Uranium Isotopic Separation by Aerodynamic Methods

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Research Project 506-1

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ABSTRACT

Two aerodynamic separation techniques for uranium enrichment were investigated for technical feasibility and economic viability. These techniques are known as the Jet Membrane and Velocity Slip Processes. Both analytical and laboratory studies were conducted to explore the technical feasibility of the subject processes. The Jet Membrane Process Studies demonstrated that the process was feasible and that a condensable gas carrier is available. The Velocity Slip studies demonstrated the predicted effects and did not identify a suitable condensable gas carrier. Hence the Velocity Slip Process exhibited a larger power consumption than did the Jet Membrane Process.

An independent contractor prepared detailed cost estimates of the processes. The independent results indicated that, based on the same costing ground rules, the Velocity Slip process would require 16 times the fixed capital costs and 12 times the cost per separative work unit as compared to the Jet Membrane Process.

The same cost structure indicated that the cost per separative work unit for the Jet Membrane process would be two to three times that for the Gas Centrifuge process. There are a number of uncertainties associated with these cost estimates, such that, in the extreme, the costs might be the same.

Further, more detailed cost analysis would be required to resolve the uncertainties associated with the initial cost estimates. The conduct of new studies was not considered to be appropriate for EPRI because of the changes in enrichment program management and security philosophy discussed in the text.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report presents the results of a series of economic and technical evaluations of aerodynamic methods of uranium isotopic separation. These activities were initiated several years ago when it appeared that the nuclear option might be inhibited by the combination of transfer of enrichment supply from federal to private ownership and the difficulty in financing the associated large-scale plants. Aerodynamic methods were investigated since they appeared to offer a method of creating modular production capacity that could be economically expanded as needed.

PROJECT OBJECTIVES

The objectives of this program were to screen aerodynamic uranium enrichment methods and to perform economic and technical evaluations of promising candidates that might lend themselves to competitive production at relatively small scale (nominally 300,000 SWU/year).

PROJECT RESULTS

The project resulted in the demonstration of uranium enrichment by an aerodynamic method as well as the development of technical and economic studies of industrial application prospects. Gas handling and transport is a major cost element of aerodynamic enrichment. Approaches that lend themselves to cost reductions in gas handling and transport (i.e., by the use of a condensable carrier gas) appear to be competitive with currently accepted alternates such as centrifuge methods and may warrant pilot scale testing. However, changes in federal policy (related to capacity additions, ownership, and security classification) tend to restrict further work at present.

M. E. Lapides, Project Manager
Nuclear Power Division

FOREWORD

This report summarizes EPRI studies of two Aerodynamic Separation Techniques that were part of the RP506 Program. EPRI also sponsored a study on Field Ionization for Laser Isotope Separation that is separately reported in EPRI Report No. NP-334, December 1976.

This report is divided into three sections.

Part I — Overview - This section discusses the results of studies of the Jet Membrane Process and the Velocity Slip Process and compares the costs of the two processes.

Part II — Jet Membrane Isotope Separation Process - This entire portion of the report, prepared by Grumman Aerospace Corporation, summarizes project effort on the process.

Part III — Velocity Slip Isotope Separation Process - This portion of the report is a review and compendium of reports and articles dealing with the Velocity Slip Process.

Project 506 also included the following related studies:

RP506-1 — July 1975 to Sept. 1978 - Theoretical and Experimental studies of the Velocity Slip Isotope Separation Process. P. Davidovitz, Boston College.

RP506-2 — July 1975 to July 1976 - Additional technical studies of Velocity Slip Process to provide basis for cost analysis. J. B. Anderson, Pennsylvania State University.

RP506-3 July 1975 to Oct. 1977 - Laboratory demonstration of use of Field Ionization for Laser Isotope Separation. T. F. Gallagher, R. M. Hill, S. A. Edelstein - Stanford Research Institute (EPRI Report NP-334).

RP506-4 Sept. 1975 to Jan. 1978 - Theoretical Experimental and Econometric Studies of Jet Membrane Isotope Separation Process. J. W. Brook, V. S. Calia, Grumman Aerospace Corporation, Report entitled the Jet Membrane Process for Uranium Separation and Enrichment Enrichment.

RP506-5 Sept. 1977 to June 1978 - Detail Cost Studies of Velocity Slip and Jet Membrane Isotope Separation Processes based on RP506-1, 2 and 4. Airesearch Manufacturing Corporation of California, a division of Garrett Corporation. Two reports were prepared that are available for inspection from the RP506 Program Manager: 78-15191, Final Report on Evaluation of Advanced Enrichment Techniques; Part I Velocity Slip, Part II, Jet Membrane.

RP506-6 Aug. 1978 to Jan. 1979 - Preparation of Integrated Report on Project 506. G. Coe, M. Stickney, Coe Associates, Mountain View, California.

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PART I

OVERVIEW

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SECTION 1
INTRODUCTION AND SUMMARY

BACKGROUND

The activities described in this report were initiated approximately four years ago, at a time when uranium enrichment technology, economics and institutional issues were substantially different from now. A brief review of these historic circumstances provides necessary perspective for this report.

During 1972-1975 the transfer of supply responsibility from federal control to private industry was a central issue of uranium enrichment. Assuming an accelerating growth in demand, planning was based on the construction of large-scale, gaseous diffusion isotopic separation plants--each capable of meeting the annual needs of more than fifty commercial nuclear electric units. The gaseous diffusion plant was emphasized since it was felt that only a service proven method could meet the targeted dates while offering reliability consistent with a commercial enterprise. The large capital investment in these plants, the cost of feed stock for continued operation and the consequential costs of interruptions in plant operations all served to make the contracting process a major focus of ownership transition activities. Potential suppliers of enrichment services desired rigorous contracting terms; utilities, faced with growing construction delays could not find ready compatibility with these constraints.

The EPRI program described in this report primarily derived from the observation that demand uncertainty might continue to characterize the uranium enrichment market for many years. Thus it was of interest to determine a) what constraints demand uncertainty imposed and b) what enrichment technology was adapted to these constraints. The essential criteria which derived were that:

a. the enrichment plant be capable of implementation in small size without serious economic penalty on unit costs.

b. that the approach be based on an existing industrial equipment base (in lieu of being dependent on a substantial investment in same); this being a prerequisite of timely implementation.

Despite recognizable limitations, the aerodynamic enrichment techniques, as typified by the German Becker Nozzle work appeared to satisfy these criteria.

Typically, aerodynamic isotopic enrichment methods are characterized by comparatively high stage separation factors, straight-forward equipment configurations and high power consumption. Accordingly, the technical focus of the EPRI-sponsored work was to determine if the desirable features of the aerodynamic processes could be retained while reducing the power consumption. Since much of the power consumption is related to carrier gas handling the emphasis was on the introduction of condensable gas carriers which can be more efficiently transported than non-condensing gases.

The costing of any enrichment plant is dependent on the state of technical definition of the approach, the degree of detailing of the specific plant and the economic assumptions related to interest, escalation, depreciation and rate of return. For these reasons comparatively few existing estimates of the costs of future enrichment capacity can be directly compared. Indeed, the usual process for achieving value comparisons is an iterative process of review and normalization. Recognizing that such effort was beyond the scope of this program the economic evaluation of selected systems was conducted in a somewhat more condensed fashion which is believed to be sufficient to portray the prospects and potential of the methods assessed. As an initial step, economic analyses were performed by the system proponents using techniques appropriate for screening and design evaluations. Subsequently, the preferred designs were given to an independent contractor who performed a more comprehensive study benchmarked against a recent commercialization program for a competitive technique. To complete the effort a second design iteration reflecting the influence coefficients identified in the detailed cost evaluation should have been conducted. However, this effort is merely restricted to an assessment of the possible cost changes which might result from such iteration.

