DOE/SF/01435 - - T3

MASTER

FINAL REPORT

GAS-COOLED FAST REACTOR FUEL-COST ASSESSMENT

OCTOBER 1978 - SEPTEMBER 1979

PREPARED FOR:

U. S. DEPARTMENT OF ENERGY
CONTRACT ~~DE-AC03-77SF01435~~

AC03-77SF01435

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TABLE OF CONTENTS

TITLE	PAGE
FOREWORD.....	i
LIST OF CONTRIBUTORS/REVIEWERS.....	ii
LIST OF TABLES.....	iii
LIST OF FIGURES.....	iv
1. INTRODUCTION.....	1
2. ASSUMPTIONS AND CONSTRAINTS.....	3
2.1 Program.....	3
2.2 Process/Equipment.....	4
2.3 Facility.....	5
2.4 Manpower.....	6
2.5 Economic.....	6
3. REFERENCE FUEL FACTORY PROCESS FLOW SHEET.....	8
4. PROCESS EQUIPMENT AND MANPOWER REQUIREMENTS.....	16
5. FUEL FACTORY FACILITY.....	31
6. COST SUMMARIES.....	32
6.1 Process Equipment.....	32
6.2 Facility.....	32
6.3 Manpower.....	32
7. COST EQUATION DEFINITION.....	36
8. GCFR FUEL ASSEMBLY COST ASSESSMENT.....	38
9. GCFR/LMFBR FUEL ASSEMBLY COMPARISONS.....	40
9.1 Differences/Cost Comparisons.....	40
9.2 Recommendations/Cost Reduction Potential.....	41
10. IMPACT OF FABRICATION COSTS ON GCFR POWER COSTS.....	42
APPENDIX	

FOREWORD

This program was sponsored by the U. S. Department of Energy (DOE) at the request of Helium Breeder Associates (HBA). Essential design information⁽¹⁾⁽²⁾, including proprietary fuel assembly drawings, was provided by the General Atomic Company (GA). To the best knowledge of the author, no proprietary information has been compromised in this report.

(1) A. R. Veca and H. J. Snyder (GA), P. Rau and M. Peeks (KWU-Germany), "Fuel Element Design for the 300 MW(e) Gas-Cooled Fast Breeder Reactor", Nuclear Engineering and Design 40(1977) 81-99, North-Holland Publishing Co.

(2) GA-10298, "Preliminary Safety Information Document", 1971-1973

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LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>	<u>PAGE</u>
4-1	Conversion.....	17
4-2	Fuel Pellet Production.....	19
4-3	Rod Fabrication.....	21
4-4	Bundle Assembly.....	22
4-5	Wet Scrap Recovery-Nitrate Preparation.....	23
	Wet Scrap Recovery-Solvent Extraction.....	25
4-6	Waste Treatment, Gas, Liquid.....	27
4-7	Waste Treatment, Solid.....	30
6-1	Reference Fuel Factory Process Equipment Cost Summary (\$000).....	33
6-2	Reference Factory Facility Cost Summary.....	34
6-3	Reference Fuel Factory Manpower Summary.....	35
8-1	GCFR Fuel Fabrication Cost Assessment (\$000).....	39

LIST OF FIGURES

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
3-1	Reference Fuel Factory Flow Sheet.....	9
3-2	Conversion.....	10
3-3	Fuel Pellet Production.....	11
3-4	Fuel Rod Production.....	12
3-5	Fuel Bundle Assembly.....	13
3-6	Wet Scrap Recovery - Nitrate Preparation.....	14
3-7	Wet Scrap Recovery - Solvent Extraction.....	15
10-1	Coal, LWR and GCFR Cost Breakdown.....	43

1. INTRODUCTION

This program, contracted with the U.S. Department of Energy (DOE) to provide a Gas Cooled Fast Reactor (GCFR) fuel assembly fabrication cost assessment, comprised the following basic activities:

- 1) Establish agreement on the ground rules for cost assessment
- 2) Prepare a fuel factory flow sheet
- 3) Prepare a cost assessment for fuel assembly fabrication

Two factory sizes, 250 and 25 MTHM*/year, were considered for fuel assembly fabrication cost assessment. The work on this program involved utilizing GE LMFBFR cost assessment and fuel factory studies experience to provide a cost assessment of GCFR fuel assembly fabrication. The recent impact of highly sensitive safety and safeguards environment policies on fuel factory containment, safety, quality assurance and safeguards costs are significantly higher than might have been expected just a few years ago.

Fuel assembly fabrication costs are significant because they represent an estimated 30-60% of the total fuel cycle costs. In light of the relative high cost of fabrication, changes in the core and assembly design may be necessary in order to enhance the overall fuel cycle economics. Fabrication costs are based on similar operations and experience used in other fuel cycle studies. Because of extrapolation of present technology (e.g., remote fuel fabrication versus present contact fabrication) and regulatory requirements, conservative cost estimates were made.

The fabrication costs are calculated based on an equation developed by HEDL⁽³⁾. This equation is identified in a later section of this report.

* Metric Tons Heavy Metal

(3) J. P. Keenan et al, "A Revised Fabrication Cost Equation For Use In FBR Core Design", HEDL, June 1978

2. ASSUMPTIONS AND CONSTRAINTS

2.1 Program

Fuel cost assessment is sensitive to the assumptions and constraints applied to the components of cost. In the initial stages of this program, agreements were reached with the customer and a general listing of program assumptions and constraints was established to provide direction for cost assessment. Assumptions and constraints applicable to the Reference Fuel Factory, process equipment, manpower and other areas are provided in Sections 2.2 through 2.5.

- 1) The Helium Breeder Associates, General Atomic and General Electric cost assessment FY 1979 contractual and proprietary information agreements will be followed.
- 2) The GCFR fuel assembly physical descriptions are per KWU drawings supplied by GA and supplemented by GA-10298, "Preliminary Safety Information Document," 1971-1973. The reference fuel assembly contains 271 pins and is assembled in a six-corner supported grid spacer.
- 3) Only the GCFR core assemblies, which will have up to two enrichments per core load, will be considered for cost estimating.
- 4) The fuel fabrication plant sizes for cost estimating purposes are as follows:
 - o "Laboratory" *(Shared overhead basis)-one GCFR fuel assembly per year
 - o "HPFL" size plant (Dedicated facility)-25 metric tons/year (approximately 250** assemblies/yr)
 - o "Production" plant/factory (Dedicated facility)-250 metric tons/yr (approximately 2500*** assemblies/yr)
- 5) GCFR fuel assembly cost estimates will be compared to current LMFBR costs on a \$/Kg heavy metal basis.
- 6) Major differences between GCFR and LMFBR fuel assemblies will be identified and the cost differences will be evaluated.

* Please note that this is not by a contractual agreement, but was requested by HBA/GA in the meeting held 12/11/78 in Sunnyvale, California.

