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A FUEL REPROCESSING PLANT FOR FAST CERAMIC REACTORS

By
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February 1, 1962

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GEAP-4028
CHEMICAL SEPARATIONS PROCESSES
FOR PLUTONIUM AND URANIUM

A FUEL REPROCESSING PLANT
FOR
FAST CERAMIC REACTORS

by
H. W. Alter

February 1, 1962

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ABSTRACT

A study has been made of the adaptation of the HAPO anion exchange process to the reprocessing of Fast Ceramic Reactor (FCR) fuel using the Idaho Small Plant Concept.

It is shown that the anion exchange flowsheet meets the reprocessing objectives of the FCR case and can be adequately accommodated in the Small Plant Concept. Capacities of up to 1550 MWe are feasible in the Small Plant and unit reprocessing costs range from 0.14 - 0.28 mills/Kwh depending on the number of reactors to be processed.

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I. INTRODUCTION

One of the well-known attractive features of the Fast Ceramic Reactor (FCR) is the cost advantage associated with high fuel burnup. To a first approximation the costs of both fuel reprocessing and fuel fabrication are inversely proportional to burnup. If fuel costs are reasonable for thermal power reactors at 10,000 MWD/T, it would seem apparent that such costs would be almost negligible at 100,000 MWD/T, the projected exposure for a FCR.

To be realistic about this cost potential, it is necessary to go further than a first approximation. As burnup is increased, the throughput of fuel per installed kilowatt decreases. Reduced throughputs through reprocessing and refabrication are generally associated with higher specific (\$/Kg) costs. Therefore, it can also be stated that a specific cost penalty will be associated with high burnup which will tend to reduce the cost advantage in the previous paragraph.

The situation is further aggravated by the present modest scale of installed nuclear kilowatt capacity. Even if we assume 2,000,000 kilowatts (corresponding to 10 Dresden type thermal reactors at a burnup of 10,000 MWD/T) fuel processing throughput would only be of the order of 700 Kg/day. This is still short of the 1000 Kg/day capacity of projected plants of the "AEC Reference Fuel-Processing Plant" ^[1] variety. Consider then the same installed capacity of FCR's at 100,000 MWD/T. The fuel throughput becomes only 180 Kg/day, including both core and blanket, or only 18% of Reference Plant capacity. Clearly a FCR-based nuclear economy must be quite extensive to support a large scale reprocessing industry.

Yet both core and blanket of FCR plants must be reprocessed efficiently to sustain the breeding on which their economic life depends. Reprocessing costs will not be negligible if we continue to think in terms of thermal reactor reprocessing. Instead, an effort must be made to minimize FCR reprocessing costs by other means than the use of current or projected large reprocessing facilities.

The purpose of this report is to discuss small plant concepts and flowsheets as they apply to selected FCR cases and to obtain cost figures which may be

used in FCR fuel cycle cost calculations. The material presented is based on work at the Hanford Atomic Products Operation (HAPO) and the Idaho Chemical Processing Plant (ICPP), together with previous work at the Knolls Atomic Power Laboratory (KAPL). Experimental reprocessing work has not been carried out here, with the exception of some observations on irradiated fuel dissolution. With these reservations, the report is a study drawing together the very capable work of others as it applies to the FCR case.

II. FAST CERAMIC REACTOR PARAMETERS AND PLANT CAPACITY

Parameters of interest to reprocessing estimates are taken from the FCR Reference Plant in the General Electric Atomic Power Equipment Department study.^[2] Its characteristics are as follows:

Load Factor	0.8
Thermal Power, MWt	
Core	1200
Axial Blanket	113
Radial Blanket	82
Total	1395
Total Electrical Power, MWe	517
Throughput, Kg (U + Pu + FP)/day	
Core	11.7
Axial Blanket	9.1
Radial Blanket	28.2
Total	49.0
Total Pu throughput, Kg/day	2.68
Equilibrium fuel exposure, MWD/2000 # U + Pu, at equilibrium discharge	
Core	100,000
Axial Blanket	12,200
Radial Blanket	2,850
Specific power, Kw/Kg U + Pu, at equilibrium	
Core	128
Axial Blanket	15.7
Radial Blanket	3.7

Although other reactor cases may be considered, this study will be confined to the above case so that cost information can be combined with other costs for the Reference FCR. The assumption will be made that the capacity of an FCR reprocessing plant adjusted for a 270-day operating year should be at the above throughput at the minimum or whole multiples thereof. For purposes

of calculating radiation damage, the weighted average power density of the core and blanket is 36 Kw/Kg U + Pu with an average in-pile time of 1,080 days. A cooling time of 20 days will be assumed, although longer cooling times will have only a small relative effect on inventory changes. Typical re-processing plant characteristics are shown in Table I.

