X-822

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Oak Ridge, Tennessee

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ORNL
CENTRAL FILES NUMBER
60-2-12

COPY NO. 52

DATE: February 1, 1960

SUBJECT: Material Balance Flowsheets

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ABSTRACT

This report presents material balance flowsheets for the dissolution of UO_2, UO_2-ThO_2 and U-Mo fuels clad in stainless steel or zirconium by the Sulfex, Darex, and Zirflex process. These fuel elements are from power reactors which have been or may be committed to ORNL for reprocessing in the PRFR Program.

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1.0 INTRODUCTION

This report presents material balance flowsheets for the dissolution of UO_2, UO_2-ThO_2, and U-Mo fuels clad in stainless steel or zirconium by the Sulfex, Darex and Zirflex processes. These fuels either are committed or may be committed to the ORNL reprocessing program which is scheduled to start in 1962 and to last about five years.

With the exception of the U-Mo fuels, all fuels are to be declad prior to core dissolution. The declad step for U-Mo fuels has been omitted as it has not been shown that either chemical or mechanical decladding is as yet satisfactory. If the elements are mechanically declad, the sodium bond will be removed and the core recanned in aluminum in which case an aluminum declad step will be carried out in the dissolver.

The mechanics of the three processes and the fuels are briefly discussed in the following sections. At the end of the last section is a list of the basic assumptions upon which the flowsheets were based.

Figure 1 presents the Darex-Sulfex process equipment flowsheet; the Zirflex process can be carried out in the Sulfex equipment. Table 1 contains a brief summary of the fuels processed in one cycle from each reactor. Table 2 is a consolidation of the reactor fuels and the solvent extraction feed resulting from each process dissolution. Tables 3 through 24 present the material balance flowsheets for the various reactors.

2.0 SULFEX

The Sulfex declad solution employs 4 $\underline{M}$ rather than 6 $\underline{M}$ H_2SO_4 as the dissolvent acid to increase the stainless steel loading. The maximum loading with 4 $\underline{M}$ H_2SO_4 was taken to be 80 g/l although this concentration is reduced by the dissolver wash water which is added to the declad product stream.

Some formic acid may have to be added to the declad solution or to a wash prior to the declad step to destroy any residual nitric acid from a previous core dissolution wich might passivate the cladding. One-tenth molar HCOOH will destroy about 0.01 $\underline{M}$ HNO_3. (CF Memo 59-8-6, Monthly Progress Report for Chemical Development Section B, July 1959) The hydrogen off-gas will be processed through the normal off-gas system.

One per cent mild steel was also added per cycle to aid in depassivation of the cladding.

After a decladding step, 60 gallons of water are used to wash the dissolver. This solution is jetted to the centrifuge and then air lifted to DS-5. The centrifuge cake is washed with an additional 60 gallons of water. In some cases it may be possible to just use the dissolver wash water as the centrifuge cake wash, thus cutting down on waste volumes.

Losses from 94% theoretical dense fuel material were assumed to be 0.05%; however, 0.1% was used in calculation to account for any losses due to entrainment.

3.0 DAREX

The Darex process, when applied to stainless steel clad UO_2 fuels, should be considered as a total dissolution process, and when applied to ThO_2-UO_2 fuels may be considered as a declad or a two-step total dissolution process.

The calculations for the Darex material balance flowsheets were based on experimental evidence found in laboratory reprocessing runs using stainless steel clad UO_2 and UO_2-ThO_2 fuel prototypes.

Aqua regia, 5-2, is favored for the decladding solution because passivation may be encountered at lower chloride concentrations and no advantage is gained in higher concentrations. Five molar HNO_3 concentration is found to give good reaction rates with 2 M HCl.

The declad solution is loaded to 60 g/l in stainless steel and sent to DS-4 where a waste acid cut is made to reduce the volume. Twelve molar recycle HNO_3 is charged and at the same time the solution is evaporated. A volume equal to that added is removed, the composition being higher in Cl^- and lower in HNO_3 than the recycle charged.

The last of the chloride is removed by adding 13.3 M HNO_3, then concentrating and steam stripping the solution. This is expected to reduce the Cl^- concentration to less than 350 ppm.

The resulting solution may be treated in one of three ways. Either it is discarded, kept for blending with the core solution after the core is dissolved, or used as the basic core dissolvent solution. The reasons for considering the latter two ways are that the soluble losses to the declad solution are not sent to waste and the insoluble losses would be solubilized by the subsequent dissolution procedure. Finely divided solids present a criticality problem and total dissolution may be the only practical answer. However, if the uranium losses are moderately high in the declad step, it may be possible to contact the declad solution with 30% TBP in Amsco to effect a single stage extraction and thus reduce the losses. Rainey and Moore have found (personal communication) that if 1% core losses to the declad solution are encountered, these may be reduced to .02% for thorium and .006% for uranium using an aqueous/organic ratio of 10/1 provided the acidity of the declad solution ≤ 0.5 M. As the acid concentration increases, recovery decreases. The organic extractant may then be sent to the first cycle of the solvent extraction facility or run through a stripping stage with the aqueous then being mixed with the normal solvent extraction feed prior to being sent to the solvent extraction facility.

If the declad step is completed and the resulting solution separated, the core may be dissolved producing a normal Thorex feed. The dissolution rate of the core material is a complex function of many things, including temperature. As the temperature is lowered, the dissolution rate is reduced. Thus, if the dissolver is constructed with two steam jackets, one on the lower several feet of the dissolver and one above this with a baffle arrangement between them, the lower one may be turned off or operated with cooling water during the declad step. After being declad the pellets would fall into the lower, cooler zone thus reducing core losses.

4.0 ZIRFLEX

The Zirflex flowsheets were adapted from those in ORNL-2558, "Decladding of PWR Blanket Fuel Elements with Aqueous Ammonium Fluoride Solutions" by L. M. Ferris. However, several difficulties encountered with this process should be noted.

To maximize the solubility of $(NH_4)_2 ZrF_6$, the ratio of F/Zr in solution should be kept at 6. Because of incomplete dissolution of the Zircaloy clad, due mainly to the difficulty in putting the end caps into solution, the F/Zr ratio usually runs about 8. With a change in ratio from 6 to 8, the room temperature solubility of $(NH_4)_2 ZrF_6$ drops from about 1 M to about 0.2 M which would increase the waste volume greatly.