** Note: This value was revised to 380 assemblies/year based on 66 Kg HM fuel/assembly.

***Note: This value was revised to 3800 assemblies/year based on 66 Kg HM fuel/assembly.

- 7) Assembly, material, and fabrication cost estimates will generally be based on the following RDT Standard criteria:

Fuel Assembly and Components

RDT E 13-1T	FFTF Ceramic Grade Plutonium Dioxide*
RDT E 13-2T	FFTF Ceramic Grade Uranium Dioxide*
RDT E 13-3T	FFTF Uranyl Nitrate Solution*
RDT E 13-4T	FFTF Plutonium Nitrate Solution*
RDT E 13-5T	FFTF Driver Fuel Pin
RDT E 13-6T	FFTF Driver Fuel Pin Fuel Pellet
RDT E 13-7T	FFTF Driver Fuel Pin Insulator Pellet
RDT M3 28T	FFTF Driver Fuel Pin Seamless Cladding Tube**
RDT E 13-9T	FFTF Driver Fuel Pin End Caps
RDT E 13-12T	FFTF Driver Fuel Pin Plenum Spring
RDT E 13-16T	Driver Fuel Assembly
RDT E 13-20T	Austenitic Stainless Steel Hexagonal Duct Tubes for Core Components and Assemblies

Inspection and Quality Control***

RDT F2-2	Quality Assurance Program Requirements
RDT F2-6T	Qualification and Control of Analytical Chemistry Laboratories for Mixed Oxide Fuel Analysis
RDT F3-2T	Calibration Program Requirements
RDT F3-10T	Nondestructive Examination of Reactor Core Components
RDT F5-1T	Cleaning and Cleanliness Requirements for Nuclear Components
RDT F6-2T	Welding of Reactor Core Components and Test Assemblies
RDT F7-3T	Marking of Components and Parts
RDT F11-1T	Analytical Chemistry Methods for Mixed Oxide Fuel
RDT F11-3T	Analytical Chemistry Methods for Metallic Core Components

* Either physically blended or coconverted fuel powder will be established as a basis for cost estimating LMFBR and GCFR fuel assemblies.

** Modified for GCFR spiral ground tubing.

***These standards were not specifically identified by HBA/GA, but application is assumed.

RDT F11-5T Determination of Fuel Pellet Homogeneity by Alpha-Autoradiography

RDT F11-6T Ceramographic Preparation of Mixed Oxide Fuel Pellets

- 8) Facility, equipment and overhead costs are assumed to be similar for LMFBR and GCFR fuel assembly fabrication. Possible exceptions could result from major differences between fabrication requirements for the LMFBR and GCFR.
- 9) Hardware component fabrication is expected to be performed by outside qualified vendors. It may be possible to demonstrate a significant cost incentive for "in-house" fabrication in the factory case but it is not considered for this cost assessment.
- 10) Fuel (2 enrichments/core load) and fuel assembly fabrication are expected to be performed "in-house".
- 11) Generally, the major steps in the fabrication flow sheet will be as follows (specific fabrication flow sheet is to be established):

Pu/U Supply and Conversion
Fuel Fabrication
Hardware Supply and Fabrication
Fuel Rod Fabrication
Fuel Assembly Fabrication
Scrap and Waste Handling
Analytical Laboratory
Assembly Shipment
Waste Disposal

2.2 Process/Equipment

The fuel fabrication process/equipment has the following features:

- o Masterblended coconverted mixed (Pu+U) oxide powder.
- o Two fuel enrichments are planned with equipment capability to accommodate four enrichments (basically four process lines) in the large facility. This results in some fuel fabrication cost penalties due to excess equipment capacity in some processes.
- o Remotely operated process with computer assistance (on line process equipment computers with data/information transmission to a central computer).
- o Whenever possible, equipment maintenance will be performed by direct contact after cleaning and removal to a low exposure area. If this is not possible the equipment will be changed out and scrapped.

- o The process is operated on the following schedules:
 250 MT/yr - 300 days/yr, 4 shifts, 7 days/week
 25 MT/yr - 250 days/yr, 3 shifts, 5 days/week
- o Scrap is generated in the total process at an estimated 15% rate and is recovered via wet processing (Wet Scrap Recycle).
- o The average fuel enrichment produced is 17% plutonium.
- o Although it is recognized that the core length for a 1200 MW power plant may be larger than the present GCFR fuel core design, the present core length design is assumed.
 450 mm lower blanket (UO_2)
 1000 mm fuel (MO_2)
 450 mm upper blanket (UO_2)
- o The 250 MT/yr factory produces 3800 fuel assemblies/year and the 25 MT/yr factory produces 380 fuel assemblies/year.
- o Equipment operating efficiency (uptime) is estimated to be about 75%.
- o The average in-process fuel storage is assumed to be one week. Finished product inventory is 8 weeks.
- o The process equipment is assumed to be critically safe, generally based on geometry with minimal use of poisons or administrative control.
- o Special Nuclear Material inventory is maintained by a "moving inventory" concept on a "real time" accountability system.
- o Whenever possible, analytical determinations will be performed on-line. Special analyses such as mass spectrometry may be performed off-line.
- o UO_2 blanket pellets are fabricated by a qualified outside vendor.
- o The process and process equipment are fully developed.
- o The expected process equipment lifetime for cost estimating purposes is 10 years.

2.3 Facility

The facilities are "stand alone" plants located near LMFBR reprocessing plants and have the following features:

- o Security hardened to meet present and near future new facility safeguards requirements (including natural phenomena requirements).

- o Safety and environmental requirements to allow no offsite releases of radioactive materials exceeding present regulatory requirements.
- o The 250 MT/yr facility was sized to provide fuel bundles for a 1200 MW power plant.
- o Facility and overhead costs are assumed to be similar for LMFBFR and GCFR fuel assembly fabrication.
- o The 25 MT/yr facility is comparable to the scope of the High Performance Fuel Laboratory (HPFL) conceptually designed by HEDL.
- o Storage facilities are assumed to be in the respective process areas. This is not necessarily the optimum facility design because storage space requirements are based on cursory criticality reviews.
- o A material transfer system is included in the factory design.
- o The facility costs do not include the following:

Environmental Impact Report
Licensing

- o The facility lifetime for cost estimating purposes is 20 years.

2.4 Manpower

Manpower costs are based on the following assumptions:

- o Average salary rates:
Nonexempt: \$10/hour
Exempt: \$15/hour
- o Security guards are subcontracted and are not included in the cost assessment.

2.5 Economic

- o Costs are in 1979 dollars.
- o The fixed overhead is sensitive to the type of financing available. The suggested uninflated cost parameters for financing a typical industry based on the NASAP/INFCE economic guidelines are:

Debt interest, %	2.7
Equity return, %	8.0
Debt fraction	0.35
Equity fraction	0.65
Effective Income Tax, %	50
Tax depreciation method	Sum of Year Digits (SYD)
Tax depreciation life	Variable
Charge for property tax plus plant insurance, %	2.75
Decommissioning sinking fund, %	5% of initial investment
Capital carrying charges	See Table below

- o Capital Charge Rate for Typical Industry based on the number of years to depreciate the plant*

<u>SYD (yrs)</u>	
20	0.142
10	0.192
4	0.360

- o For simplicity, accelerated depreciation is not assumed, which is the favored method by industry. Tax guidelines need to be further examined to reflect accelerated depreciation and investor tax credit. The effect is to lower the capital charge rates.
- o Interest during construction (I_C) as a percentage of the total cost of a plant-typical industry, 6 year construction: 18.7%.
- o The interest during construction is an important consideration in the facility cost. A six year construction period (2.5, 6.5, 18.2, 44.2, 27.1, 1.5%) is assumed consistent with the NASAP/INFCE economic guidelines. It should be noted that the appropriate rate for interest during construction is determined as (1) return on equity, plus (2) return on debt, minus (3) the tax credit on return on debt.

