.0 E 7
	U-238	Gaseous	UO_2F_2,UO_2	1.8 E-18	1.3 E-4	4.5 E-5	1.7 E 6
	U-236		UO_2F_2,UO_2	2.2 E-19	8.7 E-8	5.5 E-6	2.0 E 5
	U-235		UO_2F_2,UO_2	7.5 E-18	8.2 E-6	1.8 E-5	6.6 E 5
	U-234		UO_2F_2,UO_2	1.5 E-18	6.0 E-8	3.7 E-4	1.3 E 7
	Th-234		NA	1.8 E-18	1.9 E-15	4.5 E-5	1.7 E 6
	Pa-234m		NA	1.8 E-18	6.3 E-20	4.5 E-5	1.7 E 6
	Th-231		NA	7.5 E-18	3.2 E-17	1.8 E-5	6.6 E 6
	Other			1.0 E-16	1.9 E-8	2.6 E-3	9.6 E 7
E MOX-Fabrication		Solid					
	U-234		NA		2.1 E-8	1.3 E-4	4.8 E 6
	U-235		NA		9.5 E-7	2.0 E-6	7.4 E 4

Table 1 -- Continued

Index	Stream	Isotopes	State		Concentration (μCi/ml)	Mass (Mg)[b]	Radioactivity	
			Physical	Chemical			(Ci)	(Bq)
		U-236		NA		7.7 E-7	5.0 E-5	1.8 E 6
		U-238		NA		1.8 E-4	6.0 E-5	2.2 E 6
		Pu-238		NA		5.8 E-7	1.0 E-1	3.7 E 11
		Pu-239		NA		1.2 E-4	7.5 E-1	2.8 E 10
		Pu-240		NA		6.6 E-6	1.5 E 0	5.6 E 10
		Pu-241		NA		4.2 E-6	4.2 E 2	1.6 E 13
			Liquid			Not released		
		U-234		UO_2		1.8 E-8	1.1 E-4	4.1 E 6
		U-235		UO_2		7.1 E-6	1.5 E-5	5.6 E 4
		U-236		UO_2		2.6 E-8	1.7 E-6	6.3 E 4
		U-238		UO_2		1.5 E-4	5.0 E-5	1.9 E 6
		Pu-238		PuO_2		1.1 E-12	7.0 E-8	2.6 E 3
		Pu-240		PuO_2		4.4 E-14	1.0 E-8	3.0 E 2
		Pu-241		PuO_2		3.9 E-13	3.9 E-5	7.4 E 6
		Am-241		NA		3.0 E-16	7.0 E-10	2.6 E 1
			Gaseous					
		U-234		UO_2	2.7 E-19	3.5 E-10	2.2 E-6	8.1 E 4
		U-235		UO_2	2.4 E-21	9.5 E-9	2.0 E-8	7.4 E 2
		U-238		UO_2	1.2 E-19	2.9 E-6	9.6 E-7	3.6 E 4

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass (Mg)[b]	Radioactivity (Ci)	(Bq)
		Physical	Chemical				
	Pu-238		PuO_2	2.4 E-21	1.0 E-15	2.0 E-8	7.4 E 2
	Pu-239		PuO_2	2.4 E-22	3.3 E-14	2.0 E-9	7.4 E 1
	Pu-241		PuO_2	9.4 E-20	7.9 E-15	7.8 E-7	2.9 E 4
F UO_2 Manufacturing		Solid					
	U-238		UO_2, $(NH_4)_2U_2O_7$		1.4 E-1	4.9 E-2	1.8 E 9
	U-235		U_3O_8		2.0 E-2	4.2 E-2	1.5 E 9
	U-234		UO_2, $(NH_4)_2U_2O_7$, U_3O_8		1.7 E-4	1.0 E 0	3.8 E 10
	Th-234		ThO_2, $Th(C_2O_4)\cdot 6H_2O$		2.1 E-12	4.9 E-2	1.8 E 9
		Liquid			7.6 E $3m^3$	Not Released	
	U-238		UO_2	3.6 E-6	8.4 E-2	2.8 E-2	1.0 E 9
	U-235		UO_2	3.6 E-6	1.3 E-2	2.8 E-2	1.0 E 9
	U-234		UO_2	3.6 E-6	4.5 E-6	2.8 E-2	1.0 E 9
	Th-234		Th(IV)	3.6 E-6	1.2 E-12	2.8 E-2	1.0 E 9
	Pa-234m		Pa(III)	3.6 E-6	1.4 E-14	2.8 E-2	1.0 E 9
		Gaseous					
	U-238		UO_2F_2, UO_2	4.3 E-22	1.1 E-8	3.6 E-9	1.4 E 2
	U-236		UO_2F_2, UO_2	2.4 E-25	3.1 E-14	2.0 E-12	7.3 E 2
	U-235		UO_2F_2, UO_2	3.5 E-22	1.4 E-9	2.9 E-9	1.1 E 2
	U-234		UO_2F_2, UO_2	7.8 E-21	1.1 E-11	6.6 E-9	8.8 E 1

Table 1 -- Continued

Index	Stream	Isotopes	State		Concentration	Mass[b]	Radioactivity	
			Physical	Chemical	(μCi/ml)	(Mg)	(Ci)	(Bq)
		Th-234		NA	4.3 E-22	1.5 E-13	3.6 E-9	1.3 E 2
		Pa-234m		NA	4.3 E-22	5.3 E-24	3.6 E-9	1.3 E 2
		Th-230		NA	7.8 E-22	3.4 E-13	6.6 E-9	8.8 E 1
		Th-231		NA	3.5 E-22	5.6 E-15	2.9 E-9	1.1 E 2
		Other			2.2 E-21	2.9 E-15	1.8 E-8	6.6 E-9
G Reactor			Solid					
		Transuranics fission products		oxides		2.5 E+2m[3]	1.8 E 4 (total)	6.6 E 14 (total)
			Liquid		3.5 E 3m[3]			
		H-3		HTO	1.1 E-7	4.2 E-12	4.0 E 2	1.5 E 13
		I-131		I, organic	1.2 E-10	3.2 E-12	4.0 E-1	1.5 E 10
		I-133		I, organic	8.3 E-12	2.6 E-14	2.9 E-2	1.1 E 9
		I-135		I, organic	1.2 E-12	1.2 E-15	4.2 E-3	1.6 E 8
		Cs-134		Cs(I)	1.7 E-10	4.7 E-10	6.0 E-1	2.2 E 10
		Cs-136		Cs(I)	1.4 E-13	7.1 E-15	5.0 E-4	1.9 E 7
		Cs-137		Cs(I)	2.9 E-10	4.2 E-11	1.0 E 0	3.6 E 10
		Ba-137m		Ba(II)	2.9 E-13	1.9 E-18	1.0 E-3	3.7 E 7
		Ba-140		Ba(II)	2.7 E-15	1.3 E-16	9.5 E-6	3.5 E 5
		La-140		La(III)	1.9 E-15	1.2 E-17	6.6 E-6	2.4 E 5

Table 1 -- Continued

Index	Stream	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity	
			Physical	Chemical			(Ci)	(Bq)
		Pa-233		Pa(II)	6.0 E-15	1.0 E-15	2.1 E-5	7.8 E 5
		Np-239		Np(III)	3.4 E-16	4.8 E-18	1.2 E-6	4.4 E 4
		Cr-51		NA		3.7 E-12	3.0 E-2	1.1 E 9
		Mn-54		NA		1.0 E-11	8.0 E-2	3.0 E 9
		Co-58		NA		2.8 E-11	8.8 E-1	3.3 E 10
		Co-60		NA		2.5 E-10	2.8 E-1	1.0 E 10
		Zn-65		NA		3.6 E-11	3.0 E-1	1.1 E 10
		Zr-95		NA		1.4 E-13	3.0 E-3	1.1 E 8
		Nb-95		NA		7.6 E-14	7.0 E-3	2.6 E 8
			Gaseous					
		Kr-83m		Kr	1.8 E-12	2.8 E-9	5.9 E 0	2.2 E 11
		Kr-85		Kr	3.9 E-10	3.4 E-6	1.3 E 3	4.8 E 13
		Kr-85m		Kr	3.0 E-11	1.2 E-11	1.0 E 2	3.7 E 12
		Kr-87		Kr	4.8 E-12	5.8 E-13	1.6 E 1	5.9 E 11
		Kr-88		Kr	3.0 E-12	7.8 E-13	1.0 E 1	3.7 E 11
		Xe-131m		Xe	3.0 E-11	1.2 E-10	1.0 E 2	3.7 E 12
		Xe-133		Xe	9.1 E-10	1.6 E-8	3.0 E 3	1.1 E 14
		Xe-133m		Xe	6.1 E-12	4.7 E-11	2.0 E 1	7.4 E 11
		Xe-135		Xe	9.1 E-11	1.2 E-10	3.0 E 2	1.1 E 13

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity	
		Physical	Chemical			(Ci)	(Bq)
	Xe-135m		Xe	4.2 E-13	1.5 E-14	1.4 E 0	5.2 E 10
	I-129		I_2	9.1 E-21	1.8 E-10	3.0 E-8	1.1 E 3
	I-131		I_2	9.1 E-14	2.5 E-12	3.0 E-1	1.1 E 10
	I-132		I_2	8.1 E-16	2.6 E-16	2.7 E-3	1.0 E 8
	I-133		I_2	1.1 E-14	3.2 E-14	3.6 E-2	1.3 E 9
	I-135		I_2	3.6 E-16	3.5 E-16	1.2 E-3	4.4 E 7
	H-3		HT	3.0 E-11	1.0 E-8	1.0 E 2	3.7 E 12
	C-14		CO, CO_2	9.5 E-13	7.2 E-7	3.2 E 0	1.2 E 11
	Sr-89		Sr	3.0 E-15	3.4 E-13	1.0 E-2	3.7 E 8
	Sr-90		Sr	3.0 E-16	7.0 E-12	1.0 E-3	3.7 E 7
	Rn-103		Rn	6.0 E-16	6.2 E-14	2.0 E-3	7.4 E 7
	Rn-106		Rn	3.0 E-16	3.0 E-13	1.0 E-3	3.7 E 7
	Cs-134		Cs	1.2 E-15	1.3 E-12	4.0 E-3	1.5 E 8
	Cs-137		Cs	2.1 E-15	8.1 E-11	7.0 E-3	2.6 E 8
H Reprocessing	transuranics	Solid			1.0 E $2m^3$	1.3 E 2	
					1.6 E $1m^3$		
		Gaseous					
	H-3		HT	1.6 E-10	1.7 E-7	4.0 E 3	1.5 E 14
	Kr-85		Kr	1.1 E-9	6.7 E-5	2.6 E 4	9.6 E 14

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass[b] (Mg)	Radioactivity	
		Physical	Chemical			(Ci)	(Bq)
	C-14		CO, CO_2	8.2 E-14	4.5 E-7	2.0 E 0	7.4 E 10
	I-129		I_2	3.7 E-17	5.7 E-6	9.0 E-9	3.3 E 7
	I-131		I_2	2.7 E-17	5.4 E-9	6.7 E-4	2.5 E 7
	Ru-106		Ru_xO_y	7.4 E-16	5.4 E-12	1.8 E-2	6.7 E 8
	Cs-134		NA	2.2 E-16	4.1 E-12	5.3 E-3	2.0 E 8
	Cs-137		NA	1.2 E-16	1.2 E-13	2.9 E-3	1.1 E 8
	Sr-90		NA	7.4 E-17	1.3 E-11	1.8 E-3	6.7 E 7
	Ce-144		NA	1.2 E-18	8.8 E-12	2.8 E-2	1.0 E 9
	Y-91		NA	3.5 E-15	3.4 E-13	8.5 E-3	3.2 E 8
	Y-90		NA	1.2 E-16	5.4 E-15	2.9 E-3	1.1 E 8
	Zr-90		NA	8.2 E-16	9.5 E-13	2.0 E-2	7.4 E 8
	Nb-95		NA	8.2 E-16	5.2 E-13	2.0 E-2	7.4 E 8
	Pm-147		NA	2.0 E-16	5.3 E-12	4.9 E-3	1.8 E 8
	Sr-89		NA	4.6 E-17	3.9 E-14	1.1 E-3	4.1 E 7
	Ce-141		NA	1.8 E-17	1.5 E-14	4.4 E-4	1.6 E 7
	U-238		oxides	1.3 E-23	9.5 E-10	3.1 E-10	1.1 E 1
	U-236		oxides	9.6 E-4	3.7 E 8	2.3 E 10	8.9 E 20
	U-235		oxides	4.2 E-25	4.6 E-12	1.0 E-11	3.7 E-1
	U-234		oxides	2.8 E-23	1.1 E-13	6.6 E-10	3.4 E 1

Table 1 -- Continued

Index	Isotopes	State		Concentration (μCi/ml)	Mass (Mg)[b]	Radioactivity	
		Physical	Chemical			(Ci)	(Bq)
	Pu-238		oxides	6.2 E-13	8.3 E-14	1.5 E-4	5.6 E 6
	Pu-239		oxides	4.5 E-19	1.8 E-10	1.1 E-5	4.1 E 5
	Pu-240		oxides	8.0 E-19	9.0 E-11	2.0 E-5	7.4 E 5
	Pu-241		oxides	2.4 E-16	5.2 E-11	5.8 E-3	2.1 E 8
	Am-241			5.8 E-19	4.3 E-12	1.4 E-5	5.2 E 5
	Am-243			2.1 E-19	2.8 E-11	5.0 E-6	1.9 E 5
	Cm-242			1.1 E-16	8.1 E-13	2.7 E-3	1.0 E 8
	Cm-244			5.0 E-17	1.4 E-11	1.2 E-3	4.4 E 7

a - Incomplete data.

b - Quantity in units of mega grams, unless otherwise noted.

c - Includes chemically contaminated wastes with the radioactivity.

NA - Not available.