TABLE I

Reprocessing Plant Characteristics
for Multiple FCR's

No. of Reactors	1	2	3	4
MWe	517	1035	1550	2070
<u>Throughput</u>				
Kg U + Pu + FP/day	49.0	98	147	196
Kg Pu/day	2.68	5.36	8.04	10.72
Kg fission product/day	1.9	3.8	5.7	7.6
Cooling time (days)	= 20			
Feed Fission Product beta watts/g (U + Pu + FP)	= 0.04			
Reprocessing plant cycle	= 270 days/year			
Reactor load factor	= 0.8			

The parameters in Table I will be used to develop subsequent plant, flow-sheet, and economic data in this report.

III. SMALL REPROCESSING PLANTS

A. Pyrometallurgical

Only two studies have been made in this country on small reprocessing plants directly tailored for fast breeders. The first is the continuing and extensive study at the Argonne National Laboratory on a pyrometallurgical plant for processing metallic fuel. Such a plant would be closely coupled to such reactors as EBR and Fermi and the program will culminate in the operation of a pilot sized plant for EBR-II. Another approach is the fused salt electrolytic method under development at HAPO. Application of the HAPO fused salt method to the FCR fuel has not been tried and cost information is not available.

Both the pyrometallurgical process for metallic fuel and the fused salt process for oxide fuel yield insufficient fission product decontamination to permit anything but remote fuel refabrication. Significant cost penalties would be associated with remote refabrication of FCR type fuel. In this report "pyro" processes will not be considered further; instead the sole emphasis will be on aqueous processes.

B. KAPL Fast Oxide Breeder

The second fast reactor reprocessing study was made at KAPL in 1955-1957 for the Fast Oxide Breeder program at that site.^[3] The KAPL processing plant was designed to reprocess and refabricate the core alone of a Fast Oxide Breeder having a capacity of 800 MWTH and 240 MWe. Plant capacity was 10.4 Kg (U + Pu)/day. Plant capacity was less than 25% of that required for a single FCR plant and consequently the KAPL cost information cannot be directly applied to the FCR cases. The KAPL costs are useful to note, however, for comparison purposes and are shown in Table II.

Of the 1.17 mills/Kwh for core processing and fabrication, approximately 0.34 mills were allocated by the KAPL group for fabrication. A net reprocessing cost for the core would therefore approximate 0.8 mills/Kwh. This relatively high figure is illustrative of the cost penalty associated with a small plant which tends to negate the cost advantage of high burnup.

TABLE II

KAPL Fast Oxide Breeder Costs

	<u>mills/Kwh</u>
Core processing and fabrication (excluding inventory charge)	1.17
Assumed blanket processing and fabrication	.55
Total (excluding Pu credit or inventory)	1.72

C. ICPP Small Scale Reprocessing Plant

A major contribution to small reprocessing plant design has recently been made by the group at ICPP.^[4] This study consists of a complete design and cost study on a reprocessing plant which could be built at a reactor site and which would have sufficient capacity for a single 180 MWe thermal reactor. The important characteristics of this plant are shown in Table III.

TABLE III

ICPP Small Reprocessing Plant Characteristics
for a Single Boiling Water Reactor (180 MWe)

Throughput	
Kg (U + Pu)/day	67.9
Kg Pu/day	0.3
Kg fission products/day	0.8
Operating year (days)	270
Cooling time (days)	120
Flowsheet	(a) Fuel chop and leach (b) 3 cycles solvent extraction
Products	Decontaminated uranium and plutonium nitrates

The Idaho small plant incorporates a unique design feature. The high level cell is a pit with removable concrete covers. Process equipment is suspended from the covers and may be removed from the pit for maintenance. Elaborate remote maintenance features are not required.

The Idaho small plant concept was designed to fill the interim need for reprocessing capacity before a substantial reprocessing market exists. In addition, the reactor site location eliminates hot shipping costs resulting in the reduction of the dependence of fuel cycle cost on reactor plant location.

