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U-AVLIS Feed Conversion Using Continuous Metallothermic Reduction of UF_4 : System Description and Cost Estimate

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**Robert M. Feinberg
Deputy Associate Director
Laser and Environmental Programs,
Isotope Separation and Advanced
Manufacturing Technology Program**

**LAWRENCE LIVERMORE NATIONAL LABORATORY
University of California • Livermore, California • 94550**

**MARTIN MARIETTA ENERGY SYSTEMS
Oak Ridge, Tennessee • 37831**

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1. Introduction

1.1 Objective

The purpose of this document is to present a system description and develop baseline capital and operating cost estimates for commercial facilities which produce U-Fe feedstock for AVLIS enrichment plants using the continuous fluoride reduction (CFR) process. These costs can then be used together with appropriate economic assumptions to calculate estimated unit costs to the AVLIS plant owner (or utility customer) for such conversion services.

1.2 Cases to be Examined

Six cases are being examined. All cases assume that the conversion services are performed by a private company at a commercial site which has an existing NRC license to possess source material and which has existing uranium processing operations. The cases differ in terms of annual production capacity and whether the new process system is installed in a new building or in an existing building on the site. The six cases are summarized in Table 1 below:

Table 1. Description of Cases

Case No.	Annual Production Capacity, MTU	AVLIS Enrichment Plant Supported	Process Building Assumption
1	1,850	One-line plant	New building
1a	1,850	One-line plant	Existing building retrofit
2	3,300	Two-line plant	New building
2a	3,300	Two-line plant	Existing building retrofit
3	9,900	Six-line plant	New building
3a	9,900	Six-line plant	Existing building retrofit

Costs will first be developed for cases 1, 2, and 3. Then, costs will be developed for cases 1a, 2a, and 3a by making the appropriate adjustments to the costs established for cases 1, 2, and 3, respectively.

2. Design Basis

2.1 Criteria and Assumptions

The following criteria and assumptions are applicable to all cases:

1. Process input Natural assay UF_4 , produced without UF_6 intermediate form, packaged in 55-gallon drums (cases 1 and 2) or 5-ton t-hoppers (case 3).
2. Process output U-Fe rods, 2" x 20", 3 to 4 wt % Fe, packaged in metal feed magazine boxes (96 rods/box)
3. Basic process $\text{UF}_4 + 2\text{Mg} \rightarrow \text{U} + 2\text{MgF}_2$; process temperature is 950-1060°C; diluent salt (NaCl assumed) added to maintain byproduct salt in molten form for continuous salt withdrawal; Fe alloyed with U in reactor, permitting continuous molten metal withdrawal; design reaction rate = 2.5gU/cm²/min.
4. Casting Assume continuous or semi-continuous casting in re-usable molds (metal or refractory) or in steel tube sleeves; specifics of casting technique are to be determined.
5. Salt disposition Assume that no post-reduction salt treatment is required or that simple in-line post-reduction treatment is employed as required to achieve a uranium content which meets current NRC exemptions granted to metal producers (<35 x 10⁻¹² Ci/g or <50 ppm for natural uranium); salt is disposed of as non-low level waste (LLW), using commercial disposal service; salt is transported in bulk form.
6. System design capacity Instantaneous (or design) throughput capacity is 1.5 times the required annual capacity (or average capacity); assume that system operates round-the-clock and year-round, at an overall on-stream availability factor of 0.66.
7. Licensing Assume that implementation of process requires plant owner to submit to NRC a request for license amendment, although it is not clear that a license amendment would be necessary.
8. Cost basis Costs are to be developed in current (FY93) dollars; use Work Breakdown Structure (WBS) for feed conversion system in *U-AVLIS Production Plant Conceptual Design Report (CDR)*, (LP-91-142) as framework for developing capital costs, using comparable costs from CDR cost estimate (Appendix E, Book 5) with adjustments and scaling applied as appropriate; use escalation factor of 1.052 to convert CDR costs to current dollars.

2.2 Material Quantities and Selected Process Parameters

Basic material quantities for primary process materials are presented in Table 2 for cases 1, 2, and 3. Quantities are based on stoichiometry, which is expected to approximate the actual situation due to the continuous nature of the process. Table 3 then presents some additional process parameters that are useful in estimating equipment, building space, and operating labor requirements.

Table 2. Material Quantities

Process Material	Unit Mass Quantity (kg/kgU)	Annual Mass Quantity (kg)			Density (g/cc)		Approx. Annual Bulk Volume (ft3)		
Inputs:		Case 1	Case 2	Case 3	Theo- retical	Assume Bulk	Case 1	Case 2	Case 3
U	1.00	1.9 x 10 ⁶	3.3 x 10 ⁶	9.9 x 10 ⁶	19	—	—	--	--
UF ₄	1.32	2.4 x 10 ⁶	4.4 x 10 ⁶	13.1 x10 ⁶	6.7	4.4	1.9 x 10 ⁴	3.5 x 10 ⁴	1.1 x 10 ⁵
Mg	0.20	3.7 x 10 ⁵	6.6 x 10 ⁵	2.0 x 10 ⁶	1.7	1.2	1.1 x 10 ⁴	1.9 x 10 ⁴	5.9 x 10 ⁴
Fe	0.04	7.6 x 10 ⁴	1.3 x 10 ⁵	4.0 x 10 ⁵	7.8	5.2	5.2 x 10 ²	8.8 x 10 ²	2.7 x 10 ³
NaCl	0.50	9.3 x 10 ⁵	1.7 x 10 ⁶	5.0 x 10 ⁶	2.2	1.4	2.3 x 10 ⁴	4.3 x 10 ⁴	1.3 x 10 ⁵
Outputs:									
U + Fe	1.04	1.9 x 10 ⁶	3.4 x 10 ⁶	1.0 x 10 ⁷	~18	~18	4.0 x 10 ³	6.7 x 10 ³	2.0 x 10 ⁴
MgF ₂	0.52	9.6 x 10 ⁵	1.7 x 10 ⁶	5.1 x 10 ⁶	3.0	—	—	--	--
NaCl	0.50	9.3 x 10 ⁵	1.7 x 10 ⁶	5.0 x 10 ⁶	2.2	—	—	--	--
MgF ₂ + NaCl	1.02	1.9 x 10 ⁶	3.4 x 10 ⁶	1.0 x 10 ⁷	2.6	1.6	4.4 x 10 ⁴	7.5 x 10 ⁴	2.2 x 10 ⁵

Table 3. Selected Process Parameters

Process Parameter	Case 1	Case 2	Case 3
System design capacity (kgU/y)	2.8×10^6	5.0×10^6	1.5×10^7
System design capacity (kgU/d)	7,600	14,000	41,000
System average capacity (kgU/d)	5,100	9,000	27,000
System design capacity (kgU/h)	320	570	1,700
System average capacity (kgU/h)	210	380	1,100
Avg. no. UF ₄ containers/wk (750 kg/55-gallon drum 4500 kg/t-hopper)	60	110	60
Avg. no. Mg drums/wk (200kgMg/55-gallon drum)	35	65	190
Blended feed volume (design basis) (liters/h)	260	470	1,400
No. & size of reactors (diameter in inches)	1 x 20	1 x 28	1 x 48
No. alloy rods cast/h (design basis)	18	32	96
Avg. no. feed rod magazines/wk (96 rods/mag)	21	38	110
Avg. no. salt shipments/wk (in/out) (5 cubic yards per bulk box)	3/6	6/11	18/32

2.3 Basic Process Facility Functions

Figure 1 presents the basic functions that must be performed in the process facility.

Figure 1. Basic Process Facility Functions

3. Scope of Work for Capital Improvements (Cases 1, 2, and 3)

The WBS established for the Feed Conversion System in the CDR has been used as a framework for capital cost estimate preparation. Since a different (but similar) process is now being examined, the scope of work in each WBS element has been adjusted accordingly. See Volume 5 of the CDR for a scope description of each original WBS element in WBS 1.3, Feed Conversion System. Additional pertinent WBS elements are WBS 1.6.2, Feed System Controls (see CDR Volume 7) and WBS 1.7, Plant Support System (see Volume 10). The general scope of work in each WBS element for cases 1, 2, and 3 is summarized in the following sections.