Considerably more effort could be identified and justified for technical evaluation of the systems selected. However EPRI decided to terminate effort at the level summarized herein because of substantial changes in government enrichment policy encountered during the period of performance. Specifically, conduct of enrichment by private industry is not currently a posture of interest and government classification procedures essentially preclude further EPRI participation. The results of this work have been reviewed with federal interests for both technical and classification review prior to publication.

In 1974, EPRI reviewed more than eighteen different potential isotope separation techniques. The objective of the review was to identify techniques that could be implemented in a modular fashion to accommodate changes in demand with unit costs that were competitive with the then currently favored separation techniques (gaseous diffusion and gaseous centrifuge). Two aerodynamic separation techniques plus a study on a technique to enhance the effective cross section of an atom in a laser separation process were selected for study.

The atom excitation technique study was conducted by Stanford Research Institute and showed favorable results. This work is reported separately (EPRI NP-334, Research Project 506-37).

This report discusses the two aerodynamic separation techniques that were selected for further study, the Jet Membrane Process and the Velocity Slip Process. The techniques were evaluated for technical feasibility by a combination of analytical and experimental studies. The report includes details on the theoretical and experimental studies of the Jet Membrane Process, which were conducted by Grumman Aerospace Corporation; an econometric study of the Jet Membrane Process also prepared by Grumman, and details on the theoretical and experimental studies on the Velocity Slip Process, which were conducted by Boston College and Pennsylvania State University.

Both processes were evaluated for economic viability by Airesearch Manufacturing Corporation of California, a division of Garrett Corporation.

STATE OF ART SUMMARY

U.S. enrichment efforts have focused on laser isotopic separation at the research level, on centrifuge enrichment at the developmental level and on capacity and process improvement of existing diffusion production facilities. The nominal judgemental criteria imposed on these various efforts include:

a. anticipated overall cost per SWU*,

b. relative power consumption,

c. state of readiness for production implementation to meet demand anticipated beyond 1985, and

d. adaptability to low tails assay production in the interests of resource conservation.

Most of the processes considered exhibit an "economy of scale". Assurance of a sustained market as well as siting for access to necessary electrical source are important considerations.

Foreign enrichment efforts have been somewhat similarly oriented except that:

a. there has been a more limited historic commitment to diffusion and,

b. there has been a reasonably intensive effort in aerodynamic separation techniques.

Classically, the aerodynamic methods have been characterized by comparatively simple construction and equipment as well as by high power consumption. The latter consideration is not regarded as significant in countries such as South Africa which have abundant sources of low cost electrical power and no internal or export market for this power.

EPRI PROGRAM

EPRI selected aerodynamic methods for investigation with the specific objective of determining if the simplicity of the equipment could be retained while reducing power consumption. Other themes of interest included:

a. the prospects for economically viable enrichment at comparatively low production rates, and,

b. use of non-electric power sources.

*SWU: Separative work unit, a relative measure of the energy required for uranium enrichment.

The Jet Membrane approach (Muntz, Hamel, Grumman) has the fundamental objective of reducing power consumption by substituting a condensable fluid for the normal helium carrier. The Velocity Slip approach was of interest because of the possibility of obtaining centrifuge-type performance and implementation without the necessity for ultraspeed equipment which could result in a major reduction in the manufacturing investment needed for equivalent centrifuge operation and maintenance.

As part of the RP506 program EPRI initiated studies with:

a. Boston College and Pennsylvania State University on the Velocity Slip Process (RP506-1,2).

b. Stanford Research Institute on Field Ionization for Laser Isotope Separation.

c. Grumman Aerospace on the Jet Membrane Process.

d. Garrett Corporation on the costs of private separation plants based on the Jet Membrane and Velocity Slip processes.

SECTION 2
KEY FINDINGS

Theoretical and experimental studies demonstrated the technical feasibility of both aerodynamic separation processes.

The results obtained on the Jet Membrane Process indicated that there are two gases that may be suitable for use as condensable working vapors which means that thermal pumping is feasible for this process.

While the Velocity Slip Process technical studies demonstrated that the velocity differences are substantial, the studies did not identify a satisfactory condensable gas that could be used as the carrier for this process.

Two cost estimates were prepared (Section 6) on the Jet Membrane Process, an econometric analysis by the group performing the theoretical and experimental studies (See Part III) and a more detailed analysis by a separate organization (See Part I, Enclosure 2). Both estimates covered a 300,000 SWU/year private plant. These estimates indicated that the cost per SWU/year for a Jet Membrane Process Plant would be in the range of $100 to $450 per SWU and that the capital costs would be appreciably less than that of a gaseous diffusion plant. Section 6 identifies a number of items that could strongly influence unit costs of the Jet Membrane Process.

A single detailed cost estimate for a Velocity Slip Process Plant of 300,000 SWU/yr. was prepared by the same organization that developed the detailed Jet Membrane Process Plant costs. The Velocity Slip Process Plant would result in costs per SWU of about $5000 per unit, substantially more than the competitive processes. Based on the study results, the Velocity Slip Process does not appear to be competitive with the Jet Membrane, Gaseous Diffusion or Gaseous Centrifuge Process.

Further cost studies would be required to establish "hard data" on a number of factors including the cost basis that should be used to describe equivalent gaseous diffusion and gaseous centrifuge plants, appropriate interest rates, contingency factors and rates of return on investment. In addition, such a study would have to examine the various cost reduction items discussed in Section 6 as possibilities for the Jet Membrane Process.

SECTION 3
ALTERNATE SEPARATION PROCESS

The currently most used uranium isotope gaseous diffusion separation process is based on the random motion vectors and velocity differences associated with differences in molecular weight which occur in the molecules of a gas. In a contained gas the individual molecules all have the same average kinetic energy. The velocity of any given molecular (or isotopic) species is therefore inversely proportional to the square root of its molecular weight. On this basis the ratio of thermal velocities of the hexaflourides of the uranium isotopes ^{238}U and ^{235}U is 1.0043. An additional pertinent factor is that the collision cross sections of the isotopic compounds are identical. Because of these considerations, the distance traveled by molecules before striking a wall of the container is statisticaly the same. The frequency with which the molecules of the two isotopes impact the container walls is proportional to the velocities. The frequency with which the lighter molecules will impact the walls will therefore average 1.0043 times more than for the heavier molecules.

In the diffusion isotope separation process a porous membrane is substituted for one wall of the container. The openings in the membrane approach molecular dimensions. The probability that molecules of a particular species will enter an opening in the membrane is equal to the probability of striking a wall. The enrichment factor per stage for ^{235}U with respect to ^{238}U is therefore theoretically 1.0043. In actual practice the factor is reported to be somewhat less and about 1000 separation stages are required to achieve 3% enrichment.

In a gaseous diffusion plant, where the goal is to produce useable quantities of an enriched (increased ^{235}U content) gas, a number of successive processing stages are used. Essentially, each stage consists of a pressurized chamber with an internal porous membrane. The gas to be enriched, UF_6, is fed into one side of the screen and the enriched product is drawn off from the other side and fed into a subsequent stage where it is again enriched. The effective enrichment factor per stage is about 1.003 so a very large facility is required to produce a practical quantity of enriched gas. The large number of stages required precludes developing a small facility that would also be economically viable.