The success of the Idaho study is indicated by their reprocessing cost of \$71/Kg U or 1.02 mills/Kwh for a 180 MWe reactor. On a comparable basis the cost of the same throughput to the "AEC Reference Plant" would be about \$26/Kg or 0.37 mills/Kwh. The fact that the Idaho small plant is less than a factor of three greater in specific cost than the Reference Plant while having only 7% of Reference Plant capacity is an encouraging example of what may be done with careful and imaginative design.

It is apparent that the Idaho Small Plant capacity shown in Table III falls in the general range of capacity requirements for 517 to 1550 MWe of FCR's given in Table I. If the costs of the small plant do not change on handling FCR feed, FCR reprocessing cost might be in the range of 0.1 - 0.2 mills/Kwh. Any cost penalty associated with the small plant therefore may be well overcome by the high burnup advantage of FCR fuel.

IV. FLWSHEET CONSIDERATIONS

A flowsheet for FCR reprocessing has in common with all reprocessing flowsheets the following objectives:

- a. Decontamination of valuable fuel material to the degree necessary for fabrication use.
- b. Loss in processing of less than 1%.
- c. Low radioactive waste volume.

Purex solvent extraction flowsheets meet these objectives admirably in most cases. Depending on the number of cycles, decontamination factors from fission products in excess of 10^7 may be routinely achieved, losses are well within economic limits, and nitric acid salting gives rise to low waste volumes.

The applicability of solvent extraction flowsheets to the FCR case is, however, somewhat in doubt. Difficulties arise in several ways: (1) the adverse effect of high radiation levels on solvent performance; (2) possible interface troubles from macro levels of fission products; and (3) the lack of incentive to recover uranium. Radiation damage to solvent was found at KAPL^[3] to reduce decontamination and increase losses by as much as a factor of ten under extreme conditions. The effect of macro fission products was not assessed at KAPL but is considered to be an unknown requiring development even at the relatively mild (10,000 MWD/T) levels.^[4]

The KAPL flowsheet recovered uranium and plutonium together after a single co-decontamination cycle. The mixed product was then fed with makeup to the fabrication plant. Fabrication had to be a remote operation in this case because of the large amount of U-237 activity in the recovered fuel.

The Idaho Small Plant was designed for an initial co-decontamination cycle followed by a partition cycle to separate U and Pu, with another cycle to complete uranium decontamination. Final decontamination of the plutonium is accomplished by anion exchange. The long cooling time for the Idaho plant

coupled with the value of enriched uranium makes uranium recovery important and non-remote handling of the final product possible.

In the FCR case, recovered uranium would be far too radioactive to handle directly even after three solvent extraction cycles. Furthermore, there is little economic incentive for uranium recovery. If \$5/Kg is assumed as an approximate cost for depleted uranium dioxide, the price penalty for discarding the uranium is about 0.003 mills/Kwh.

If the assumption is made that non-recovery of uranium leads to desirable process simplification, some modified objectives for an FCR reprocessing plant may be listed:

- a. Decontamination of plutonium from hard beta and gamma activity to the point where beta, gamma and neutron activity from recycled plutonium alone limits biological exposure times in direct refabrication.
- b. Greater than 99% recovery of plutonium.
- c. Discard of uranium and transplutonium elements to waste together with fission products. Subsequent recovery of uranium or other values from waste can be made at some future date if justifiable economically.
- d. Nitric acid based aqueous phase for low waste volume.

A variety of direct precipitants for plutonium out of a simulated Fast Oxide Breeder feed solution were studied by the KAPL group.^[2] None of the methods with the possible exception of a hydrogen peroxide (H_2O_2) strike were found to have promise. The H_2O_2 procedure was not checked to determine its applicability in the presence of high radiation, macro fission products and iron; it is considered that much further study would be required.

In the years since 1957, workers at HAPO^[5] have developed the anion exchange technique for the separation of plutonium to a high degree. A slight variation of their flowsheet fulfills all the required objectives stated above. Little additional development work seems necessary. The anion exchange

flowsheet coupled with the Idaho small plant concept seems an excellent solution to the FCR processing problem and will be examined in more detail in the final sections of this report.