3.1 Feed Buildings (WBS 1.3.1)

WBS 1.3.1.1 Feed Conversion Building

The new building is constructed with necessary high efficiency ventilation/filtration systems to assure radiological protection of workers and to maintain radiological emissions as low as reasonably achievable. The building is steel-framed, with metal siding and a metal roof, built on a concrete slab which utilizes spread footings. Basic plan and elevation views for the new building to support Case 1 are presented in Figures 2, 3 and 4. The layouts are not optimized and have been prepared for the purpose of defining building cross sectional size and gross floor space needed for process and process support functions.

Figure 2. First floor plan view

Figure 3. Second floor plan view

Figure 4. Elevation section A-A

Table 4 summarizes the process and process support areas that are associated with various functions in the Case 1 building shown in the previous figures and then lists the corresponding areas judged to be required for those functions for Cases 2 and 3. No specific facility layouts were prepared for Cases 2 and 3.

Table 4. Floor Space Required for Various Facility Functions

Function	Floor Area, ft ²		
	Case 1	Case 2	Case 3
Feed unloading and blending ¹	900	1,200	2,400
Metal reduction and casting ¹	900	1,200	1,500
Salt processing & rod inspection ¹	900	1,200	2,100
Material receiving, storage, shipment ²	1,800	2,400	5,100
Change rooms, offices, control area ²	1,100	1,100	2,000
Analytical laboratory ¹	400	400	800
Maintenance and refurbishment ¹	1,200	1,500	2,400
Mechanical, HVAC, & electrical ²	2,700	2,700	5,200
Total category 1 area	4,300	5,500	9,200
Total category 2 area	5,600	6,200	12,300
Total building area	9,900	11,700	21,500

Note: Category 1 areas are those where airborne uranium particulates are possible, requiring higher cost ventilation and filtration services as well as other more costly building support services.

Category 2 areas are those requiring only conventional industrial building services.

Scope of WBS 1.3.1.1 includes building foundation and structure, HVAC and HEPA systems, conventional building electrical and mechanical systems (but not process utilities), all interior and exterior architectural treatments, air sampling system for radiological surveillance, building communications systems, security systems, and fire protection systems.

WBS 1.3.1.2 Magnesium Chloride Building
No required scope in this WBS element.

3.2 Feed Chemical Systems (WBS 1.3.2)

WBS 1.3.2.1 Oxide Pretreatment (Feed Unloading and Blending)

The CFR process has no UO₃ reduction equipment as in the CDR Feed System, but this WBS element is the proper place for feed unloading and blending equipment. This includes unloading equipment for drums, t-hoppers, and/or bulk boxes; storage hoppers for UF₄, Fe, and Mg streams; conveying equipment; in-line sampling equipment; and automatic weigh feed systems. These streams feed into a solids mixing system, which feeds directly into the metallothermic reactor (no mixed feed storage is provided). If feed supply to the reactor is curtailed, the reactor will automatically go into standby mode. Also

required are process enclosures surrounding portions of system where airborne uranium particulates may be generated. All cases employ a single feed blending line, with spare units (e.g., weigh feed systems, mixer) purchased under startup costs to permit off-line unit repair. Local instrumentation is included.

To recycle scrap uranium/iron metal, this WBS element also includes a size reduction unit and a sized scrap storage hopper which feeds into the blended feed line for introduction of the scrap back into the reactor and caster.

WBS 1.3.2.2 Chlorination System

No required scope in this WBS element.

WBS 1.3.2.3 UCl₄ Recovery System

No required scope in this WBS element.

WBS 1.3.2.4 Metal Reduction

This WBS element includes the metallothermic reduction reactor system, automatic weigh feed system and feed line for blended feed stream, metal and salt withdrawal piping (local to reactor), power and cooling water hookups, and local instrumentation and controls. Reactor system is similar in design to UCl₄ reduction reactor system design in the CDR. Reactor system consists of inner reactor vessel made of refractory material (inner diameter of reactor vessel given for each case in Table 2), electric heater system, insulating layer of refractory brick, and water-cooled outer steel containment vessel. Entire unit is capable of being moved on rollers from operating location to refurbishment area for inner vessel replacement as required. Reactor process and support service connections (feed, salt withdrawal, metal withdrawal, power, water, buffer gas supply/exhaust, and controls) are designed for routine connection and disconnection during each reactor change-out cycle. WBS 1.3.2.4 also includes permanently installed heated vessel into which molten salt is dumped prior to change-out and from which molten salt is removed to recharge new reactor. The reactor operates at ambient pressure.

WBS 1.3.2.5 Feed Off-Gas Treatment System

CFR process has no process off-gas except for (1) buffer air for process equipment enclosures, and (2) a low volume flow of inert gas (e.g., argon) exhausted from reactor unit. For item 1, process enclosures are costed with process equipment. Ductwork, fans, HEPA filters and controls are costed with building. For item 2, cost of local filters and roof exhaust is costed with reactor system. Thus, there is no required scope in this WBS element.

3.3 Feed Casting Systems (WBS 1.3.3)

WBS 1.3.3.1 Casting System

Details of rod casting technique are to be determined. For cost estimation purposes, a casting system essentially the same as that described in the CDR has been assumed. This is a continuous casting system utilizing a plasma torch metal re-heat system. Casting system is assumed to be a turn-key system purchased from a vendor who has experience in designing and manufacturing such systems. This WBS element also includes molten metal transfer line from reactor area and equipment and hoods for withdrawal of finished rods from caster and for their inspection, packaging, and indoor transport.

WBS 1.3.3.2 Material Handling Systems

Included in WBS 1.3.3.1 above. No scope here.

3.4 Feed Support Systems (WBS 1.3.4)

WBS 1.3.4.1 Feed Receiving and Storage (and Product Shipping)

This WBS element includes two accountability scales, fork trucks required for dock operations and material movements, large capacity fork truck for salt container unloading and loading, computer system and hardware for materials inventory control and nuclear material accountability, and miscellaneous shipping/receiving items. Containers owned by facility owner are costed under start-up category, not in this WBS element.

WBS 1.3.4.2 $MgCl_2$ Electrolysis (By-Product Salt Granulation and Handling)

The major systems needed for electrolysis of $MgCl_2$ for the chloride-based metal production process in the CDR are not required for the CFR Process, which does not recycle its by-product salt. However, included here is the equipment for salt solidification and granulation, the molten salt transfer line from the reactor area to the granulator, automated in-line sampling and nondestructive assay equipment to verify that uranium content in the salt is below the prescribed limit for uncontrolled use or conventional disposal, and conveying equipment to load salt into bulk containers on the pad outside the building and adjacent to the granulator area. Design basis (1.5 x avg.) flow rates are 340 kg salt/hr, 600 kg salt/hr, and 1,800 kg salt/hr for cases 1, 2, and 3, respectively.

WBS 1.3.4.3 Chlorine Recycle

No required scope in this WBS element.

WBS 1.3.4.4 Feed Process Utilities

Process utility requirements include electrical power, cooling water (no chilled water required), compressed air, and buffer gas supply (nitrogen and/or argon). Electrical power enters building as 480v, 60hz, 3-phase power. Cooling water enters building at design (maximum) temperature of 87° F, from cooling tower on site. Electrical power supply to building boundary and cooling water supply and return beyond building boundary is covered in WBS 1.7.2. Included in WBS 1.3.4.4 are requirements for distribution of these utilities to process equipment. Tower cooling water is used directly for process equipment cooling (no water-to-water heat exchangers). Principal cooling water users are reactor shell, salt granulator, and caster system. Table 5 presents estimated electrical power and cooling water requirements for the various cases. Included here for air and buffer gas are requirements for both supply and distribution.