* These rates include 2.75% for property tax plus insurance and a 5% of total cost decommissioning sinking fund (0.14% for 20 years, 0.38% for 10 years, 1.5% for 4 years).

3. REFERENCE FUEL FACTORY PROCESS FLOW SHEET

In order to provide a fuel fabrication cost assessment basis, including facility layout and process equipment and manpower requirements, it was necessary to establish a reference fuel factory flow sheet. The following flow sheet (see Figure 3-1) shows the major steps for the fuel assembly fabrication process used for cost assessment in this report. Figures 3-2 through 3-7 show the process steps required in the respective major processes indicated in Figure 3-1.

Figure 3-1
Reference Fuel Factory Flow Sheet

Figure 3-2

Conversion

Figure 3-3
Fuel Pellet Production

Figure 3-4
Fuel Rod Production

*Buy/Fab.-Separate Location

Figure 3-5
Fuel Bundle Assembly

Figure 3-6
Wet Scrap Recovery - Nitrate Preparation

Figure 3-7
Wet Scrap Recovery - Solvent Extraction

4. PROCESS EQUIPMENT AND MANPOWER REQUIREMENTS

The following tables (4-1 through 4-7) provide listings of process equipment and manpower requirements for the two factories being considered. The equipment is identified for each major process step. It should be noted that identified equipment costs do not include instrumentation and installation costs. However, these costs are included in the cost summary section. As indicated in the assumptions and constraints, in some cases, excess equipment with excess capacity is identified in the 250 MT/yr factory to accommodate up to four fuel enrichments with one process line per enrichment.

An organization chart for the 250 MT/yr reference fuel factory is shown in the Appendix.

TABLE 4-1
CONVERSION

<u>PROCESS STEP</u>	<u>250 MT/Yr (22 Kg/Hr)</u>			<u>25 MT/Yr (3 Kg/Hr)</u>		
	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Feed Receiving</u>	4-3000 P vessels	120K	12 NE/Shift	1- 800 P vessel	25K	6 NE/Shift
<u>Recycle Receiving</u>	2-2400 l vessels	60K		2- 300 l vessels	30K	
<u>Blend & Feed</u>	5-6000 l vessels	220K		3-1000 l vessels	80K	
<u>Precipitation</u>	8- 17 l precipitators	120K		2- 17 l precipitators	30K	
<u>Calcination</u>	8- 28 l calciners w/furnaces	160K		2- 28 l calciners w/furnaces	40K	
<u>Powder Collection</u>	8- 28 l powder collectors	160K		2- 28 l powder collectors	40K	
<u>& Condensing System</u>	3-2000 l condensate vessels	60K		2- 300 l condensate vessels	30K	
<u>Powder Reduction and Stabilization</u>	8- 28 l reduction vessels w/furnaces	160K		2- 28 l reduction vessels w/furnaces	40K	

(See Next Page)

(See Next Page)

TABLE 4-1 (Continued)
CONVERSION (Continued)

<u>PROCESS STEP</u>	<u>250 MT/Yr (22 Kg/Hr)</u>		<u>25 MT/Yr (3 Kg/Hr)</u>	
	<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>
<u>Powder Screening/Weighing/Loading</u>	2 powder handling systems	80K	2 powder handling systems	80K
<u>Powder Storage</u>	150-22 μ containers	350K	15-22 μ containers	50K
		12 NE/Shift		6 NE/Shift
<u>Totals</u>		<u>\$1490K</u>	<u>\$445K</u>	<u>6 NE/Shift</u>
		<u>5 E Total</u>		<u>4 E Total</u>

TABLE 4-2
FUEL PELLET PRODUCTION

<u>PROCESS STEP</u>	<u>250 MT/Yr (35 Kg/Hr)</u>			<u>25 MT/Yr (4 Kg/Hr)</u>		
	<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>		<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>	
<u>Powder Receiving</u>	2-hoppers (UO ₂)	20K	4 NE/Shift	2-hoppers (UO ₂)	15K	2 NE/Shift
<u>Powder Blending/ Weighing</u>	8-weighing systems	80K		2-weighing systems	20K	
	4-8 quart V blenders	80K		4-8 quart V blenders	40K	
<u>Powder Prepressing & Granulation</u>	4-prepress feed systems	80K	2 NE/Shift	2-prepress feed systems	40K	2 NE/Shift
	4-30 ton presses (1-1/2 die)	600K		2-10 ton presses (3/4 die)	200K	
	4 granulators	50K		2-granulators	25K	
<u>Pellet Pressing</u>	8-pressing feed systems	80K	14 NE/Shift	2-pressing feed systems	20K	3 NE/Shift
	8-10 ton presses (3 cavity)	760K		2-10 ton presses (3 cavity)	190K	
	8-boat loading & weighing systems	120K		2-boat loading & weighing systems	30K	
<u>Pellet Sintering</u>	4-sintering furnaces	450K	2 NE/Shift	2-sintering furnaces	220K	1 NE/Shift
	200-boats	80K		75-moly boats	30K	
	4-unloading & weighing systems	80K		2-unloading & weighing systems	40K	
<u>Pellet Grinding</u>	4-feeder systems	40K	3 NE/Shift	2-feeder systems	20K	1 NE/Shift
	4-grinders	80K		2-grinders	40K	

(See Next Page)

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TABLE 4-2 (Continued)
FUEL PELLETT PRODUCTION (Continued)

<u>PROCESS STEP</u>	<u>250 MT/Yr (35 Kg/Hr)</u>			<u>25 MT/Yr (4 Kg/Hr)</u>		
	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Pellet Inspection</u>	4-pellet inspection stations	400K	2 NE/Shift	2-pellet inspection stations	200K	1 NE/Shift
	4-loading/lineup canister systems	80K		2-loading/lineup canister systems	40K	
<u>Pellet Storage</u>	15000-rod lineup position storage	1200K	1 NE/Shift	1500 position storage	120K	1 NE/Shift
<u>Totals</u>		<u>\$4280K</u>	<u>28 NE/Shift</u>		<u>\$1290K</u>	<u>11 NE/Shift</u>
			<u>6 E Total</u>			<u>4 E Total</u>

TABLE 4-3
ROD FABRICATION

<u>PROCESS STEP</u>	<u>250 MT/Yr (143 rods/hr)</u>			<u>25 MT/Yr (17 rods/hr)</u>		
	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Rod Pre-Assembly (Bottom Plug Welding)</u>	2-assembly stations	50K	4 NE/Shift	1-assembly station	25K	2 NE/Shift
	2-welders	100K		1-welder	50K	
	2-leak checkers/ x-ray stations	150K		1-leak checker/ x-ray station	75K	
<u>Rod Loading</u>	4-assembly stations	400K	12 NE/Shift	1-assembly station	100K	2 NE/Shift
<u>Rod Inerting & Top Plug Welding</u>	4-welders	300K	5 NE/Shift	1-welder	75K	2 NE/Shift
<u>Rod Inspection</u>	4-x-ray units	200K	1 NE/Shift	1-x-ray unit	50K	1 NE/Shift
	4-inspection tables & equip- ment (including leak checking)	600K 80K		1-inspection table & equip- ment (including leak checking)	150K	
<u>Reject Rod Handling</u>	1-handling station	20K		1-handling station	15K	
<u>Rod Storage</u>	15000 position rod storage	800K		1500 position rod storage	150K	
<u>Totals</u>		\$ 2620K	22 NE/Shift		\$ 690K	7 NE/Shift
			<u>5 E Total</u>			<u>4 E Total</u>