V. ANION EXCHANGE FLOWSHEET

As developed by Ryan and Wheelwright at HAP^[5], the anion exchange flow-sheet for plutonium reactor fuels consists of the following steps:

- a. Adsorption of Pu on Permutit SK anion resin from a 7.2 M HNO_3 feed containing U, Pu and fission products. Uranium and fission products are not held on the resin and go directly to waste.
- b. Decontamination of Pu on the resin by a 7.2 M HNO_3 - 0.01 M HF wash solution.
- c. Elution of Pu by 0.6 M HNO_3 , yielding a decontaminated 60 g Pu/l product.
- d. Final decontamination by a repetition of steps a.-c., using clean resin in a second cycle.

All operations are conducted at 60°C.

Using this basic flowsheet, decontamination has been demonstrated to be adequate, losses negligible and radiation damage effects within control.

In the following discussion this flowsheet will be applied to the three-FCR case described in Table I (1550 MWe)

A. Fuel Dissolution

The Idaho Small Plant head end equipment appears adaptable to chop-leach dissolution of FCR fuels.

1. Chopping

The smaller diameter (0.25 inch) FCR fuel as compared to 0.5 inch diameter fuel would require some modification of chopper design. This modification to achieve the required throughput is not considered unfeasible in view of successful experimental chopping work already done^[3] on similar material. Delivery of chopped material to the dissolver could be identical to the Idaho Small Plant design with its provisions for radioactive gas and particulate control.

2. Leaching

The ease of dissolution of mixed PuO_2 - UO_2 fuel in nitric acid was originally discovered at KAPL. Rapid leaching of Pu and U from irradiated chopped fuel specimens has been amply confirmed in the FCR work at Vallecitos. A FCR dissolver vessel must be geometry controlled for criticality. If dissolution rates are insufficient in a critically safe cylindrical geometry it is likely that sufficient throughput could be retained by going to a critically safe slab.

The dissolver would be operated to give a feed with 150 g U/l and 7.2 M HNO_3 . It is quite possible that suitable in-line instrumentation and control will eliminate the need for any but minor feed adjustments before ion exchange. Stainless steel ring waste would be stored in high level waste tankage as in the Idaho scheme. Gas handling, scrubbing and storage or disposal are the same as for the Idaho Small Plant although somewhat larger fission gas storage facilities would be required.

Dissolver product goes to critically safe column run tanks for sampling, minor acid adjustment and NO_2 treatment to stabilize Pu(IV).

B. Adsorption

The HAPD workers^[5] specify 150 g/l as a safe uranium feed concentration since the solubility limit of uranyl nitrate in 7 M HNO_3 is 275 g/l. High uranium concentration also adversely affects Pu adsorption. Column feed would be adjusted to the composition shown in Table IV.

TABLE IV

Anion Resin Feed Composition

Uranium	150 g/l
Plutonium	8.9 g/l
Fission Products	5.8 g/l
HNO_3	7.2 M

For a throughput of 147 Kg U + Pu + FP/day the total feed volume is 890 liters/day.

The number of resin columns required are set by the critically safe size (6 inch diameter), the capacity of the column for Pu, and the cycle time which is a function of feed, wash and elution flow rates. As will be shown later, total cycle time is less than 12 hours and two service cycles per day can be expected of a single column. Two columns must then have a capacity per cycle of $8.04/4 = 2.01$ Kg Pu where the plant throughput is 8.04 Kg Pu/day.

HAP0 work has shown that a column loading of 70 g Pu/liter of Permutit SK resin bed is feasible. Each of the two primary resin columns therefore requires a volume corresponding to a bed 6 inches in diameter and 5 feet long. Each primary column is followed by a 5 foot clean-up column to absorb the Pu breakthrough of the fully loaded primary column. The cleanup columns are washed but not eluted each cycle. They are periodically eluted after several cycles and their product recycled to the feed.

Since Pu may be fed to a 6 inch column at 875 g/hr, the adsorption time per cycle is $2.01/0.875 = 2.3$ hours.

C. Wash

A decontaminating wash of the loaded columns is necessary to remove residual amounts of uranium and fission products. HAP0 recommends a 15 column-volume wash containing 7.2 M HNO_3 and 0.01 M HF. The linear flow rate is 20 ml/min-cm². Each primary column has a bed volume of 28 liters requiring a 410 liter wash per cycle. The washing time per cycle is 1.86 hours at the specified linear flow rate and the total throughput of wash for four daily cycles is 1640 liters.