The Jet Membrane Process is analagous to the gas diffusion process. In the Jet Membrane Process a conical gas jet is used instead of a membrane as a diffusion barrier and takes advantage of other gas dynamic characteristics. Since higher stage enrichment factors are feasible, smaller facilities than those required for gaseous diffusion can be used.

An earlier process, the German Becker Nozzle, which triggered the interest in aerodynamic separation processes, used the mass differences between molecules as reflected in centrifugal forces to effect separation. This device requires a curved nozzle with very small precise mechanical structure to obtain separation of species. The effectivity of the process is in part limited by the fact that the isotopic molecular populations have a distribution of velocities that overlap. This process also allows the use of smaller facilities.

In the gaseous centrifuge process the gas is mechanically spun in a centrifuge to separate the ^{235}U on the basis of centrifugal forces. The life of the equipment, which involves very high speed rotating machinery, is one of the major economic considerations in the process. The stage separation capability of this process is higher than that for gaseous diffusion which means relatively small facilities are feasible.

The Velocity Slip Process is based on differences in velocity of the heavy isotope containing molecules as enhanced by acceleration in a light gas "seeded" beam. Separation is by passing the beam through a mechanical velocity separator. This process also potentially allows the use of smaller facilities (See Section 5).

SECTION 4
JET MEMBRANE TECHNIQUE

Saclay (1966) reported an "invasive separation effect" through a free jet shock wave structure that was the basis for a patent by Campargue in 1967. This was followed by a proposal by Muntz and Hamel to replace Campargue's downstream sampling configuration by an upstream sampling configuration which is the basis for the Jet Membrane Process discussed in Part II of this report.

DESCRIPTION OF JET MEMBRANE PROCESS

The Jet Membrane Process is analgous to the gaseous diffusion process in that a jet of gas acts, in part, as though it were a diffusing membrane. Conceptually, the term Jet Membrane can be misleading. Higher separation efficiencies than are theoretically available from straight gaseous diffusion differences are obtained with the invasive separation apparatus. The actual separation mechanisms involved are complex and discussed in detail in Part II of this report. The discussion in Part II shows that the cost of the process per unit of separative work is reduced if a condensable gas can be used which allows thermal rather than mechanical pumping of the gas. The apparatus that is the basis for the cost estimates in this report is shown schematically in Figure 4-1.

A heavy condensable gas such as perfluorotributylamine (FC-43) is allowed to flow as an annular free jet into a chamber containing UF_6. A collector probe is positioned within the Jet annulus and used to draw out the central fraction enriched in the lighter ^{235}U which preferentially penetrated the jet. The depleted portion of the working gas is collected and recycled or removed. The working gas (FC-43) is condensed, collected, and recycled in the process.

Laboratory and experimental studies have shown that the dimensional relationship of the jet orifice and the collecting probe are critical and involve relatively small dimensions.

A theoretical discussion of the process is presented in Part II, Section 5. The factors that relate to the energy consumption and cost of the process are discussed in Part II, Section 4.

BASIS FOR COST ESTIMATES

The basis for the Jet Membrane cost estimates prepared by Garrett Corporation is presented in Part I, Enclosure 2.

The units were based on a stage separation factor of 1.009402, a plant with a capacity of 300,000 separative work units per year, a condensable working gas (FC-43), a private plant on a site shared with a power plant and a 100 percent duty factory. Project unit costs were $441 per SWU. There are a number of areas of cost uncertainties that could lead to lower unit costs (See Section 6.0).

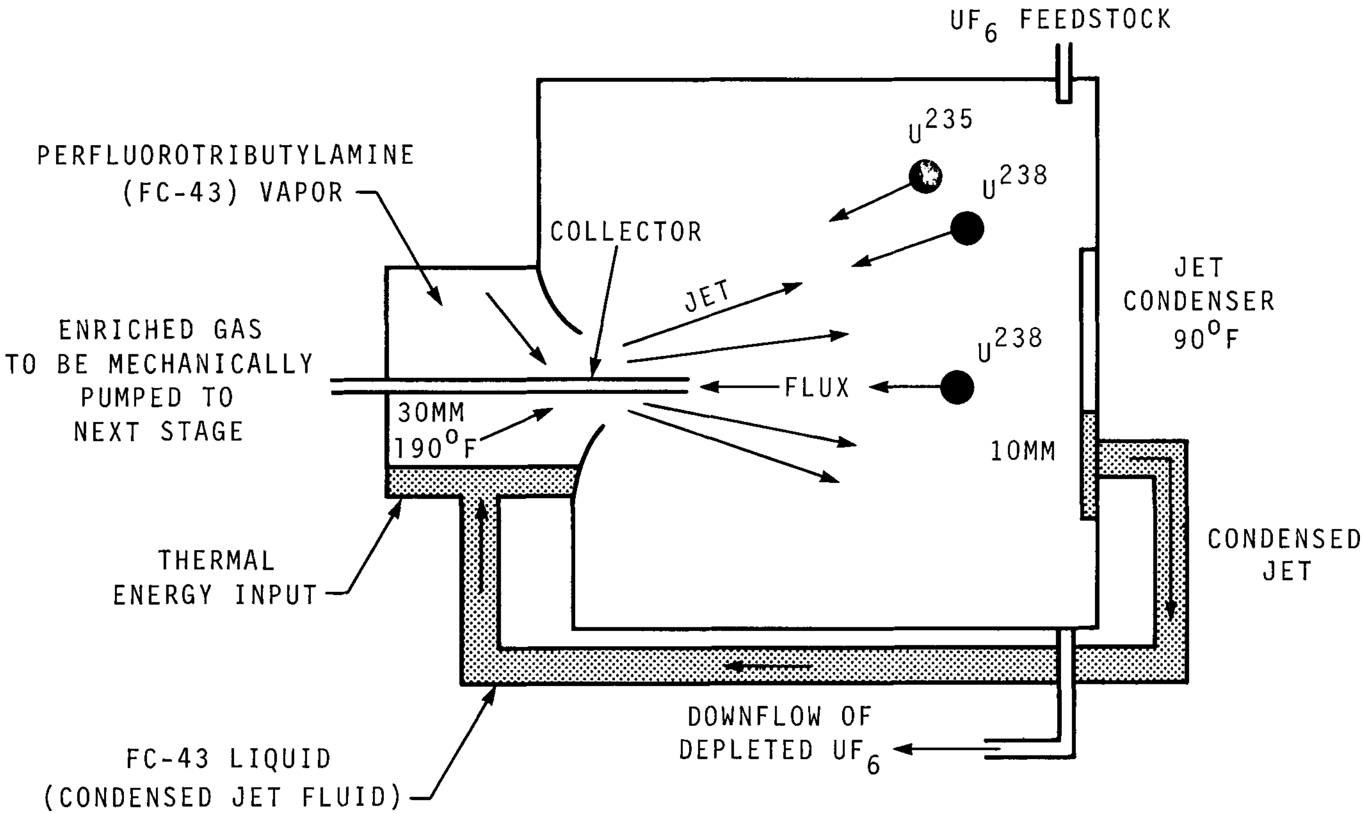


FIGURE 4-1 JET-MEMBRANE PROCESS SCHEMATIC

SECTION 5
VELOCITY SLIP TECHNIQUE

The Velocity Slip technique of isotope enrichment was proposed by J. B. Anderson of Pennsylvania State University and P. Davidovits of Boston College. Their initial estimate indicated a separation factor of 1.1, a value so high that even in the event of substantial disadvantages there was the possibility of development of an economically attractive isotope separation process.