Table 5. Process Utility Requirements

Process Requirement	Case 1	Case 2	Case 3
Connected electrical load, kW	600	850	1,900
Avg. electrical load, kW	360	500	1,100
Design cooling water flow, gpm	300	450	1,050

WBS 1.3.4.5 Laboratory Equipment

Laboratory will have equipment and capabilities for subsampling process samples and samples of incoming and outgoing materials (UF_4 , metal alloy, byproduct salt, etc.). Titration units are provided, along with analytical equipment for impurity analyses. No isotopic analysis capability is assumed to be required. Outside commercial labs (including AVLIS plant lab) are used as required. Measurement requirements to support nuclear

material accountability are assumed to be of the same level of precision now practiced by source material licensees, with uranium element and ^{235}U isotope quantities in incoming and outgoing containers documented to the nearest kilogram. Sampling requirements for U-Fe alloy product during casting process will be established to provide representative samples to support the more precise nuclear material accounting practices required for the AVLIS plant feed stream, but analyses to support these needs will not be performed by the feed converter (samples will be made available for analysis by others).

Also included in this WBS is health physics instrumentation needed to support the facility's radiological protection and contamination control programs.

WBS 1.3.4.6 Maintenance Equipment

Included in this WBS element are standard basic maintenance equipment as well as more specialized equipment to support reactor and caster refurbishment.

3.5 Feed Control System (WBS 1.6.2)

WBS 1.6.2 Feed Control System

This WBS covers the supervisory control system for the feed preparation, reduction, casting, salt processing, and process utility functions. The system is based on vendor supply of a standard supervisory control package (hardware, software, and control area panels). The system includes vendor engineering and adaptive programming.

3.6 Plant Support System (WBS 1.7)

WBS 1.7.1 Land Improvements

The facility site is assumed to be flat and ready for construction. Minimal rough grading, final grading, seeding, and landscaping is required. Pavements for access road, dock area, salt container storage pads, outdoor storage pads, and truck/car parking are provided. Also included here are storm drainage, fencing, and lighting additions to existing site systems.

WBS 1.7.2 Outside Utilities

This WBS element provides the site improvements required to supply the following services to the building boundary: electrical power, natural gas (for building space heating), cooling water, potable water, and sanitary sewer. For electrical power, gas, potable water, and sewer, it is assumed that existing on-site services can be extended a modest distance (average of 200-300 feet). For cooling water, a small cooling tower of standard design is assumed.

WBS 1.7.3 Waste Management Facilities

No required scope. Commercial waste management services are utilized. Storage pads for waste containers are included in WBS 1.7.1.

WBS 1.7.4/1.7.5 Direct and Indirect Support Facilities

Needed administrative and support facilities are assumed to exist already at the site. However, included here are requirements for environmental monitoring equipment. Specifics of this are to be determined.

4. Costs for Capital Improvements

4.1 Procurement and Construction Costs

Table 6 presents estimated procurement and construction costs for the capital improvements identified in the preceding scope descriptions for each WBS element. The costs in the table do not include engineering costs; these are added in Section 4.2. WBS elements without an identified scope are not shown on the table.

In many cases, comparable costs from the CDR cost estimate (Appendix E, Book 5) are used, with adjustments and scaling applied as appropriate. Footnote information explaining the basis used to develop selected costs is provided following the table. All costs are presented in current dollars (FY93\$). Escalation between CDR costs (91\$) and current costs has been taken into account (~5%).

Table 6. Procurement and Construction Costs for Capital Improvements

WBS Element	Estimated Procurement/Construction Cost (\$K)		
	Case 1	Case 2	Case 3
1.3.1 Feed buildings			
1.3.1.1 Feed conversion building ¹	2,620	3,230	5,650
1.3.2 Feed chemical systems			
1.3.2.1 Oxide pretreatment ² (Feed unloading and blending)	1,000	1,100	1,990
1.3.2.4 Metal reduction ³	1,130	1,380	1,680
1.3.3 Feed casting systems			
1.3.3.1 Casting system ⁴	2,450	3,300	4,680
1.3.4 Feed support systems			
1.3.4.1 Feed receiving & storage (and product storage)	260	260	400
1.3.4.2 MgCl ₂ electrolysis (salt granulation and handling)	700	800	1,300
1.3.4.4 Feed process utilities ⁵	760	1,000	1,520
1.3.4.5 Laboratory equipment	500	500	800
1.3.4.6 Maintenance equipment	180	180	300
1.6 Control systems			
1.6.2 Feed control system	450	450	550
Process systems subtotal (WBS 1.3.2 - 1.6.2)	7,430	8,970	13,220
1.7 Plant support system			
1.7.1 Land improvements	370	400	630
1.7.2 Outside utilities ⁶	400	570	1,100
1.7.4 Direct support facilities (environmental monitoring equipment)	250	250	250
Plant support system subtotal	1,020	1,220	1,980
Total estimated procurement and construction cost	11,070	13,420	20,850

Footnotes to Table 6 -- Basis for selected costs

- Building costs are based on unit costs of \$440/ft² for Category 1 areas and \$130/ft² for Category 2 areas (see Table 4). These unit costs are the same as those used by Westinghouse Corporation in development of capital improvement costs at their Columbia facility. Use of these unit costs for building construction results in average unit costs of \$265 to \$275/ft² for the overall buildings required in cases 1, 2, and 3. The fact that engineering design costs and contingency allowances are applied later in capital cost development was taken into account in the use of the Westinghouse unit costs.

2. Costs for feed unloading and blending equipment for the three cases are based on the following breakdown:

	Case 1 (\$K)	Case 2 (\$K)	Case 3 (\$K)
Drum unloading equipment	\$60	\$60	\$60
T-hopper unloading equipment	0	0	50
Supply hoppers	80	120	280
Conveying equipment & valves	160	160	280
Scrap alloy size reduction unit	20	20	20
Solids sampling systems	40	40	60
Automatic weigh feed systems	100	120	180
Solids mixer	30	40	60
Process enclosures	100	100	250
Misc. piping and materials to install	70	70	160
Labor to install	220	250	440
Instrumentation/controls	<u>120</u>	<u>120</u>	<u>150</u>
Total	<u>\$1,000</u>	<u>\$1,100</u>	<u>\$1,990</u>

3. Costs for metal reduction for case 3 are the same as those in the CDR for metal reduction except several items not required here were removed (UCL₄ surge hopper, MgCl₂ transport carts, Mg and Fe feed hoppers). For cases 1 and 2, all the same items are required, only smaller. Labor costs and costs for instrumentation and miscellaneous materials were left unchanged. Costs for major hardware items were scaled as follows (costs for items for cases 1 and 2 are presented as percentages of case 3 costs):

	Case 3 Costs (K)	Case 1 (%)	Case 2 (%)
Reactor Unit	\$730	60%	80%
Automatic weigh feeder	120	50%	70%
Liquid salt catch pot	170	35%	60%
Process enclosures	230	60%	80%

4. Costs for casting system for the three cases are based on the following breakdown:

	Case 1 (K)	Case 2 (K)	Case 3 (K)
Vendor supplied caster system	\$2,100	\$2,900	\$4,100
Heat traced molten alloy line	50	50	60
Rod withdrawal and loading equipment	100	130	200
Ventilated hood for rod inspection	30	30	50
Miscellaneous equipment	70	70	100
Labor to install	<u>100</u>	<u>120</u>	<u>170</u>
Total	<u>\$2,450</u>	<u>\$3,300</u>	<u>\$4,680</u>

5. Costs for process utilities for case 3 are based directly on costs in the CDR, excluding those utilities which are not applicable (MgCl₂ electrolysis DC power supply and bus distribution, CO supply, chilled water system, steam supply, and safety class power system). Costs for cases 1 and 2 are scaled versions of the remaining Case 3 costs.
6. Process utility requirements shown in Table 5 were added to estimated building requirements to establish total facility utility needs.

4.2 Engineering, Project Support, and Contingency Costs

Table 7 summarizes procurement and construction costs and adds to them costs for engineering, project management, licensing and regulatory permits, and contingency allowance. Total capital costs are shown in the table.