D. Elution

Plutonium product is eluted by a 0.6 M HNO_3 elutriant. The product cut is at 60 g Pu/l and the elution linear flow rate is held to 1 ml/min-cm². For each cycle, therefore, the total volume of product solution is $2.01/0.06 = 33.5$ liters. The elution time is 3.05 hours and the daily volume of product and elutriant is 134 liters.

E. Second Cycle

The second cycle flowsheet is identical to the first already described, except that uranium is absent and fission product activity levels may be a factor of 10^5 below the first cycle. The second cycle product can be expected to have a decontamination factor in excess of 10^8 . The Pu at a product concentration of 60 g/l may be evaporated to yield a concentrated product for shipping or used directly in a fabrication plant to produce mixed PuO_2 - UO_2 powder.

F. Cycle Time

A summary of cycle times is given in Table V. Times for conditioning and recycle together with analysis and make-up are approximate and conservative. Even so, the total cycle time will readily permit two daily cycles per column.

TABLE V

FCR Anion Exchange Flowsheet Cycle Times

	<u>Hours/cycle</u>
Adsorption	2.30
Wash	1.86
Elution	3.05
Conditions and recycle	1.0
Analysis and make-up	<u>2.0</u>
Total cycle time	10.21

G. Waste

The total radioactive liquid waste consists of NaNO_3 from the dissolution caustic scrubbers, stainless steel cladding waste, uranium, fission products and HNO_3 from the adsorption step and HNO_3 from the wash step.

It will be assumed that HNO_3 will be recovered by evaporation and recycle. The final concentrated waste will be assumed to have the following composition:

NaNO ₃	5 M
Uranium	300 g/l

Concentrated waste will have the following daily volume in liters:

NaNO ₃	57
Uranium	424
Stainless steel	5
	<hr/>
Total	486 liters

Initial heat generation from fission products is at a level of 27 watts/liter of waste at 20 day cooling. This high and prolonged heat generation rate will require more than usual attention to cooling requirements in waste tankage and to the problems introduced by radiolytic gas generation.

H. Radiation Damage

In the HAPO study Permutit SK anion resin was favored for use in high activity levels because of high resistance to radiation together with good capacity and mechanical properties. Based on cobalt-60 irradiations of the resin it was found that Permutit SK retains adequate capacity and mechanical properties up to an exposure of 3×10^8 roentgens (R).

For the calculation of radiation damage to the resin, beta radiation is considered controlling. Only the radiation during the absorption step will be significant. A discharge value of 0.04 beta watts/gram of FCR fuel will yield 6.6 beta watts/l of feed solution. Since the resin bed can be considered 50% void, exposure in the bed is 3.4 beta watts/liter of bed. The exposure level can therefore be approximated at 1.2×10^6 R/hour during the adsorption step.

For an exposure of 3×10^8 R the service life of the two primary and two cleanup columns will be 250 hours. At two cycles per day, the resin life is 57 days and 4.4 batches of resin are required for the 270 day operating year. Annual resin consumption is therefore 20 cubic feet, representing a minor chemical and waste storage cost.

Discarded resin would be stored with the other high level solid waste. Simplified plant design may favor discard and replacement of entire resin columns rather than remote emptying and loading of fixed columns with fresh resin.

A simple flow diagram for the anion exchange flowsheet is shown in Figure 1. With the addition of daily throughput volumes to provide the capacity required for the 3 FCR case and changes in concentrations, it is identical to one of the HAPO flowsheets.^[5]

FIGURE 1 - ANION EXCHANGE FLOW DIAGRAM FOR THREE FCR PLANT CAPACITY (1550 MWe)

VI. ADAPTATION OF IDAHO SMALL PLANT TO ANION EXCHANGE

No attempt will be made in this section to design an anion exchange plant. Instead, it will be shown that the Idaho Small Plant is sized for the anion exchange flowsheet and that replacement of solvent extraction by anion exchange can result in plant simplification.

A. Head End

As mentioned previously, it is probable that with some modification the Idaho Small Plant head end equipment could handle the FCR case. Criticality limitations in chopper, dissolver and run tanks will require careful study but do not appear at first glance to be insurmountable. Fission gas handling and storage capacity would need to be increased by about a factor of seven over the 10,000 MWD/T case. Other volatile fission products such as iodine and ruthenium in semi-macro concentrations may require some scrubber redesign. In general, however, basic equipment and tankage would be very similar in function and space to the Idaho Small Plant.