APPENDIX B

COMPUTER PROGRAM "COPRO"

B.1 Introduction

COPRO is a program to calculate the wastes and the main stream composition for a model nuclear fuel coprocessing plant with a maximum capacity of 3000 Mg/yr. This calculation includes wastes (Fig. 1) and effluent streams associated with transportation of fuel from the reactor pool to the coprocessing plant, the fuel receiving and storage station (FRSS), the "head end" consisting of the shearing, tritium removal and dissolver steps and the feed preparation.

COPRO is a comparatively short program with one data library. This library contains data for a "Base Case" which is for a U-Pu LWR fuel cycle. The data contained in the library is composed of 806 isotopes identification* members and their half lifes.

COPRO is written FORTRAN EXTENDED VERSION IV and is tested on a CYBER-175 digital computer. The program is constructed in a semi-modular manner, which allows the user to add or eliminate stages.

The input/output files and the main processes (FRSS, head end) are contained in the main program of COPRO.

---

* Code number is a six-digit number which identifies each isotope for the program. For more information, see section in Inputs.

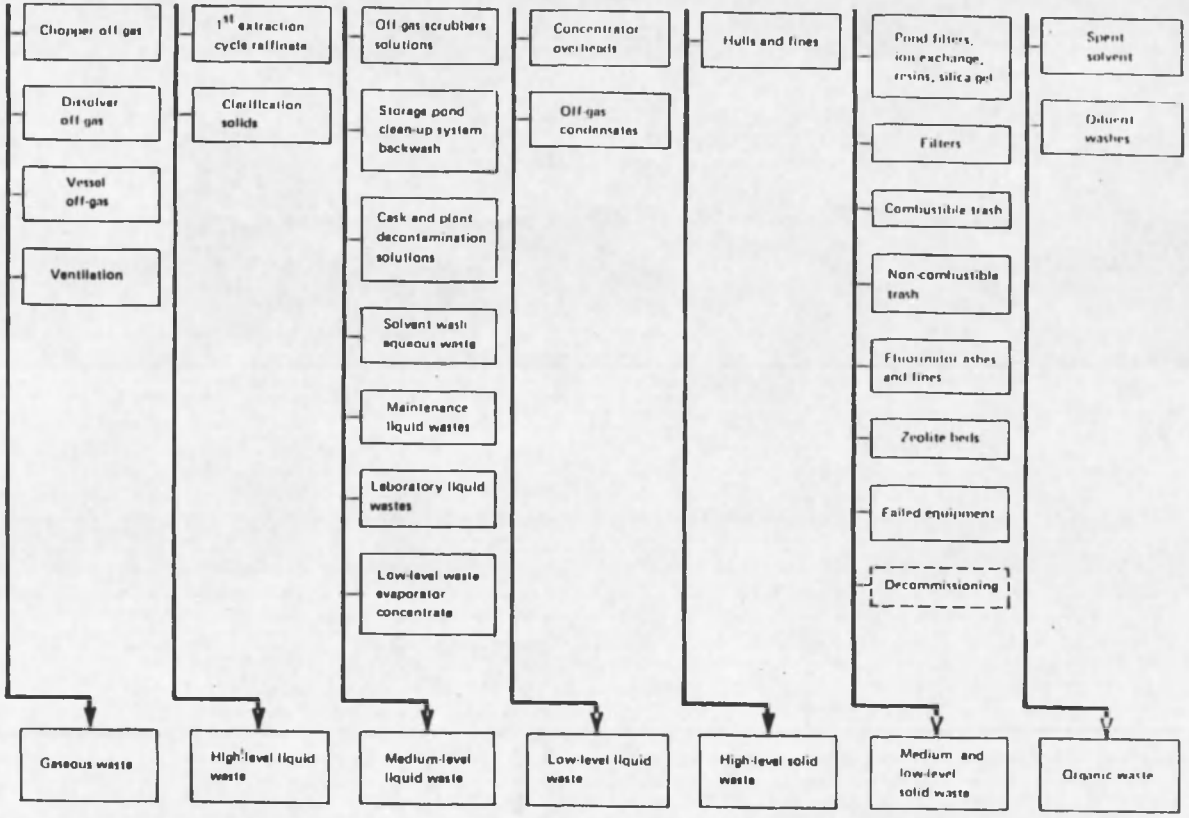


Fig. 1 Origins of the Various Catagories of Waste.

The mathematical model of the individual system was simplified in most cases by the assumption of a linear relationship bwtween waste production and the amount of material processed.

B.2 Input/Output

B.2.1 Input

The input data are to be prepared in the order shown in Table B.2.1 "Subroutine" indicates the subroutine into which the data from the card are read. "Card number" denotes the order within the group of input cards. "Columns" refers to the actual columns on the computer card in which the data must be punched. "Remarks, variables, etc." gives an explanation as to the variable name, definitions, and the format how data must be punched. Table B.2.1 lists all of the card inputs that are required to perform a variety of calculations with the COPRO code. An example of input cards for a sample case is illustrated in Table B.2.2.

The cards numbered "4" contain the most important set of input data. These cards include the amount of each isotope charged to the coprocessing plant. These values are calculated using the computer code ORIGEN (Bell 1973). The program COPRO uses the same identification code for isotopes as ORIGEN. The isotope identification code used has a maximum of six digits and is used by the program to allocate data from the library to parameters in the program.

NUCL 3 (I) = atomic number x 1000 + atomic weight x 10 + M

where

M = 0 for ground state

M = 1 for excited state

(NUCL 3 (I) is the isotope identification code used in the program.)

B.2.2. Output

The output exhibits in a first table the amount of waste and the composition of different contaminated streams of fuel receiving and storage facilities and possible material flow throughout the process.

A second table will summarize the waste and different streams in sharing. The units of these tables are Gram/M^3 or Curie/M^3 of flow of a specific stream. The final table gives the main streams isotope composition at different location of head end process. (Table 3 shows the listing of program COPRO.) The tables are divided into three subgroups; structural, heavy elements and fission products.

B.3 Further Research Efforts

Program COPRO does not take into account the isotopic decay. To improve the code it would be necessary to include a subroutine to calculate such a decay. The next step is to expand the program COPRO to process HTGR and LMFBR fuel.

Table 1 Input Data Cards for "COPRO"

Subroutine	Card No.	Columns	Remarks, Variables, etc.
COPRO	1	1 to 10	RPOWR - Specific power of reactor. Unit: MW Format: F10.3
	1	10 to 20	INMASS - The mass which datas of card number 4 is normalized to: Unit: Mg Format: F10.3
	1	20 to 30	BURNUP - The average burning of fuel discharged from reactor. Unit: MWD/Mg of heavy metal Format: F10.3
	1	30 to 40	CAP - Maximum capacity of coprocessing plant. Unit: MgHM/yr. Format: 10.3
	1	40 to 45	RTYPE - Reactor type. Enter: 0 for BWR 1 for PWR 2 for LWR Format: I5
	1	45 to 50	INCOOL - Cooling period after reactor discharge and Unit: Day Format: I5

Table 1 -- Continued

Subroutine	Card No.	Columns	Remarks, Variables, etc.
COPRO	2	1 to 80	TITLE - A title for calculation can contain up to 80 alphabets. Format: 10A8
	3	1 to 5	IFUEL - This variable defines the fuel type of reactor. Enter: 1 u-Pu fuel 2 Th-u fuel Format: I5
	3	5 to 10	IOUT - Indicates that the output values are in units of curies or grams. Enter: 1 curie 2 gram
	3	10 to 15	ISOTS - The number of structural isotope inputed. Format: I5
	3	15 to 20	ISOTH - The number of heavy isotope imputed. Format: I5
	3	20 to 25	ISOTFP - The number of fission product isotope inputed. Format: I5
	3	25 to 30	KJZ - A flag to print the library. Enter: 0 do not print 1 print Format: I5

Table 1 -- Continued

Subroutine	Card No.	Columns	Remarks, Variables, etc.
COPRO	4	1 to 2	ELE - The chemical name, such as Pu, U, etc. Format: A2
	4	2 to 5	MWT - The atomic weight of the isotope. Format: I3
	4	5 to 6	STA - Indicates the isotope is in excited state or ground state. Format: A2
	4	11 to 20	FD - The amount of isotope in curies or grams in IMASS of fuel discharged. Discharge means after the cooling off period in the reactor pool. Format: PB 9.2
	4	26 to 33	LNUC3 - The isotope code number. Format: I7
	4	43 to 47	K - Kind of isotope. Enter: 1 Structural 2 Heavy elements 3 Fission Products

Table 2 Input Cards for COPRO

```
  30.00       1.0     33000.0    3000.00       2  160
 HLW ,LAW AND  LLW FOR LWR FUEL COPROSSING CASE.(INPUT IN GRAM)
    1     1     0   38    30    35     0     1
 H  3          1.61E-09          10030                1
HE  4          2.39E-02          20040                1
 C 14          1.29E-10          60140                1
AL 27          1.08E+02         130270                1
 P 32          1.96E-16         150320                1
 S 32          7.22E-12         160320                1
 S 35          8.19E-24         160350                1
TI 48          1.31E+02         220480                1
CR 50          2.45E+02         240500                1
CR 53          2.98E+03         240530                1
MN 54          2.16E-02         250540                1
MN 55          1.78E+02         250550                1
FE 54          2.17E+02         260540                1
FE 55          7.10E-01         260550                1
FE 56          3.40E+03         260560                1
FE 59          3.94E-04         260590                1
CO 58          2.14E-02         270580                1
CO 59          4.83E+01         270590                1
CO 60          5.15E+00         270600                1
NI 59          5.08E+01         280590                1
NI 63          9.12E+00         280630                1
CU 65          2.74E+01         290650                1
ZN 64          1.69E-04         300640                1
ZN 65          2.93E-08         300650                1
ZN 66          8.99E-04         300640                1
ZR 90          1.28E+05         400900                1
ZR 91          2.76E+04         400910                1
ZR 92          4.28E+04         400920                1
ZR 93          4.03E+01         400930                1
ZR 94          4.32E+04         400940                1
ZR 95          2.48E-01         400950                1
ZR 96          6.96E+03         400960                1
NB 95          2.48E-01         410950                1
MO 94          5.00E+01         420940                1
MO 95          9.06E+01         420950                1
MO 96          2.47E-01         420960                1
RU101          2.47E-01         441010                1
SN125          2.45E-10         501250                1
HE  4          3.35E-01          20040                2
RN220          2.49E-12         862200                2
RN222          1.30E-13         862220                2
RA224          1.43E-08         882240                2
RA225          8.89E-13         882250                2
RA226          2.02E-08         882260                2
 U232          3.49E-04         922320                2
 U233          4.87E-03         922330                2
 U234          1.22E+02         922340                2
 U235          7.98E+03         922350                2
 U236          4.55E+03         922360                2
 U238          9.43E+05         922380                2
NP236          1.38E-58         932360                2
NP237          4.82E+02         932370                2
NP238          1.77E-23         932380                2
NP239          7.81E-05         932390                2
PU236          5.93E-04         942360                2
PU238          1.67E+02         942380                2
PU239          5.27E+03         942390                2
```

Table 2 -- Continued

PU240	2.17E+03	942400	2
PU241	1.01E+03	942410	2
PU242	3.54E+02	942420	2
AM241	4.63E+01	952410	2
AM242	1.13E-05	952420	2
AM243	9.44E+01	952430	2
AM244	1.90E-25	952440	2
AM245	6.12E-15	952450	2
CM242	5.14E+00	962420	2
CM243	7.99E-02	962430	2
CM244	2.97E+01	962440	2
H 3	7.13E-02	10030	3
KR 84	1.12E+02	360840	3
KR 85	2.83E+01	360850	3
KR 86	1.93E+02	360860	3
ZR 90	2.80E+01	400900	3
ZR 91	6.05E+02	400910	3
ZR 92	6.64E+02	400920	3
ZR 93	7.36E+02	400930	3
ZR 94	7.91E+02	400940	3
ZR 95	1.18E+01	400950	3
ZR 96	8.32E+02	400960	3
NB 95	1.20E+01	410950	3
RU101	7.77E+02	441010	3
RU103	2.31E+00	441030	3
RU104	5.45E+02	441040	3
RU106	1.29E+02	441060	3
RH103	3.83E+02	451030	3
RH103M	2.31E-03	451031	3
RH106	1.13E-04	451060	3
AG110	7.34E-08	471100	3
CD133	2.23E-01	481130	3
SN125	9.14E-07	501250	3
SN126	1.92E+01	501260	3
I129	2.29E+02	531290	3
I131	7.45E-06	531310	3
I132	1.76E-16	531320	3
XE133M	7.20E-23	541331	3
XE133	7.70E-09	541330	3
XE136	2.31E+03	541360	3
CS133	1.01E+03	551330	3
CS134	1.63E+02	551340	3
CS135	3.24E+02	551350	3
CS137	1.23E+03	551370	3
CE141	1.59E+00	581410	3
CE144	2.36E+02	581440	3