Table 7. Development of Total Capital Costs

Category	Case 1 (K)	Case 2 (K)	Case 3 (K)
Building construction cost	\$2,620	\$3,230	\$5,650
Engineering for bldg. (18% of bldg. costs)	470	580	1,020
Process system costs	7,430	8,970	13,220
Engineering for process system (28%)	2,080	2,510	3,700
Plant support system costs	1,020	1,220	1,980
Engineering for plant support system (12%)	120	150	240
Project management costs (@ \$100K/MY)			
Project administration	300	300	400
Construction management	400	400	600
License amendment preparation/NRC fees*	200	200	200
Other regulatory permit costs	100	100	100
Subtotal of all above costs	14,740	17,660	27,110
Contingency allowance (20%)	2,950	3,530	5,420
Total capital cost	<u>\$17,690</u>	<u>\$21,190</u>	<u>\$32,530</u>

* Preliminary information from domestic metal producers indicates that amending their source material licenses to permit implementation of this process will be a minor activity involving substantially lower costs than included here.

5. Annual Operating Costs

Steady-state annual operating costs for Cases 1, 2, and 3 include the following cost categories:

1. Labor
2. Materials
3. Power & Utilities
4. Waste Disposal and Other Contract Services
5. Annual NRC Fees
6. Decommissioning Escrow Costs

Annual operating costs are developed in current dollars. Rates for labor include direct wages, payroll taxes, and wage benefits. Except where noted, rates for labor and services are the same as those used in *U-AVLIS Single-Separator-Line Plant Design Study* (LP-93-082, May 1993).

5.1 Labor

Labor is subdivided into direct labor, indirect labor, and front-office support. Table 8 summarizes labor requirements and costs for Cases 1, 2, and 3. Shift coverage factors have been applied to convert positions filled on a given number of shifts to payroll units (full-time equivalents or FTE's). For example, 5.3 FTE's are required to provide continuous year-round coverage (21 shifts/wk) for one position. Some positions have been judged to require less than continuous coverage and a modified factor has been applied. Also, the anticipated need for overtime labor is included in the factor used for each category. Front-office support is based on a "best-guess" pro-rating of overall site/company "overhead" labor requirements.

Table 8. Operating Labor Requirements

Table of Operating Labor Requirements										
		Case 1			Case 2			Case 3		
FUNCTION	Type of Labor*	No. Pos.	Shifts per Week	FTE's	No. Pos.	Shifts per week	FTE's	No. Pos.	Shifts per week	FTE's
Direct labor										
Receiving/shipping/warehouse	H	2	5	2.5	3	5	3.8	1 3	21 5	5.3 3.8
Feed prep, reduction, salt proc.	H	2	21	10.6	2	21	10.6	2	21	10.6
Casting, rod inspection	H	2	21	10.6	3	21	15.9	5	21	26.5
Reactor & caster refurbishment	H	2	5	2.5	2	5	2.5	3	5	3.8
Shift supervisors	M	1	21	5.3	1	21	5.3	1	21	5.3
Facility Manager	M	1	5	1.0	1	5	1.0	1	5	1.0
Clerical support	W ₁	1	5	1.3	1	5	1.3	1	5	1.3
Indirect labor										
Mechanical maintenance	H	1	5	1.3	1	5	1.3	2	5	2.0
Electrical maintenance	H	1	5	1.3	1	5	1.3	1	5	1.3
Instrument maintenance	H	1	5	1.0	1	5	1.0	1	5	1.3
Laboratory/health physics	M	1	5	1.0	1	5	1.0	1	5	1.0
	W ₂	1	21	5.3	2	21	10.6	3	21	15.9
Facility engineer	M	1	5	1.3	1	5	1.3	1	5	1.3
Front-Office Support										
Finance/purchasing	M	1	5	1.0	1	5	1.0	1	5	1.0
	W ₁	1	5	1.0	1	5	1.0	1	5	1.0
Human resources	M	0.5	5	0.5	0.8	5	0.8	1	5	1.0
Technical support	M	1	5	1.0	1	5	1.0	1	5	1.0
Marketing/customer affairs	M	0.5	5	0.5	0.8	5	0.8	1	5	1.0
Regulatory affairs/NMC&A	M	0.5	5	0.5	0.8	5	0.8	1	5	1.0
	W ₁	0.5	5	0.5	0.8	5	0.8	1	5	1.0
Security	H	0.5	21	2.7	0.5	21	2.7	0.5	21	2.7
TOTAL FTE's		H=32.5 W ₂ =5.3 W ₁ =2.8 M=12.1			H=40.6 W ₂ =10.6 W ₁ =3.1 M=13.0			H=57.3 W ₂ =15.9 W ₁ =3.3 M=13.6		

- * H = hourly
W₁ = weekly (non-technical)
W₂ = weekly (technical)
M = monthly

Labor costs are based on annual wage rates (including wage benefits and payroll taxes) of \$55K for monthly employees, \$26K for weekly (non-technical) employees, \$37K for weekly (technical) employees, and \$43K for hourly employees. Using these rates and the labor requirements in Table 8, annual labor costs are as follows:

$$\text{Case 1: } (12.1 \times \$55K) + (2.8 \times \$26K) + (5.3 \times \$37K) + (32.5 \times \$43K) = \underline{\$2,330K}$$

$$\text{Case 2: } (40.6 \times \$55K) + (3.1 \times \$26K) + (10.6 \times \$37K) + (13.0 \times \$43K) = \underline{\$3,260K}$$

$$\text{Case 3: } (57.3 \times \$55K) + (3.3 \times \$26K) + (15.9 \times \$37K) + (13.6 \times \$43K) = \underline{\$4,410K}$$

5.2 Materials

Feed Chemical Costs

Uranium:

Assume that UF_4 is provided to metal converter on a "toll" basis. That is, UF_4 feedstock is supplied by others (utility company or AVLIS plant owner) with sufficient lead time for performance of conversion tasks. Thus, there is no cost for uranium feedstock.

Mg, NaCl, and Fe:

Table 9 presents unit costs for delivered Mg, NaCl, and Fe. Based on annual quantities given in Table 2, the table also presents annual costs for these feed chemicals.

Table 9. Costs for Non-Uranium Feed Materials

Chemical	Unit cost (\$/kg)	Annual Costs (\$K)		
		Case 1	Case 2	Case 3
Magnesium	4.07	\$1,506	\$2,686	\$8,140
NaCl	0.07	65	119	357
Iron	1.00	76	130	400
TOTAL	--	<u>\$1,647</u>	<u>\$2,935</u>	<u>\$8,897</u>

Miscellaneous Materials, Supplies, and Equipment Replacement/Refurbishment:

	Case 1 (K)	Case 2 (K)	Case 3 (K)
Supplies @ 10% of labor costs	\$244	\$341	\$455
Equipment replacement/refurbishment @ 3% of capital costs	530	636	975
Subtotal	774	977	1,430
Feed materials (from Table 9)	1,647	2,935	8,897
Total annual materials cost	<u>\$2,421</u>	<u>\$3,912</u>	<u>\$10,327</u>

5.3 Power and Utilities

Average process electrical power loads are given in Table 5. In addition to these, there will be estimated average building power loads of 300kW, 350kW, and 650kW for cases 1, 2, and 3, respectively. A power cost of \$50/MW-hr is assumed. This is higher than the rate used in the *U-AVLIS Single-Separator-Line Plant Design Study* and is judged to be the industrial rate that a metal conversion facility would be required to pay. Annual power costs are calculated as follows:

$$\text{Case 1 -- } (300 + 360) \times 8,760 \times 50 \times 10^{-3} = \$289K/\text{yr}$$

$$\text{Case 2 -- } (350 + 500) \times 8,760 \times 50 \times 10^{-3} = \$372K/\text{yr}$$

$$\text{Case 3 -- } (650 + 1,100) \times 8,760 \times 50 \times 10^{-3} = \$767K/\text{yr}$$