It may be possible to circumvent the large waste volume by going through a precipitation and resolution step, but this approach may present more difficulties than does the large waste volume. These problems are being studied.

5.0 ThO_2-UO_2 FUELS

A Thorex flowsheet has been prepared by Rainey and Moore. This flowsheet requires a feed to the IA extraction column having a composition of 250 g/liter thorium and 0.1 M acid deficient. This was used as the criteria in preparing the ThO_2-UO_2 fuel flowsheets. However, if one considers total dissolution by the Darex process, the solvent extraction feed cannot be acid deficient due to the iron loading, but must have an acid concentration between 0.3 and 0.5 M.

To produce these solutions, the preferred Thorex FAT procedure consists of boiling down the dissolver solution to 1/4 the original volume and the steam stripping to the desired acidity. The resulting solution can then be diluted to 250 g/l Th and the correct acidity depending upon the process as noted above.

The ruthenium decontamination factor can be significantly increased if, just prior to performing the solvent extraction, the feed solution is digested with Na_2HSO_3 (0.02 M in solution) at 55°C for one hour.

6.0 UO_2 FUELS

The criteria for solvent extraction feed used when calculating the material balance flowsheet for the Sulfex process was a maximum U loading consistent with solution stability with a 2 M acid concentration. This was obtained with all three UO_2 fuels (see Table 2). However, when these fuels are processed by a Darex total dissolution, the criteria were changed to roughly 1 M in acid and stainless steel and 0.5 M in uranium. This is obtainable in the NMSR fuel because of the high stainless steel to uranium ratio. However, when the FWC-EC and EGCR flowsheets were calculated, these criteria were again modified, due to the lower stainless steel to uranium ratio, to increase the U loading to 1 M and drop the stainless steel loading to about 40 g/liter keeping the acid concentration 1 M.

7.0 U-Mo FUELS

No decladding step was assumed for these fuels because at the present time it is still in question. Both mechanical and chemical decladding procedures of sodium bonded fuels are being studied, but neither has yet been demonstrated satisfactorily.

The core material of each fuel was treated in two ways: one method assumes a precipitation step and one does not. If a normal Purex dissolution using HNO_3 is carried out on either 3 or 10% Mo fuels, a flocculent precipitate is produced, the amount depending upon the terminal acid and Mo concentration (Reference: Hanford unpublished report). The precipitate appears to be a form of uranyl molybdate which may be removed by centrifuging. This precipitation may be prevented by increasing the terminal acidity in the dissolution step. However, the desirability of precipitating the Mo and thus reducing its concentration in solution stems from the fact the Mo-HNO_3 solutions cannot be concentrated to any great extent. Thus the IAW stream from the solvent extraction facility could not be greatly volume reduced. In order to obtain 25 g/liter of Mo in the waste stream, the HNO_3 concentration must be less than 0.5 M and $Fe(NO_3)_3$ must be added (> 0.67 M) to complex the Mo. On the other hand, it is more desirable to process homogeneous solutions, from a safety standpoint, than those which contain solids.

A second method of preventing precipitation is to add $Fe(NO_3)_3$. Employing $Fe(NO_3)_3$, one may obtain higher terminal uranium concentrations and lower terminal acidities in the product solution. The use of Fe^{+3} to prevent precipitation presents a waste problem, however. The wastes cannot be neutralized nor very highly concentrated without precipitating iron or molybdenum.

If the precipitation method is used, then the uranyl molybdate precipitate may be metathesized to sodium diuranate and molybdate solutions by treatment with sodium hydroxide. The sodium diuranate may be washed, filtered and reprocessed.

If the precipitation method is used, then nuclear safety dictates that critically safe equipment be used in processing the precipitate. This includes such equipment as the centrifuge and the centrifuge catch tank.

These problems, their solutions, and their effect on the process equipment are presently being studied.

8.0 BASIC ASSUMPTIONS

1. Nuclear poisons were added to any fuel whose enrichment is greater than 2% (J. P. Nichols, personal communication).

2. All spent fuel was calculated at 180 days decay prior to reprocessing.

3. After 180 days cooling, the only significant gaseous activity left is Kr-85 which makes up about 0.1% of the total activity.

4. The SiO_2 content was taken as a 1% maximum of the 304 stainless steel cladding with the exception of the Consolidated Edison fuel in which 0.75% has been specified as a maximum.

