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Chemistry-Separation Processes for Plutonium and Uranium

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THROW-AWAY FUEL CYCLE

J. W. Ullmann

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J. W. Ullmann

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0.0 ABSTRACT

Estimates are made of the cost of reprocessing irradiated fuel. Break-even costs for fuel discard versus recovery are computed for U as a function of enrichment and burnup, U^{235} as a function of burnup, and Th for two specific cases.

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1.0 INTRODUCTION

In a "throw-away" cycle irradiated fuel discharged from a nuclear power reactor is stored (perhaps buried) rather than reprocessed. The question has periodically arisen of the cost of recovery compared to the cost of storage and fuel values discarded.

Project Separation(1) concluded that a throw-away cycle was more economic than reprocessing in a small plant integrated with a single reactor but that reprocessing was preferable if a large chemical plant were available. Coplan and Davidson(2) for 10,000 Mwd/t exposure found the throw-away cycle cheaper than reprocessing if the total nuclear electric capacity was under 1,000 Mw. Mott(3) has indicated that, for 1.5% U^{235} irradiated to 5,000 Mwd/t, reprocessing offers no economic advantage. Kallman(4) found only a 10% cost difference between a fuel element discarded after two years' irradiation and one reprocessed after one year's irradiation. The cost of fuel with discard after one year was, however, doubled by not reprocessing. Jenkins(5) has indicated that throw-away is unlikely unless 20,000 Mwd/t (over 60% burnup) can be achieved.

This memo will attempt to define some of the limiting conditions of throw-away.

2.0 CONCLUSIONS

Reprocessing 0.7 - 3.0% U^{235} exposed to 2,000 - 10,000 Mwd/t is preferable to throw-away of irradiated fuel based on an estimated combined decontamination and conversion cost of $46/kg U. The margin in favor of reprocessing increases with higher percent U^{235} irradiated and decreases with irradiation level.

Reprocessing of U^{235} of burnups of 20 - 60% U^{235} can be performed at an estimated combined decontamination and conversion cost of $3 per gram U^{235}. Since the value of the material is $17 per gram, throw-away should not be performed if batches of significant size are available (at least 20 kilos U^{235} of a fuel type) to off-set cleanout charges.

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Recovery of U^{233} and U^{235} from irradiated Th or U^{235}-Th combinations is estimated to cost about $6 per gram fissionable material. If fuel value of $16/gm U^{233} is maintained the material should be recovered, even if thorium is discarded after irradiation.

In all cases examined the reprocessing offered a credit to the net fuel cycle cost by virtue of the recovery of unburned fertile and fissionable material.

3.0 PARTIALLY ENRICHED U CYCLE

The savings obtainable by throw-away are:

(a) Shipping cost irradiated fuel
(b) Inventory charge while cooling fuel
(c) Decontamination cost including waste disposal
(d) Conversion charges from nitrate to saleable or reusable product
(e) Any incremental fabrication costs due to residual radioactivity
(f) Reduced U^{236} load on the diffusion cascades which at present is not reflected in AEC price schedules

The added costs due to throw-away are:

(a) Loss of value of residual uranium
(b) Loss of value of plutonium
(c) Loss of fission - product, Np, Am, and Cm sales, which will be neglected for the purposes of this report
(d) Cost of disposal of fuel elements. This item is sensitive to the mode of disposal, fuel configuration, cooling time, and distance between reactor and disposal site. It will be neglected in this work though the cost may be in the range of 0.1 - 0.3 mills/kwh.[6][7]

The break-even computations of Table 1 indicate that decontamination and conversion costs below $50 per kilogram of uranium are economical. Remote refabrication should not be necessary since a U^{237} cooling period can be provided after processing. As an example, 120 days' cooling will produce inventory charges (at 4% per annum) of $3/kg U for 2% U^{235}. Undocumented cost estimates made at ORNL indicate decontamination costs of $10 - $40/kg U in a one-ton-a-day

Table 1

BREAK-EVEN DECONTAMINATION AND CONVERSION COSTS
FOR PARTIALLY ENRICHED URANIUM
(INITIAL URANIUM RESONANCE ESCAPE PROBABILITY = 0.8)

	Value, $ per Kg U After Irradiation[a]			Break-even Reprocessing Cost, mills/kwh[b]
	U	Pu	Total	
2,000 Mwd/t Irradiation				
0.7% U^{235} charged	20	29	49	4.1
1.0% U^{235} charged	50	42	92	7.6
2.0% U^{235} charged	175	41	216	17.9
3.0% U^{235} charged	352	38	390	32.4
4,000 Mwd/t Irradiation				
0.7% U^{235} charged	8	50	58	2.4
1.0% U^{235} charged	31	44	75	3.2
2.0% U^{235} charged	151	57	208	8.7
3.0% U^{235} charged	297	65	362	15.2
10,000 Mwd/t Irradiation				
0.7% U^{235} charged	1	55	56	0.9
1.0% U^{235} charged	5	55	60	1.0
2.0% U^{235} charged	102	54	156	2.6
3.0% U^{235} charged	205	88	293	5.0

(a) AEC Confidential Price Schedule of 1/5/55.