Annual costs for other utilities (gas, water, sewer, and nitrogen) are estimated to be \$70K, \$90K, and \$150K respectively for cases 1, 2, and 3. Thus, total annual costs for power and utilities are as follows:

$$\text{Case 1 -- } 289 + 70 = \$359K/\text{yr}$$

$$\text{Case 2 -- } 372 + 90 = \$462K/\text{yr}$$

$$\text{Case 3 -- } 767 + 150 = \$917K/\text{yr}$$

5.4 Waste Disposal and Other Contract Services

By-product salt is assumed to have uranium content below the level established by NRC or agreement states for uncontrolled use or disposal. By-product salt is loaded directly into bulk containers that are 5 ft x 8 ft x 4 ft and which will hold about 5 cubic yards of salt. Final disposition of salt is TBD. Alternate uses are quite possible, or disposal contractor could separate NaCl from MgF_2 by water leaching, with MgF_2 landfilled and NaCl sold back to conversion facility. Cost for disposal contractor is assumed to be \$3.00/ft². Using annual volumes in Table 2, annual costs for salt disposal are:

$$\text{Case 1 -- } 4.4 \times 10^4 \times \$3 = \$132\text{K/yr}$$

$$\text{Case 2 -- } 7.5 \times 10^4 \times \$3 = \$225\text{K/yr}$$

$$\text{Case 3 -- } 2.2 \times 10^5 \times \$3 = \$660\text{K/yr}$$

Low level radioactive wastes (LLW) will include casting scrap that cannot be recycled through the process, reactor refurbishment materials, filters, lab wastes, and miscellaneous compactible wastes (paper, plastic, gloves, etc.) from routine operations. Based on scaling of values developed for the feed conversion facility in the CDR (Table 8-4 in Volume 11), the following LLW generation rates are assumed (55-gallon drums per month):

	Case 1	Case 2	Case 3
Non-compactible wastes	8	10	25
Compactible filters, paper, plastic, etc.	12	15	20
Liquid wastes from lab, etc.	6	10	25

Waste is picked up by a commercial disposal firm. Transportation, handling, and compaction of compactible waste (10 to 1 compaction ratio) is provided for \$250/drum. Disposal cost is in addition to this at \$350/ft². Treatment cost for liquid waste is \$5/gal. Total costs per drum are:

$$\text{Non-compactible wastes -- } \$250 + (\$350/\text{ft}^3 \times 7.3 \text{ ft}^3) = \$2,805/\text{drum}$$

$$\text{Compactible wastes -- } \$250 + (\$350/\text{ft}^3 \times 7.3 \text{ ft}^3 \times 0.1) = \$505/\text{drum}$$

$$\text{Liquid wastes -- } \$250 + (55 \text{ gal} \times \$5/\text{gal}) = \$525/\text{drum}$$

Based on these unit costs per drum, LLW disposal costs for the three cases are:

$$\text{Case 1 -- } [(8 \times \$2,805) + (12 \times \$505) + (6 \times \$525)] \times 12 = \$380,000/\text{yr.}$$

$$\text{Case 2 -- } [(10 \times \$2,805) + (15 \times \$505) + (10 \times \$525)] \times 12 = \$491,000/\text{yr}$$

$$\text{Case 3 -- } [25 \times \$2,805) + (20 \times \$505) + (25 \times \$525)] \times 12 = \$1,120,000/\text{yr}$$

No significant amounts of hazardous or mixed hazardous/radioactive wastes will be generated. Costs for disposal of small quantities of hazardous wastes and for disposal of conventional solid wastes (garbage) by commercial disposal firms are estimated to be \$10K, \$15K, and \$25K for Cases 1, 2, and 3.

In addition to waste disposal, other contracted services will include laundry, custodial, garage, maintenance shop services, radiological dosimetry support, equipment calibrations/certifications, and maintenance contracts. Using the costs for these types of services estimated in the *U-AVLIS Single-Separator-Line Plant Design Study*, the estimated annual costs for this group of services are \$250K, \$300K, and \$500K for cases 1, 2, and 3, respectively.

Total annual costs for waste disposal and other contract services are tallied below:

	Case 1 (K)	Case 2 (K)	Case 3 (K)
Salt disposal	\$132	\$225	\$660
LLW disposal	380	491	1,120
Hazardous/conventional waste disposal	10	15	25
Other contract services	<u>250</u>	<u>300</u>	<u>500</u>
TOTAL	<u>\$772</u>	<u>\$1,031</u>	<u>\$2,305</u>

5.5 Annual NRC Fees

For all cases, it is assumed that the annual NRC costs for licensing fees, inspections, license amendment reviews, etc. for the overall licensed site are 65% of those for the Allied-Signal Metropolis site (65% of \$350K/yr) and that the AVLIS feed conversion facility is charged half of these overall costs. This totals \$114K/yr.

5.6 Decommissioning Escrow Costs

An assumption is made that a decommissioning escrow fund must be established with an annual contribution made from facility operating funds. Further assumptions are that total fund requirements are equal to 50% of facility operating costs. These are accumulated over a 30 year period, using a straight-line calculation. Thus, using costs from Table 7, annual decommissioning escrow costs are \$290K, \$350K, and \$540K for Cases 1, 2, and 3, respectively.

5.7 Summary of Annual Operating Costs

Table 10 presents a summary of annual operating costs for cases 1, 2, and 3.

Table 10. Annual Operating Cost Summary

Cost Category	Case 1 (K)	Case 2 (K)	Case 3 (K)
Labor	\$2,330	\$3,260	\$4,410
Materials	2,421	3,912	10,327
Power and utilities	359	462	917
Waste disposal/services	772	1,031	2,305
NRC fees	114	114	114
Decommissionary fund	<u>290</u>	<u>350</u>	<u>540</u>
Total annual operating costs	<u>\$6,286</u>	<u>\$9,129</u>	<u>\$18,613</u>

6. One-Time Costs for Facility Start-Up

Key categories for one-time facility start-up costs are:

1. Operating procedures and plans
2. Manpower staffing and training
3. Spare equipment and stores items
4. Facility start-up

Some of these costs would likely be determined to be capitalized. Their placement in capital costs vs. start-up costs would have no effect on the results of this cost study.

6.1 Operating Procedures and Plans

For all cases, it is assumed that one facility engineer and one technical writer are required for 24 months to prepare facility procedures. Costs for this category are:

$$4 \text{ man-years} \times \$55\text{K/man-year} = \$220\text{K}$$

6.2 Manpower Staffing and Training

It is assumed for all cases that two months of total labor costs are incurred to bring new staff onto the payroll and to adequately train these employees so that facility start-up activities can commence. Costs for this category are:

$$\begin{aligned} \text{Case 1 -- } & \$2,330\text{K} \times 2/12 = \$388\text{K} \\ \text{Case 2 -- } & \$3,260\text{K} \times 2/12 = \$543\text{K} \\ \text{Case 3 -- } & \$4,410\text{K} \times 2/12 = \$735\text{K} \end{aligned}$$

6.3 Spare Equipment and Stores Items

A complete spare reactor unit will be purchased as a line replacement unit. This provides a second reactor for off-line refurbishment. Also, spare subsystems for the caster system will be purchased for similar purpose. These are assumed to be 30% of the caster system procurement cost. In addition to these two items, miscellaneous initial spares and stores items will be purchased equal to one year's estimated costs for supplies and replacement equipment (see Section 5.2), and a two-week supply of feed materials (from Table 9) will be purchased as an initial supply. Those costs are summarized in the following table.