Table 3 List of COPRO

```
00001          PROGRAM  COPRO(INPUT,OUTPUT,LIBRAY,TAPE5,TAPE6=OUTPUT,
00002         X   TAPE7)
00003    C
00004    C      THIS PROGERAM COMPUTES ACTIVITY AND  AMOUNT OF THE HIGH LEVEL AND
00005    C      NON HIGH LEVEL WASTE OF FUEL COPROCESSING PLANT. THE MODEL
00006    C      PROCESS ,PWR,BWR,LWR FUEL.
00007    C
00008    C      ******** DIMENSION STATMENTS  *******
00009          DIMENSION ELE(800),MWT(800),STA(800),LNUC1(800),LNUC2(800),FD(800)
00010          DIMENSION  ELE1(800),MWT1(800),STA1(800)
00011          DIMENSION OGI(800),KIND(800),T(800),LNUC3(800),WW2(800),WW3(800)
00012          DIMENSION WW(800),F1(800),WW1(800),VILLW(800),HEDE(800)
00013          DIMENSION AIR(20),FD1(800),FD3(800),FDI(4,800),SW1(7),SWF(20)
00014          DIMENSION SLSL(3,800),HALL(2,800),SOLL(800),CINCOL(800)
00015          DIMENSION CINCO(800,2),SOLI(800,2),FI1(800),FD2(800)
00016          DIMENSION FI2(800),FI3(800),FI4(800) ,TITLE(8)
00017          REAL INMASS ,ISS
00018          INTEGER RTYPE
00019    C
00020    C      ******** INPUT STATMENTES *******
00021    C
00022          READ(5,9001)RPOWER,INMASS,BURNUP,CAP,RTYPE,INCOOL
00023          READ(5,9003)TITLE
00024          READ(5,9005)IFUEL,IOUT,IIN,ISOTS,ISOTH,ISOTFP,KJZ,JZK
00025          NTOTAL=ISOTS+ISOTH+ISOTFP
00026          DO 10 I=1,NTOTAL
00027          READ(5,9007)ELE(I),MWT(I),STA(I),FD(I),LNUC3(I),KIND(I)
00028            MWT1(I)=MWT(I)
00029            STA1(I)=STA(I)
00030       10   ELE1(I)=ELE(I)
00031          IF(JZK.NE.1) GO TO 13
00032          WRITE(6,9501) RPOWER,INMASS,BURNUP,CAP,RTYPE,INCOOL,IFUEL,IOUT,IIN
00033         1,ISOTS,ISOTH,ISOTFP,KJZ,JZK
00034          WRITE(6,9006)TITLE
00035          WRITE(6,9502)
00036          DO 11 I=1,NTOTAL
00037       11 WRITE(6,12)ELE(I),MWT(I),STA(I),FD(I),LNUC3(I),KIND(I)
00038       13 WRITE(6,9518)
00039          IF(KJZ.EQ.1) WRITE(6,9503)
00040    C
00041    C                              THE LIBRARY INPUT
00042    C              IF KJZ IS EQUAL TO 1 PRINTS THE LIBRARY
00043    C
00044          KL=1    $KH=3
00045          DO 5 I=1,246
00046          READ(7,9008)(LNUC2(K),T(K), K=KL,KH)
00047          IF(KJZ.NE.1) GO TO 2
00048          WRITE(6,9516)(LNUC2(K),T(K),K=KL,KH)
00049        2 KL=3+KL
00050        5 KH=KH+3
00051       35 IF(RTYPE.LE.3) GO TO 40
00052          WRITE(6,9050)
00053          GO TO 10000
00054       40 IF(IFUEL.EQ.2)WRITE(6,9052)
00055          IF(IFUEL.EQ.2) GO TO 10000
00056       55 IF(IIN.NE.0) GO TO 60
00057          CALL GRAM(FD,T, NTOTAL,LNUC3,LNUC2,0,MWT)
00058          GO TO 70
00059       60  CALL CURIE(FD,T,NTOTAL,LNUC3,LNUC2,0)
00060    C
00061    C      ******** VALUES OF YEAR OF OPERATION ***********
00062    C
```

Table 3 -- Continued

```
00063      70 OPE=.8219178
00064         CCK=CAP/(365*OPE*10.0)
00065         ICAP=800.0*CCK
00066         ISS=10.0*CCK
00067         DO 75 I=1,NTOTAL
00068         OGI(I)=FD(I)
00069         FDI(1,I)=FD(I)
00070      75 continue
00071         DO 99 KIN=1,3
00072         MM=0
00073         CALL KINDX(KIN,ISOTS,ISOTH,ISOTFP,N,NISOT,MM)
00074         IF(MM.EQ.1) GO TO 99
00075         CALL NUC1(N,NISOT,KIN,LNUC1,LNUC3,FD,MWT,STA,ELE)
00076         IF(KIN.EQ.2) GO TO 205
00077         CALL CURIE(FD,T,NISOT,LNUC1,LNUC2,1)
00078   C
00079   C     MAXIMUM POOL WATER ACTIVITY IS 10**-2 CI/M**3 DOKET NO 70 1729
00080   C     FRSS INVENTORY 800 TONNES OF FUEL ,STEADY STATE FUEL FLOW
00081   C     OF 10 MTHM FOR 3000 MT FUEL REPROCESSING PLANT.
00082   C
00083         DO 80  I=1,NISOT
00084         FI1(I)=0.0
00085         WRITE(6,12)ELE(I),MWT(I),STA(I),FD(I),LNUC3(I),KIND(I)
00086         IF(LNUC1(I).EQ.270580.OR.LNUC1(I).EQ.270600) FI1(I)=0.1
00087         IF(LNUC1(I).EQ.400950.OR. LNUC1(I).EQ.410950) FI1(I)=.06
00088         IF(LNUC1(I).EQ.441060.OR. LNUC1(I).EQ.451060) FI1(I)=0.080
00089         IF(LNUC1(I).EQ.531290.OR. LNUC1(I).EQ.531310) FI1(I)=.01
00090         IF(LNUC1(I).EQ.551340.OR.LNUC1(I).EQ.551370) FI1(I)=.5
00091         IF(LNUC1(I).EQ.511240)FI1(I)=.05
00092         IF(LNUC1(I).EQ.581440) FI1(I)=0.05
00093         IF(LNUC1(I).EQ.250540)FI1(I)=0.05
00094         F1(I)=FI1(I)
00095      80 CONTINUE
00096         MM=0
00097         DO 100 I=1,NISOT
00098         IF(LNUC1(I).EQ.270580.OR.LNUC1(I).EQ.270600) GO TO 95
00099         IF(LNUC1(I).EQ.400950.OR. LNUC1(I).EQ.410950) GO TO 94
00100         IF(LNUC1(I).EQ.441060.OR. LNUC1(I).EQ.451060) GO TO 94
00101         IF(LNUC1(I).EQ.531290.OR. LNUC1(I).EQ.531310) GO TO 94
00102         IF(LNUC1(I).EQ.551340.OR.LNUC1(I).EQ.551370) GO TO 94
00103         GO TO 100
00104      94 IF(CK1.GT.1)MM=0.0
00105      95 MM=MM+1
00106         IF(MM.EQ.1) GO TO 98
00107         IF(FI1(I).NE.FI1(M))GO TO 97
00108         ALPHA=FD(M)/FD(I)
00109         FI1(M)=FI1(I)/(1+ALPHA)
00110         FI1(I)=ALPHA*FI1(M)
00111         MM=0
00112         CK1=2.
00113         GO TO 100
00114      97 M=I
00115         CK1=1.
00116         GO TO 100
00117      98 M=I
00118         CK1=MM
00119     100 CONTINUE
00120   C
00121   C     ***************  FISSION GASES ***********
00122   C
00123         DO 170 I=1,NISOT
00124         WW(I)=0.0
00125         IF(LNUC1(I).EQ.10030)WW(I)=0.01
00126         IF(LNUC1(I).GE.360800.AND.LNUC1(I) .LE.360940)WW(I)=0.3
00127         IF(LNUC1(I).GE.531290.AND.LNUC1(I) .LE.531390)WW(I)=0.3
00128         IF(LNUC1(I).GE.541280.AND.LNUC1(I) .LE.541430)WW(I)=0.3
```

Table 3 -- Continued

```
00129          IF(LNUC1(I).EQ.531310)WW(I)=.02
00130        170 CONTINUE
00131    C
00132    C      ******** LEAKERS IN TRANSIT ********
00133    C      70 PERCENT OF FUEL TRANSPORTED BY RAIL  AND 30 PERCENT BY TRUCK
00134    C      1 PERCENT FAI D FUEL ,EVERY DAY THERE WILL BE ONE TRUCK AND 3 RAIL ROAD
00135    C         CARS   COMING IN. TOTAL CARGO WILL BE 53 FUEL OF BWR(GE) OR 22 FUEL OF
00136    C       PWR (WH).
00137    C      VOLUME OF  WATER IN TRUCK CASK 10**5 CC
00138    C      VOLUME OF WATER IN RAIL ROAD CASK 2.3*10**6 CC
00139    C     1 PRESENT OF 4 CASK WILL HAVE CONTAMINATED WATER .
00140    C
00141        175 VGAST=110.0*0.02832*CCK
00142          VWAT=1.5665*CCK*(10.0/3.7)
00143    C
00144    C     ******** FAILD FUEL OFF GAS VENT AND SHIPPING CASK VENT*****
00145    C
00146          DO 180 I=1,NISOT
00147          WW1(I)=FD(I)*0.02*WW(I)*ISS/VGAST
00148          FD(I)=FD(I)*(1.-WW(I)*.02)
00149        180 CONTINUE
00150    C
00151    C      **** AIR FROM STORAGE POOL BLDG , VENT AND FUEL UNLOADING VENT******
00152    C            GOING TO SAND FILTER AND UP THE STACK.
00153    C
00154          AIR(1)=5664000*CCK
00155    C
00156    C     ******* EXTRNAL CASK WASH DEION SOL'N AND FILTER DEONIZER REGEN .WASTE
00157    C       VALUE IN M**3 .
00158    C
00159          AGP1=4.7318*CCK
00160    C
00161    C
00162    C      ******** SOLID WASTE FROM FRSS HEPA FILTERS AND SPENT FILTER
00163    C       FOR DEIONIZER (COMBUSTIBLE BETA-GAMA )
00164    C
00165          HEPE(1)=.00283*CCK
00166    C
00167    C      ******* POOL CONTAMINATION  ILLW FROM DEMINERAIZER.*********
00168    C       ******* CONTAMINATED CASK WATER ********
00169    C
00170          C1=(300.0*1440*3.785E-03)*CCK
00171          VILLW(1)=14.3846*CCK
00172          DO 190 I=1,NISOT
00173          FI3(I)=FI1(I)*1.E-02
00174          FI4(I)=FI3(I)*C1/VILLW(1)
00175          FI2(I)=FI3(I)*C1*ISS/(ICAP*VWAT*2.0)
00176          IF(KIN.NE.3)GO TO 185
00177          FD1(I)=FI2(I)
00178          FD2(I)=FI3(I)
00179          FD3(I)=FI4(I)
00180        185 IF(FD(I).EQ.0.0) GO TO 190
00181          F1(I)=FI3(I)*C1/(FD(I)*ICAP)
00182          FD(I)=FD(I)-(FI2(I)*VWAT/ISS)-(FI3(I)*C1/ICAP)
00183        190 CONTINUE
00184    C
00185    C     ***************** OUTPUT   ******************
00186    C
00187          if(kin.eq.3)go to 192
00188          WRITE(6,9500)
00189          WRITE(6,9006)TITLE
00190          WRITE(6,9504)ICAP ,ISS,BURNUP,INCOOL
00191          WRITE(6,9508)
00192          WRITE(6,9512)
00193        192 do 200 i=1,NISOT
00194          IF(KIN.EQ.3) GO TO 195
```

Table 3 -- Continued

```
00195         IF(FI2(I).EQ.0.0.AND.FI3(I).EQ.0.0.AND.FI4(I).EQ.0.0
00196        X.AND.WW1(I).EQ.0.0)
00197        1 GO TO 200
00198         if(i.eq.1)write(6,9013)
00199         WRITE(6,9014)ELE(I),MWT(I),STA(I),FI2(I),ww1(i),FI3(I),FI4(I)
00200        1,F1(I)
00201         GO TO 200
00202      195 IF(FD1(I).EQ.0.0.AND.FD2(I).EQ.0.0.AND.FD3(I).EQ.0.0
00203        1 .AND.WW1(I).EQ.0.0) GO TO 200
00204         if(i.eq.1)write(6,9555)
00205         WRITE(6,9014)ELE(I),MWT(I),STA(I),FD1(I),WW1(I),FD2(I),FD3(I)
00206        1,F1(I)
00207      200  CONTINUE
00208    C
00209    C
00210         CALL CURIE(FD,T,NISOT,LNUC1,LNUC2,0)
00211      205 DO198 I=1,NISOT
00212         IF(KIN.EQ.1)K=I
00213         IF(KIN.EQ.2)K=ISOTS+I
00214         IF(KIN.EQ.3)K=ISOTS+ISOTH+I
00215          IF(FD(I).EQ.0.0) FD(I)=OGI(K)
00216         OGI(K)=FD(I)
00217         FDI(2,K)=FD(I)
00218      198 CONTINUE
00219    C
00220    C
00221       99 CONTINUE
00222         DO 206 I=1,NTOTAL
00223         ELE(I)=ELE1(I)
00224         MWT(I)=MWT1(I)
00225         STA(I)=STA1(I)
00226      206 CONTINUE
00227         DO 215 I=1,NTOTAL
00228      215 FD(I)=FDI(2,I)
00229         WRITE(6,9515)VWAT,AIR(1),VGAST,AGP1,VILLW(1),HEDE(1)
00230    C
00231    C************ PRAMETER FOR SHEARING AND H-3 REMOVAL AND DISSOLVER******
00232    C                  ALL PRAMETERS ARE IN M**3/DAY
00233    C
00234         VGAS2=1700.0*CCK
00235         AIR(2)=5664*CCK
00236         AIR(3)=CCK*4.08E+05
00237         VGAS3=5664.0*CCK
00238         VGAS4=CCK*2.832E+04
00239         AGP2=2.271*CCK
00240         FLNUM1=5*CCK
00241         FLNUM2=2*CCK
00242         HEDE(2)=CCK*9.6288E-02
00243         DISF=CCK*3.028E-01
00244         VILLW(2)=3.028*CCK
00245         VILLW(3)=3.028*CCK
00246         RAWM=31.0*CCK
00247         PRINT*,IOUT
00248         IF(IOUT.GT.0) GO TO 216
00249         CALL GRAM(FD,T,NTOTAL,LNUC3,LNUC2,1,MWT)
00250         GO TO 217
00251      216 CALL CURIE(FD,T,NTOTAL,LNUC3,LNUC2,1)
00252      217 DO 520 KIN=1,3
00253         MM=0
00254         CALL KINDX(KIN,ISOTS,ISOTH,ISOTFP,N,NISOT,MM)
00255         IF(MM.EQ.1)GO TO 520
00256         CALL NUC1(N,NISOT,KIN,LNUC1,LNUC3,FD,MWT,STA,ELE)
00257    C
00258    C***************SHEARING OPERATION **********************
00259    C      MASS OF  BWR (GE) FUEL 276 KG/ASSEMBLY
00260    C      MASS OF  PWR (WH) FUEL 668.6 KG/ASSEMBLY
```