5. In Sulfex decladding operations, 1% mild steel was added to aid in depassivating the clad.

6. All steam jetted streams were given a 7% increase in volume due to dilution.

L. B. Shappert

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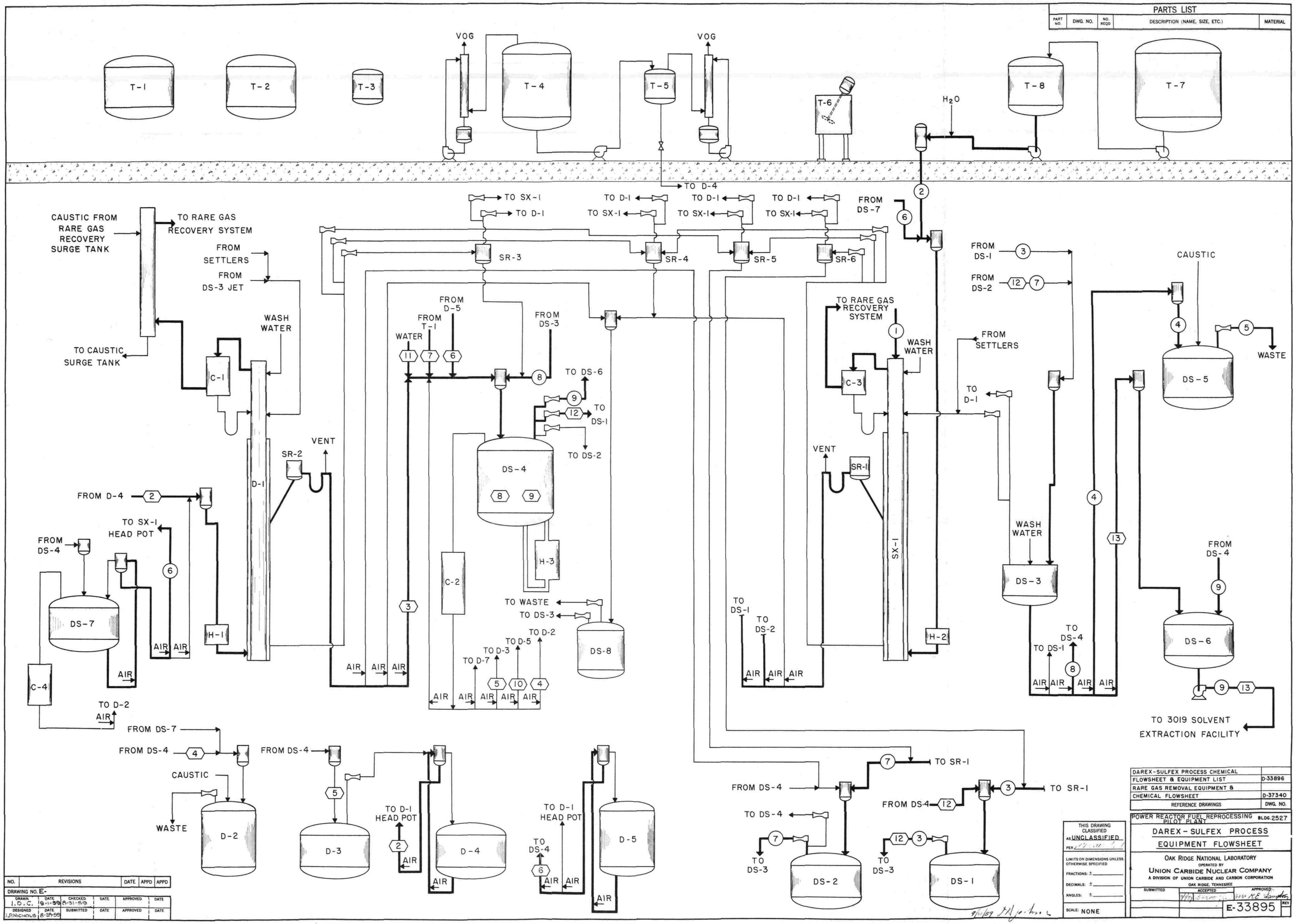
PARTS LIST
PART NO. | DWG. NO. | NO. REQD | DESCRIPTION (NAME, SIZE, ETC.) | MATERIAL
VOG
T-1
T-2
T-3
T-4
T-5
T-6
T-7
T-8
H2O
TO D-4
TO SX-1
TO D-1
TO SX-1
FROM DS-7
CAUSTIC FROM RARE GAS RECOVERY SURGE TANK
TO RARE GAS RECOVERY SYSTEM
FROM SETTLERS
FROM DS-3 JET
WASH WATER
TO CAUSTIC SURGE TANK
C-1
D-1
SR-2
VENT
SR-3
SR-4
SR-5
SR-6
FROM D-5
FROM T-1
WATER
FROM DS-3
TO DS-6
TO DS-1
TO DS-2
DS-4
H-3
C-2
TO WASTE
TO DS-3
DS-8
TO D-2
TO D-5
TO D-3
TO D-7
AIR
FROM D-4
TO SX-1 HEAD POT
FROM DS-4
DS-7
H-1
C-4
TO D-2
FROM DS-1
FROM DS-2
CAUSTIC
WASTE
DS-5
C-3
SR-1
SX-1
H-2
DS-3
DS-6
TO 3019 SOLVENT EXTRACTION FACILITY
FROM DS-7
FROM DS-4
D-2
D-3
TO D-1 HEAD POT
D-4
TO DS-4
D-5
TO SR-1
DS-2
DS-1
DAREX-SULFEX PROCESS CHEMICAL FLOWSHEET & EQUIPMENT LIST D-33896
RARE GAS REMOVAL EQUIPMENT & CHEMICAL FLOWSHEET D-37340
REFERENCE DRAWINGS DWG. NO.
POWER REACTOR FUEL REPROCESSING PILOT PLANT BLDG. 2527
DAREX - SULFEX PROCESS
EQUIPMENT FLOWSHEET
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OAK RIDGE, TENNESSEE
E-33895
THIS DRAWING CLASSIFIED
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SCALE: NONE
NO. REVISIONS DATE APPD APPD
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DRAWN I.D.C. DATE 9-1-58
CHECKED 8-31-58
DESIGNED J.R.NICHOLS DATE 8-28-58

TABLE 1

SUMMARY OF SOME PROPERTIES OF FUELS PROPOSED IN THE PRFR PROGRAM (1 CYCLE)

	Consolidated Edison	Rural Cooperative	NMS Savannah	FWC EC	CPPD	PRDC axial	PRDC radial	EGCR	PWR-1	Commonwealth Edison
Burnup - Mwd/t	23,200 Mwd/mt Th	5,500 Th + U	7,400 ave U		3,000 ave 6,000 peak	400-1000 U	2500 U	10,000	8,200	10,000 max.
Kg/cycle	250 (Th)	276 (Th)	222	162[a]	212	200	252	200	230	216
Irradiation time - days	600	360	825	730[b]	330	178	1350	1460	750	~1100
Decay time - days	180	180	180	180	180	180	180	180	180	180
Spent fuel activity -curies/cycle	8.30×10^5	3.14×10^5	1.89×10^5	2.52×10^5	1.4×10^5	3.0×10^4	2.7×10^4	1.63×10^5	2.52×10^5	2.56×10^5
Heat power - watts/cycle[c]	4150	1570	950	1,260	700	150	135	815	1,260	1,280
SiO_2/cycle-Kg	1.6	.92	1.0	0.31	0.13	0.152	0.132			