Table 11. Costs for Initial Complement of Spare Equipment and Stores Items

Spares/Stores Item	Case 1 (K)	Case 2 (K)	Case 3 (K)
Spare reactor unit	\$440	\$580	\$730
Caster spares	630	870	1,230
Misc. spares/stores	530	636	975
Initial feed materials	63	113	342
TOTAL	\$1,663	\$2,199	\$3,277

6.4 Facility Start-Up

It is assumed that a one-month period will be required for system checkout and startup at full operating costs. It is also assumed that system output averages only 75% of steady-state output (50% of the design throughput rate) over the first 6 months of operation. This is equivalent to an extra one-time cost equal to 1.5 months of full operating cost. Using annual operating costs from Table 10, the facility start-up costs are:

$$\begin{aligned}\text{Case 1 -- } & (1 \text{ month} + 1.5 \text{ month}) \times \$6,286\text{K} + 12 = \$1,309\text{K} \\ \text{Case 2 -- } & (1 \text{ month} + 1.5 \text{ month}) \times \$9,129\text{K} + 12 = \$1,901\text{K} \\ \text{Case 3 -- } & (1 \text{ month} + 1.5 \text{ month}) \times \$18,613\text{K} + 12 = \$3,878\text{K}\end{aligned}$$

6.5 Summary of One-Time Costs for Facility Start-Up

Based on information in Sections 6.1 through 6.4, Table 12 presents a summary of one-time costs for facility start-up.

Table 12. Summary of One-Time Costs for Facility Start-Up

Cost category	Case 1 (K)	Case 2 (K)	Case 3 (K)
Operating procedures and plans	\$220	\$220	\$220
Manpower staffing and training	388	543	735
Spare equipment and stores items	1,663	2,199	3,277
Facility start-up	<u>1,309</u>	<u>1,901</u>	<u>3,878</u>
TOTAL	<u>\$3,580</u>	<u>\$4,863</u>	<u>\$8,110</u>

7. Project Schedule and Spending Profile

Capital costs, annual operating costs, and one-time costs for facility start-up for cases 1, 2, and 3 (given in Tables 7, 10, and 12) are summarized below (contingency allowances for capital improvements are included in each of the subcategories shown in the table):

Table 13. Summary of Capital, Start-Up, and Operating Costs

Cost Category	Case 1 (K)	Case 2 (K)	Case 3 (K)
Capital Costs			
Engineering, licensing, permits, project admin.	\$3,925	\$4,610	\$6,790
Construction cost (including constr. mgmt.)	13,765	16,580	25,740
Total capital costs	17,690	21,190	32,530
Facility start-up	3,580	4,863	8,110
Annual operating cost	6,286	9,129	18,613

In order to calculate unit costs of production, a yearly spending profile for these costs needs to be developed, based on a given project schedule. A total project schedule of four years is assumed. This includes the several months required for facility start up. This schedule is based on the assumption that the actions required to amend the site's license to permit facility construction will be minimal. This is consistent with information on this subject obtained to date from the domestic feed suppliers. The basic schedule milestones are as follows:

- Project starts; engineering design begins Month 0
- License amendment presented to NRC (if needed) Month 10
- License amendment approved; construction begins; design 80% complete, long-lead procurements initiated Month 16
- Design complete Month 20
- Building construction complete, process equipment installation begins Month 30
- Process system installation complete Month 44
- System check-out complete; uranium introduced into system; operations begins Month 46
- Project complete; steady state operation commences* Month 48

* Note: Although production begins in Month 46, facility product output is lower than steady state level for first six months. This is accounted for by assuming no output in Months 46-48 (operating costs during these months are included in one-time facility start-up costs) and assuming full output after month 48.

Based on these schedule milestones, the spending profile for the project is shown in the following table (spreading the costs given in Table 13):

Table 14. Spending Profile for Cases 1, 2, and 3

Cost Category	Year 1 (K)	Year 2 (K)	Year 3 (K)	Year 4 (K)	Year 5+ (K)	Total (K)
CASE 1						
Engineering, etc.	\$2,110	\$1,415	\$200	\$200	--	\$3,925
Construction	--	3,300	6,700	3,765	--	13,765
Facility start-up	--	--	300	3,280	--	3,580
Operating costs	--	--	--	--	\$6,286	Ongoing
Total annual cost	\$2,110	\$4,715	\$7,200	\$7,245	\$6,286	--
Annual product output (MTU/y)	--	--	--	--	1,850	Ongoing
CASE 2						
Engineering, etc.	\$2,490	\$1,660	\$230	\$230	--	\$4,610
Construction	--	3,980	8,070	4,530	--	16,580
Facility start-up	--	--	300	4,563	--	4,863
Operating costs	--	--	--	--	\$9,129	Ongoing
Total Annual cost	\$2,490	\$5,640	\$8,600	9,323	9,129	--
Annual product output (MTU/y)	--	--	--	--	3,300	Ongoing
CASE 3						
Engineering, etc.	\$3,670	\$2,440	\$340	\$340	--	6,790
Construction	--	6,180	12,530	7,030	--	25,740
Facility start-up	--	--	300	7,810	--	8,110
Operating costs	--	--	--	--	\$18,613	Ongoing
Total Annual Costs	\$3,670	\$8,620	\$13,170	\$15,180	\$18,613	--
Annual Product Output (MTU/y)	--	--	--	--	9,900	Ongoing

8. Revised Costs for Cases 1a, 2a and 3a

Cases 1a, 2a, and 3a are the same as cases 1, 2, and 3, respectively, except existing building space at the licensed site is used for installation of the continuous fluoride reduction process system, and new facility space is not constructed. The following assumptions and guidelines are applied to development of these cases:

- The existing building space and associated support systems and equipment are assumed to be fully depreciated and are not given any value in terms of calculating unit costs to the AVLIS plant owner for feed conversion services.
- Costs for facility start-up and for ongoing facility operations will be charged to the AVLIS feed conversion activity even if existing personnel, consumables, and support contracts are utilized. Costs for facility start-up and annual operations should be different from those in cases 1, 2, and 3 only to the extent that specific functions are no longer required. An item by item review of these costs has been made to identify such differences. These differences are itemized in Section 8.2. The total value of such differences is small.
- A shorter project schedule will be possible since no building construction is required.

Based on these assumptions and guidelines, the following steps are required to develop cost information for these cases similar to that summarized for cases 1, 2, and 3 in Table 14:

1. Identify capital start-up, and operating cost savings and remove these from costs developed for cases 1, 2, and 3.
2. Define revised project schedule milestones.
3. Establish revised spending profile using revised costs and schedule milestones.

8.1 Capital Costs

The following table lists estimated cost savings for cases 1a, 2a, and 3a with respect to the procurement and construction costs for cases 1, 2, and 3 that are shown in Table 6. Footnotes explaining some values follow the table.

Table 15. Capital Costs Savings for Cases 1a, 2a, and 3a

WBS Element	Estimated Procurement/Construction Cost Savings (\$K)		
	Case 1a	Case 2a	Case 3a
1.3.1 Feed buildings			
1.3.1.1 Feed conversion building ¹	\$2,215	\$2,690	\$4,750
1.3.2 Feed chemical systems			
1.3.2.1 Oxide pretreatment (feed unloading and blending)	0	0	0
1.3.2.4 Metal reduction	0	0	0
1.3.3 Feed casting systems			
1.3.3.1 Casting system	0	0	0
1.3.4 Feed support systems			
1.3.4.1 Feed receiving and storage (and product storage)	160	160	250
1.3.4.2 MgCl ₂ electrolysis (salt granulation and handling)	0	0	0
1.3.4.4 Feed process utilities ²	530	700	1,065
1.3.4.5 Laboratory equipment ³	175	175	280
1.3.4.6 Maintenance equipment ⁴	125	125	210
1.6 Control systems			
1.6.2 Feed control system	0	0	0
Process system subtotal (WBS 1.3.2 thru 1.6.2)	990	1,160	1,805
1.7 Plant support system	320	350	580
1.7.1 Land improvements ⁵			
1.7.2 Outside utilities ⁶	400	570	1,100
1.7.4 Direct support facilities (environ. monitoring equip.)	250	250	250
Plant support system subtotal	970	1,170	1,930
Total est. procurement and construction cost savings	\$4,175	\$5,020	\$8,485

Footnotes to Table 15 -- Basis for Selected Cost Savings:

- Costs for building modifications for installation of process equipment assume a cost of \$150/ft² (1/3 the cost of new Category 1 building space -- see footnote 1 to Table 6). This unit cost applies to the floor space listed in Table 4 for feed unloading and blending, metal reduction and casting, and salt processing and rod inspection. All other building space is assumed to be usable with little or no modifications.
Example: Case 1 -- (900 ft² + 900 ft² + 900 ft²) x 150/ft² = \$405,000. From Table 6, building construction cost is \$2,620K.
So, savings is \$2,620K - \$405K = \$2,215K.
- Feed process utilities for retrofit cases are judged to cost 30% of base case costs. Adequate cooling water supply is assumed to be in place and adequate incoming electrical power is assumed to be available. Cooling water piping modifications will be required and electrical switch gear and distribution wiring changes will be needed. Thus, savings are 70% of values shown in Table 6.
- Laboratory equipment cost savings are assumed to be 35% of base case costs.
- Maintenance equipment cost savings are assumed to be 70% of base case costs.
- All land improvement costs are saved except \$50K in each case for pavement modifications to support salt loading and unloading requirements.
- All outside utilities costs in Table 6 will be saved, as will direct support facilities costs.