Table 3 -- Continued

```
C
C*********************************************************
      IF(KIN.NE.1)GO TO 390
      IF(RTYPE-1)220,250,300
C
C*********************************************************
C     END FITTING FOR BWR FUEL(GE);STAINLESS STEEL
C     ,INCONAL X750 AND ZIRCALOY 2AND 4
C
C*********************************************************
  220 ENUM=CCK*10000.0/188.7
      COL=ENUM*759.0
      SST=ENUM*8535.0
      ZR2=ENUM*1960.0
      ZR4=ENUM*2386.0
      DO 230 I=1,NISOT
      WW(I)=0.
       WW2(I)=0.
      WW3(I)=0.
       F1(I)=0.
       FI1(I)=0.
      IF(LNUC1(I).GE.60120.AND.LNUC1(I).LE.60130) GO TO 221
      IF(LNUC1(I).GE.130270.AND.LNUC1(I).LE.130290) WW(I)=100.
      IF(LNUC1(I).GE.140280.AND.LNUC1(I).LE.140310) GO TO 222
      IF(LNUC1(I).GE.150310.AND.LNUC1(I).LE.150340) WW2(I)=100.
      IF(LNUC1(I).GE.160320.AND.LNUC1(I).LE.160370) GO TO 223
      IF(LNUC1(I).GE.220460.AND.LNUC1(I).LE.220510) WW(I)=100.
      IF(LNUC1(I).GE.240500.AND.LNUC1(I).LE.240550) GO TO 224
      IF(LNUC1(I).GE.250540.AND.LNUC1(I).LE.250580) GO TO 225
      IF(LNUC1(I).GE.260540.AND.LNUC1(I).LE.260590) GO TO 226
      IF(LNUC1(I).GE.280580.AND.LNUC1(I).LE.280650) GO TO 227
      IF(LNUC1(I).GE.200400.AND.LNUC1(I).LE.200480)  WW(I)=100.
      IF(LNUC1(I).GE.290620.AND.LNUC1(I).LE.290660)  WW(I)=100.
      IF(LNUC1(I).GE.340760.AND.LNUC1(I).LE.340850)  WW2(I)=100.
      IF(LNUC1(I).GE.400900.AND.LNUC1(I).LE.400980)  GO TO 228
      IF(LNUC1(I).GE.501140.AND.LNUC1(I).LE.501320)   GO TO 229
      GO TO 230
  221 WW(I)=2.717    $  WW2(I)=97.283
      GO TO 230
  222 WW(I)=1.7480   $  WW2(I)=98.252
      GO TO 230
  223 WW(I)=1.0320   $  WW2(I)=98.968
      GO TO 230
  224 WW(I)=6.4171   $  WW2(I)=90.4976
      WW3(I)=.13314 $  F1(I)=.1531      $ FI1(I)=2.79906
      GO TO 230
  225 WW(I)=2.8083   $  WW2(I)=97.192
      GO TO 230
  226 WW(I)=.82813   $  WW2(I)=97.0309
      WW3(I)=.04806 $  F1(I)=.07507     $  FI1(I)=1.01029
      GO TO 230
  227 WW(I)=41.0121  $  WW2(I)=57.03531
      WW3(I)=.09269 $  FI1(I)=1.86012
      GO TO 230
  228 WW3(I)=4.37774    $  F1(I)=3.9054
      FI1(I)=91.71686
      GO TO 230
  229 WW3(I)=4.367  $ F1(I)=3.827
      FI1(I)=91.806
  230 CONTINUE
      GO TO 350
C
C*****************************************************************
C    PWR (WH) END FITTING AND OTHER PARTS OF FUEL ASSEMBLY
C*****************************************************************
C
```

Table 3 -- Continued

```
00327     250 ENUM=CCK*10000./461.4
00328         COL=ENUM*5500.0
00329         SST=ENUM*10000.0
00330         ZR4=ENUM*129700.
00331         DO 260 I=1,NISOT
00332         WW(I)=0.
00333          WW2(I)=0.
00334         WW3(I)=0.
00335          F1(I)=0.
00336          FI1(I)=0.
00337         IF(LNUC1(I).GE.60120.AND.LNUC1(I).LE.60130)  GO TO 251
00338         IF(LNUC1(I).GE.130270.AND.LNUC1(I).LE.130290)  WW(I)=100.
00339         IF(LNUC1(I).GE.140280.AND.LNUC1(I).LE.140310) GO TO 252
00340         IF(LNUC1(I).GE.150310.AND.LNUC1(I).LE.150340)  WW2(I)=100.
00341         IF(LNUC1(I).GE.160320.AND.LNUC1(I).LE.160370)  GO TO 253
00342         IF(LNUC1(I).GE.220460.AND.LNUC1(I).LE.220510)  WW(I)=100.
00343         IF(LNUC1(I).GE.240500.AND.LNUC1(I).LE.240550)  GO TO 254
00344         IF(LNUC1(I).GE.250540.AND.LNUC1(I).LE.250580) WW2(I)=100.
00345         IF(LNUC1(I).GE.260540.AND.LNUC1(I).LE.260590)  GO TO 255
00346         IF(LNUC1(I).GE.280580.AND.LNUC1(I).LE.280650)  GO TO 256
00347         IF(LNUC1(I).GE.270540.AND.LNUC1(I).LE.270620)  WW(I)=100.
00348         IF(LNUC1(I).GE.290620.AND.LNUC1(I).LE.290660)  WW(I)=100.
00349         IF(LNUC1(I).GE.340760.AND.LNUC1(I).LE.340850)  WW2(I)=100.
00350         IF(LNUC1(I).GE.400900.AND.LNUC1(I).LE.400980)  GO TO 257
00351         IF(LNUC1(I).GE.420920.AND.LNUC1(I).LE.421050)  WW(I)=100.
00352         IF(LNUC1(I).GE.501140.AND.LNUC1(I).LE.501340)  GO TO 257
00353         IF(LNUC1(I).GE.410940.AND.LNUC1(I).LE.411010)  WW(I)=100.
00354         IF(LNUC1(I).GE.731800.AND.LNUC1(I).LE.731821)  WW(I)=100.
00355         GO TO 260
00356     251 WW(I)=12.51  $WW2(I)=87.49
00357          GO TO 260
00358     252 WW(I)=9.01  $  WW2(I)=90.99
00359         GO TO 260
00360     253 WW(I)=.2197 $  WW2(I)=99.7803
00361         GO TO 260
00362     254 WW(I)=33.37 $  WW2(I)=60.8194
00363         F1(I)=.2906 $  FI1(I)=5.52
00364         GO TO 260
00365     255 WW(I)=12.16 $  WW2(I)=84.1766
00366         F1(I)=.1834 $  FI1(I)=3.48
00367         GO TO 260
00368     256 WW(I)=78.06 $  WW2(I)=21.94
00369         GO TO 260
00370     257 F1(I)=5.0  $  FI1(I)=95.0
00371     260 CONTINUE
00372         GO TO 350
00373   C
00374   C*********************************************************************
00375   C          LWR CLADDING AND STRUCTURAL MATERIAL ERDA-76-43 VOL 1.
00376   C*********************************************************************
00377   C
00378     300 ENUM=CCK*10000./311.4
00379         COL=ENUM*2500.
00380         SST=ENUM*9000.0
00381         ZR4=ENUM*89550.0
00382         DO 310 I=1,NISOT
00383         WW(I)=0.
00384          WW2(I)=0.
00385         WW3(I)=0.
00386          F1(I)=0.
00387          FI1(I)=0.
00388         IF(LNUC1(I).GE.130270.AND.LNUC1(I).LE.130290)  WW(I)=100.
00389         IF(LNUC1(I).GE.60120.AND.LNUC1(I).LE.60130)  GO TO 301
00390         IF(LNUC1(I).GE.140280.AND.LNUC1(I).LE.140310)  GO TO 302
00391         IF(LNUC1(I).GE.150310.AND.LNUC1(I).LE.150340)  WW2(I)=100.
00392         IF(LNUC1(I).GE.160320.AND.LNUC1(I).LE.160370)   GO TO 303
```

Table 3 -- Continued

```
00393          IF(LNUC1(I).GE.220460.AND.LNUC1(I).LE.220510)  WW2(I)=100.
00394          IF(LNUC1(I).GE.240500.AND.LNUC1(I).LE.240550)  GO TO 304
00395          IF(LNUC1(I).GE.250540.AND.LNUC1(I).LE.250580)   WW2(I)=100.
00396          IF(LNUC1(I).GE.260540.AND.LNUC1(I).LE.260590)   GO TO 305
00397          IF(LNUC1(I).GE.280580.AND.LNUC1(I).LE.280650)  GO TO 306
00398          IF(LNUC1(I).GE.270540.AND.LNUC1(I).LE.270620)  WW(I)=100.
00399          IF(LNUC1(I).GE.290620.AND.LNUC1(I).LE.290660)  WW(I)=100.
00400          IF(LNUC1(I).GE.340760.AND.LNUC1(I).LE.340850)  WW2(I)=100.
00401          IF(LNUC1(I).GE.400900.AND.LNUC1(I).LE.400980)  GO TO 307
00402          IF(LNUC1(I).GE.420920.AND.LNUC1(I).LE.421050)  WW(I)=100.
00403          IF(LNUC1(I).GE.501140.AND.LNUC1(I).LE.501340)  GO TO 307
00404          IF(LNUC1(I).GE.410940.AND.LNUC1(I).LE.411010)  WW(I)=100.
00405          IF(LNUC1(I).GE.731800.AND.LNUC1(I).LE.731821)  WW(I)=100.
00406          GO TO 310
00407      301 WW(I)=6.67  $  WW2(I)=93.33
00408          GO TO 310
00409      302 WW(I)=4.72  $  WW2(I)=95.28
00410          GO TO 310
00411      303 WW(I)=3.8   $  WW2(I)=96.2
00412          GO TO 310
00413      304 WW(I)=20.52$   WW2(I)=74.59
00414          F1(I)=.24   $  FI1(I)=4.65
00415          GO TO 310
00416      305 WW(I)=6.54  $  WW2(I)=90.5
00417          F1(I)=.15   $  FI1(I)=2.81
00418          GO TO 310
00419      306 WW(I)=61.82  $WW2(I)=38.18
00420          GO TO 310
00421      307 F1(I)=5.0   $  FI1(I)=95.0
00422      310 CONTINUE
00423      C
00424      C*****************************************************************
00425      C      CALCULATION OF SHEARING AND DISSOLVER PRODUCT
00426      C      (STRUCTURAL MATERIAL IS SEND TO SOLID WASTE FACILITY)
00427      C*****************************************************************
00428      C
00429      350 DO 370 I=1,NISOT
00430          IF(WW(I).EQ.0.0.AND.WW2(I).EQ.0.0.AND.F1(I).EQ.0.0.AND
00431         1.WW3(I).EQ.0.0.AND.FI1(I).EQ.0.0) GO TO 360
00432          CINCO(I,1)=FD(I)*WW(I)*ISS/100.
00433          SLSL(1,I)=FD(I)*WW2(I)*ISS/100.
00434          SLSL(3,I)=FD(I)*F1(I)*ISS/100.
00435          SLSL(2,I)=FD(I)*WW3(I)*ISS/100.
00436          OGI(I)=FD(I)*(100.0-(WW(I)+WW2(I)+WW3(I)+F1(I)+FI1(I)))*ISS
00437          IF(OGI(I).NE.0.0)OGI(I)=0.0
00438          GO TO 370
00439      360 CINCO(I,2)=FD(I)*ISS
00440          OGI(I)=0.0
00441      370 CONTINUE
00442      C
00443      C*****************************************************************
00444      C        DISSOLVER INPUT; FUEL BASKET FROM H-3 REMOVAL FACILITY
00445      C        DISSOLVER OUTPUT; RAW METAL SOLUTION
00446      C                          DISSOLVER OFF GAS
00447      C                          HALL RINSE(2M  NAOH)
00448      C                          EQUIPMENT FLUSH(F-)
00449      C                          HALL
00450      C                          DISSOLVER FLUSH
00451      C*****************************************************************
00452      C
00453           DO 380 I=1,NISOT
00454           HALL(1,I)=(FD(I)*FI1(I)*ISS+CINCO(I,2))*.9877*ISS
00455           SOLI(I,1)=(FD(I)*FI1(I)*ISS+CINCO(I,2))*.0112*ISS
00456           SOLI(I,2)=(FD(I)*FI1(I)*ISS+CINCO(I,2))*.0011*ISS
00457      380 CONTINUE
00458           GO TO 450
```