[a]Dissolver size limits charge

[b]Estimated

[c]Untermeyer & Weills curves - 50% accuracy

TABLE 2

SOLVENT EXTRACTION FEEDS FROM PRFR PROGRAM

Types of Fuel		ThO_2 UO_2	ThO_2 UO_2	ThO_2 UO_2	UO_2	UO_2	UO_2	U-3% Mo	U-3% Mo	U-10% Mo	U-10% Mo	UO_2
Reactors		Rural-Coop CETR	Rural-Coop CETR	BORAX IV	NMSR FWC-EC EGCR	FWC-EC EGCR	NMSR	PRDC radial	PRDC radial	CPPD	CPPD	PWR Comm. Edison
Process		Sulfex	Darex (Total)	Al-Pb	Sulfex	Darex (Total)	Darex (Total)	Purex[a]	Purex[b]	Purex[a]	Purex[b]	Zirflex
H^+	M	-0.1	0.3	-0.1	2	1.0	1.0	1.0	2.0[c]	2.9	2.5[d]	1.6
Th	g/l	250	250	250								
	M	1.08	1.08	1.08								
U	g/l				321	238	120	245	237	146	147	310
	M				1.35	1.0	0.5	1.03	1.0	0.6	0.6	1.3
Fe^{+3}	M							0	.74	0	0.77	
Mo	g/l							1.6	7.5	4.9	16.7	
SS	g/l		~90			~40	54					
Al^{+3}	M			0.135								

[a] Using precipitation method

[b] Using no precipitation method

[c] Based on stable dissolver product of H^+ = 2.0 M, U = 1.35 M, Fe^{+3} = 1.0 M

[d] Based on stable dissolver product of H^+ = 3.0 M, U = 0.8 M, Fe^{+3} = 1.0 M

TABLE 3

CONSOLIDATED EDISON

DAREX DECLAD

		Dissolver Charge	Declad Acid Feed	Dissolver Product	Waste Cut	Mixed Acid Cut [5]	Recycle Acid (Into Fat)	Concentrated HNO_3 Addition	Recycle Acid Cut	Steam Strip	Waste Acid	Declad Concentrate	Dissolvent Acid Feed [2]	Dissolver Product	Centrifuged Dissolver Product	Concentrated Dissolver Product	Solvent Extraction Feed
Stream or Vessel	No.	1	2	DS-4	D-2	(D-3)	6	7	8			DS-1	D-1	DS-2	DS-4	DS-4	DS-6
Stream Vol.	Gal		457	440	123	380	380	270	380	350	350	210	360	360	450	90	265
H^+	M		7	3	.5	6.4	12.0	13.3	2.0		4.7	0.8	13	9.65	7.7	~2	-0.1
NO_3^-	M		5	4.4	.3	5.5	12.4	13.3	12.4		4.7		13	9.65	7.7		
Cl^-	M		2	1.75	.2	0.9	Trace		Trace								
304 SS	Kg	100		100								100					
	g/l			60								126					
U	Kg	20												19.97	19.97	19.97	19.97
	g/l													14.5	11.6	58	19.7
	M																
Th	Kg	250												249.6	249.6	249.6	249.6
	g/l													184	147	736	250
	M													0.8	0.64	3.2	1.08
F^-	M												0.04	0.04	0.032	0.16	0.054
$Al(NO_3)_3$	M												0.07	0.07	0.056	0.28	0.095
SiO_2	g/l	(.75 kg)		0.45								0.95					
Cd^{+2}	M												0.025	0.025	0.020	0.1	0.034
B^{+3}	M		0.1	0.104								0.218					
ρ (20°C)	g/cc		1.19	1.25	1.01	1.18	1.35	1.36	1.35		1.14	1.41	1.37	1.53	1.42	2.30	1.51
Activity	Curies	8.30×10^5		830								830		8.29×10^5	8.29×10^5	8.29×10^5	8.29×10^5

TABLE 4

RURAL COOPERATIVE

DAREX DECLAD

		Dissolver Charge	Declad Acid Feed	Dissolver Product	Waste Cut	Mixed Acid Cut	Recycle Acid (Into Fat)	Concentrated HNO_3 Addition	Recycle Acid Cut	Steam Strip	Waste Acid	Declad Concentrate	Dissolvent Acid Feed	Dissolver Product	Centrifuged Dissolver Product	Concentrated Dissolver Product	Solvent Extraction Feed
Stream or Container No.		1	2	DS-4	D-2	5 (D-3)	6	7	8			DS-1	D-1	DS-2	DS-4	DS-4	DS-6
Stream Vol.	Gal		420	405	113	352	352	247	352	320	320	187	396	396	488*	99	292
H^+	M		7	3	0.5	6.4	12.0	13.3	12.0		4.7	0.8	13.0	9.7	7.9	~ 2	-0.1
NO_3^-	M		5	4.4	0.3	5.5	12.4	13.3	12.4		4.7	0.8	13.0				
Cl^-	M		2	1.75	0.2	0.9	Trace		Trace								
304 SS	Kg	92		92								92					
	g/l			60								130					
U	Kg	13		6.5 g								6.5 g		12.98	12.98	12.98	12.98
	g/l													8.7	7.1	34.8	11.8
	M													0.037	0.030	0.15	0.046
Th	Kg	276		138 g								138 g		275.6	275.6	275.6	275.6
	g/l													184	149	736	250
	M													0.8	0.64	3.2	1.09
F^-	M												0.04	0.04	0.033	0.16	0.054
$Al(NO_3)_3$	M												0.07	0.07	0.057	0.28	0.60
SiO_2	g/l	(.925 kg)		0.6								1.3					
Cd^{+2}	M		0.025									0.056	0.025	0.025	0.021	0.1	0.034
ρ (20°C)	g/cc		1.19	1.25	1.01	1.18	1.35	1.37	1.35			1.41	1.37	1.53	1.43	2.30	1.51
Activity	Curie	3.14×10^5		315								315		3.13×10^5	3.13×10^5	3.13×10^5	3.13×10^5

*Solution is now evaporated and steam stripped to acid deficient conditions.