DESCRIPTION OF VELOCITY SLIP TECHNIQUE

In "seeded" molecular beams formed from jet nozzles operating at Knudsen numbers less than 1 and more than 0.001 ($0.001<Kn<1$) the velocities of the minor molecular species depart from the normal Maxwellian thermal distributions. A "seeded" beam is one in which up to a few percent of a vapor phase component is dispersed in a relatively lighter carrier gas. Incomplete acceleration in the beam of the heavy species by the light gas is termed "velocity slip". Furthermore, the velocity ratios between mixed heavy species, such as isotopes, may be much larger than the normal thermal velocity ratios. This enhanced velocity difference could be the basis for separation of the heavy components.

Isolation of the desired component from the beam requires a "velocity selector". The velocity selector chosen was all mechanical in the form of a pitched bladed wheel (eg., turbine like) rotating at a peripheral velocity such that the desired component would pass through without interference while all other components would be dispersed by impinging on the blades.

Figure 1 displays the elements of an isotope separation system based on the velocity slip phenomenon as follows:

a. The "seeded" carrier gas source manifold at a pressure defined by the relationship between the selected Knudsen number and orifice dimensions.

b. A suitably shaped orifice to define the beam.

c. A drift space long enough to permit the optimum interactions between the carrier gas and the seeded isotopes.

d. The rotating velocity selector.

e. A second drift space, probably minimal, determined by mechanical tolerances.

f. A pumped expansion chamber enclosing the drift spaces and the velocity selector.

g. The orifice which defines the beam of the isotope to be accepted.

h. A pumped product receiving chamber.

One main pumped chamber and selector wheel can accommodate many beam defining and accepting orifices when aligned with the bladed radius of the selector wheel.

A review of the theoretical and experimental studies on this process is presented in Part III, Section 5.

The investigators were able to demonstrate that the velocity differences between the isotope species would be enhanced from about 1.0043 to 1.05. While the importance of using a condensable carrier to reduce separation costs was known to the investigators they were not able to identify such a gas.

BASIS FOR COST ESTIMATES

The basis of the Velocity Slip Process cost estimates prepared by Garrett Corporation is presented in Part I, Enclosure 3.

These costs were based on a stage separation factor of 1.0658, a plant with a capacity of 300,000 separation work units per year, a non-condensable working gas, a private plant on a site shared with a power plant and a 100 percent duty factor. Projected unit costs were $5228 per SWU.

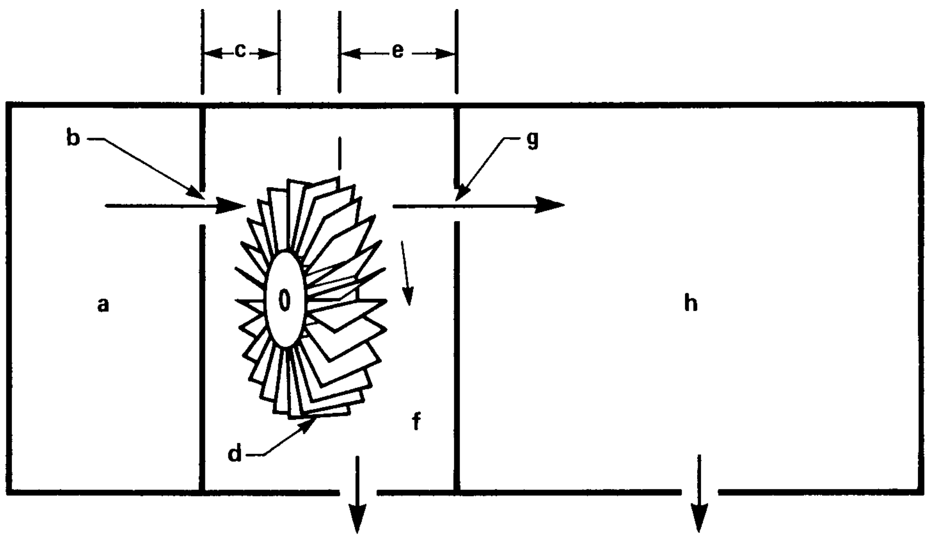


FIGURE 5-1 SIMPLIFIED DIAGRAM,VELOCITY-SLIP APPARATUS

SECTION 6
COST ANALYSIS

GENERAL

Preliminary cost estimates (See Part II) were developed that were based on the findings of the technical and experimental studies (RP506-1,2 and 4). These cost estimates were, in part, derived by scaling available data on the costs of gaseous diffusion and gaseous centrifuge plants. There are a considerable number of uncertainties inherent in the RP506 cost estimates including assumptions on the true costs of the competitive process, interest rate return on investment, and the mathematical relationship that should be used to scale costs from one separation process to another and to adjust from one annual level of separative work units to another.

The technical studies indicated that the product cost for private plants based on aerodynamic separation processes is considerably less if a condensable working gas can be used (See Part II). The Project 506 technical/experimental studies demonstrated that a suitable working fluid was available for the Jet Membrane Process. The studies (see Part III) did not identify a specific practical condensable working fluid that would suffice for the Velocity Slip Process. Consequently, as shown in the following section, the Jet Membrane Process appears to be more economical and require less capital investment than the Velocity Slip Process.

COMPARISON OF THE RELATIVE COSTS OF JET MEMBRANE AND VELOCITY SLIP PROCESS

Detailed cost estimates were developed for both processes based on privately owned plants in Texas with an annual capacity of 300,000 separative work units per year. The detailed estimates were based on the same assumptions for the costs of the gaseous diffusion and gaseous centrifuge processes and the scaling relationships that should be used to apply these costs to the Jet Membrane and Velocity Slip Processes.

Table 6-1 summarizes the findings in terms of the ratio of the costs for the Velocity Slip Process to those for the Jet Membrane Process. On a relative basis the Jet Membrane Process appears to be a considerably more economical and less capital intensive process than the Velocity Slip Process. Table 6-2 presents some of the results of the Airesearch cost studies. The distribution of costs for the Jet Membrane, Velocity Slip and Gaseous Diffusion Process are shown in Figures 6-1, 6-2, 6-3. Additional data on the Jet Membrane and Velocity Slip Processes are presented in Tables 6-3, 6-4, 6-5, and 6-6.

DISCUSSION

The cost estimates developed in this study are sensitive to assumptions on the achievable stage separation factor, return on investment, interest rates, capital recovery requirements etc. There is some indication that the annual unit cost per separative work unit for a large gaseous diffusion plant and for 300,000 SWU per year gaseous centrifuge or jet membrane plants are in the range of $100 to $500.

The objectives of the RP506 Program were satisfied by the development of the technical data and the various cost estimates. These estimates were dependent upon the accuracy of externally derived data, particularly data on gaseous diffusion plant costs. Further pursuit of the Velocity Slip process seems to be inappropriate.

Investigation and resolution of the uncertainties presented in the following section would be appropriate if some private or government interest was actively seeking a competitive alternative to gas centrifuge process for plants with capacities below 1,000,000 SWU per year. In this circumstance, the Jet Membrane Process would warrant further study. Since the Jet Membrane Process costs are dependent upon heating costs, consideration of sitings in areas where geothermally derived heat and electrical power are available might warrant further investigation. Alternatively, there might be an opportunity to locate these plants in an area where Solar heating is practical such as parts of Texas and Arizona.