Based on the procurement/construction savings listed in Table 15, the total capital costs for Cases 1a, 2a, and 3a are tabulated in Table 16, which is a revised version of Table 7.

Table 16. Capital Costs for Cases 1a, 2a, and 3a.

Category	Case 1a (K)	Case 2a (K)	Case 3a (K)
Building construction cost	\$405	\$540	\$900
Engineering for bldg. (18% of bldg. costs)	75	100	160
Process system costs	6,440	7,810	11,420
Engr. for process system (28%)	1,800	2,190	3,200
Plant support system costs	50	50	50
Engr. for plant support system (12%)	--	--	--
Project management costs (@ \$100K/MY)			
Project administration	300	300	400
Construction management	200	200	400
License amendment preparation & NRC fees	200	200	200
Other regulatory permit costs	100	100	100
Subtotal of all above costs	<u>\$9,570</u>	<u>\$11,490</u>	<u>\$16,830</u>
Contingency allowance (20%)	1,910	2,300	3,370
Total Capital Costs	<u>\$11,480</u>	<u>\$13,790</u>	<u>\$20,200</u>

8.2 Annual Operating Costs

Differences in annual operating costs for cases 1a, 2a, and 3a, in comparison to such costs for cases 1, 2, and 3, are presented below:

Labor -- No changes

Materials -- No changes

Power & Utilities:

Building power loads (given in Section 5.3) can be reduced by 50% due to sharing of support areas with other site activities. Resulting cost savings are as follows:

Case 1a -- $300 \text{ kW} \times 0.50 \times 8760 \times \$0.05/\text{kW hr} = \$ 66\text{K/yr}$

Case 2a -- $350 \text{ kW} \times 0.50 \times 8760 \times \$0.05/\text{kW hr} = \$ 77\text{K/yr}$

Case 3a -- $650 \text{ kW} \times 0.50 \times 8760 \times \$0.05/\text{kW hr} = \$142\text{K/yr}$

Waste Disposal and Other Contract Services -- No changes

Annual NRC Fees -- No changes

Decommissioning Escrow Costs:

Annual costs for the decommissioning escrow fund can be reduced in proportion to capital cost reductions. The following savings result:

Case 1a -- $\$ 6,210\text{K} \times 0.5 \times 1/30 = \100K/yr

Case 2a -- $\$ 7,400\text{K} \times 0.5 \times 1/30 = \125K/yr

Case 3a -- $\$12,330\text{K} \times 0.5 \times 1/30 = \205K/yr

Based on the information given above, total annual operating savings are \$166K, \$202K, and \$347K for Cases 1a, 2a, and 3a. Using base costs from Table 10, revised annual operating costs for these cases become:

Case 1a -- \$ 6,120K/yr

Case 2a -- \$ 8,927K/yr

Case 3a -- \$18,266K/yr

8.3 One-Time Facility Start-Up Cost Differences

Differences in one-time facility start-up costs for cases 1a, 2a, and 3a, in comparison to such costs for cases 1, 2, and 3, are presented below:

Operating Procedures and Plans -- No changes

Manpower Staffing and Training -- No changes

Spare Equipment and Stores Items:

Costs for the initial complement of miscellaneous spares and stores items can be reduced by the following amounts:

Case 1a -- \$200K

Case 2a -- \$240K

Case 3a -- \$370K

Facility Start-up -- No changes

Based on the information given above, and base costs from Table 12, revised one-time facility start-up costs for cases 1a, 2a, and 3a become:

Case 1a -- \$3,380K

Case 2a -- \$4,623K

Case 3a -- \$7,740K

8.4 Project Schedule and Spending Profile

Table 17 summarizes the capital costs, annual operating costs, and one-time facility start-up costs for cases 1a, 2a, and 3a. The table parallels Table 13, which provides the same data for cases 1, 2, and 3.

Table 17. Summary of Capital, Start-Up, and Operating Costs

Cost Category	Case 1a (K)	Case 2a (K)	Case 3a (K)
Capital Costs			
Engineering, licensing, permits, project admin.	\$2,970	\$3,470	\$4,870
Construction cost (including constr. mgmt.)	8,510	10,320	15,330
Total capital cost	11,480	13,790	20,200
Facility start-up	3,380	4,620	7,740
Annual operating cost	6,120	8,930	18,270

The following schedule milestones will be used to establish yearly spending profiles for the costs given in Table 17. The spending profiles are presented in Table 18.

Schedule Milestones for Cases 1a, 2a and 3a

- Project starts; engineering design begins Month 0
- License amendment presented to NRC (if needed) Month 10
- License amendment approved; facility modifications begin; design 80% complete; long-lead procurements begin Month 14
- Design complete Month 18
- Facility modifications complete; process equipment installation begins Month 20
- Process system installation complete Month 32
- System check-out complete; uranium introduced into system; operations begin Month 34
- Project complete; steady state operation commences Month 36

Table 18. Spending Profiles for Cases 1a, 2a, and 3a

Cost Category	Year 1 (K)	Year 2 (K)	Year 3 (K)	Year 4 (K)	Years 5+ (K)	Total
Case 1a						
Engineering, etc.	\$1,780	\$1,040	\$150	--	--	\$2,970
Construction	--	4,680	3,830	--	--	8,510
Facility start-up	--	300	3,080	--	--	3,380
Operating costs	--	--	--	6,120	6,120	Ongoing
Total Annual cost	<u>\$1,780</u>	<u>\$6,020</u>	<u>\$7,060</u>	<u>\$6,120</u>	<u>\$6,120</u>	--
Annual product output (MTU/y)	--	--	--	1,850	1,850	Ongoing
Case 2a						
Engineering, etc.	\$2,080	\$1,215	\$175	--	--	\$3,470
Construction	--	5,680	4,640	--	--	10,320
Facility start-up	--	300	4,320	--	--	4,620
Operating costs	--	--	--	8,930	8,930	Ongoing
Total annual cost	<u>\$2,080</u>	<u>\$7,195</u>	<u>\$9,135</u>	<u>\$8,930</u>	<u>\$8,930</u>	--
Annual product output (MTU/y)	--	--	--	3,300	3,300	Ongoing
Case 3a						
Engineering, etc.	\$2,920	\$1,710	\$240	--	--	\$4,870
Construction	--	8,430	6,900	--	--	15,330
Facility start-up	--	300	7,440	--	--	7,740
Operating costs	--	--	--	18,270	18,270	Ongoing
Total annual cost	<u>\$2,920</u>	<u>\$10,440</u>	<u>\$14,580</u>	<u>\$18,270</u>	<u>\$18,270</u>	--
Annual product output (MTU/y)	--	--	--	9,900	9,900	Ongoing

9. Conclusion

The costs and spending profiles given in Tables 14 and 18 establish baseline costs that are to be used to calculate fair unit prices for feed conversion services (\$/kg), based on reasonable returns for the conversion facility owner. The costs and spending profiles given in Table 18 for cases 1a, 2a, and 3a (existing building used) represent the baseline costs for the recommended lowest cost feed conversion option for U-AVLIS commercialization. Recommended prices calculated using these cost data were provided in the letter "Lowest Cost U-AVLIS Feed Conversion Options," R. M. Feinberg, to J. Longenecker, October 20, 1993, L-16305, for use by the United States Enrichment Corporation in its economic assessment of AVLIS technology commercialization. A copy of this letter is provided as an appendix in this document.