Table 3 -- Continued

```
00459     390 IF(KIN.NE.2) GO TO 420
00460     C
00461     C*****************************************************************
00462     C  DISSOLVER RINSE ACTINID AND HEAVY ELEMENT CONSENTERATION
00463     C  PU LESS THAN 0.02 0/0
00464     C  U  LESS THAN 0.05 0/0
00465     C  OTHERS LESS THAN 0.01  0/0
00466     C*****************************************************************
00467     C
00468           DO 400 I=1,NISOT
00469           PR=0.0001
00470           IF(LNUC1(I).GE.942360.AND.LNUC1(I).LE.942450)PR=.0002
00471           IF(LNUC1(I).GE.922400.AND.LNUC1(I).LE.922700)PR=.0005
00472           SOLI(I,2)=FD(I)*ISS*PR
00473           OGI(I+N-1)=FD(I)*(1-PR)*ISS
00474     400 CONTINUE
00475     C     ********************* OFF GAS FROM DISSOLVER *****************
00476           PR=5.7E-7
00477           DO 410 I=1,NISOT
00478           WW3(I)=PR*FD(I)*ISS
00479     410 OGI(I+N-1)=OGI(I+N-1)*(1-PR)
00480           GO TO 450
00481     C
00482     C*****************************************************************************
00483     C     TRITIUM REMOVER
00484     C     FURNACE  PURGE 5664 M**3/DAY CONTAMINATED (DOG) AIR
00485     C     CELL VENTILATION 5664 M**3/DAY CLEAN   (TO STACK) AIR
00486     C     FURNACE COOLING 4.08E+5 M**3/DAY 11 DEGREE TEMP. RISE (TO STACK) AIR
00487     C*****************************************************************************
00488     C
00489     C  ***************** OFF GAS CALCULATION  H-3 REMOVER ********************
00490     C
00491     420 DO 440 I=1,NISOT
00492           PR=0.0
00493           PR1=5.7E-07
00494           PR2=.0001
00495           IF(LNUC1(I).EQ.10030) GO TO 421
00496           IF(LNUC1(I).GE.360800.AND.LNUC1(I).LE.360900) GO TO 422
00497           IF(LNUC1(I).GE.441000.AND.LNUC1(I).LE.441600)  PR=.207
00498           IF(LNUC1(I).GE.531290.AND.LNUC1(I).LE.531330)  GO TO 423
00499           IF(LNUC1(I).GE.541290.AND.LNUC1(I).LE.541340)  GO TO 424
00500           GO TO 425
00501     421 PR=.99  $  PR1=0.0  $  PR2=0.0
00502           GO TO 425
00503     422 PR=.742E-03  $  PR1=1.0   $ PR2=0.0
00504           GO TO 425
00505     423 PR=.00487  $  PR1=1.0  $  PR2=0.0
00506           GO TO 425
00507     424 PR=.708E-03  $PR1=1.0  $PR2=0.0
00508     425 SOLI(I,2)=PR2*FD(I)*ISS
00509           WW2(I)=FD(I)*ISS*PR
00510           WW3(I)=FD(I)*ISS*PR1
00511           IF(PR1.NE.1.0) GO TO 430
00512           WW3(I)=FD(I)*ISS*(1-PR)
00513           PR1=1-PR
00514     430 OGI(N+I-1)=FD(I)*ISS*(1-PR1-PR-PR2)
00515     440 CONTINUE
00516     450 WRITE(6,9520)
00517           WRITE(6,9006)TITLE
00518           IF(INUT.GT.0)GO TO 453
00519           WRITE(6,9505)ICAP,ISS,BURNUP,INCOOL
00520           GO TO 455
00521     453 WRITE(6,9504)ICAP,ISS,BURNUP,INCOOL
00522     455 WRITE(6,9525)
00523           IF(RTYPE.GT.0)GO TO 457
00524           WRITE(6,9530)
```

Table 3 -- Continued

```
00525          GO TO 459
00526      457 WRITE(6,9535)
00527      459 IF(KIN-2)456,480,500
00528      456 WRITE(6,9537)
00529          DO 470 I=1,NISOT
00530          WW2(I)=0.0
00531           SOLI(I,1)=SOLI(I,1)/DISF
00532           SOLI(I,2)=SOLI(I,2)/VILLW(2)
00533           PR=0.0
00534           IF(LNUC1(I).EQ.60140)PR=1.0
00535           IF(LNUC1(I).GE.360800.AND.LNUC1(I).LE.360900) PR=1.0
00536           IF(PR.EQ.0.0) GO TO 460
00537           WW3(I)=FD(I)*ISS/VGAS4
00538           HALL(1,I)=0.0
00539           SOLI(I,2)=0.0
00540           SOLI(I,1)=0.0
00541          OGI(I)=0.0
00542      460 FD(I)=OGI(I)/RAWM
00543           WRITE(6,9540)ELE(I),MWT(I),STA(I),SLSL(1,I),CINCO(I,1),SLSL(2,I),
00544         1SLSL(3,I),HALL(1,I),SOLI(I,2),SOLI(I,1),WW3(I),WW2(I),FD(I)
00545      470 CONTINUE
00546          GO TO 520
00547      480 WRITE(6,9545)
00548           DO  490 I=1,NISOT
00549          SLSL(1,I)=0.0
00550          SLSL(2,I)=0.0
00551          SLSL(3,I)=0.0
00552          CINCO(I,1)=0.0
00553          HALL(1,I)=0.0
00554          SOLI(I,1)=0.0
00555          WW2(I)=0.0
00556           SOLI(I,2)=SOLI(I,2)/VILLW(2)
00557           WW3(I)=WW3(I)/VGAS4
00558           FD(I)=OGI(N+I-1)/RAWM
00559           WRITE(6,9540)ELE(I),MWT(I),STA(I),SLSL(1,I),CINCO(I,1),SLSL(2,I),
00560         1SLSL(3,I),HALL(1,I),SOLI(I,2),SOLI(I,1),WW3(I),WW2(I),FD(I)
00561      490 CONTINUE
00562          GO TO 520
00563      500 WRITE(6,9555)
00564          DO 510 I=1,NISOT
00565          SLSL(1,I)=0.0
00566          SLSL(2,I)=0.0
00567          SLSL(3,I)=0.0
00568          CINCO(I,1)=0.0
00569          HALL(1,I)=0.0
00570          SOLI(I,1)=0.0
00571          SOLI(I,2)=SOLI(I,2)/VILLW(2)
00572          WW2(I)=WW2(I)/VGAS3
00573          WW3(I)=WW3(I)/VGAS4
00574          FD(I)=OGI(N+I-1)/RAWM
00575           WRITE(6,9540)ELE(I),MWT(I),STA(I),SLSL(1,I),CINCO(I,1),SLSL(2,I),
00576         1SLSL(3,I),HALL(1,I),SOLI(I,2),SOLI(I,1),WW3(I),WW2(I),FD(I)
00577      510 CONTINUE
00578      520 CONTINUE
00579          WRITE(6,9550)AIR(1),AIR(2),VGAS2,VGAS3,VGAS4,AGP2,VILLW(2)
00580         1,VILLW(3),DISF,RAWM
00581          IF(IOUT.EQ.0) GO TO 505
00582          CALL CURIE(OGI,T,NTOTAL,LNUC3,LNUC2,0)
00583          GO TO 530
00584      505 CALL GRAM(OGI,T,NTOTAL,LNUC3,LNUC2,0,MWT1)
00585      530 DO 525 I=1,NTOTAL
00586          ELE(I)=ELE1(I)
00587          MWT(I)=MWT1(I)
```

Table 3 -- Continued

```
00588          STA(I)=STA1(I)
00589       525 FDI(3,I)=OGI(I)/ISS
00590          WRITE(6,9560)
00591          WRITE(6,74)(ELE(I),MWT(I),STA(I),FDI(1,I),FDI(2,I),FDI(3,I)
00592         1,I=1,NTOTAL)
00593          STOP
00594    C
00595    C************** FORMAT STATEMENTES ********************
00596    C
00597     9001 FORMAT(4F10.3,2I5)
00598     9003 FORMAT(8A10)
00599     9005 FORMAT(8I5)
00600     9007 FORMAT(A2,I3,A2,5X,1PE9.2,6X,I7,10X,I4)
00601     9501 FORMAT(1H1,//,40X,'INPUT DATA ',//,10X,'RPOWER',F10.3,'INMASS'
00602         1,F10.3,'BURNUP',F10.3,
00603         1/,10X,'CAP',3X,F10.3,'RTYPE',6X,I5,'INCOOL',5X,I5
00604         1,/,10X,'INFUEL',I5,5X,'IOUT',I5,8X,'IIN',I5,8X,/,10X,'ISOTS',I5,6X,
00605         1'ISOTH',I5,5X,'ISOTFP',I5,5X,/,10X,'KJZ',I5,8X,'JZK',I5,7X,//)
00606     9502 FORMAT(1H1,///,4X,'ISOTOPES WHICH ARE READ IN BY FORMAT 9007 ')
00607       12 FORMAT(10X,A2,I3,A2,5X,1PE9.2,6X,I7,10X,I4)
00608     9518 FORMAT(1H1,////)
00609     9503 FORMAT(10X,'    DATA IN THE LIBRARY IS ......,',//)
00610     9008 FORMAT(3(I7,3X,1PE10.4))
00611     9516 FORMAT(10X,3(I7,3X,1PE15.4))
00612     9050 FORMAT(15X,'DATA FOR THIS TYPE OF REACTOR NOT AVALIBLE')
00613     9052 FORMAT(15X,'DATA FOR THORIUM FUEL IS NOT AVALIBLE ')
00614     9500 FORMAT(1H1,37X,'**** WASTE  FROM SHIPING AND FUEL RECIVEING - STORA
00615         1GE POOL *****')
00616     9006 FORMAT(10X,8A10)
00617     9504 FORMAT(///,10X,'FUEL POOL CAPACITY ',I5,'MTHM',5X,'STEADY STA
00618         1TE FLOW OF MATERIAL',F6.2,'MTHM/DAY',4X,'BURNUP',F10.3,'MWD',/,10X
00619         2 ,'COOLING TIME',I5,'DAY,',//,10X,'ALL VALUES OF THIS TABLE IS IN
00620         3 UNITS OF CURIE/M**3 OF FLOW OF MATERIAL PER DAY',//)
00621     9508 FORMAT(3X,'ISOTOPE',4X,'FAILED FUEL',6X,'FAILED FUEL AND',8X,'POOL
00622         1WATER',9X,'ILLW',10X,'POOL WATER')
00623     9512 FORMAT(14X,'CASK WATER',5X,'SHIPPING CASK VENT',5X,'          ',3X
00624         1,'DEIONIZER FLUSHES ',10X,'DF')
00625     9013 format(3X,'CLADDING AND STRUCTURAL MATERIAL')
00626     9014 FORMAT(3X,A2,I3,A2,4X,1PE9.2,9X,1PE9.2,12X,1PE9.2,6X,1PE9.2
00627         1,10X,1PE15.4)
00628     9515 FORMAT(1X,//,'*****************************************',/,10X,
00629         1'VOLUME OF THE CASK WITH FAILED FUEL',5X,1PE10.2,'M**3/DAY',/,10X,
00630         2'VOLUME OF STORAGE POOL BLDG VENT   ',5X,1PE10.2,'M**3/DAY',/,10X,
00631         3'          AIR  TO SAND FILTER      ',/,10X,
00632         4'VOLUME OF FAILED FUEL AND CASK VENT',5X,1PE10.2,'M**3/DAY',/,10X,
00633         5'HELIUM',/,10X,
00634         6'VOLUME OF EXTERNAL CASK DEION SOL'N',5X,1PE10.2,'M**3/DAY',/,10X,
00635         7'VOLUME OF FILTER DEIONIZER  REGEN  ',5X,1PE10.2,'M**3/DAY',/,10X,
00636         8'WASTE.   (EQUAL AMTS. OF 5 PERSENT  ',/,10X,
00637         9' NA- OH AND 5 PERSENT H- NO3)       ',/,10X,
00638         A'VOLUME OF SPENT HEPA,DEIONIZER FILTER',3X,1PE10.2,'M**3/DAY')
00639     9520 FORMAT(1H1,37X,'***** WASTES AND PRODUCT OF SHEARING AND TRITIUM
00640         1 REMOVAL AND DISSOLVER *****')
00641     9505 FORMAT(///,10X,'FUEL POOL CAPACITY ',I5,'MTHM',5X,'STEADY STATE
00642         1 FLOW OF MATERIAL',F6.2,'MTHM/DAY',4X,'BURNUP',F10.3,'MWD',/,10X
00643         2 ,'COOLING TIME',I5,'DAY,',//,10X,'ALL VALUES OF THIS TABLE IS IN
00644         3 UNITS OF  GRAM/M**3 OF FLOW OF MATERIAL PER DAY',//)
00645     9525 FORMAT(30X,'SHEARING',40X,'DISSOLVER',20X,'H-3 REMOVAL',/
00646         1,3X,'ISOTPE',4X,'STAINLESS',3X,'INCONAL',10X,'ZIRCALOY',10X
00647         1,'HALL',7X,'RINSE',7X,'FLUSH',10X,'DOG',9X,'OFF GAS',5X,
00648         1'FEED TO SX')
00649     9530 FORMAT(15X,'STEEL',6X,'X750',10X,'TWO',6X,'FOUR')
00650     9535 FORMAT(15X,'STEEL',6X,'718',11X,'TWO',6X,'FOUR')
00651     9537 FORMAT(3X,'STRUCTRAL*****************')
00652     9540 FORMAT(3X,A2,I3,A2,3X,1PE9.2,2X,1PE9.2,5(2X,1PE9.2),9X,1PE9.2,
00653         1     2X,1PE9.2,5X,1PE9.2)
```