TABLE 5

CONSOLIDATED EDISON

DAREX

TOTAL DISSOLUTION

		Dissolver Charge	Declad Acid Feed	Declad Product	Waste Cut	Recycle Acid	Mixed Acid Cut	Concentrated Acid Addition	Refluxed Concentrate (Core Dissolvent)	Dissolver Product	Recycle Acid	Product	Centrifuged Dissolver Product	Concentrated Dissolver Product	Steam Strip	Solvent Extraction Feed
Stream or Vessel No.		1	2	3	4	5	6	7	8	9	10	12	DS-4	DS-4	DS-4	13
Stream Vol.	Gal		456	440	170	380	380	244	515	515	248	264	324	88	88	264
H^+	M		7	3	0.5	12	5.5	13.3	11	8.7	10.4	7.6	6.2	~ 2		0.3
NO_3^-	M		5	4.4	0.4	12.0	4.9	13.3			10.4					
Cl^-	M		2	1.5	0.1	Trace	0.6		Trace							
304 SS	Kg	100		100					100	100		100	100	100		100
	g/l			60					51.5	51.5		100	81	300		100
U	Kg	20								20		20	20	20		20
	g/l									10.3		20	16.2	60		20
	M									0.043		0.084	0.068	0.252		0.084
Th	Kg	250								250		250	250	250		250
	g/l									130		250	203	750		250
	M									0.56		1.08	0.88	3.24		1.08
F^-	M								0.04	0.04	0.01	0.07	0.057			0.07
Cd^{+2}	M		0.025							0.0222		0.039	0.032	0.11		0.035
Activity	Curies	8.3×10^5								8.3×10^5		8.3×10^5	8.3×10^5	8.3×10^5		8.3×10^5
ρ (20°C)	g/cc		1.19	1.25	1.01	1.17	1.35	1.37	1.43	1.46	1.31	1.61	1.51	2.37		1.46

TABLE 6

RURAL COOPERATIVE

DAREX

TOTAL DISSOLUTION

		Dissolver Charge	Acid Feed	Declad Product	Waste Cut	Mixed Acid Cut	Recycle Acid	Concentrated Acid Addition	Refluxed Concentrate (Core Dissolvent)	Dissolver Product	Recycle Acid	Product	Centrifuged Dissolver Product	Concentrated Dissolver Product	Steam Strip	Solvent Extraction Feed
Stream or Vessel No.		1	2	3	4	5	6	7	8	9	10	12	DS-4	DS-4	DS-4	13
Stream Vol.	Gal		420	405	155	350	350	225	475	475	205	270	330	98	98	296
H^+	M		7	3	0.5	5.5	12	13.3	11	8.8	10.4	7.6	6.2	~ 2		0.3
NO_3^-	M		5	4.4	0.4	4.9	12	13.3			10.4					
Cl^-	M		2	15	0.1	0.6	Trace		Trace							
304 SS	Kg	92		92					92	92		92	92	92		92
	g/l			60					51	51		90	74	248		83
U	Kg	13								13		13	13	13		13
	g/l									7.2		12.7	10.4	35		11.7
	M									0.030		0.053	0.044	0.147		0.049
Th	Kg	276								276		276	276	276		276
	g/l									154		270	220	745		250
	M									0.66		1.16	0.95	3.2		1.08
F^-	M								0.04	0.04	0.01	0.06	0.05	0.17		0.056
Cd^{+2}	M															
ρ (20°C)	g/l		1.19	1.25	1.01	1.17	1.35	1.37	1.43	1.46	1.31	1.61	1.51	2.32		1.45
Activity	Curies	3.14×10^5								3.14×10^5		3.14×10^5	3.14×10^5	3.14×10^5		3.14×10^5

TABLE 7

FWC-EC

DAREX

TOTAL DISSOLUTION

		Dissolver Charge	Acid Feed	Dissolver Product	Waste Cut	Mixed Acid Cut	Recycle Acid	Fresh HNO_3 Addition	Concentrate Before Reflux	Concentrate After Reflux	Recycle Acid Cut	Fat Product	Diluted Fat Product	Solvent Extraction Feed
Stream or Vessel No.		1	2	3	4	5	6	7	DS-4	DS-4	10	DS-4	DS-1	DS-6
Stream Vol.	Gal.		210	205	56	177	177	130	280	280	177	103	110	180
H^+	<u>M</u>		7	1.9	0.4	5.6	12	13.3	10.2	10.0	12.0	1.75	1.64	1.0
Cl^-	<u>M</u>		2	1.7	0.1	0.5	Trace		0.2	<350 ppm	Trace		<350 ppm	<350 ppm
NO_3^-	<u>M</u>		5	4.0	0.3	5.1	12	13.3	12.75	12.75	12.0			
SS	Kg	31		31					31	31		31	31	31
	g/l			40					29	29		80	75	46
U	Kg	162		162					162	162		162	162	162
	g/l			209					153	153		415	388	238
	<u>M</u>			0.88					0.64	0.64		1.75	1.64	1.0
Solids	Kg			15.5					15.5	15.5		15.5	15.5	0
	Gal			4.1					4.1	4.1		4.1	4.1	0
Cd^{+2}	<u>M</u>		0.025	0.026					0.019	0.019		0.052	0.048	0.30
ρ (25°C)	g/cc		1.20	1.44					1.61	1.57		1.84	1.79	1.49
Activity	Curies	2.52×10^5		2.52×10^5					2.52×10^5	2.52×10^5			2.52×10^5	2.52×10^5
Heat	Watts	1260		1260					1260	1260			1260	1260

TABLE 8

NUCLEAR SHIP SAVANNAH

DAREX

TOTAL DISSOLUTION

		Dissolver Charge	Acid Feed	Dissolver Product	Waste Cut	Mixed Acid Cut	Recycle Acid	Fresh HNO_3 Addition	Acidified Concentrate Before Reflux	Acidified Concentrate After Reflux	Recycle Acid Cut	Dilution Water	Fat Product	Solvent Extraction Feed
Stream or Vessel No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Stream Vol.	Gal		450	440	120	380	380	280	590	590	380	225	440	490
H^+	M		7	1.5	0.4	5.5	12	13.3	10.7	10.5	12	0.01	1.1	1.0
Cl^-	M		2	1.3	0.1	0.6	Trace		0.2	~ 0.03	Trace	-	<350 ppm	<350 ppm
NO_3^-	M		5	4.4	0.3	5.1	12	13.3	13.6	13.6	12	0.01	5.3	4.7
304L SS	Kg	99		99					99	99			99	99
	g/l			60					44	44			60	54
U	Kg	222		222					222	222			222	222
	g/l			134					99	99			134	120
Solids	Kg			54					54	54			54	0
	Liters			54					54	54			54	0
Cd^{+2}	M		0.025	0.026									0.026	0.023