TABLE 6-1

COMPARISON OF RELATIVE COSTS (1)
OF JET MEMBRANE AND VELOCITY SLIP PROCESSES

ITEM	RATIO OF COSTS VELOCITY SLIP vs JET MEMBRANE,
Fixed Capital Cost	16.42
Unit Cost (Per SWU)	11.87
Operation Cost	7.05
Working Capital	1.0

(1) Reference: Enclosures 2 and 3

TABLE 6-2

SUMMARY COMPARISON - JET MEMBRANE AND VELOCITY SLIP PROCESS
BASED ON AIRESEARCH COST ANALYSIS

ITEM	JET MEMBRANE PROCESS	VELOCITY SLIP PROCESS	GASEOUS CENTRIFUGE	COMMENT
Plant Capacity (Annual SWU)	300,000	300,000	350,000	
Siting	Sharing with Texas Power Plant	Sharing with Texas Power Plant	Stand alone in Texas	
Ownership	Private	Private	Private	
Capacity Scale Factor	0.6	0.6		
Product Assay Wt. percent $^{235}UF_6$	3.2	3.2	3.2	
Tails Assay Wt. percent $^{235}UF_6$	0.25	0.25	0.25	No cost for disposal
Feed Assay Wt. percent $^{235}UF_6$	0.711	0.711	0.711	Available in sufficient quantity at acceptable cost..
Duty Factor Plant	100%	100%	100%	
Cost Basis	Jan 1978 value	Jan 1978	Jan 1978	
Capital Cost Recovery	6.144%/yr.	6.144%/yr.	6.144%/yr.	Full recovery in initial vendor costs
Fixed Capital Costs $	410x106	6732x106	184x106	
Unit Cost Per SWU	$441/SWU	$5228/SWU	$128/SWU	

SOURCE: GARRETT CORP.

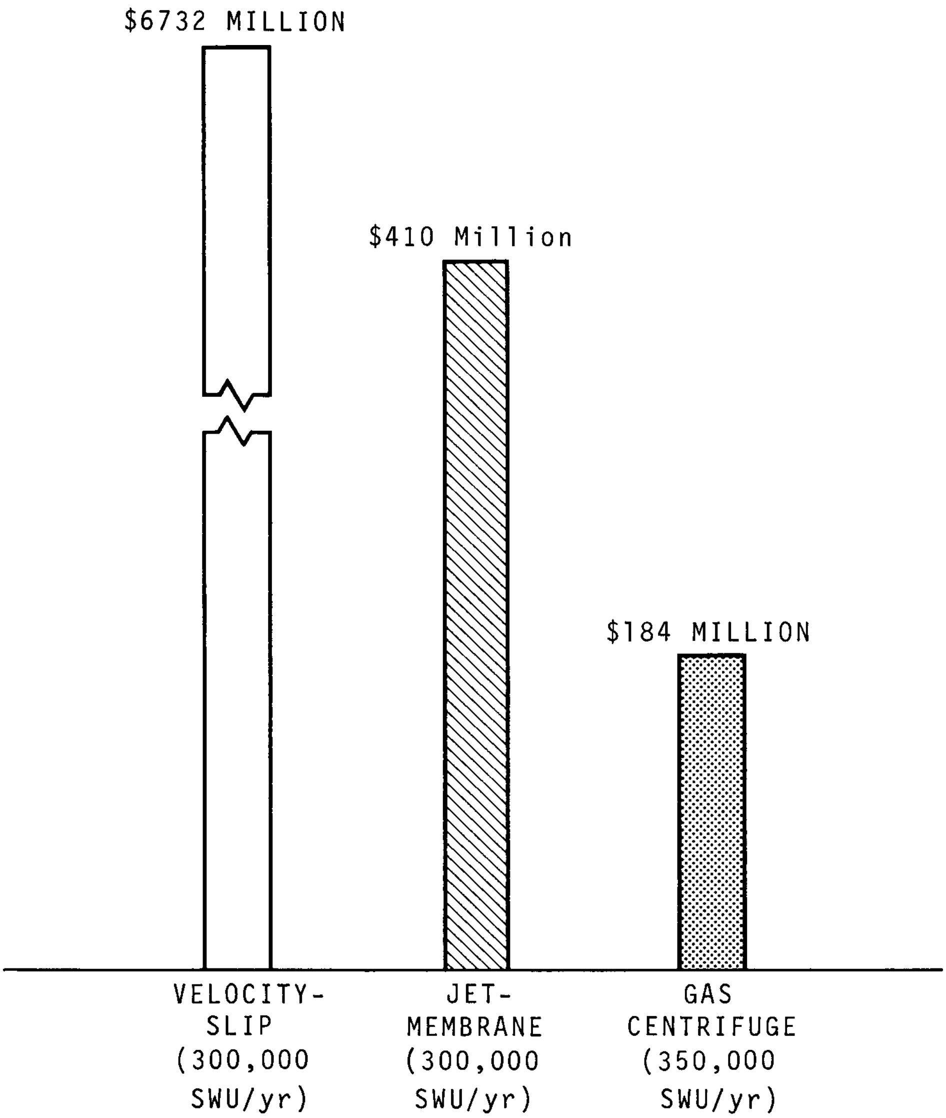


FIGURE 6-1 RELATIVE FIXED CAPITAL COSTS

SOURCE: GARRETT CORP.