Table 3 -- Continued

```
00654    9545 FORMAT(3X,'HEAVY ELEMENTS*****************')
00655    9555 FORMAT(3X,'FISSION PRODUCT*****************')
00656    9550 FORMAT(1X,//,'*****************************************',/,10X,
00657        1'TRITIUM REMOVAL.CELL VENTILATION',5X,1PE10.2,'M**3/DAY',/,10X,
00658        2'AIR TO SAND FILTER',/,10X,
00659        3'TRITIUM REMOVAL FURENACE COOLING',5X,1PE10.2,'M**3/DAY',/,10X,
00660        4'AIR TO SAND FILTER (11 DEGREES C',/,10X,
00661        5'TEMP. RISE)',/,10X,
00662        6'SHEARING CELL PURGE. ARGON WITH ',5X,1PE10.2,'M**3/DAY',/,10X,
00663        7'TRACE OF KR,XE,I AND H',/,10X,
00664        8'TRITIUM REMOVAL OFF GAS          ',5X,1PE10.2,'M**3/DAY',/,10X,
00665        9' (FURENACE PURGE)',/,10X,
00666        A'DISSOLVER OFF GAS (DOG).         ',5X,1PE10.2,'M**3/DAY',/,10X,
00667        B'SHEARING FILTER DEIONIZER REGEN ',5X,1PE10.2,'M**3/DAY':/,10X,
00668        C'(ILLW) 5 0/0 NAOH AND 5 0/0 HNO ',/,10X,
00669        D'HALL RINSE .                     ',5X,1PE10.2,'M**3/DAY',/,10X,
00670        E'(NAOH ,NANO3 AND H20)',/,10X,
00671        F'DISSOLVER RINSE (NITRIC ACID)    ',5X,1PE10.2,'M**3/DAY',/,10X,
00672        G'DISSOLVER FLUSH (NAOH AND H20)   ',5X,1PE10.2,'M**3/DAY',/,10X,
00673        H'RAW METAL SOL'N TO SOLVENT       ',5X,1PE10.2,'M**3/DAY',/,10X,
00674        I'EXTRACTION (HNO3 AND NH4OH)')
00675    9560 FORMAT(1H1,5X,'MAIN STREAM FLOW IN NUMBER OF ATOMS/MTHM'
00676        1,/,3X,'ISOTOPE',10X,'FDI(1,I)',8X,'FDI(2,I)',8X,'FDI(3,I)')
00677      74 FORMAT((3X,A2,I3,A2,4X,3(E14.7,4X)),/)
00678   10000 END
00679         SUBROUTINE GRAM(FD,T,NISOT,LNUC1,LNUC2,M1,MWT)
00680         DIMENSION FD(800),CON1(800),T(800),LNUC1(800),LNUC2(800),MWT(800)
00681    C
00682    C      THIS SUBROUTIN CHANGES ISOTOPE QUANTITIES FROM GRAM TO ATOM DENSITY
00683    C       OR ATOM DENSITY TO GRAM
00684    C
00685         DO 10 I=1,NISOT
00686         DO 10 J=1,738
00687         IF(LNUC2(J).NE.LNUC1(I)) GO TO 10
00688         CON1(I)=(6.02252/MWT(I) )*10.0**23
00689      10 CONTINUE
00690         IF(M1.NE.0) GO TO 30
00691    C
00692    C       ************* GRAM TO ATOMS ***************
00693    C
00694         DO 20 I=1,NISOT
00695      20 FD(I)=FD(I)*CON1(I)
00696         GO TO 50
00697    C        *********** ATOMS TO GRAM  **********
00698      30 DO 40 I=1,NISOT
00699      40 FD(I)=FD(I)/CON1(I)
00700      50 RETURN
00701         END
00702         SUBROUTINE  CURIE (FD,T,NISOT,LNUC1,LNUC2,M2)
00703         DIMENSION FD(800),T(800),LNUC1(800),LNUC2(800),CON(800)
00704    C
00705    C      THIS SUBROUTIN CHANGES CURIES TO ATOMS OR THE OTHER WAY
00706    C
00707         C=3.7*10**10
00708         DO 10 I=1,NISOT
00709         DO 10 J=1,738
00710         IF(LNUC2(J).NE.LNUC1(I)) GO TO 10
00711         CON(I)=C*T(J)/ALOG(2.0)
00712      10 CONTINUE
00713         IF(M2.NE.0) GO TO 30
00714    C       ************  CURIE TO ATOM  ****************
00715         DO 20 I=1,NISOT
```

Table 3 -- Continued

```
00716      20 FD(I)=FD(I)*CON(I)
00717         GO TO 50
00718    C      ************ ATOM TO CIURIE  ***************
00719      30 DO 40 I=1,NISOT
00720         IF(CON(I).EQ.0.0) GO TO 42
00721         FD(I)=FD(I)/CON(I)
00722         GO TO 40
00723      42 FD(I)=0.0
00724      40 CONTINUE
00725      50 RETURN
00726         END
00727         SUBROUTINE KINDX (KIN,ISOTS,ISOTH,ISOTFP,N,NISOT,MM)
00728    C     THIS SUBROUTINE SETS THE PRAMETERS FOR DIFFERENT KIND OF INPUTED ISOTOPE
00729    C*********************************************************************************
00730    C
00731    C       IF KIND IS 1 THE ELEMANT IS CLADDING OR STRUCTUAL MATERIAL
00732    C       IF KIND IS 2 THE ELEMENT IS A HAVEY MATERIAL
00733    C       IF KIND IS EQUAL TO 3 THE ELEMENT IS FISSION PRODUCTS
00734    C    ***************************************************************************

00735         IF(KIN-2) 20,25,30
00736      20 NISOT=ISOTS
00737         IF(NISOT.EQ.0) MM=1
00738         N=1
00739         GO TO 35
00740      25 NISOT=ISOTH+ISOTS
00741         IF(ISOTH.EQ.0)MM=1
00742         IF(ISOTS.EQ.0) GO TO 35
00743         N=ISOTS+1
00744         GO TO 35
00745      30 NISOT=ISOTS+ISOTH+ISOTFP
00746         IF( ISOTFP.EQ.0) MM=1
00747         IF(ISOTS.EQ.0.AND.ISOTH.EQ.0)GO TO 35
00748         N=ISOTS+ISOTH+1
00749      35 RETURN
00750          END
00751         SUBROUTINE NUC1(N,NISOT,KIN,LNUC1,LNUC3,FD,MWT,STA,ELE)
00752    C
00753    C
00754    C     THIS SUBROUTINE TRANSFERS LNUC3 VALUES TO LNUC1 FOR CALCULATION
00755    C    ###################################################################
00756    C
00757         DIMENSION LNUC1(800),LNUC3(800),FD(800),MWT(800),STA(800),ELE(800)
00758         J=1
00759         DO 51 I=N,NISOT
00760         IF(KIN.NE.1) GO TO 50
00761         LNUC1(I)=LNUC3(I)
00762         GO TO 51
00763      50 LNUC1(J)=LNUC3(I)
00764         FD(J)=FD(I)
00765         MWT(J)=MWT(I)
00766         STA(J)=STA(I)
00767         ELE(J)=ELE(I)
00768      51 J=J+1
00769         NISOT=J-1
00770         RETURN
00771         END
*
```

APPENDIX C

COMPUTER PROGRAM "SX"

C.1 Introduction

SX is a program utilized to calculate the flow ratios for a compound or a simple column of solvent extraction cycles. The program is developed for a common type of solvent extraction. This problem can be expressed as follows. In a particular two phase system of immiscible solvents, it estimates the number of equilibrium extraction and scrub stages, and the solvent flow rate above and below of feed stage that are required to achieve a given separation between two distributing solutes. Figure 1 shows a simple diagram of two types of columns.

Nomenclature

A $(\alpha - 1)/(\alpha^{n+1} - 1)$

B $(\beta^{m+1} - 1)/(\beta - 1)$

D y/x = distribution coefficient in catraction section

$D'^{y'}/x'$ = distribution coefficient in scrub section

R Flow rate of raffinates aqueous in extraction reaction

S Flow rate of scrub aqueous in scrub section

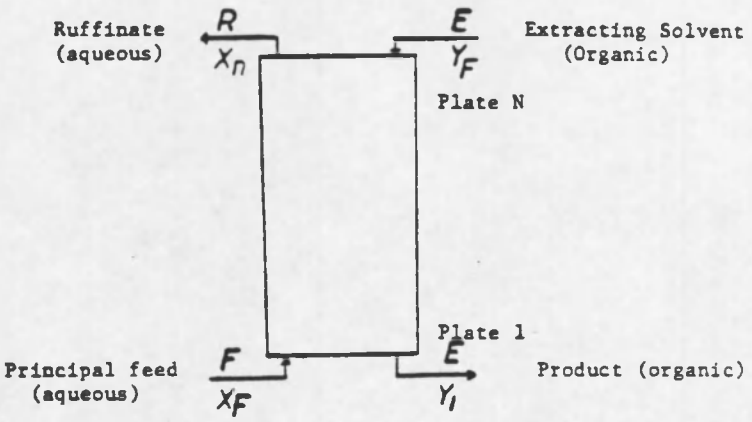
F Flow rate of feed aqueous in principal stream

E Flow rate of extracting organic

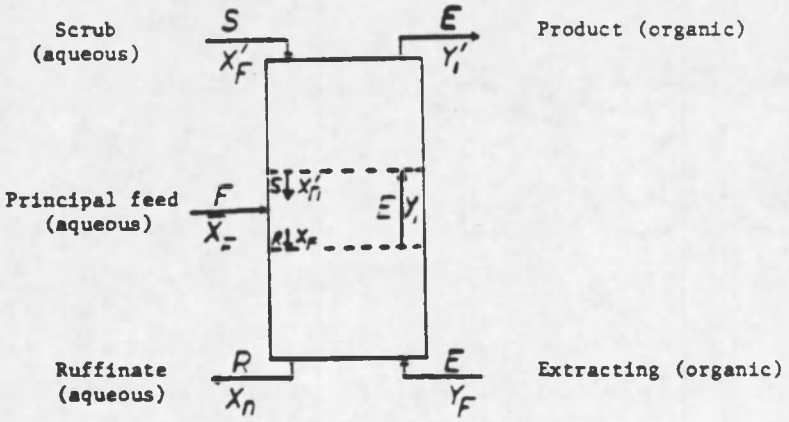
n	Number of extracting states
m	Number of scrub stages
f	$(1 - A)/(1 - A + AB)$
x	Concentration of solute in feed or scrub phase in extraction section
x'	Concentration of solute in feed or scrub phase in scrub section
$\bar{x}$	Concentration of solute in feed or scrub phase in principal feed stream.
y	Concentration of solute in extract phase in extraction section
y'	Concentration of solute in extract phase in scrub section
Z	$x - Y_F/D$
α	$\Sigma D/_R$ = extraction factor
β	S/ED' = scrub factor
ρ	$EY'/_{F\bar{x}}$

Subscripts

1,2,....,	Effluent from stage
F	Feed
P	Plutonium
r	Rare earth
u	Uranium



Simple Extraction Column



Compound Extraction Column

Fig. 1 Schematic Diagram of Extraction Column.

C.2 Method of Solution

The Kremser-Brown Equation is used to design an equation relating the composition of different streams and their flow (Smith 1963). As mentioned in chapter 4 several assumptions are made, here are some additional assumptions:

1 - The distribution coefficients are constant throughout the scrubbing and the extraction section ($D \neq D'$).

2 - The principal feed to the column is only an organic or aqueous solution.

The derivation presented here for the equation of the compound column can be reduced to a simple column by setting one of the subscript n or m to zero, then the equation will be applicable to the scrubbing or the extraction column respectively (ANL - 7165).

1 - Case 1: Derivation of compound column equation with pure aqueous feed to scrubbing section;

The Kremser-Brown equation below the feed is

$$\frac{x_F - x_n}{x_F - \frac{y_F}{D}} = 1 - A = \frac{\alpha^{n+1} - \alpha}{\alpha^{n+1} - \alpha}$$

Define $z = x - \frac{y_F}{D}$. Then

$$\frac{x_F - \frac{y_F}{D} - x_n - \frac{y_F}{D}}{x_F - \frac{y_F}{D}} = 1 - \frac{z_n}{z_F} = 1 - A. \tag{2}$$

The Kremser-Brown equation above the feed is

$$\frac{y_1 - y_1'}{y_1 - x_F'D'} = 1 - \frac{y_1'}{y_1} = 1 - \frac{1}{B} = \frac{\beta^{m+1} - \beta}{\beta^{m+1} - 1}. \tag{3}$$

Solving for A and B, one obtains

$$B = \frac{y_1}{y_1'}; \qquad A = \frac{z_n}{z_F}. \tag{4}$$

The material-balance equation above the feed is

$$Ey_1 = EBy_1' = Ey_1' + Sx_n'. \tag{5}$$

Then,

$$Sx_n' = Ey_1'(B - 1). \tag{6}$$

The material-balance equation below the feed is

$$Ey_F + Rx_F = Ey_1 + Rx_n = EBy_1' + Rx_n. \tag{7}$$

Rearranging Eq. (7) results in

$$E(y_F - By_1') = R(x_n - x_F). \tag{8}$$

Substituting Eq. (2) into Eq. (8) results in

$$E(y_F - By_1') = R(A - 1)\, z_F \tag{9}$$

or

$$Rz_F = \frac{E(y_F - By_1')}{A - 1} \tag{11}$$

The material-balance equation around the feed is

$$Rx_F = F\bar{x}_F + Sx_n', \tag{12}$$

or

$$Rx_F = R(z_F + \frac{y_F}{D}) = \frac{E(y_F - By_1')}{A - 1} + R\frac{y_F}{D}. \tag{13}$$

Substituting Eqs. (6) and (19) into Eq. (13) produces

$$\frac{Ey_F - EBy_1'}{A - 1} + R\frac{y_F}{K} = F\bar{x}_F + Ey_1'(B - 1). \tag{14}$$

Rearranging Eq. (14) results in

$$\rho = f\left[1 - \frac{R}{F}\frac{y_F}{\bar{x}_F D}\right] + g\frac{Ey_F}{F\bar{x}_F}, \tag{15}$$

where

$$f = \frac{1 - A}{1 - A + AB}, \tag{16}$$

$$g = \frac{1}{1 - A + AB}, \tag{17}$$

$$1 - A = \frac{\alpha^{n+1} - \bar{\alpha}}{\alpha^{n+1} - 1}, \tag{18}$$

$$1 - \frac{1}{B} = \frac{\beta^{m+1} - \beta}{\beta^{m+1} - 1}, \tag{19}$$

$$\alpha = ED/R = \text{extraction factor}, \tag{20}$$

and

$$\beta = S/ED' = \text{scrub factor} \tag{21}$$

and

$$\rho = \frac{Ey'_1}{F\bar{x}_F} = \text{recovery factor.} \tag{22}$$

If the extraction solvent is pure, Eq. (15) would reduce to

$$\rho = f = \frac{1 - A}{1 - A + AB} \tag{23}$$

- Case 2: In a similar manner, an analogous expression can be derived for the case of impure scrub solvent (aqueous) and a pure extracting solvent, i.e., $y_F = 0$, $x'_F \neq 0$. The result is;

$$\frac{Ey'_1}{Fx_F + Sx'_F} = f + (1 - g)\frac{ED'x'_F}{F\bar{x}_F + Sx'_F} \tag{24}$$

The program SX utilizes the equation 15 and 23 for its numerical calculation. Both of these equations are polynomials of m^{th} or n^{th} order (depending on magnitude of m or n). The solution to these polynomials are the flow ratios E/F and S/E. If the composition of different streams, distribution coefficient, principal feed flow and number of stages in scrubbing and extraction are known values.