TABLE 9

EGCR

DAREX

TOTAL DISSOLUTION

		Dissolver Charge	Acid Feed	Dissolver Product	Waste Cut	Mixed Acid Cut	Recycle Acid	Fresh Acid Addition	Concentrated Product Before Reflux	Concentrated Product After Reflux	Recycle Acid Cut	Fat Product	Diluted Fat Product	Jetted Fat Product	Solvent Extraction Feed
Stream or Vessel No.		1	2	3	4	5	6	7	DS-4	DS-4	10	DS-4	DS-4	DS-2	DS-6
Stream Vol.	Gal		227	222	60	192	192	140	302	302	192	110	141	151	222
H^+	M		7	1.9	0.4	5.6	12	13.3	10.2	10.0	12	6.55	1.58	1.48	1.0
Cl^-	M		2	1.7	0.1	0.5	Trace		0.2	<350 ppm	Trace	<350 ppm	<350 ppm	<350 ppm	<350 ppm
NO_3^-	M		5	4.0	0.3	5.1	12	13.3	13.8	13.6	12				
SS	Kg	30		30					30	30		30	30	30	30
	g/l			36					27	27		72	56	53	36
U	Kg	200		200					200	200		200	200	200	200
	g/l			238					175	175		480	374	350	238
	M			1.0					0.735	0.735		2.02	1.58	1.48	1.0
Solids	Kg			15					15	15		15	15	15	0
	Gal			4					4	4		4	4	4	0
Cd^{+2}	M		0.025	0.026					0.019	0.019		0.052	0.041	0.038	0.025
$\rho(25^\circ C)$	g/cc		1.20	1.47					1.63	1.60		2.01	1.72	1.67	1.46
Activity	Curies	1.63×10^5		1.63×10^5								1.63×10^5	1.63×10^5	1.63×10^5	1.63×10^5
Heat	Watts	815		815								815	815	815	815

TABLE 10

CONSOLIDATED EDISON[a]

SULFEX

		Dissolver Charge	Declad Acid Feed	Declad Solution	Centrifuged Declad Solution	Neutralized Declad Solution	Dissolvent Acid Feed	Dissolver Product	Centrifuged Dissolver Product	Concentrated Dissolver Product	Solvent Extraction Feed
Stream or Container No.		1	2	DS-1	4	DS-5	6	DS-2	8	DS-4	DS-6
Stream Vol.	Gal		330	390	477[b]	562					
H_2SO_4	M		4	2.02	1.65	0					
304L SS	Kg	100		101[c]	101	101					
	g/l			68	56	48					
SiO_2	g/l	(.75 Kg)		0.51	0.0042	0.0037					
B^{+3}	M		0.1	0.085	0.069	0.059					
Activity[e]	Curies	8.30×10^5		830[d]	415	415		8.28×10^5	8.28×10^5	8.28×10^5	8.28×10^5
Density (20°C)	g/cc		1.24	1.32	1.30	1.29	1.37	1.53	1.42	2.30	1.51
Stream Vol.	Gal						360	360	450[b]	90	265
HNO_3	M						13	9.65	7.7		-0.1
NaF	M						0.04	0.04	0.032	0.16	0.054
Al^{+3}	M						0.07	0.07	0.056	0.28	0.6
U	Kg	20		10 g	0.1 g	0.1 g		19.97	19.97	19.97	19.97
	g/l			.0068	5.5×10^{-5}	4.7×10^{-5}		14.5	11.6	58	19.7
Th	Kg	250		125 g	1.25 g	1.25 g		249.6	249.6	249.6	249.6
	g/l			0.085	6.9×10^{-4}	5.9×10^{-4}		184	147	736	250
	M							.8	0.64	3.2	1.08
Cd^{+2}	M						0.025	0.025	0.020	0.1	0.034

[a] All below notations are given in the report but are repeated here for convenience

[b] Jet dilution + 60 gal wash water

[c] 1% mild steel added as depassivent

[d] From 94% theoretical density ThO_2 pellets

[e] 180 days cooled

TABLE 11

RURAL COOPERATIVE

SULFEX

		Dissolver Charge	Declad Acid Feed	Declad Solution and Wash Water	Centrifuged Declad Solution and Wash Water	Neutralized Declad Solution Waste	Dissolver Acid Feed	Dissolver Product	Centrifuged Dissolver Product and Wash Water	Concentrated Dissolver Product	Solvent Extraction Feed
Stream or Container Number		1	2	DS-1	4	DS-5	6	DS-2	8	DS-4	DS-6
Stream Vol.	Gal		304	364	454	530					
H_2SO_4	<u>M</u>		4	2.01	1.62	0					
304L SS	Kg	92.2		93.1	93.1	93.1					
	g/l			68	55	47					
SiO_2	g/l	(.925 Kg)		.67	.0054	.0046					
B^{+3}	<u>M</u>		0.10	0.0835	0.067	0.057					
Activity	Curies	3.14×10^5	0	315	155	155		3.13×10^5	3.13×10^5	3.13×10^5	3.13×10^5
Density	g/cc(20°C)		1.24	1.32	1.30	1.29	1.37	1.53	1.43	2.30	1.51
Stream Vol.	Gal						396	396	488	99	292
HNO_3	<u>M</u>						13	9.7	7.9		-0.1
Al^{+3}	<u>M</u>						0.07	0.07	0.057	0.28	0.095
U	Kg	13		6.5 g	.065 g	.065 g		12.98	12.98	12.98	12.98
	g/l			0.0047	3.8×10^{-5}	3.2×10^{-5}		8.7	7.1	34.8	11.8
Th	Kg	276		138 g	1.38 g	1.38 g		275.6	275.6	275.6	275.6
	g/l			0.10	8.0×10^{-4}	6.9×10^{-4}		184	149	736	250
NaF	<u>M</u>						0.04	0.04	0.033	0.16	0.054
Cd^{+2}	<u>M</u>						0.025	0.025	0.021	0.1	0.034
Th	<u>M</u>							0.8	0.644	3.2	1.09