TABLE 4-4
BUNDLE ASSEMBLY

	250 MT/Yr (13/day)			25 MT/Yr (1.5/day)		
<u>PROCESS STEP</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Fuel Bundle Assembly</u>	1-assembly equipment (welder, leak checker, hold-down/inspection table)	100K	2 NE/Shift	1-assembly equipment (welder, leak checker, hold-down/inspection table)	100K	1 NE/Shift
<u>Final Assembly</u>	3-assembly equipment (rod drilling/ inspection indexing table, welder, leak tester, hold-down/inspec- tion table)	675K	7 NE/Shift	1-assembly equipment (rod drilling/ inspection indexing table, welder, leak tester, hold-down/inspec- tion table)	225K	4 NE/Shift
<u>Channel Installtion & Inspection</u>	3-installation/ inspection table	300K		1-installation/ inspection table	100K	
<u>Storage Preparation</u>	1-protective sleeve fix- ture	10K		1-protective sleeve fix- ture	10K	
<u>Assembly Storage</u>	770-storage positions	350K		200 storage positions	100K	
<u>Totals</u>		\$ <u>1435K</u>	<u>9 NE/Shift</u>		\$ <u>535K</u>	<u>5 NE/Shift</u>
			<u>5 E Total</u>			<u>2 E Total</u>

TABLE 4-5
WET SCRAP RECOVERY - NITRATE PREPARATION

PROCESS STEP	250 MT/Yr (6 Kg/Hr)*			25 MT/Yr (0.6 Kg/Hr)*		
	EQUIPMENT NEEDS		MANPOWER NEEDS	EQUIPMENT NEEDS		MANPOWER NEEDS
<u>Furnace Charge Make-Up</u>	20-storage containers	50K	7 NE/Shift	5-storage containers	15K	5 NE/Shift
	1-feed hopper/weight/boat loader	40K		1-feed hopper/weight/boat loader	35K	
	100-boats	15K		50-boats	8K	
<u>Oxidation</u>	2-electric pusher furnaces	120K		1-electric pusher furnace	60K	
<u>Dissolution Charge Make-Up</u>	1-feed hopper/ weigh station	40K		1-feed hopper/ weigh station	35K	
<u>Dissolver</u>	2-6" ID, 30 ¢ thermosyphons w/condensers	100K		2-6" ID 10 ¢ thermosyphons w/condensers	70K	
	2-8" ID x 20' long, 200 ¢ condensate tanks	30K		1-8" ID x 20' long, 200 ¢ condensate tank	15K	
<u>Feed Storage</u>	3-4" ID x 20' long, 50 ¢ tanks	30K		2-4" ID x 6' long, 15 ¢ tanks	10K	

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(See Next Page)

*Based on 15% scrap rate

TABLE 4-5 (Continued)
WET SCRAP RECOVERY - NITRATE PREPARATION(Continued)

	250 MT/Yr (6 Kg/Hr)*			25 MT/Yr (0.6 Kg/Hr)*		
<u>PROCESS STEP</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Feed Concentrator</u>	2-4" ID, 30 ℓ thermosyphons w/condensers	120K	↓	1-4" ID, 30 ℓ thermosyphon w/condensers	60K	↓
<u>Valence</u>	2-8" ID x 20' long, 200 ℓ condensate tanks	30K		1-8" ID x 20' long, 200 ℓ condensate tank	15K	
<u>&</u>						
<u>Acid Adjustment</u>	6-4" ID x 20' long, 50 ℓ tanks	60K		2-4" ID x 8' long, 20 ℓ tanks	15K	
<u>Feed Storage</u>	2-5" ID x 25' long, 80 ℓ tanks	25K		1-5" ID x 15' long, 50 ℓ tank	10K	
<u>Totals</u>		<u>\$660K</u>			<u>\$348K</u>	
		(See Next Page)			(See Next Page)	

*Based on 15% scrap rate

TABLE 4-5 (Continued)
WET SCRAP RECOVERY - SOLVENT EXTRACTION

PROCESS STEP	250 MT/Yr (6 Kg/Hr)		MANPOWER NEEDS	25 MT/Yr (0.6 Kg/Hr)		MANPOWER NEEDS
	EQUIPMENT NEEDS			EQUIPMENT NEEDS		
<u>Solvent Extraction</u>	4-4" ID x 35' long columns	120K	↓	4-2" ID x 35' long columns	120K	↓
<u>Pu+U Product Concentrator</u>	2-4" ID x 15' long, 30 & thermosyphons w/condenser	120K		1-4" ID x 15' long, 30 & thermosyphon w/condenser	60K	
<u>Condensate Storage Make-Up</u>	2-8" ID x 20' long, 200 & condensate tanks	30K		1-8" ID x 20' long, 200 & condensate tank	15K	
<u>Pu+U Concentrated Product Storage</u>	2-6" ID x 20' long, 100 & tanks	20K		2-6" ID x 4' long 20 & tanks	10K	
<u>Uranium Concentrator</u>	2-4" ID x 15' long 30 & thermosyphons w/condenser	120K		1-4" ID x 15' long, 30 & thermosyphon w/condenser	60K	
<u>Condensate Storage</u>	4-8" ID x 20' long, 200 & condensate tanks	60K		2-8" ID x 20' long, 200 & condensate tanks	30K	
<u>Uranium Storage</u>	2-8" ID x 20' long, 200 & tanks	30K		2-8" ID x 3' long, 30 & tanks	15K	

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TABLE 4-5 (Continued)
WET SCRAP RECOVERY - SOLVENT EXTRACTION (Continued)

	250 MT/Yr (6 Kg/Hr)				25 MT/Yr (0.6 Kg/Hr)		
<u>PROCESS STEP</u>	<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>		<u>EQUIPMENT NEEDS</u>		<u>MANPOWER NEEDS</u>
<u>Solvent Exchange Waste Storage</u>	6-8" ID x 20' long, 200 ℓ tanks	90K	↓		1-8" ID x 20' long tank	15K	↓
<u>Organic Recycle Storage</u>	2-8" ID x 20' long, 200 ℓ tanks	30K			1-8" ID x 20' long, 200 ℓ tank	15K	
<u>Liquid & Solvent Waste Storage</u>	9-12" ID x 20' long, 450 ℓ	180K			3-12" ID x 20' long, 450 ℓ	60K	
<u>Totals</u>		<u>\$800K</u>				<u>\$400K</u>	
			<u>7 NE/Shift</u>			<u>5 NE/Shift</u>	
			<u>5 E Total</u>			<u>4 E Total</u>	