The program in its inner iteration calculates the E/F and S/E ratios using the equation 23;

$$\rho_1 = \frac{1 - A_1}{1 - A_1 + A_1B_1} \qquad \text{element number 1.} \tag{25}$$

$$\rho_1 = \frac{1 - A_2}{1 - A_2 + A_2B_2} \qquad \text{element number 2.} \tag{26}$$

The separation is performed on element No. 1 and element number No. 2. The program SX assumes a set of constant values (increasing linearly) for S/E and then it calculates the scrub factor. Knowing all parameters for both elements, SX then calculates the value of extraction factors (α) in subroutine ALFAZ independently. The ratio of E/R for element no. 1 should be equal to the ratio of E/R for element no. 2 ($\Delta = 0$) in an ideal calculation;

$$\Delta = \frac{E}{R}_{\text{Element No. 1}} - \frac{E}{R}_{\text{Element No. 2}} \tag{27}$$

The program utilizes this fact and finds the minimum value of Δ and expands the value of S/E about this point. Then the procedure is repeated until the error is less or equal to the one set by the user.

The program SX then does outer the integration using equation 15 if the organic feed to the extraction cycle is impure. At this stage of calculation, SX uses the value of E/R found by the inner iteration as a first estimate and using a procedure very similar to the inner iteration it calculates the new S/E and then E/R which met the specification set by error conditions.

The program SX calculates the flows in most realistic cases. One of the limitations on the program arises if the distribution coefficients of two elements are equal or if they are more than 3 order of difference from each other.

In each case the program gives an error message.

The data obtained by SX is in agreement with the result published in ANL-7165 within accuracy of 10^{-4} and comparing with actual operation with 10 percents (TID-7534 1957).

C.3 Input/Output

C.3.1 Input

The input data are to be prepared in order Table 1. Description of different columns of this table is presented in Section 3.2.1 of Apprndix B. An example of input cards for a sample case is illustrated in Table 2. The important parameters are distribution coefficients which can be obtained in lithenature (Cleveland 1979).

C.3.2 Output

The output exhibits in the first table the solution to the inner iteration and then in the next table the solution of the problem with impure organic. Table 3 illustrates the output. Also a listing of program is shown in Table 4.

Table 1 Input Data Card for "SX"

Subroutine	Card No.	Columns	Remarks, Variables, Etc.
SX03	1	1 to 5	N - Number of extraction stages Format: I5
	1	5 to 10	NP - Number of scrubbing stages Format: I5
	1	10 to 15	LCH - A flag for output Enter: 1 Prints all values of Alpha 0 Values of Alpha are not printed Format: I5
	1	15 to 20	LAF - A flag for dumping all information in outer iteration Format: I5
SX03	2	1 to 10	GUK - Distribution coefficient of uranium. Format: F10.3
	2	10 to 20	PUK - Distribution coefficient of element No. 1 extracted in raffinate Format: F10.3
	2	20 to 30	FAK - Distribution coefficient of element No. 2 inproduct stream. Format: F10.3
SX03	3	1 to 10	FPU - Mass fraction of element No. 1 in raffinate (Feed/raffinate) Format: F10.7
	3	10 to 20	FFA - Mass fraction on element No. 2 in raffinate (Feed/raffinate) Format: F10.7
	3	20 to 30	SU - Uranium solubility in feed Unit: U/kg of solute-free solvent metal. Format: F10.7

Table 1 -- Continued

Subroutine	Card No.	Columns	Remarks, Variables, Etc.
SX03	4	1 to 10	GUMASS - Mass of uranium in principal feed. Unit: Kg/day Format: F10.3
	4	10 to 20	PUMASS - Mass of element No. 1 in principal feed. Unit: Kg/day Format: F10.3
	4	20 to 30	FAMASS - Mass of element No. 2 in principal feed. Unit: Kg/day Format: F10.3
SX03	5	1 to 10	YEORG - Concentration of element No. 2 in organic feed to extraction section Unit: Kg/kg solvent solt Format: E10.3

Table 2 Input Data for SX. -- 3x3 Compound-Column.

```
00001         3     3     3     3
00002        .015        0.035        1.2
00003       .992        .20000       .0267
00004       40.0          8.0          .8
00005     00008.E-05
```

Table 3 Sample Output for SX. -- 3x3 Compound Column.

```
00001        PRINCIPAL FEED FLOW IN KG/HR =     1498.12734     PRINCIPAL PRODUCT FLOW KG/HR =     1513.12189
00002
00003       FEED TO SCRUB SECTION KG/HR=       56.12986     RAFFINATE FLOW KG/HR =     1554.25720
00004
00005       ALFA URANIUM IS    .01515     BETA=   2.47303
00006       RFOE=    .03710     ROEP=   1.02719     ROEFA=   1.02719              NUMBER OF INT.=   2
00007       ALPHA FU  .341E-01     ALPHA F.P  .117E+01     BETA FU  .106E+01     BETA F.P  .309E-01
00008
00009
00010
00011
00012                                    SOLUTION TO COMPOUND COLUMN WITH UNFURE ORGANIC
00013
00014
00015
00016
00017
00018            FLOW OF FEED =  1498.127     KG/HR
00019            FLOW OF THE PRODUCT STREAM =  2573.497     KG/HR
00020            FLOW OF THE AQUEOUS STREAM =   127.645     KG/HR
00021            FLOW OF THE WASTE STREAM   =  1625.773     KG/HR
00022            LOCATION OF SOLUTION IN METRIX          COLUMN =    1     ROW =   23     ERROR=  .287E-02
```

Table 4 List of SX

```
00001          PROGRAM SX03 (INPUT,OUTPUT,PLOT,TAPE5=INPUT,TAPE6=OUTPUT,
00002         4 TAPE99=PLOT)
00003    C
00004    C       THIS PROGERAM WILL FIND THE FLOW RATIO
00005    C      OF A COMPOUND COLUMNS BY USING KREMSER - BROWN EQ. FOR MORE
00006    C      INFORMATION SEE ANL -7165 'OPERATING  PRAMETERS FOR COMPOUND
00007    C      SOLVENT EXTRACTION COLUMNS.
00008    C
00009    C
00010          DIMENSION RPOE(100),BETAP(100),BETAFA(100),ALFAPU(100)
00011          DIMENSION ALFAFA(100),DELT(100)
00012          DIMENSION ROEP(100), ROE1P(100), ROE1F(100),ROEFA(100)
00013          DIMENSION DELT2(100)
00014          DIMENSION  DELT3(100), DELT4(100),JXY(100)
00015          DIMENSION ROEPX(100),ROEFX(100),RPOEX(100)
00016          DIMENSION RPOES(11,101),ROEFAS(11,100),ROEPS(11,100),ALEX(11,100)
00017          DIMENSION ALSC(11,100),BETEX(11,100),BETSC(11,100)
00018          COMMON N,NP,BETAP,BETAFA,FFA1,FPU1,ALFAPU,ALFAFA,LAF,J
00019          READ(5,800)N,NP,LCH,LAF
00020      800 FORMAT(4I5)
00021          READ(5,802)GUK,PUK,FAK
00022      802 FORMAT(3F10.5)
00023          READ(5,804)FPU,FFA,SU
00024      804 FORMAT(3F10.7)
00025          READ(5,806)GUMASS,PUMASS,FAMASS
00026      806 FORMAT(3F10.5)
00027          PRINT*,N,NP,LCH,LAF
00028          PRINT*,FPU,FFA,SU
00029          PRINT*,GUK,PUK,FAK
00030          PRINT*,GUMASS,PUMASS,FAMASS
00031    C
00032    C       INTIAL VALUES
00033    C
00034          PN=NP*1.0
00035          ZZN=1.0*N
00036          FPU1=1.0-FPU
00037          JK=0
00038          FFA1=1.0-FFA
00039          RPOE(1)=.01
00040          DO 10 I=2,100
00041          IF(I-50) 30,20,20
00042       20 RPOE(I)=RPOE(I-1)+((.9)/50.0)
00043          GO TO 10
00044       30 RPOE(I)=RPOE(I-1)+((0.09)/50.0)
00045       10 CONTINUE
00046    C       CALCULATION STEATMENTS
00047    C
00048          DO 5 I=1,100
00049          BETAP(I)=RPOE(I)/PUK
00050        5 BETAFA(I)=RPOE(I)/FAK
00051          CALL ALFAZ
00052          DO 40 I=1,100
00053          ROEP(I)=PUK/ALFAPU(I)
00054          ROEFA(I)=FAK/ALFAFA(I)
00055          ROE1P(I)=ROEP(I)-RPOE(I)
00056       40 ROE1F(I)=ROEFA(I)-RPOE(I)
00057          IF(LCH.EQ.0) GO  TO 210
00058          WRITE(6,900)
00059          WRITE(6,902)
00060          J=0
00061          DO 50 I=1,50
```

Table 4 -- Continued

```
00062          J=I+50
00063       50 WRITE(6,903)RPOE(I),ROEFA(I),ROEP(I)   ,RPOE(J),ROEFA(J),ROEP(J)
00064      210 CALL XMINX(ROEP,ROEFA,DELT2,DELT,IIII,ZMIN)
00065          CALL STORE(RPOE,ROEFA,ROEP,ALFAFA,ALFAPU,BETAFA,BETAP,
00066         1RPOES,ROEFAS,ROEPS,ALEX,ALSC,BETEX,BETSC,IIII,JK)
00067           IF(ZMIN.EQ.0.) GO TO 251
00068          XXXJ=(0.0018)/(100.0)
00069          DO 250 JX=1,10
00070      220 RPOE(1)=RPOE(IIII)
00071          BETAP(1)=RPOE(1)/PUK
00072           BETAFA(1)=RPOE(1)/FAK
00073          DO 230 I=2,100
00074          RPOE(I)=RPOE(I-1)+XXXJ
00075          BETAP(I)=RPOE(I)/PUK
00076      230 BETAFA(I)=RPOE(I)/FAK
00077          N=ZZN*1          $       NP=PN*1
00078          CALL ALFAZ
00079          DO 240 I=1,100
00080          ROEP(I)=PUK/ALFAPU(I)
00081      240 ROEFA(I)=FAK/ALFAFA(I)
00082          CALL XMINX(ROEP,ROEFA,DELT2,DELT,IIII,ZMIN)
00083          CALL STORE(RPOE,ROEFA,ROEP,ALFAFA,ALFAPU,BETAFA,BETAP,
00084         1RPOES,ROEFAS,ROEPS,ALEX,ALSC,BETEX,BETSC,IIII,JK)
00085           IF(ZMIN.EQ.0.) GO TO 251
00086          IF(LCH.EQ.0)GO TO  242
00087           PRINT*,DELT2(IIII),IIII,JX,XXXJ,N,NP
00088          WRITE(6,900)
00089      900 FORMAT(1H1, 7X,'RATIO OF FLOW R/E',  5X,'SCRUB',8X
00090         1 ,'EXTRACTION',23X,'SCRUB',8X,'EXTRACTION',///)
00091          WRITE(6,902)
00092      902 FORMAT(38X,'RARE-EARTH',3X,'PU',31X,'RARE-EARTH',3X,'PU')
00093          J=0
00094          DO 51 I=1,50
00095          J=I+50
00096       51 WRITE(6,903)RPOE(I),ROEFA(I),ROEP(I)   ,RPOE(J),ROEFA(J),ROEP(J)
00097      903 FORMAT(10X,2(16X,E10.3,E10.3,E10.3))
00098      242 IF(ABS(DELT2(IIII))-0.0001)260,260,245
00099      245 XXXJ=(ABS(RPOE(IIII)-RPOE(IIII+1)))/100.
00100      250 CONTINUE
00101      251 RPOEX(JX)=RPOE(IIII)
00102          ROEPX(JX)=ROEP(IIII)
00103          ROEFX(JX)=ROEFA(IIII)
00104          DELT4(JX)=ABS(DELT2(IIII))
00105          DELT3(JX)=ABS(DELT2(IIII))
00106          JXY(JX)=IIII
00107          DO 265 I=2,JX
00108          ZZMI=AMIN1(DELT3(JX-1),DELT3(JX))
00109          write(6,903)delt3(Jx-1),ZZMI,RPOE(Jx),Roepx(Jx)
00110      265 DELT3(JX)=ZZMI
00111          DO 267 I=1,JX
00112      267 IF(DELT4(JX).EQ.ZZMI) IIII=JXY(JX)
00113      260 I=IIII
00114      270 RPOE1=RPOE(I)
00115          ROEP1=ROEP(I)
00116          ROEFA1=ROEFA(I)
00117          ROE1=ROEP1-RPOE1
00118          FSF=GUMASS/SU
00119          PF=FSF/ROE1
00120          FSS=PF*RPOE1
00121          RAF=fsf+FSS
00122          ALFAX=GUK/ROE1
00123          BETAX=RPOE1/GUK
00124          WRITE(6,909)FSF,PF
00125      909 FORMAT(1H1,5X,'PRINCIPAL FEED FLOW IN KG/HR =',F15.5,
00126         +5X,'PRINCIPAL PRODUCT FLOW KG/HR =',F15.5)
00127          WRITE(6,911)FSS,RAF
```