TABLE 12

FWC-EC

SULFEX

		Dissolver Charge	Declad Acid Feed	Declad Solution & Wash Water	Centrifuged Declad Solution & Wash Water	Neutralized Declad Solution (Waste)	Dissolver Acid Feed	Dissolver Product	Wash Water	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-1	4	DS-5	6	DS-2	To DS-4	DS-6
Stream Vol.			100	160	231	257				
H_2SO_4	M		4	1.56	1.08	0				
SS	Kg	31		31.3	31.3	31.3				
	g/l			52	36	32				
Activity	Curies	2.52×10^5		252	126	126		2.51×10^5		2.51×10^5
Density	g/l		1.24	1.29	1.275	1.27	1.25	1.75		1.57
Stream Vol	Gal						100	100	120[a]	132
HNO_3	M						8	2.64		2.00
U	Kg	162		162 g	81 g	81 g		161.9		161.9
	g/l			0.27	0.093	0.083		425		321
	M							1.79		1.35

[a] Two 60 gal washes evaporated to 32 gal in FAT

TABLE 13

NUCLEAR SHIP SAVANNAH

SULFEX

		Dissolver Charge	Declad Acid Feed	Declad Solution & Wash Water	Centrifuged Declad Solution & Wash Water	Neutralized Declad Solution (Waste)	Dissolver Acid Feed	Dissolver Product	Wash Water	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-1	4	DS-5	6	DS-2	To DS-4	DS-6
Stream Vol.	Gal		330	390	477	562				
H_2SO_4	M		4	2.02	1.65	0				
304 SS	Kg	100		101	101	101				
	g/l			68	56	48				
SiO_2	g/l	(1.0 Kg)		.68	.0055	.0047				
B^{+3}	M		0.1	0.085	0.069	0.059				
Activity	Curies	1.89×10^5		190	95	95		1.89×10^5		1.89×10^5
Density (20°C)	g/cc		1.24	1.32	1.30	1.29	1.25	1.75		1.57
Stream Vol.	Gal						140	140	120	185
HNO_3	M						8	2.68		2.00
U	Kg	222		.222	.111	.111		221.8		221.8
	g/l			0.15	.062	.052		425		318
	M							1.79		1.35
Cd^{+2}	M						0.025	0.025		0.019

TABLE 14

EGCR

SULFEX

		Dissolver Charge	Declad Acid Feed	Declad Solution & Wash Water	Centrifuged Declad Solution & Wash Water	Neutralized Declad Solution (Waste)	Dissolver Acid Feed	Dissolver Product	Wash Water	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-1	4	DS-5	6	DS-2		DS-6
Stream Vol.	Gal		100	160	231	244				
H_2SO_4	M		4	1.48	1.03	0				
304 SS	Kg	30		30.3	30.3	30.0				
	g/l			50	34.7	32.8				
SiO_2	g/l	(0.3 Kg)		0.5	0.34	0.32				
B^{+3}	M		0.1	0.0625	0.0432	0.041				
ρ (20°C)	g/cc		1.24	1.29	1.26	1.26	1.25	1.75		1.57
Activity	Curies	1.63×10^5		163	80	80		1.63×10^5		1.63×10^5
Stream Vol.	Gal						124	124	120	165
HNO_3	M						8.05	2.68		2.0
U	Kg	200		.20	.10	.10		199.8		199.8
	g/l							425		321
	M							1.79		1.35
Cd^{+2}	M						0.025	0.025		0.0188

TABLE 15

PRDC

Radial Blanket with Mo Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Solids Cake	To Solvent Extraction
Stream or Vessel No.		1		To DS-3	DS-3	DS-6
Stream Vol.	Gal		207	207	5.6	261.4[a]
HNO_3	M		7	1		1
U	Kg	252		252	8.5	243.5
	g/l			321		245
	M			1.35		1.03
Mo	Kg	8		8	6.4	1.6
	g/l			10.2		1.62
	M			.106		.017
Fe^{+3}	M		0			
Solids	Kg				21.3	
Density-g/cc (20°C)			1.22	1.55		1.43
Activity	Curies	2.7×10^4		2.7×10^4	2.2×10^3	2.48×10^4

[a] Wash Water - 1 M HNO_3

TABLE 16

PRDC

Axial Blanket with Mo Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Solids Cake	Solvent Extraction Feed
Stream or Vessel No.		1	6	To DS-3	DS-3	DS-6
Stream Vol.	Gal		165	165	4.5	220.5[a]
HNO_3	M		7.1	1.0		1.0
U	Kg	200		200	6.75	193.25
	g/l			321		231
	M			1.35		.97
Mo	Kg	6.0		6.0	5.06	0.94
	g/l			9.6		1.13
	M			0.1		.012
Fe^{+3}			0			
Solids	Kg				16.9	
Density-g/cc (20°C)			1.22	1.55		1.41
Activity	Curies	3.0×10^4		3.0×10^4	2.5×10^3	2.75×10^4

[a]Wash Water - 1 M HNO_3

TABLE 17

PRDC

Radial Blanket Without Mo Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-2	DS-6
Stream Vol.	Gal		207	207	282[a]
HNO_3	M		8	2	2
U	Kg	252		251.7	251.7
	g/l			321	237
	M			1.35	1.0
Mo	Kg	8		8	8
	g/l			10.2	7.5
	M			.106	.078
Fe^{+3}	M		1.0	1.0	.735
Activity	Curies			2.7×10^4	2.7×10^4
Density (20°C)	g/cc			1.74	1.59

[a] 2.64 M HNO_3 Wash Water

TABLE 18

PRDC

Axial Blanket Without Mo Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Product Plus Wash	Solvent Extraction Feed
Stream or Vessel No.		1	6	DS-2		DS-6
Stream Vol.	Gal		165	165	225	240[a]
HNO_3	M		8.1	2.0	2.14	2.0
U	Kg	200		200	200	200
	g/l			321	235	219
	M			1.35	0.99	0.925
Mo	g/l			9.6	7.0	6.54
	M			0.1	0.073	0.068
Fe^{+3}	M		1.0	1.0	0.74	0.69
Density - g/cc (20°C)			1.36	1.68		1.47
Activity	Curies			3.0×10^4	3.0×10^4	3.0×10^4