TABLE 4-6
WASTE TREATMENT - GAS, LIQUID

PROCESS STEP	250 MT/Yr		MANPOWER NEEDS	25 MT/Yr		MANPOWER NEEDS	
	EQUIPMENT NEEDS			EQUIPMENT NEEDS			
<u>Offgas Scrubbing</u>	2-8" ID x 20' long, 200 ¢ tanks w/demister & condenser	150K	7 NE/Shift	1-8" ID x 20' long, 200 ¢ tank w/demister & condenser	75K	5 NE/Shift	
	2-8" ID x 14' long, 140 ¢ condensate tanks	30K			1-8" ID x 14' long, 140 ¢ condensate tank		15K
<u>Liquid Waste Storage</u>	6-12" ID x 20' long, 440 ¢ tanks	120K			1-12" ID x 20' long, 440 ¢ tank		20K
<u>Solvent Waste Storage</u>	3-12" ID x 20' long, 440 ¢ tanks	60K			1-12" ID x 20' long, 440 ¢ tank		20K
<u>Solvent Waste Distillation & Storage</u>	2-6" ID x 15' long, distiller w/condenser	60K			1-6" ID x 15' long distiller w/condenser		30K
	6-12" ID x 20' long, 440 ¢ distillate and spent solvent storage tanks	120K		2-12" ID x 20' long, 440 ¢ distillant and spent solvent storage tanks	40K		
<u>Liquid Waste Concen- tration</u>	2-8" ID x 20' long, 200 ¢ thermosyphons w/demisters & condensers	120K	↓	1-8" ID x 20' long, 200 ¢ thermosphyon w/demister & condenser	60K	↓	

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(See Next Page)

TABLE 4-6 (Continued)
WASTE TREATMENT - GAS, LIQUID (Continued)

PROCESS STEP	250 MT/Yr		MANPOWER NEEDS	25 MT/Yr		MANPOWER NEEDS
	EQUIPMENT NEEDS			EQUIPMENT NEEDS		
<u>Acid Recovery</u>	2-4" ID x 25' long thermo-syphon with fractionator	100K	↓	1-4" ID x 25' long thermo-syphon with fractionator	50K	↓
	2-12" ID x 20' long acid collector tanks	40K		1-12" ID x 20' long acid collector tank	20K	
	2-12" ID x 20' long water collector tanks	40K		1-12" ID x 20' long water collector tank	20K	
	6-12" ID x 20' long acid & water recycle storage tanks	120K		2-12" ID x 20' long acid & water recycle storage tanks	40K	
<u>Extraction and Strip Solution Makeup</u>	4-12" ID x 20' long storage tanks	80K		2-12" ID x 20' long storage tanks	40K	
<u>Interim Waste (slurry) Collection</u>	6-6" ID x 20' long tanks	60K		2-6" ID x 20' long tanks	20K	
<u>Interim Waste Neutralization</u>	2-6" ID x 18' long neutralizer w/heat exchanger & demister	40K		1-6" ID x 18' long neutralizer w/heat exchanger & demister	20K	

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(See Next Page)

TABLE 4-6 (Continued)
WASTE TREATMENT - GAS, LIQUID (Continued)

<u>PROCESS STEP</u>	<u>250 MT/Yr</u>			<u>25 MT/Yr</u>		
	<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>		<u>EQUIPMENT NEEDS</u>	<u>MANPOWER NEEDS</u>	
<u>Neutralized Interim Waste Storage</u>	4-8" ID x 20' long, 200 ℓ tanks 40K	↓		1-8" ID x 20' long, 200 ℓ tank 10K	↓	
<u>Liquid Waste Solidification</u>	2-solidification stations 60K			1-solidification station 30K		
<u>Totals</u>	<u>\$1240K</u>	<u>7 NE/Shift</u>		<u>\$510K</u>	<u>5 NE/Shift</u>	
		<u>3 E Total</u>			<u>3 E Total</u>	

TABLE 4-7
WASTE TREATMENT - SOLID

PROCESS STEP	250 MT/Yr			25 MT/Yr		
	EQUIPMENT NEEDS		MANPOWER NEEDS	EQUIPMENT NEEDS		MANPOWER NEEDS
<u>Waste Sorting (Combustible versus Non-Combustible)</u>	1-sorting sta- tion	100K	7 NE/Shift	1-sorting sta- tion	100K	5 NE/Shift
<u>Non-Combustible Waste Disposal</u>	1-decon, rinse, packaging equipment	100K	↓	1-decon, rinse packaging equipment	100K	↓
<u>Combustible Waste Shredding</u>	1-shredder w/elevated hopper	80K		1-shredder w/elevated hopper	80K	
<u>Combustible Waste Incineration</u>	3-incinerators (primary, secondary, solvent)	1000K		3-incinerators (primary, secondary, solvent)	700K	
<u>Waste Preparation (Fixation) and Handling</u>	1-handling station (fixation & packaging)	200K		1-handling station (fixation & packaging)	175K	
<u>Miscellaneous Waste Treatment and Central Offgas Scrubber System</u>	1-waste treat- ment and off- gas scrubber system	800K		1-waste treat- ment and off- gas scrubber system	600K	
<u>Totals</u>		<u>\$2280K</u>	<u>7 NE/Shift</u>		<u>\$1755K</u>	<u>5 NE/Shift</u>
			<u>3 E Total</u>			<u>2 E Total</u>

5. FUEL FACTORY FACILITY

The 250 MT/yr factory facility overall layout to 1"=16' scale is shown in the sketch AFL PL-1107 in the appendix.

6. COST SUMMARIES

The tables in this section summarize costs for the two fuel factories under consideration.

6.1 Process Equipment

The process equipment and installation costs for each process step are included in Table 6.1.

6.2 Facility

The reference factory facility cost summary is shown in Table 6.2. These costs are based on contemporary building costs.

6.3 Manpower

The reference fuel factory manpower summary is shown in Table 6.3.

The manpower cost summaries are based on the following average salary rates:

Nonexempt - \$10/hr

Exempt - \$15/hr

TABLE 6.1
REFERENCE FUEL FACTORY PROCESS EQUIPMENT COST SUMMARY (\$000)

MAJOR PROCESSING AREA	250 MT/Yr			25 MT/Yr		
	EQUIP. COST	INSTALLATION	TOTAL	EQUIP. COST	INSTALLATION	TOTAL
Conversion	1,490	1,060	2,550	445	310	755
Fuel Pellet Production	4,280	2,175	6,455	1,290	635	1,925
Fuel Rod Production	2,620	1,310	3,930	690	350	1,040
Fuel Bundle Assembly	1,435	360	1,795	535	180	715
Wet Scrap Recovery	1,460	1,300	2,760	748	680	1,428
Support Functions						
Instrumentation (Incl. Quality Assurance)	5,000	2,500	7,500	3,000	1,500	4,500
Analytical	2,000	500	2,500	1,500	350	1,850
Liquid Waste Treatment	1,240	1,160	2,400	510	450	960
Solid Waste Treatment	2,280	1,710	3,990	1,755	1,320	3,075
Chemical Supply	500	250	750	250	150	400
Safety & Safeguards	6,000	3,000	9,000	5,000	2,500	7,500
Administration & Materials (Furniture, Spare Parts, etc.)	2,500	500	3,000	1,000	300	1,300
Maintenance	<u>200</u>	<u>80</u>	<u>280</u>	<u>100</u>	<u>40</u>	<u>140</u>
	31,005	15,905	46,910	16,823	8,765	25,588
Contingency (25%)	<u>7,750</u>	<u>3,975</u>	<u>11,725</u>	<u>4,207</u>	<u>2,190</u>	<u>6,397</u>
TOTALS	38,755	19,880	58,635	21,030	10,955	31,985