Table 4 -- Continued

```
00128     911 FORMAT(/,5X,'FEED TO SCRUB SECTION KG/HR=',F15.5,
00129        +5X,'RAFFINATE FLOW KG/HR =',F15.5)
00130         WRITE(6,913) ALFAX,BETAX
00131     913 FORMAT(/,5X,'ALFA URANIUM IS',F10.5,5X,'BETA='F10.5)
00132         WRITE(6,906)RPOE1,ROEP1,ROEFA1,JX
00133     906 FORMAT(5X,'RPOE=',F10.5,5X,'ROEP=',F10.5,5X,'ROEFA=',F10.5
00134        1,15X,'NUMBER OF INT.=',I4)
00135     .   write(6,907)ALFAPU(I),ALFAFA(I),BETAP(I),BETAFA(I)
00136     907 format(5x,'alpha pu',e10.3,5x,'alpha f.p',e10.3,5x,'beta pu',
00137        1e10.3,5x,'beta f.p',e10.3)
00138         IF(JX.EQ.10) GO TO 290
00139         IF(RAF/FF.LT.RPOE1) GO TO 300
00140         READ(5,908)YEORG
00141     908 FORMAT(E10.3)
00142         PRINT*,YEORG
00143         DVALUE=FAMASS*FFA
00144         KJ=JK
00145     275 IIII=RPOES(KJ,101)
00146         DO 280 IJ=IIII,100
00147         JI=IJ
00148         ALEX(KJ,JI)=FAK/ROEPS(KJ,JI)
00149         FF=FSF/(ROEPS(KJ,JI)-RPOES(KJ,JI))
00150         RAF=FSF+(FF*RPOES(KJ,JI))
00151         A=((ALEX(KJ,JI))-1.)/((ALEX(KJ,JI)**(N+1))-1.)
00152         B=((BETEX(KJ,JI)**(NP+1))-1.)/(BETEX(KJ,JI)-1.)
00153         F=(1.0-A)/(1.0-A+A*B)
00154         G=1.0/(1.0-A+A*B)
00155         EYS=F*(FAMASS-(RAF*YEORG)/FAK)+G*FF*YEORG
00156         IF(ICH.EQ.0) GO TO 277
00157         PRINT*,RPOES(KJ,JI),BETEX(KJ,JI),ALEX(KJ,JI),A,B,G,EYS,JI,F
00158     277 ERROR=ABS(DVALUE-(FAMASS+FF*YEORG-EYS))
00159         IF(ERROR.LE..01) GO TO 310
00160     280 CONTINUE
00161         KJ=KJ-1
00162         IF(KJ.EQ.0)GO TO 320
00163         GO TO 275
00164     290 WRITE(6,909)
00165         STOP
00166     300 WRITE(6,910)RAF,FF,RPOE1
00167         STOP
00168     310 WRITE(6,912)
00169         FSS=RAF-FSF
00170         WRITE(6,914)FSF,FF,FSS,RAF
00171         WRITE(6,916)KJ,JI,ERROR
00172         STOP
00173     320 WRITE(6,918)
00174         STOP
00175     910 FORMAT(10X,'***** RATIO S+F/F IS LESS THAN S/F  ****',/,
00176        110X,'ROE=',E10.3,5X,'FF=',E10.3,5X,'RPOE=',E10.3)
00177     912 FORMAT(1H1,40X,'SOLUTION TO COMPOUND COLUMN WITH UNPURE ORGANIC'
00178        1,5(/))
00179     914 FORMAT(10X,'FLOW OF FEED =',F10.3,5X,'KG/HR',/,
00180        110X,'FLOW OF THE PRODUCT STREAM =',F10.3,5X,'KG/HR',/,
00181        110X,'FLOW OF THE AQUEOUS STREAM =',F10.3,5X,'KG/HR',/,
00182        110X,'FLOW OF THE WASTE STREAM   =',F10.3,5X,'KG/HR')
00183     916 FORMAT(10X,'LOCATION OF SOLUTION IN METRIX',10X,'COLUMN -'
00184        1,I5,5X,'ROW =',I5,5X,'ERROR=',E10.3)
00185     918 FORMAT(10X,'****** SEARCH FOR NEW VALUE OF FLOW FAILD******')
00186         END
00187         SUBROUTINE ALFAZ
00188         DIMENSION BETAP(100),BETAFA(100),ALFAPU(100),ALFAFA(100)
00189         DIMENSION ALFA(100),BETA(100)
00190         COMMON N,NP,BETAP,BETAFA,FFA1,FPU1,ALFAPU,ALFAFA,LAF,I
00191         DO 2001 I=1,2
00192         DO 190 I=1,100
00193         IF(II-2)10,20,20
```

Table 4 -- Continued

```
00194      10 BETA(I)=BETAP(I)
00195         FF=FFU1
00196         GO TO 30
00197      20 BETA(I)=BETAFA(I)
00198         FF=FFA1
00199      30 B=1.
00200         DO 40 K=1,NP
00201      40 B=B+BETA(I)**K
00202         ALFA(I)=.000995
00203         ID=1
00204      50 A=0.0
00205         DO 60 MM=1,N
00206      60 A=A+ALFA(I)**MM
00207         FOFA=(A/(A+B))-FF
00208         IF(ID-2)70,100,130
00209      70 ID=2
00210         IF(FOFA)90,160,80
00211      80 ALFA(I)=0.0
00212         GO TO 160
00213      90 ALFAKP=.000995
00214         ALFA(I)=1000.0
00215         GO TO 50
00216     100 ID=3
00217         IF(FOFA)160,160,120
00218     110 IF(ALFA(I)-ALFAKP-(ALFAKP*0.0001))160    ,120
00219     120 ALFAH=ALFA(I)
00220         ALFA(I)=(ALFAH+ALFAKP)*0.5
00221         GO TO 50
00222     130 IF(FOFA)140,160,110
00223     140 IF(ALFAH-ALFA(I)-(ALFA(I)*0.0001))160,160,150
00224     150 ALFAKP=ALFA(I)
00225         ALFA(I)=(ALFAH+ALFAKP)*0.5
00226         GO TO 50
00227     160 IF(II-2)170,180,180
00228     170 ALFAPU(I)=ALFA(I)
00229         GO TO 190
00230     180 ALFAFA(I)=ALFA(I)
00231     190 CONTINUE
00232     200 CONTINUE
00233         IF(LAF-2)230,201,205
00234     201 IF(J.GT.0) GO TO 230
00235     205 WRITE(6,900)
00236     900 FORMAT(1H1,20X,'TABLE OF VALUES OF BETA AND ALFA  FOR PU',
00237        1 //)
00238         WRITE(6,905)
00239     905 FORMAT(2(11X,'BETA',10X,'ALFA'),///)
00240         DO 210 I=1,50
00241         J=I+50
00242         WRITE(6,906)BETAP(I),ALFAPU(I),BETAP(J),ALFAPU(J)
00243     906 FORMAT(2(5X,F10.5,5X,F10.5))
00244     210 CONTINUE
00245         WRITE(6,907)
00246     907 FORMAT(1H1,20X,'TABLE OF VALUES OF BETA AND ALFA  FOR RARE-EARTH'
00247        1 ,///)
00248         WRITE(6,905)
00249         DO 220 I=1,50
00250         WRITE(6,906)BETAFA(I),ALFAFA(I),BETAFA(J),ALFAFA(J)
00251     220 CONTINUE
00252     230 RETURN
00253         END
00254         SUBROUTINE XMINX(ROEP,ROEFA,DELT2,DELT,IIII,ZMIN)
00255         DIMENSION ROEP(100),ROEFA(100),DELT(100),DELT2(100)
00256         DO 10 I=1,100
00257         DELT2(I)=ROEP(I)-ROEFA(I)
00258      10 DELT(I)=ABS(DELT2(I))
00259         DO 20 I=2,100
```

Table 4 -- Continued

```
00260          ZMIN=AMIN1(DELT(I),DELT(I-1))
00261          IF(ZMIN.LE..0001)GO TO 110
00262          if(delt2(i).lt.0.0)go to 25
00263       20 DELT(I)=ZMIN
00264       25  DO 30 I=1,100
00265       30 IF(ABS(DELT2(I)).EQ.ZMIN)GO TO 50
00266       50 IIII=I
00267          IF(DELT2(IIII))60,70,100
00268       60 IIII=IIII-1
00269          GO TO 100
00270       70 IF(DELT2(IIII+1))80,90,100
00271       80 IIII=IIII-1
00272          GO TO 100
00273       90 IIII=I
00274           GO TO 100
00275      110 IIII=I
00276      100 DELT2(IIII)=ZMIN
00277           RETURN
00278          END
00279          SUBROUTINE STORE (RPOE,ROEFA,ROEF,ALFAFA,ALFAPU,BETAFA,
00280         1BETAF,RPOES,ROEFAS,ROEFS,ALEX,ALSC,BETEX,BETSC,IIII,JK)
00281          DIMENSION RPOES(11,101),ROEFAS(11,100),ROEFS(11,100),ALEX(11,100)
00282          DIMENSION ALSC(11,100),BETEX(11,100),BETSC(11,100)
00283          DIMENSION RPOE(100),ROEFA(100),ROEF(100),ALFAFA(100)
00284          DIMENSION ALFAPU(100),BETAFA(100),BETAF(100)
00285           JK=JK+1
00286           DO 10 I=1,100
00287           RPOES(JK,I)=RPOE(I)
00288           ROEFAS(JK,I)=ROEFA(I)
00289           ROEFS(JK,I)=ROEF(I)
00290           ALEX(JK,I)=ALFAFA(I)
00291           ALSC(JK,I)=ALFAPU(I)
00292           BETEX(JK,I)=BETAFA(I)
00293           BETSC(JK,I)=BETAF(I)
00294       10 CONTINUE
00295           RPOES(JK,101)=IIII
00296           RETURN
00297           END
```

REFERENCES

ANL-7185, "Tables for the Calculation of Operating Parameters for Compound Solvent-Extraction Columns", Argonne National Laboratory, February 1966.

Bell, M. J., "ORIGEN-The ORNL Isotope Generation and Depletion Code", Oak Ridge National Laboratory, ORNL-4628, May 1973.

Benedict, M., and Thomas H. Pigford, "Nuclear Chemical Engineering", McGraw Hill, N. Y., 1957.

Carter, J., "Control of Nuclear Proliferation" 95th Congress, First Session, U. S. Government Printing Office, Washington D. C., April 28, 1977.

Cleveland, J. M., "The Chemistry of Plutonium" American Nuclear Society, 1979.

CONF-780304, "Back End of the LWR Fuel Cycle", Proceedings of the American Nuclear Society Topical Meeting, Savannah, Georgia, March 19-23, 1978.

Docket 50-332-57, "Alied-General Nuclear Service Final Safety Analysis Report", Barnwell Nuclear Fuel Plant, Barnwell, S. C., 1974.

DPST-AFCT-77-1-2, "Savannah River Laboratory Quarterly Report April-June 1977, Alternate Fuel Cycle Technologies", Savannah River Laboratory, Aiken, South Carolina, September 1977.

DPST-LWR-76-1-4, "Savannah River Laboratory Quarterly Report October-December 1976, Light Water Reactor Fuel Recycle", Savannah River Laboratory, Aiken, South Carolina, March 1977.

DPST-LWR-77-1-1, "Savannah River Laboratory Quarterly Report January-March 1977, Light Water Reactor Fuel Recycle", Savannah River Laboratory, Aiken, South Carolina, May 1977.

EPRI 310, "Denatured Plutonium: A Study of Deterrent Action", Electric Power Research Institute, July 1975.

ERDA-76-43, "Alternative for Managing Wastes from Reactors and Post Fission Operations in LWR Fuel Cycle", Energy Research and Development Administration, Vol. 1, May 1976.

General Electric Co., "Standard Safety Analysis Report", Vol. 2 BWR/6.

Notz, J. J., A. B. Maservey, and R. D. Ackley, "The Solubility of Krypton and Xenon in Liquid Co_2", American Nuclear Society Transaction, San Francisco Meeting, Vol. 17, November 1973.

NUREG-0009, "Safety Evaluation Related to Operation of Barnwell Fuel Receiving and Storage Station", Allied-General Nuclear Services, January, 1976.

Nye, J. S., "Time to Plan for Next Generation of Nuclear Technology", The International Conference on Nuclear Power and Its Fuel Cycle, Salzburg, Austria, May 2-13, 1977.

LA-7411-MS, "Preliminary Concepts: Coordinated Safeguards for Material Management in a Thorium-Uranium Fuel Reprocessing Plant", Informal Report, Los Alamos, New Mexico, October 1978.

ORNL/NUREG/TM-6, B. C. Finney, R. E. Blaneo, R. C. Dahlman, G. S. Hill F. G. Kitts, R. E. Moore, and J. P. Witherspoon, "Correlation of Radioactive Waste Treatment Costs and Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle-Reprocessing Light-water Reactor Fuel", Oak Ridge National Laboratory, January 1977.

ORNL/NUREG/TM-37, J. W. Roddy, R. E. Blanco, B. C. Finney, and C. S. Hill, "Correlation of Radioactive Waste Treatment Costs and Environmental Impact of Waste Effluents in the Nuclear Fuel Conversion of Recycle Uranium to UF_6", Oak Ridge National Laboratory, August 1977.

Papp, R., "Fuel Man Flow, Radioactive Inventories and Releases of LWR's and LMFBR's", KFK 2453, Karlsruhe Germany, 1977.

Patrasharn, S., "Recycling of Actinides in Light Water Reactors", Nuclear Technology, Vol. 51, Number 1, November 1980.

Pobereskin, M., et al., "Coproning-An Evaluation of Chemical Reprocessing without Plutonium Separation", BMI-EQAC-1, October 28, 1977.

Puechl, K., "Low Concentration Pu-Recycle", Nuclear Engineering International, June 1977.

"Regional Nuclear Fuel Cycle Centers, Basic Study", Vol. II, IAEA, Vienna, 1977.

Smith, D. Buford, "Design of Equilbrium Stage Processes", McGraw Hill Inc., N. Y., 1963.

TID-7534, "Symposium on the Reprocessing of Irradiated Fuels", held at Brussels Belgium May 20-25, 1957, USAEC, Book 1, 1957.

Wash 1238, "Environmental Survey of Transportation of Radioactive Material to and from Nuclear Plants", U. S. Atomic Energy Commission, December 1975.

Wash 1322, "Proceedings of the Second AEC Environmental Protection Conference", U. S. Atomic Energy Commission, Albuquerque, N. M., 1974.

Westinghouse Co., "Standard Safety Analysis Report",Vol. II, RESAR-35, July 1975.

Williams, D. C., and B. Rosenstroch, "A Review of Nuclear Fuel Cycle Alternatives Including Certain Features Pertaining to Weapon Proliferation", Sandia Laboratories, SAND-77-1727, January 1978.

Yarbro, O. O., F. E. Harrington, and D. S. Joy, "Effluent Control in Fuel Reprocessing Plants", Chemical Technology Division, ONRL-TM-3899, March 1974.