[a] 2.5 M HNO_3 Wash Water

TABLE 19

CPPD

With Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Centrifuge Cake	Solvent Extraction Feed
Stream or Vessel No.		1	6	DS-2	DS-3	DS-6
Stream Vol.	Gal		294	294	15.5	338.5[a]
HNO_3	M		7.0	3.33		2.9
U	Kg	212		212	24.6	187.4
	g/l			190		146
	M			0.8		.615
Mo	Kg	24		24	17.7	6.3
	g/l			21.6		4.93
	M			.225		.051
$Fe(NO_3)_3$	M		0	0	0	0
Cd^{+2}	M		0.025	0.025		0.027
Density (20°C)	g/cc		1.22	1.39		1.32
Activity	Curies	1.4×10^5		1.4×10^5	1.6×10^4	1.24×10^5

[a] 1 M HNO_3 wash water

TABLE 20

CPPD

Without Precipitation

		Dissolver Charge	Dissolver Acid Feed	Dissolver Product	Product Plus Wash	Extraction Feed
Stream or Vessel No.		1	6	DS-2	DS-6	DS-6
Stream Vol.	Gal		294	294	354[a]	378
HNO_3	M		6.6	3.0	2.66	2.48
U	Kg	212		212	212	212
	g/l			190	158	147
	M			0.8	0.665	0.62
Mo	Kg	24		24	24	24
	g/l			21.6	17.9	16.7
	M			.225	.187	.175
$Fe(NO_3)^3$	M		1.0	1.0	0.83	0.775
Cd^{+2}	M		0.025	0.025	0.021	0.019
Density (20°C)	g/cc		1.21	1.50		1.42
Activity	Curies	1.4×10^5		1.4×10^5	1.4×10^5	1.4×10^5

[a] 1 M HNO_3 wash water

TABLE 21

PWR

ZIRFLEX

		Dissolver Charge	Declad Feed	Declad Product	Core Dissolvent	Core Dissolution Product	Wash Water	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-1	6	DS-2		DS-6
Vol.	Gal		264	488[a]				
F^-	M		6	3.25				
NH_4NO_3	M		1	0.54				
Zr	Kg	84		84				
	g/l			45.5				
	M			0.50				
Sn	Kg	1.2		1.2				
	g/l			0.71				
Activity	Curies	2.52×10^5		50		2.52×10^5		2.52×10^5
Vol.	Gal				135	135	60	195
HNO_3	M				8	2.34		1.62
U	Kg	230				230		230
	g/l			0.024		450		310
	M			0.0001		1.88		1.30

[a] 224 gal wash water added

TABLE 22

COMMONWEALTH EDISON

ZIRFLEX

		Dissolver Charge	Declad Feed	Dissolver Product	Core Dissolvent	Core Dissolvent Product	Wash Water	Solvent Extraction Feed
Stream or Vessel No.		1	2	DS-1	6	DS-2		DS-6
Stream Vol.	Gal		200	372[a]				
F^-	M		6	3.22				
NH_4NO_3	M		1	0.54				
Zr	Kg	64		64				
	g/l			45.5				
	M			0.5				
Sn	Kg	1		1				
	g/l			0.72				
Activity	Curies	2.56×10^5		50		2.56×10^5		2.56×10^5
Vol.	Gal				127	127	58	185
HNO_3	M				8	2.32		1.6
U	Kg	216				216		216
	g/l			0.031		450		310
	M			.00013		1.88		1.30

[a] 172 gal of wash water added

TABLE 23

Al-Pb

BORAX IV

		Dissolver Charge	Declad Acid Feed	Declad Product Plus Wash Water	Declad Off Gas	Pb Bond Acid Feed	Pb Dissolution Waste	Pb Off Gas	Dissolvent Acid Feed	Dissolver Product	Centrifuged Dissolver Product and Waste Water	Concentrated Dissolver Product	Solvent Extraction Feed
Stream or Vessel No.		1	2	3		2	3		2	3	8	DS-4	9
Vol.	Gal		945	945		350	410		216	216	296	54	160
NaOH	M		2.0	1.0									
$NaNO_3$	M		1.78	0.6									
Al	Kg	116		116									
	M			1.2					0.10	0.10	0.073	0.40	0.135
Pb	Kg	102					102						
	g/l						66						
Off Gas	ft^3				4250			260					
Activity	Curies	8.75×10^5		38		114				8.75×10^5	8.75×10^5	8.75×10^5	8.75×10^5
Heat	Watts	2620								2620	2620	2620	2620
B^{+3}	M		0.1	0.1		0.1	0.085						
Cd^{+2}	M								.025	0.025	0.018	0.10	0.034
HNO_3	M					15	0.43		13	9.7	7.1		-0.1
U	Kg	10.45		7 g			21 g			10.42	10.42	10.42	10.42
	g/l									12.7	9.2	51	17.2
Th	Kg	152								152	152	152	152
	g/l									185	135	745	250
	M									0.80	0.58	3.2	1.08
NaF	M								0.04	0.04	0.029	0.16	0.054
Density (20°C)	g/cc		1.17			1.05			1.37	1.52	1.38	2.27	1.44

TABLE 24

FRR

PUREX

		Dissolver Charge	Acid Feed	Wash Water	Centrifuged Cake	Solvent Extraction Feed
Feed Stream or Vessel No.		1				
Stream Vol.	Gal		365	60	17	408
HNO_3	<u>M</u>		6.5			1.2
Hg^{+2}	<u>M</u>		0.005			0.0043
U	Kg	9.6			0.4	9.2
	g/l					6
	<u>M</u>					0.025
Al	Kg	49.3			2.1	47.2
	g/l					30.8
	<u>M</u>					1.15
SiO_2	Kg	1.32			1.32	

Distribution

1. R. E. Blanco
2. J. C. Bresee
3. K. B. Brown
4. F. R. Bruce
5. W. E. Clark
6. F. L. Culler, Jr.
7. W. K. Eister
8. D. E. Ferguson
9. L. M. Ferris
10. B. C. Finney
11. J. R. Flanary
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