TABLE 6.2
REFERENCE FACTORY FACILITY COST SUMMARY

	250 MT/YR.		25 MT/YR.	
	AREA (FT ²)	COST (\$MILLIONS)	AREA (FT ²)	COST (\$MILLIONS)
(1) Fuel Building (Hardened Area)*				
o High Bay 60'	44,400	53.30	26,700	32.00
o Low Bay 40'	39,300	31.50	23,600	19.00
o Exhaust Vent System	20,000	10.00	12,000	6.00
o Cranes & Manipulators		3.00		2.00
Subtotal	103,700	97.80	62,300	59.00
(2) Support Facilities (Unhardened Area)**				
o Generator Bldg.	3,000	1.20	1,500	0.60
o Utility Service Bldg.	4,800	1.68	2,400	0.89
o Hot Shop Maint. & Repair	3,600	1.10	1,800	0.55
o Cold Chem. Supply & UO ₂ Powder Storage (3 story)	9,000	2.70	4,500	1.35
o Waste Handling & Packaging Facilities	4,800	1.44	2,400	0.72
o Analytical Chem. Lab.	4,800	1.44	2,400	0.72
o Pellet (Blanket) Prep. Facility	2,400	0.48	1,200	0.24
o Rod Prep. Facility	4,200	0.84	2,100	0.42
o Bundle Handling Facility	3,300	0.66	1,700	0.33
o Hardware & Equipment Storage	8,400	1.68	4,200	0.89
o Bulk Storage Area (Gas, Liquid)	2,400	0.12	2,400	0.12
Subtotal	50,700	13.34	26,600	6.83
(3) Administration and Engineering (2 story)	37,400	5.61	20,000	3.40
(4) Architect and Engineering Fees		10.00		6.00
Total	191,800	126.75	88,900	75.23
25% Contingency		31.69		18.81
Grand Total		\$158.44		\$ 94.04

* 3 Foot Wall Thickness

** 1 Foot Wall Thickness

TABLE 6.3
REFERENCE FUEL FACTORY MANPOWER SUMMARY

MAJOR PROCESSING AREA	250 MT/Yr			25 MT/Yr		
	DIRECT	INDIRECT		DIRECT	INDIRECT	
	NE	E	NE	NE	E	NE
Conversion	48	5	0.5	18	4	0.5
Fuel Pellet Production	112	6	0.5	33	4	0.5
Fuel Rod Production	88	5	0.5	21	4	0.5
Fuel Bundle Assembly	36	5	0.5	5	2	-
Wet Scrap Recovery	28	5	0.5	15	4	0.5
Support Functions						
Analytical	-	10	40	-	7	18
Waste Treatment (L&S)	56	6	0.5	30	5	-
Materials	-	13	5		9	3
Safety & Safeguards	-	17	18	-	15	16
Administration	-	43	69	-	30	41
Quality Assurance	-	21	28	-	19	22
Process Support (Incl. Chem. Supply)	10	3	-	5	1	-
Maintenance & Projects	-	8	34	-	6	17
Advanced Engineering	-	3	2	-	2	1
TOTALS	378	150	199	127	112	120
GRAND TOTALS		<u>727</u>			<u>359</u>	

7. COST EQUATION DEFINITION

The HEDL cost equation was established to include fixed and variable overhead costs and components which explicitly depend on the sub-assembly design. The basic form of the HEDL fabrication cost equation is maintained but the equation, shown below, is modified slightly for this cost assessment.

$$C = [C_{1,b}(1 + I_c)R_b + C_{1,e}R_e] \frac{1}{A} \\ + C_2 + (C_{3,l}L + C_{3,R}L_R + C_{3,h})N_f + C_4(1 + OH) + C_5E_f \\ + C_6M_b + C_7,$$

where:

C = fabrication cost per assembly (\$)

$C_{1,b}$ = building cost excluding interest during construction

I_c = interest during construction

R_b = annual levelized charge on building capital

$C_{1,e}$ = equipment cost

R_e = annual levelized charge on equipment capital

A = number of assembly throughput per year

C_2 = fabrication cost of duct and nosepiece. Does not include the cost of fabricating the individual rods and assembly.

$C_{3,l}$ = cost of cladding (\$/ft)

L = cladding length (ft) per rod

C_{3R} = cost (\$/ft) of roughening the cladding

L_R = length of roughening (ft.) per rod

$C_{3,h}$ = cost of hardware per rod, end caps, springs....

N_f = number of rods/assembly

C_4 = total direct labor dollars per assembly

OH = overhead factor

C_5 = cost of waste disposal \$/kg HM

E_f = kg of HM per assembly

C_6 = cost of fabricating or procuring blanket pellets (\$/kg)

M_b = kg of blanket fuel

C_7 = general and administrative cost of 10% of direct costs given
by the terms above

8. GCFR FUEL ASSEMBLY COST ASSESSMENT

The GCFR fuel assembly cost assessment is presented in Table 8.1 for the two fuel factories. The costs are shown per component of the cost equation introduced in the previous section. Also shown is the breakdown by percentage contributed by each cost component.

One GCFR fuel assembly fabricated in a "laboratory" is estimated to cost approximately 500 thousand dollars. The breakdown of the estimated costs is as follows:

Rod hardware	60,000
Bundle hardware	115,000
Fuel rod/bundle fabrication	325,000
	<hr/>
	\$500,000

TABLE 8.1
GCFR FUEL FABRICATION COST ASSESSMENT (\$000)

Cost Component	250 MT/YR.			25 MT/YR		
	Factors	\$/Assembly	%	Factors	\$/Assembly	%
Overhead, Fixed (Facility & Equipment)	$C_{1,b} = \$158.4M$ $I_c = 0.187$ $R_b = 0.142$ $C_{1,e} = \$58.6M$ $R_e = 0.192$ $A = 3800$	9,990	8.6	$C_{1,b} = \$94.0M$ $I_c = 0.187$ $R_b = 0.142$ $C_{1,e} = \$31.9M$ $R_e = 0.192$ $A = 380$	57,790	27.2
Bundle Hardware	$C_2 = \$45,300$	45,300	38.9	$C_2 = \$58000$	58,000	27.2
Fuel Pin Hardware	$C_{3,l} = \$6.30$ $L = 7'$ $C_{3,R} = \$28$ $L_R = 2.5'$ $C_{3,h} = \$36$ $N_f = 271$	40,700	34.9	$C_{3,l} = \$7$ $L = 7'$ $C_{3,R} = \$32$ $L_R = 2.5'$ $C_{3,h} = \$40$ $N_f = 271$	45,800	21.5
Fuel Fabrication (Incl. Direct Labor Overhead, and Utility Costs)	$C_4 = \$1800$ $OH = 2.5$	6,300	5.4	$C_4 = \$5925$ $OH = 3.8$	28,400	13.3
Waste Disposal	$C_5 = \$20$ $E_f = 66$	1300	1.1	$C_5 = \$20$ $E_f = 66$	1,300	0.6
Blanket Urania	$C_6 = \$35$ $M_b = 66$	2,300	2.0	$C_6 = \$35$ $M_b = 66$	2,300	1.1
G & A	$C_7 = \$$	10,590	9.1	$C_7 = \$$	19,360	9.1
Total Cost/Assembly	C	116,480	100.0	C	212,950	100.0
Cost/Kg Heavy Metal of Core Material		\$1,765			\$3,227	