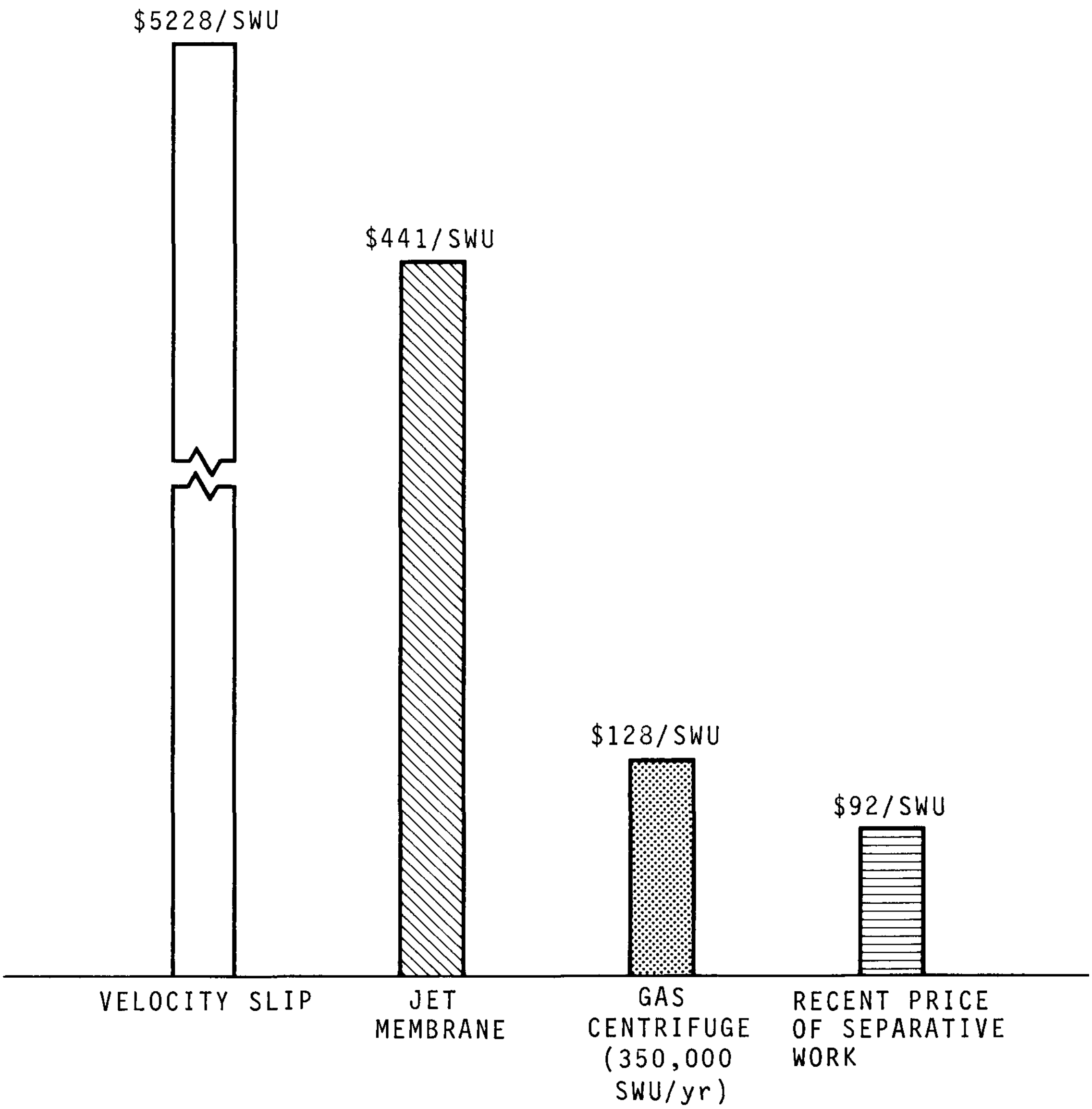
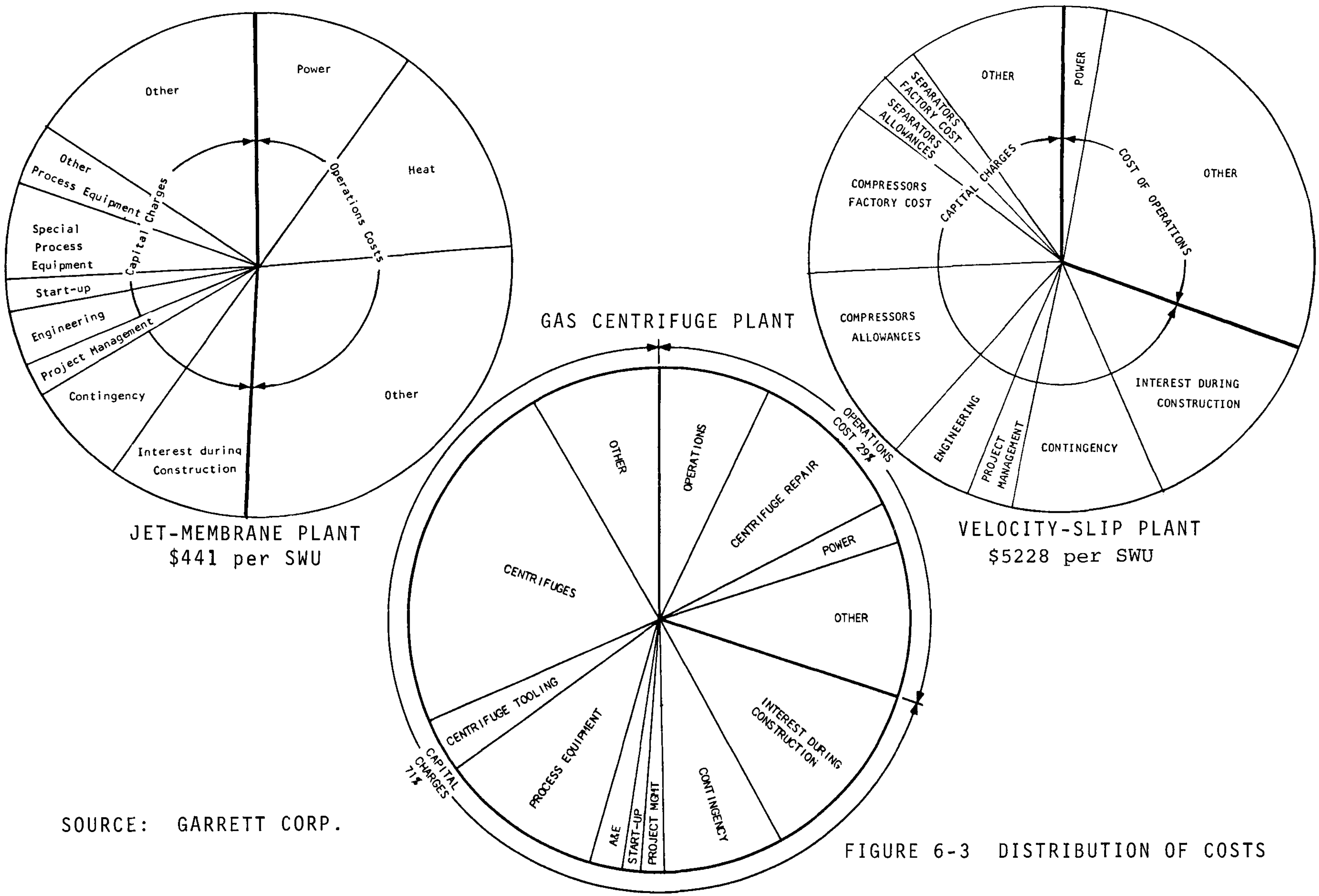


FIGURE 6-2 RELATIVE UNIT COSTS



SOURCE: GARRETT CORP.

FIGURE 6-3 DISTRIBUTION OF COSTS

TABLE 6-3

JET-MEMBRANE PROCESS FIXED CAPITAL COSTS

FIXED-CAPITAL COSTS EXTENSION
millions of dollars

	Land	Other Architectural Systems	Structural Systems	Special Process Equipment	Other Process Equipment	Mechanical Systems	Electrical Systems	Industrial Systems	Instrumentation	Totals
Base Cost Estimate	10.0	4.7	17.3	49.5	19.8	3.6	13.6	4.7	6.4	119.6
Freight in				1.5						1.5
Subtotal	10.0	4.7	17.3	51.0	19.8	3.6	13.6	4.7	6.4	121.1
Allowances for Indirect, Procurement, Insurance, FICA, State and Local Taxes, Small Tools, Scrappage and Overage, Premium Labor Rates Costs	0	1.3	4.8	25.7	5.5	1.0	3.8	1.3	1.8	45.2
Subtotal	10.0	6.0	22.1	76.7	25.3	4.6	17.4	6.0	8.2	166.3
Subcontractors' Markups and Fees	0	0	2.3	7.5	2.6	0.5	1.8	0.6	0.8	16.1
Subtotal	10.0	6.0	24.4	84.2	27.9	5.1	19.2	6.6	9.0	182.4
Construction Contractor's Indirect Costs	0	0.9	3.6	0	0	0.7	2.8	1.0	0	9.0
Operations Contractor's Overhead	0	0	0	12.3	4.2	0	0	0	1.4	17.9
Subtotal	10.0	6.9	28.0	96.5	32.1	5.8	22.0	7.6	10.4	209.3
Construction Project Cost (less land)										209.3
Engineering (A&E) Fees Cost										29.3
Subtotal										238.6
Project Management Costs										16.7
Subtotal										255.3
Contingency for Oversight and Unidentified Miscellaneous										54.5
Subtotal										309.8
Interest during Construction										73.4
Land										10.0
Subtotal										393.2
Start-up Costs										16.8
Total										410.0

SOURCE: GARRETT CORP.