(b) 25% Thermal Efficiency Assumed.

plant. Conversion of UNH to UF_6 for recycle has been estimated by Lane[8] at $4 per kg U and at $2.60 per kg,[9] both of which are higher than current Commission costs. Plutonium nitrate conversion to metal has been estimated[9] at slightly below $3 per gram Pu, which for 3,000 g/t material would add $9 per kg U. The above estimates are summarized in Table 2.

Table 2

TYPICAL RECYCLE CHARGES, PARTIALLY ENRICHED U

	$/kg U
Shipping[7]	5
Inventory	3
Uranium Conversion	4
Plutonium Conversion	9
Decontamination	25[a]
Total	$46

(a) C. E. Guthrie's unpublished work indicates that $33/kg U is possible in a 1 ton/day plant including shipping, profit, taxes, and inventory.

If the above total cost of $46/kg U can be achieved, it is therefore more economical to reprocess than to discard irradiated fuel. It should be noted that in the case of 0.7% U^{235} irradiated to 10,000 Mwd/t, the $4/kg U uranium conversion charge should not be applied since it exceeds the value obtainable by recycle of the uranium.

4.0 HIGHLY ENRICHED URANIUM

The advantages and disadvantages of throw-away are the same as in section 3.0 except plutonium is not a cost factor.

Table 3 gives the break-even decontamination and conversion costs for various burnups.

Table 3

BREAK-EVEN DECONTAMINATION AND CONVERSION COSTS
FOR 90% ENRICHED U^{235}

% U^{235} Burnup	Value After Irradiation, $/gm U^{235} Remaining [a]	Break-even Reprocessing Cost, mills/kwh [b]
20	17.0	15.2
30	17.0	8.9
40	17.0	5.7
50	16.9	3.8
60	16.9	1.5

(a) AEC Confidential Price Schedule of 1/5/55.
(b) 25% Thermal Efficiency Assumed.

Table 3 indicates that decontamination and conversion costs below $17/g U^{235} are economical. Remote refabrication should not be necessary if a U^{237} cooling period is provided. If 160 days' cooling is necessary, the inventory charge (at 4% per annum) will be $0.30 per gram U^{235}. If the material is privately owned this charge might be 3 to 4 times higher. Decontamination costs have been estimated at $0.40 - $2.00 per gram U^{235} in 25 kg U^{235} per day plants.[10][11] Conversion of decontaminated nitrate to oxide in a small plant[12] cost $0.10 per gram U^{235}, and cost of conversion to UF_6 (4 pounds UF_6 per hour)[13] is $0.024 per gram U excluding overhead and depreciation. The total conversion costs should therefore be under $0.20 per gram U^{235}. For comparison, the reduction of UF_6 to metal is estimated at $0.07 per gram U^{235} [14].

Table 4 summarizes the above data.

Table 4

TYPICAL U^{235} RECYCLE CHARGES

	$/g U^{235}
Shipping[7]	0.40
Inventory	0.30
Uranium Conversion	0.20
Decontamination	2.00
Total	$2.90

The total of approximately $3 per gram U^{235} for recycle compared to its value of $17 per gram indicates that the material should be recycled at burnups of 60% or higher if the estimates of Table 4 can be met.

5.0 THORIUM - U^{233}

The situation with thorium differs from that of either partially or highly enriched uranium because the U^{232} produced during irradiation can by α-decay make the recovered thorium radioactive to the point where direct refabrication is impossible. In Table 5 below the value of the mass-233 chain is given for various thorium exposures and the value of the irradiated material is expressed assuming all Pa^{233} has decayed to U^{233}. No credit is listed for the irradiated thorium though it is notworthless since it can be stored for decay and future recovery.

Thorium may be used either independently as a fertile material or intimately mixed with U^{233} or U^{235}. Some typical cases are given in Table 5 to indicate the value of residual uranium after irradiation (and cooling).

Table 5

TYPICAL BREAK-EVEN DECONTAMINATION AND CONVERSION COSTS FOR URANIUM (U^{233} and U^{235}) IN THORIUM

Case	Value[a]	Reactor Mwd Heat/ton Th	Break-Even Decontamination and Conversion, mills/kwh[b]
10,000 g/t U^{233}	\$16/g	20,000	1.3
25,000 g/t U^{233} + U^{235}	\$16/g	20,000	3.2

(a) U^{233} and U^{235} taken at U^{233} fuel value from AEC confidential price schedule of 1/5/55.
(b) 25% thermal efficiency assumed.

The inventory for cooling of irradiated thorium taken at 4% for one year will amount to \$0.64 per gram of U^{233} and U^{235}. Undocumented ORNL estimates of decontamination cost for thorium are \$20 - \$40 per kg Th in a one-ton-per-day plant. Conversion costs for U^{233} nitrate reduction to metal are estimated at \$2.50 per gram.[9] A summary of estimated reprocessing costs for the two cases of Table 5 is given below.

Table 6

TYPICAL REPROCESSING CHARGES FOR U FROM Th

	\$/g U^{233} and U^{235}	
	10,000 g/t	25,000 g/t
Shipping[7]	\$0.60	\$0.24
Inventory	0.64	0.64
Conversion	2.50	2.50
Decontamination (\$30/kg Th)	3.00	1.20
Total	\$6.24	\$5.58

If the above costs of the order of \$6 per gram U^{233} and U^{235} can be obtained, the recovery appears more desirable than the discard.

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