9. GCFR/LMFBR FUEL ASSEMBLY COMPARISONS

9.1 Differences/Cost Comparisons

For purposes of this GCFR fuel assembly cost assessment, it is assumed that GCFR and LMFBR fuel and assembly fabrication is similar (assumes similar size assemblies and specifications). The factory layout, process and process equipment, manpower levels, operating materials, etc. are essentially equivalent for both assembly types. One exception to similar equipment and manpower requirements is apparent in the GCFR bundle assembly operation. More complex or additional bundle assembly equipment is required to:

- (1) puncture the membrane in each fuel rod to allow for pressure equilization
- (2) screw each fuel rod into place
- (3) leak check each layer of fuel rods, and
- (4) tack weld the fuel rods to the holddown ring

The following differences between the GCFR and LMFBR costs were developed as part of this cost assessment:

- (a) The GCFR roughened cladding requirement adds an estimated \$70-80 per fuel rod to the GCFR assembly costs.
- (b) The respective grid spacer costs are estimated as follows:
GCFR (modified honeycomb grid) approximately \$500 each, \$4,000 per assembly.
LMFBR (wave beam grid) approximately \$50 each, \$800 per assembly.
- (c) The respective bundle hardware costs for large quantities are estimated as follows:

GCFR approximately \$45,000

LMFBR approximately \$20,000

This difference is primarily a result of the contoured shapes of the GCFR inlet and outlet nozzle assemblies.

- (d) The respective total costs per assembly for large quantities are estimated as follows:

GCFR approximately \$116.5K

LMFBR approximately \$80K

9.2 Recommendations/Cost Reduction Potential

- o RDT Standards have a significant impact on the fabrication cost of assemblies. It is not obvious that all the applicable standards are necessary for production of high quality assemblies. A review and relaxation of some or all of these standards could reduce fabrication costs by as much as 50%. A significant contribution to the increased cost of fabricating fuel assemblies per RDT Standards is due to documentation requirements. For a mature industry, these procedures could be automated or simplified at considerable cost savings. These need to be reviewed from the perspective of both economic and performance impacts.
- o Welded clad tubes could cost significantly less than drawn tubes.
- o A major component of fabrication cost is inspection and record keeping. These areas could be greatly simplified in a commercial facility with resultant cost reductions.
- o Significant savings could result from using welded ducts instead of cast or forged ducts. Welded ducts are used in several countries.
- o Expensive machining of many separate bundle hardware parts could be avoided by utilizing welded parts.
- o Further cost evaluations, particularly for hardware fabrication, should be considered on a design/fabrication sensitivity basis to evaluate potential cost reductions.

10. IMPACT OF FABRICATION COSTS ON GCFR POWER COSTS

Fabrication cost estimates are important in meeting two cost goals for GCFR development: the first, in determining when GCFR power costs will be competitive with other energy technologies; and second, in determining which areas of GCFR fuel and plant development may most profitably be improved to reduce total power costs. Both goals tend to emphasize areas like fabrication where cost improvements make significant improvements to the total cost of power from GCFR's.

A utility choosing between different plants, such as a coal, an LWR or a GCFR plant, weighs many factors in its choice of which plant to build. One relatively important factor in choosing a power plant traditionally has been the total cost of power. Power costs are made up of two parts: fuel and an amortized capital debt, which represents a predictable series of payments for the original plant investment. Each power plant option will have different portions of capital and fuel, and different rates of escalation for fuels and services (see Figure 10-1).

For a capital intensive concept such as a GCFR to be competitive with less capital intensive concepts, such as LWR's and coal plants, GCFR fuel cycle costs must be lower than those of its competitors. The required fuel cycle cost advantage is determined by the additional capital investments needed to construct a GCFR and the cost of fuel to an LWR or coal plant. As a point of comparison the fabrication costs of Section 9 (approximately \$1800/Kg Heavy Metal of core material) will produce GCFR core fabrication charges equivalent to \$50 per pound uranium* in an LWR, to 40 cents per million Btu coal or to \$330 per kilowatt (1979 \$) capital costs.

Fabrication costs also represent both a significant element in the fuel cycle as well as in the total cost of operating a GCFR. The fabrication estimate of Section 9 (approximately \$1800/Kg Heavy Metal of core material) makes fabrication currently about 60% of the fuel cycle cost and about 15% of the total cost of operating a GCFR over its lifetime.

*Conversion, enrichment, fabrication and spent fuel storage not included.

Figure 10-1
Coal, LWR and GCFR Cost Breakdown

APPENDIX

APPENDIX A
REFERENCE FUEL FACTORY ORGANIZATION CHART - 250 Metric Tons/Year

APPENDIX A
REFERENCE FUEL FACTORY ORGANIZATION CHART - 250 Metric Tons/Year

Direct	378
Indirect Exempt	150
Non-Exempt	199
TOTAL	727

PROCESS AND
EQUIPMENT IDENTIFICATION

CONVERSION

- C-1 Liquid Feed Storage and Blending (11)
- C-2 Precipitators (8)
- C-3 Calciners (8)
- C-4 Powder Collectors (8)
- C-5 Batch Reduction and Stabilizing Furnaces (8)
- C-6 Condensate Storage (8)
- C-7 Powder Screening and Can Loading (2)
- C-8 Powder Storage (150 Places)

FUEL PELLET PRODUCTION

- FP-1 Powder Blending (4)
- FP-2 Powder Prepress and Granulation (4)
- FP-3 Pellet Pressing (4)
- FP-4 Pellet Sintering (4)
- FP-5 Pellet Grinding (4)
- FP-6 Pellet Inspection (4)
- FP-7 Pellet Canister Loading
- FP-8 Pellet Storage

FUEL ROD PRODUCTION

- FR-1 Fuel and Blanket Pellet Storage
- FR-2 Rod Storage (Canister)
- FR-3 Rod Loading (4) Fuel Pellets
- FR-4 Rod Loading (4) Blanket Pellets
- FR-5 Hardware Inserts (4)
- FR-6 End Plug Insert and Welding (4)
- FR-7 Helium Leak Check (4)
- FR-8 Rod Canister Unload and Layup (4)
- FR-9 Rod Inspection (4)
- FR-10 Rod Storage Table Transfer (1)
- FR-11 Rod Storage (15,000)
- FR-12 Reject Rod Disassembly and Pellet Salvage (1)

BUNDLE ASSEMBLY

- BA-1 Rod Insertion-Indexing Table (3)
- BA-2 Bundle Assembly-Trim Table (3)
- BA-3 Bundle Inspection (3)
- BA-4 Bundle Wrap-Protective (1)
- BA-5 Bundle Storage-Holdup (29)

BUNDLE STORAGE

- BS-1 Bundle-Assembly Storage (~270)
- BS-2 Bundle-Assembly Protective Cover Removal