B. Decontamination

It may be noted that the three-cycle Purex process for the Idaho Small Plant employs eleven pulse columns ranging from 8-18 feet in length and with disengaging sections up to 12 inches in diameter. There are, in addition three ion exchange columns for final Pu purification. The anion exchange flowsheet calls for eight 5 foot x 6 inch ion exchange columns for the two cycles. It seems apparent that space for replacement of pulse columns with ion columns is more than available in the Small Plant. The inherent simplicity of ion exchange columns as compared to solvent extraction devices suggests plant simplification and economy. No pulsers, plates, disengaging sections, etc. are required for ion exchange, and flow control, while necessary within limits, is much less critical than with solvent extraction.

The entire organic solvent treatment system is not required by the anion exchange flowsheet nor do the potential chemical hazards in handling organic solvent and nitric acid exist. Admittedly, solvent

treatment problems are replaced, in anion exchange, by resin handling problems. It is hard to foresee, however, how resin handling could approach in complexity the treatment of solvent.

Besides concentrated HNO_3 for feed adjustment, the anion exchange flowsheet uses only two other cold feeds, the wash and elutriant. In contrast, the Purex solvent extraction case requires at least seven cold feeds, although three of these are straight nitric acid streams made by continuous metering. Anion exchange promises simplification in cold feed make-up.

Total evaporator capacity in the Small Plant would require some increase to handle the some 10,000 liters/day of 7 M HNO_3 requiring recovery in the anion exchange flowsheet. Modification in evaporator design for different acid conditions would have to be made but again space requirements should not be exceeded.

Other makeup, run and product tankage although modified for criticality control should be sufficient for the anion exchange flowsheet within the Small Plant space.

C. Tail End

Somewhat larger facilities would be required in the FCR case for final plutonium concentration, if required, or packaging. Such expanded facilities could be accommodated in the available Small Plant space for plutonium and uranium.

D. Process Instrumentation

The Idaho Small Plant is heavily instrumented both with usual flow control, temperature, density and liquid level indicators and modern in-line analytical instruments. The simpler flow control requirements of the anion exchange flowsheet imply that fewer of the usual instruments will be required.

The nature of the radiation and criticality hazards of a plutonium rich feed, however, requires close process control of uranium, plutonium and

HNO₃ concentrations. Careful attention must be paid to the potential hazard of critical quantities of plutonium breaking through resin columns and into unsafe geometries. At a minimum, continuous assay of feed and wash acid concentrations and in-line monitoring of the plutonium content of waste streams must be made. Special run tanks and sampling stations will be required to provide material balance knowledge at all times. Valve interlocks, criticality alarms and special air samplers in addition to usual radiation alarms are among the many other devices needed to assure and maintain safety.

No hazards review of the FCR plant is intended or will be presented as a thorough review has been given in the Small Plant Report.^[4] From the foregoing it is clear, however, that the additional instrumentation required for hazard control may well compensate in cost for the simplification in instrumentation resulting from the process itself.

E. Low Level Waste Handling

The Idaho Small Plant ventilation, off-gas treatment and air filtration should be adequate for the FCR case.

F. High Level Waste

Tankage costs may be higher than in the Small Plant because of increased cooling requirements for FCR waste and possible complications due to radiolytic gas formation.

G. Building and Facilities

The previous discussion suggests that the Small Plant building, pool and cell layouts are adequate for the three FCR case (1550 MWe) as are also the supporting facilities. No special requirements other than those already mentioned would be expected to change the basic building and cell design. The cell-pit design philosophy, an important feature of cost reduction, can and should be readily retained with the FCR flow-sheet.

VII. FCR REPROCESSING ECONOMICS

Idaho Small Plant costs for the Small Plant case,^[4] may be summarized as follows:

	<u>Annual Cost</u>
(1) Operating labor	\$ 511,100
(2) Chemicals and expendable material	42,900
(3) Waste storage	29,100
(4) Utilities	11,000
(5) Product losses	9,000
(6) Miscellaneous supplies	13,700
Total direct operating cost	\$ 616,800
Fixed charges on investment (based on 16.9% of \$4,001,000)	676,000
Total Annual Cost	\$ 1,292,800

A. General

Of the costs above it will be assumed that all costs except waste storage and product losses will be the same for an anion exchange plant which processes fuel from three FCR's at a total of 1550 MWe. Charges for one and two FCR processing rates will be assumed to vary approximately directly with throughput for Chemicals and Expendable Materials, Utilities, and miscellaneous supplies. Fixed charges on investment will remain the same. Operating Labor is assumed to scale with a factor of about 0.8. These "General Costs are summarized in Table VI.