TABLE 6-4

VELOCITY-SLIP PROCESS FIXED CAPITAL COSTS

FIXED-CAPITAL COSTS EXTENSION
millions of dollars

	Land	Other Architectural Systems	Structural Systems	Separator & Compressor Systems	Other Process Equipment	Mechanical Systems	Electrical Systems	Industrial Systems	Instrumentation	Totals
Base Cost Estimate	10.0	6.0	41.8	1417.0	272.0	9.0	30.9	5.1	168.9	1960.8
Freight in				42.5						42.5
Subtotal	10.0	6.0	41.8	1459.5	272.0	9.0	30.9	5.1	168.9	2003.3
Allowances for Indirect, Procurement, Insurance, FICA, State and Local Taxes, Small Tools, Scrappage and Overage, Premium Labor Rates Costs	0	1.7	11.7	729.8	76.2	2.5	8.7	1.4	47.3	879.3
Subtotal	10.0	7.7	53.5	2189.3	348.2	11.5	39.6	6.5	216.2	2882.5
Subcontractors' Markups and Fees	0	0	5.4	219.6	35.3	1.2	4.0	0.7	22.0	288.2
Subtotal	10.0	7.7	58.9	2408.9	383.5	12.7	43.6	7.2	238.2	3170.7
Construction Contractor's Indirect Costs	0	1.1	8.8	0	0	1.9	6.5	1.1	0	19.4
Operations Contractor's Overhead	0	0	0	354.3	57.1	0	0	0	35.4	446.8
Subtotal	10.0	8.8	67.7	2763.2	440.6	14.6	50.1	8.3	273.6	3636.9
Construction Project Cost (less land)										3626.9
Engineering (A&E) Fees Cost										507.8
Subtotal										4134.7
Project Management Costs										290.1
Subtotal										4424.8
Contingency for Oversight and Unidentified Miscellaneous										943.0
Subtotal										5367.8
Interest during Construction										1235.5
Land										10.0
Subtotal										6613.3
Start-up Costs										118.6
Total										6731.9

SOURCE: GARRETT CORP.

TABLE 6-5

JET-MEMBRANE OPERATIONAL COSTS

OPERATIONS VARIABLES

VARI-ABLE	DESCRIPTION	DIRECT COSTS, $000/YR	BURDEN COST, $000/YR	TOTAL OPERATIONS COST $000,000/YEAR		
				NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
16	LABOR	5.0	1.2	6.2	6.0	6.5
17	PROCESS EQUIPMENT UPKEEP	3.5	0	3.5	3.0	7.0
18	STANDARD EQUIPMENT AND BUILDING UPKEEP	17.4	0	17.4	15.0	20.0
19	UTILITIES	32.0	0	32.0	32.0	40.0
20	OVERHEAD AND MISCELLANEOUS	8.1	0	8.1	7.0	9.0
	TOTAL*	66.0	1.2	67.2		

VARI-ABLE	DESCRIPTION	CAPACITY, MILLION SWUS/YEAR		
		NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
21	PRODUCTION	0.3	0.25	0.31

*The minimum and maximum values for the total are determined by Monte Carlo simulation.

SOURCE: GARRETT CORP.

TABLE 6-6

VELOCITY-SLIP OPERATIONAL COSTS

OPERATIONS VARIABLES

VARI-ABLE	DESCRIPTION	DIRECT COSTS, $000/YR	BURDEN COST, $000/YR	TOTAL OPERATIONS COST* $000,000/YEAR NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
16	LABOR	5,411	1,353	6,764	5,500	7,000
17	PROCESS EQUIPMENT UPKEEP	298,960	0	298,960	200,000	400,000
18	STANDARD EQUIPMENT AND BUILDING UPKEEP	22,907	0	22,907	20,000	25,000
19	UTILITIES	30,220	0	38,220	35,000	41,000
20	OVERHEAD AND MISCELLANEOUS	107,540	0	107,540	100,000	150,000
	TOTAL	473,038	1,353	474,391		
				CAPACITY, MILLION SWUS/YEAR		
VARI-ABLE	DESCRIPTION			NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
21	PRODUCTION			0.3	0.25	0.31

*The minimum and maximum values for the total are determined by Monte Carlo simulation,

SOURCE: GARRETT CORP.

COST UNCERTAINTIES

Factors that would warrant further investigation to improve the quality of Jet Membrane Plant cost estimates are:

a. Definition of the attainable stage separation factor. Since some of the test results with SF* have indicated factors of as high as 1.043, it would appear likely that improvements over the 1.0094 figure used by Airesearch might be feasible.

b. Investigation of sources of thermal energy and possibilities for shared plants where energy costs could be reduced seems appropriate.

c. Staffing levels used in the cost analysis warrant further investigation.

d. Definitive data on the actual costs of the gaseous diffusion process, particularly with regard to equipment that could be used for the Jet Membrane Process.

e. Use of cooling ponds rather than cooling towers.

f. Reappraisal of penalty factors, interest rates, costs for "special" process equipment, contingency factors, return on investment and rate of capital recovery. The potential for tax incentive programs or some form of subsidy that deals with taxes and interest rates shoud also be considered.

g. Reassessment of maintenance and operation costs.

The degree of cost changes associated with the above uncertainties is indicated in Tables 6-7 and 6-8. These changes could reduce the cost/SWU by $100 or more over the Garrett estimates.

CONCLUSION

There is a possibility that the Jet Membrane Process would be economically competitive with the gaseous centrifuge process. The Velocity Slip Process does not appear to warrant further consideration unless major technical improvements can be identified.

TABLE 6-7

EFFECT OF COST UNCERTAINTIES ON CAPITAL COSTS

Item	Change	Cost Increase	Cost Decrease
Land	Add 200 acres for cooling ponds.	$2,000,000	
Special Process Equipment	o Cost of collector probes down 1/2.		$8,400,000
	o Compressor HP from 15 to 11.		1,600,000
	o Reduced Freight In.		300,000
Other Process Equipment	o Eliminate cooling towers.		1,400,000
	o Waste heat powered plant.		5,900,000
Electrical Systems	Associated with elimination of cooling towers.		600,000
Miscellaneous	o Add on from 50% to 28%.		14,300,000
	o Contingency from 21% to 15%		24,600,000
	o Startup.		8,400,000
Gross Effect			$104,600,000

TABLE 6-8

EFFECT OF COST UNCERTAINTIES ON OPERATING COSTS

Item	Change	Cost Increase	Cost Decrease
Process Equipment Maintenance	Replacement Parts		$840,000
Other Maintenance	Scaling Change		8,722,000
Electrical Power	Associated with change in cooling and HP (Table 6-7)		9,155,000
Thermal Power	Use Waste Heat		14,978,000
Gross Effect Annually			33,695,000

ENCLOSURE 1

TO PART I

FIELD IONIATION FOR LASER ISOTOPE SEPARATION

Final Report, December 1976, EPRI NP-334

Project 506-3

ABSTRACT

The use of laser excitation for isotopic separations and particularly for the enrichment of uranium is under intensive investigation at many laboratories. Laser separation has been the subject of much publicity on claims of performance, but process details are generally classified. Scale-up from present small laboratory experiments to industrial practice requires extrapolation of laser and vacuum technology to reach reasonable efficiency, reliability, and producibility. For some cases of interest, it is evident that the requisite laser has not yet been obtained on even a laboratory scale.