WET SCRAP RECOVERY - NITRATE PREPARATION

- NP-1 Hard and Green Scrap Storage (800 Kg)
- NP-2 Powder Unloading and Boat Feet
- NP-3 Oxidation-Furnace (2)
- NP-4 Boat Unload and Screw Feeder (2)
- NP-5 Thermosphon Dissolver and Condensate Receiver (2)
- NP-6 Nitrate Feed Storage Vessels (3)
- NP-7 Nitrate Concentrator-Thermosphon (2)
- NP-8 Acid and Valence Adjust - Feed Storage (6)
- NP-9 Condensate Storage (2)

WET SCRAP RECOVERY - SOLVENT EXTRACTION

- SE-1 Solvent Extraction Columns (4)
- SE-2 (PuH₂) Product Storage (2)
- SE-3 (PuH₂) Product Concentrator-Thermosphon (2)
- SE-4 (PuH₂) Product Concentrate Storage
- SE-5 (U) Product Concentrator-Thermosphon (2)
- SE-6 (U) Product Concentrate Storage (2)
- SE-7 Raw and Saw Waste and Solvent Storage (8)
- SE-8 Liquid Waste and Solvent Waste Storage (9)

WASTE TREATMENT - GAS & LIQUID

- WT-1 Solvent Distillation and Storage (2)
- WT-2 Waste Concentrator (2) and Acid Recovery (2)
- WT-3 Off-Gas Scrubber (2)
- WT-4 Spent Solvent Storage
- WT-5 HCl, H₂S, and Solvent Makeup (8)
- WT-6 Interim Waste Storage (4)
- WT-7 Acid Recovery Storage (4)
- WT-8 Waste Neutralizer (2)
- WT-9 Neutralized Waste Storage
- WT-10 Waste Solidification and Storage

WASTE TREATMENT - SOLID

- WTS-1 Waste Receive and Storage
- WTS-2 Waste Sorting (Combustibles and Non-Combustibles)
- WTS-3 Waste Assay (Combustibles and Non-Combustibles)
- WTS-4 Waste Shredding and Feed Station
- WTS-5 Incinerator (Solid Waste)
- WTS-6 Incinerator (Secondary)
- WTS-7 Incinerator (Solvent)
- WTS-8 Conveyor System
- WTS-9 NDA Assay Station
- WTS-10 Off-Gas Scrubber System
- WTS-11 Non-Combustibles Decon Tanks
- WTS-12 Decon Solution and Waste Storage
- WTS-13 Primary Packaging
- WTS-14 Below Grade Transfer Cart

PROCESS AND EQUIPMENT IDENTIFICATION

- CONVERSION**
- C-1 Liquid Fec Storage and Blending (11)
 - C-2 Precipitators (8)
 - C-3 Calciners (8)
 - C-4 Powder Collectors (8)
 - C-5 Batch Reduction and Stabilizing Furnaces (8)
 - C-6 Condensate Storage (8)
 - C-7 Powder Screening and Can Loading (2)
 - C-8 Powder Storage (150 Places)

- FUEL PELLET PRODUCTION**
- FP-1 Powder Blending (4)
 - FP-2 Powder Prepress and Granulation (4)
 - FP-3 Pellet Pressing (4)
 - FP-4 Pellet Sintering (4)
 - FP-5 Pellet Grinding (4)
 - FP-6 Pellet Inspection (4)
 - FP-7 Pellet Gansitor Loading
 - FP-8 Pellet Storage

- FUEL ROD PRODUCTION**
- FR-1 Fuel and Blanket Pellet Storage
 - FR-2 Rod Storage (Canister)
 - FR-3 Rod Loading (4) Fuel Pellets
 - FR-4 Rod Loading (4) Blanket Pellets
 - FR-5 Hardware Factors (4)
 - FR-6 End Plug Insert and Welding (4)
 - FR-7 Helium Leak Check (4)
 - FR-8 Rod Gansitor Unload and Layup (4)
 - FR-9 Rod Inspection (4)
 - FR-10 Rod Storage Table Transfer (1)
 - FR-11 Rod Storage (15,000)
 - FR-12 Reject Rod Disassembly and Pellet Salvage (1)

- BUNDLE ASSEMBLY**
- BA-1 Rod Insertion-Indexing Table (3)
 - BA-2 Bundle Assembly-Index Table (3)
 - BA-3 Bundle Inspection (3)
 - BA-4 Rod Group-Protective (1)
 - BA-5 Bundle Storage-Holdup (25)

- BUNDLE STORAGE**
- BS-1 Bundle Assembly Storage (~770)
 - BS-2 Bundle Assembly Protective Cover Removal

- WET SCRAP RECOVERY - NITRATE PREPARATION**
- NP-1 Hand and Wagon Scrap Storage (800 Kg)
 - NP-2 Scrap Unloading and Boil Feet
 - NP-3 Oxidation Furnace (2)
 - NP-4 Heat Exchanger and Screw Feeder (2)
 - NP-5 Thermosyphon Dissolver and Condensate Receiver (2)
 - NP-6 Nitrate Feed Storage Vessels (8)
 - NP-7 Nitrate Concentrator-Thermosyphon (2)
 - NP-8 Acid and Valence Adjust - Feed Storage (6)
 - NP-9 Condensate Storage (2)

- WET SCRAP RECOVERY - SOLVENT EXTRACTION**
- SE-1 Solvent Extraction Columns (4)
 - SE-2 (Purified) Product Storage (2)
 - SE-3 (Purified) Product Concentrator-Thermosyphon (2)
 - SE-4 (Purified) Product Concentrate Storage
 - SE-5 (U) Product Concentrator-Thermosyphon (2)
 - SE-6 (U) Product Concentrate Storage (2)
 - SE-7 Raw and Saw Waste and Solvent Storage (8)
 - SE-8 Liquid Waste and Solvent Waste Storage (9)

- WASTE TREATMENT - GAS & LIQUID**
- WT-1 Solvent Distillation and Storage (2)
 - WT-2 Waste Concentrator (2) and Acid Recovery (2)
 - WT-3 Off-gas Scrubber (2)
 - WT-4 Spent Solvent Storage
 - WT-5 HCA, H₂S, and Solvent Makeup (8)
 - WT-6 Interim Waste Storage (6)
 - WT-7 Acid Recovery Storage (4)
 - WT-8 Waste Neutralizer (2)
 - WT-9 Neutralized Waste Storage
 - WT-10 Waste Solidification and Storage

- WASTE TREATMENT - SOLID**
- WTS-1 Waste Receive and Storage
 - WTS-2 Waste Sorting (Combustibles and Non-Combustibles)
 - WTS-3 Waste Shredding (Combustibles and Non-Combustibles)
 - WTS-4 Waste Shredding and Feed Station
 - WTS-5 Incinerator (Solid Waste)
 - WTS-6 Incinerator (Secondary)
 - WTS-7 Incinerator (Solvent)
 - WTS-8 Conveyor System
 - WTS-9 NOA Assay Station
 - WTS-10 Off-gas Scrubber System
 - WTS-11 Non-combustibles Decon Tanks
 - WTS-12 Decon Solution and Waste Storage
 - WTS-13 Primary Packaging
 - WTS-14 Below Grade Transfer Cart

SCALE - 1" = 10'

DESCRIPTION	DATE
APL	