APPENDIX

October 20, 1993
L- 16305-1

Mr. John Longenecker
United States Enrichment Corporation
2300 M. Street, NW 5th Floor
Washington, DC 20037

Dear Mr. Longenecker:

SUBJECT: Lowest Cost U-AVLIS Feed Conversion Options

An engineering study has been completed defining the costs for U-AVLIS feedstock production via continuous fluoride reduction (CFR). The study is based on private deployment of a new CFR process system at an existing commercial uranium processing site licensed by NRC for possession of source material. Costs for six cases have been developed. These cases examine new CFR process systems sized to support one, two, and six-line U-AVLIS plants and installed in new buildings (cases 1, 2, and 3, respectively) or in existing building space (cases 1a, 2a, and 3a, respectively) at the commercial site. Table 1 summarizes the six cases and their capital, start-up, and operating costs. It also gives annual spending profiles for these costs based on project schedules defined in the study.

Cases 1a, 2a, and 3a are recommended for use in your assessment as the lowest cost feasible options for U-AVLIS feed production. Prices for the UF₄ to alloy feed rod conversion service can be calculated from the annual cost data given in Table 1 using criteria of your choice. Table 2 presents some example prices derived from these data as well as the methods used to calculate them. Table 3 presents the UOC to UF₄ conversion prices that we recommend be used to accompany the conversion prices derived from the data in Table 1. Table 3 also summarizes the bases for these UF₄ production prices.

The CFR process employed in the engineering study is based on (1) proof-of-concept experiments performed by Santa Fe Alloys, Inc. in 1992 (documented in *Production of Uranium-Iron Alloys by Continuous Metallothermic Reduction of Uranium Tetrafluoride*, L-15028, September 1992), (2) a series of twelve pilot-scale experiments accomplished at the Y-12 plant over the past year (technical documentation of these runs is in preparation and will be issued by December), and (3) the feed conversion system described in the *U-AVLIS Production Plant Conceptual Design Report* (LP-91-142, Volume 5) which employs continuous reduction of UCl₄, some steps of which are very similar to those required for the CFR process.

For each of the cases examined, uranium is received at the CFR facility in the form of UF₄; blended with magnesium, iron, and a diluent salt; reduced and alloyed in a continuously operating reactor; and cast into alloy feed rods using a continuous casting process like that described in the *U-AVLIS CDR*. The feed rods are packaged and shipped to the U-AVLIS plant, and the byproduct salt, a mixture of MgF₂ and NaCl, is granulated, packaged, and shipped for disposal as non-radioactive waste or for alternate use. Our test data indicate that the uranium level in the byproduct salt can be reduced in the process to levels below that now approved by at least one NRC agreement state for

"uncontrolled use" by the uranium metal producer. All of the cases examined make use of existing site infrastructure to support the CFR operation. The cases that involve retrofit of the new process into existing building space are recommended for use in the economic assessment because sufficient space for this purpose is known to exist today at the sites of both domestic uranium metal producers.

In summary, we recommend that (1) the costs for cases 1a, 2a, and 3a presented in Table 1 be used in your assessment to establish prices for production of U-AVLIS feedstock from UF_4 and (2) the prices in Table 3 be used for production of UF_4 from UOC. Please refer any questions about this information to me at 510-422-0182 or Roger Miller at 510-423-3416.

Robert M. Feinberg
Deputy Associate Director
Laser and Environmental Programs
Isotope Separation and Advanced
Manufacturing Technology Program

RMF:dv

Table 1. Costs¹ for Conversion of UF₄ to Alloy Feed Rods Via Continuous Fluoride Reduction (Shaded cases are those recommended for use in the assessment).

Case No.	U-AVLIS Plant Supported	Annual Production Rate (mtU/y)	Process Building Assumption	Total Capital Cost (\$K)	Total Start-up Cost (\$K)	Annual Operating Cost (\$K/y)	Cost in Year n (\$K) ²				
							n=-3	n=-2	n=-1	n=0	n=1,2...
1	one-line	1,850	new building	17,690	3,580	6,290	2,110	4,715	7,200	7,245	6,290
1a	one-line	1,850	existing building	11,480	3,380	6,120	0	1,780	6,020	7,060	6,120
2	two-line	3,300	new building	21,190	4,860	9,130	2,490	5,640	8,600	9,320	9,130
2a	two-line	3,300	existing building	13,790	4,620	8,930	0	2,080	7,195	9,135	8,930
3	six-line	9,900	new building	32,530	8,110	18,610	3,670	8,620	13,170	15,180	18,610
3a	six-line	9,900	existing building	20,200	7,740	18,270	0	2,920	10,440	14,580	18,270

Notes: 1. All costs are presented in today's dollars.

2. For cost profiles, year n=0 is the last year of the construction project and the year in which start-up activities occur. Year n=1 is the first year of steady-state operation. For the cases that require construction of a new process building (cases 1, 2, and 3), a four-year period is required for engineering, construction, and start-up. For the recommended building retrofit cases (cases 1a, 2a, and 3a), a three-year period is required. For each of these three or four-year project periods, the sum of the annual costs equals the sum of total capital and start-up costs.

Table 2. Example Prices¹ for Conversion of UF₄ to Alloy Feed Rods Via Continuous Fluoride Reduction. (Shaded cases are those recommended for use in the assessment).

Case No.	U-AVLIS Plant Supported	Annual Production Rate (mtU/y)	Process Building Assumption	Example Prices (\$/kgU)	
				Using Levelized Unit Price Method ²	Using ENTERprise Model ³
1	one-line	1,850	new building	5.10	7.40
1a	one-line	1,850	existing building	4.40	6.60
2	two-line	3,300	new building	3.90	5.80
2a	two-line	3,300	existing building	3.50	5.20
3	six-line	9,900	new building	2.50	3.70
3a	six-line	9,900	existing building	2.20	3.40

- Notes: 1. Prices are those calculated to be charged by the feed converter who incurs the costs in Table 1. Prices are in today's dollars.
2. Levelized unit price method calculates the price which, if charged for all production over a 15 year operating campaign results in a net present value for the venture of zero, based on use of a discount rate of 10 % applied to constant dollar cash flows. This method does not consider taxes on corporate profits.
3. ENTERprise model is used to determine the price which provides an internal rate of return for the venture of 10 % on current dollars. This method accounts for corporate taxes and all other private venture considerations incorporated into the ENTERprise code.

Table 3. Recommended Prices for Conversion of UOC to UF₄.¹

Quantities Purchased	U-AVLIS Plant Supported	Recommended Price ²	Basis for Recommended Price
1,850 to 3,300 mtU/y	one or two-line	\$5/kgU	This price is based on information from feed converters and engineering judgment. The converters have indicated that high fixed costs, need to renegotiate contracts, and required facility modifications will result in UF ₄ prices that are only a few dollars less than those for UF ₆ , even though the steps to produce fluorine, fluorinate UF ₄ and cold trap UF ₆ are unnecessary. For the smaller quantities of UF ₄ production required to support one or two-line U-AVLIS plants, the reasons given by the converters for being unable to significantly reduce prices below those charged for UF ₆ production are judged to be valid, so a price that is only about 28% below the UF ₆ conversion price was selected.
6,600 to 9,900 mtU/y	four or six-line	\$4/kgU	For the significantly larger quantities of UF ₄ required to support a large U-AVLIS plant, it is judged that competition and economies of scale should result in lower UF ₄ production prices than those associated with smaller production quantities. Thus, a price that is about 43% below the UF ₆ conversion price is recommended.

- Notes: 1. These prices and the information explaining their bases supersedes the information on UOC to UF₄ conversion prices given in Table 3 of L-16294-1, dated October 15, 1993.
2. These prices are referenced against a UF₆ conversion price of \$7/kgU.

DATE

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END