The two categories not appearing in Table VI are waste storage and product losses. Both costs are directly dependent on throughput and are a substantial part of FCR costs. Either cost may be directly expressed in mills/Kwh.

TABLE VI

"General Costs" for FCR Reprocessing Plant

Number of Reactors MWe	Annual Cost (\$)		
	1	2	3
	517	1035	1550
Operating Labor	238,000	425,000	511,100
Chemicals and Expendable Material	14,300	28,800	42,900
Utilities	5,100	7,300	11,000
Miscellaneous Supplies	4,600	9,100	13,700
Fixed Charges on Investment	676,000	676,000	676,000
Total "General Costs"	938,000	1,146,200	1,254,700

B. Waste Storage

The three FCR plant with 1550 MWe capacity will produce 1.1×10^{10} Kwh/year. High level liquid waste generated at the rate of 495 liters/day will approximate 35,000 gallons/year. The Idaho Small Plant assumed \$1.67/gal. for liquid storage. In view of extra cooling problems \$3.00/gal. will be assumed for FCR waste.

Gaseous waste storage costs the Small Plant case \$5,910 annually. Since fission gas will be generated in proportion to thermal energy in the reactor, gas storage for the FCR case will cost 7.5 times as much.

Solid waste storage at 270 cubic feet/year will be assumed to be the same as for the Small Plant. Table VII gives waste storage costs which lead to 0.014 mills/Kwh.

C. Product Losses

Mention has already been made of the small (0.003 mills/Kwh) net cost of discarding uranium. This cost is chargeable, however, to fuel refabrication and will not be included here.

Some product losses must be assumed for plutonium although by the nature of the batch anion process they will be of the order of 0.1%. If a 1.0%

TABLE VII

FCR Plant Annual Waste Storage Costs
(1550 MWe Capacity)

Gas	\$ 44,500
Liquid	105,000
Solid	1,400
Total Annual Cost	\$150,900

loss is conservatively assumed for a total annual throughput of 2170 Kg of Pu, 21.7 Kg are lost at a projected 1975 cost of \$5.00/gram. Product loss will accordingly cost \$108,500 annually, which is 0.009 mills/Kwh.

D. Reprocessing Unit Costs

Modest increases in small plant capacity were foreseen by the Idaho group with as much as a factor of two increase possible. In assessing unit costs for three multiples of a single FCR we shall assume that the anion exchange-small plant could handle a twofold increase in capacity and thus up to three FCR's. The unit reprocessing costs are shown in Table VIII. Shipping costs are not included.

TABLE VIII

FCR Plant Unit Reprocessing Costs

Number of Reactors	mills/Kwh		
	1	2	3
MWe	517	1035	1550
Waste and Product Loss	0.023	0.023	0.023
"Fixed" Costs	0.255	0.156	0.114
Total mills/Kwh	0.278	0.179	0.137
\$/Kg (U + Pu)	\$80.50	\$51.50	\$39.40

IX. CONCLUSIONS

The following conclusions result from this study:

- A. The Idaho Small Plant concept seems adequately sized for economic FCR reprocessing. Furthermore, cost information on this plant is sufficiently well developed to yield specific and unit reprocessing costs for Fast Ceramic Reactors.
- B. The anion exchange flowsheet studied at HAPO meets the reprocessing objectives of the FCR case. This flowsheet does not present major development problems. Furthermore, it can be readily accommodated in the Idaho Small Plant facility. Discard of natural or depleted uranium imposes only a small cost penalty.
- C. The coupling of anion exchange and the Idaho Small Plant concept could provide reprocessing capacity for up to 1,550,000 installed kilowatts of FCR's either as a central reprocessing facility or as a package plant at a single reactor site.
- D. Unit reprocessing costs for this FCR plant and flowsheet range from 0.14-0.28 mills/Kwh depending on the number of reactors processed.

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