A concept for reducing the demands on laser technology is selective excitation of the source material in a manner that increases the effective cross-section for optical frequency energy interactions. (If the isotope of interest can be made into a better "target", the laser can be less efficient or selective.) Such potential is offered by creating "High Rydberg Number Atoms", an excitation state which serves to increase effective size of atoms to as much as 1000 times their normal values. The purpose of this study was to demonstrate that such excitation could be achieved and was, in principle, applicable to isotopic separation. The study achieved these initial objectives. It also became apparent that the basic processes examined might permit extension of available laser wavelengths as well as simplify scale-up problems related to through-put. These important results, which have been made available to ERDA and other researchers, may help to accelerate scale-up of laser methods.

This report provides a background study of laser isotopic separation methods together with a description of field ionization methodology and experiments. Technical journal articles which further describe the work and its implications are provided.

ENCLOSURE 2

TO PART I

PART 1

JET-MEMBRANE ISOTOPE SEPARATION PLANT CONCEPT

INTRODUCTION

The following work presents the proposed engineering design for a 300,000 SWU/yr uranium enrichment plant which utilizes the jet membrane isotope separation process. The plant product is 3.2% (by weight) $U^{235}F_6$ and the plant tails contain 0.25% (by weight) $U^{235}F_6$. The theory and performance of the jet membrane device is based on work done at Grumman Energy Systems as reported in References 1 through 6. The jet-membrane device consists of a single annular jet-forming nozzle and an enriched-isotope collector probe. The design task included a review of jet-membrane isotope separation phenomenon. Optimistic values of stage separation factor and line pressure losses were used in the design. Processing modules containing the required number of jet devices were sized for each cascade stage and the peripheral boilers, condensers, pumps, and fans were designed as was the interface flow diagram between processing modules.

JET-MEMBRANE ISOTOPE SEPARATION PLANT DESIGN PARAMETERS

A processing module, which contains a variable number of jet-membrane devices, is illustrated schematically in Figure 1. This figure shows cross-section of a single cluster of jet-membrane devices. Feed process gas, consisting of UF_6 with a small mole fraction of jet gas, enters the vacuum chamber at 280 torr static pressure. The heads process-gas stream is siphoned from the vacuum chamber by the collector probes which empty into a collecting manifold at 85 torr pressure. The heads stream consists of a 0.334 nominal mole fraction of jet gas, after passing across the jet membrane. The tails process-gas stream leaves the vacuum chamber by way of a condenser which removes most of the jet gas from the mixture. Jet gas is fed into the nozzle manifold at 420 torr pressure and discharges through the jet nozzles into the processing chamber. FC 43 (perfluorotributylamine, 3M Company) has been chosen for use as the jet gas. The jet gas is continuously removed from the vacuum chamber as a condensed liquid and is circulated parallel to the heads and tails UF_6 streams. A cross section of the jet-membrane device is also shown in Figure 2. The nozzle cluster is two-dimensional with a depth of 2 centimeter. The collector probe is surrounded by two converging jet-gas nozzles. Each jet-membrane device has a total jet throat area of 0.02 square centimeters and a collector probe inlet area of 0.018 square centimeters.

The design of the jet-membrane isotope separation plant is based on the following performance characteristics of the individual jet-membrane device given by Grumman Energy Systems in References 1, 2, and 3.

Stage separation factor	α = 1.009402
Vacuum chamber pressure	P_b = 280 torr
Collector probe suction pressure	P_ℓ = 88.5 torr
Jet-gas plenum pressure	P_s = 420 torr

Compressor pressure ratio (P_b/P_ℓ)	PR = 3.1638
Process-gas feed temperature	T = 360 Kelvin
Width of jet nozzle (each side)	D_j = 0.01 cm
Inside width of collector probe	W_c = 0.009 cm
Jet gas	FC-43 (perfluorotributylamine, 3M Company)
Stage cut	$\theta_i \approx 0.5$
Mole fraction of UF_6 in process-gas heads stream	0.666 mole percent

The product flow (P) for the 300,000 SWU/yr plant is 105,457.6 kg/year of UF_6 or 0.007368 lb/sec of UF_6 for a 0.00711% (by weight) $U^{235}F_6$ plant feed.

ISOTOPE SEPARATION CASCADE

The preliminary-design plant layout has been prepared according to the principles given by Benedict and Pigford in Reference 7 for an ideal, symmetric cascade, with separation factor independent of composition.

The stage heads-to-feed separation factor, β, is calculated as:

$$\beta = \sqrt{\alpha} = 1.00469$$

The total feed and tails flows are calculated as:

$$F = \frac{X_P - X_W}{X_F - X_W} P = 0.047147 \text{ lb/sec}$$

$$W = \frac{X_P - X_F}{X_F - X_W} P = 0.039779 \text{ lb/sec}$$

Number of stages in the enriching section (including the feed stage) is:

$$n_E \geq \frac{\ln\left(\frac{X_P(1 - X_F)}{X_F\,(1 - X_P)}\right)}{\ln(\beta)} \;;\quad n_E = 327 \text{ stages}$$

Number of stages in the stripping (not including the feed stage) section is:

$$n_S \geq \frac{\ln\left(\frac{X_F(1 - X_W)}{(1 - X_F)X_W}\right)}{\ln(\beta)} - 1 \;;\quad n_S = 224 \text{ stages}$$

Total number of stages is:

$$n = n_E + n_S = 551 \text{ stages}$$

The feed stage is No. 225

The heads flow in stage i of the enriching section is calculated from the equation:

$$L_i' = \left\{ 1 + \frac{1}{\beta - 1} \left[X_P(1 - \beta^{i-n}) + (1 - X_P)\beta(\beta^{n-i} - 1) \right] \right\} P$$

The heads flow in stage j of the stripping section is:

$$L_j' = \frac{W}{\beta - 1} \left[X_W \beta(\beta^j - 1) + (1 - X_W)(1 - \beta^{-j}) \right]$$

where n = total number of stages

The maximum stage inlet flow rate is 11.1075 lb UF_6/sec at the feed stage.

Table 1 presents selected cascade flows and $U^{235}F_6$ assays as functions of the stage number.*

Although the stage tails flow differs slightly from the heads flow in an ideal symmetric cascade with low stage separation factor, the difference is small, so that practically the stages have the same tails and heads flows.

The total cascade flow is calculated as follows by summing the stage heads and tails flows:

$$J_{TOT} = \frac{\beta + 1}{(\beta - 1)\ln(\beta)} \left[W(2X_W - 1) \ln\left(\frac{X_W}{1 - X_W}\right) + P(2W_P - 1) \ln\left(\frac{X_P}{1 - X_P}\right) - F(2X_F - 1) \ln\left(\frac{X_F}{1 - X_F}\right) \right]$$

$$J_{TOT} = 2831.95 \text{ lb/sec of } UF_6 \text{ flow}$$

---

*The nomenclature of the Table 1 printout is as follows:

- i - stage number
- X - inlet assay
- X_i' - heads assay
- X'' - tails assay
- L - inlet flow - lb/sec
- L_i' - heads flow - lb/sec
- L_i'' - tails flow - lb/sec

JET-MEMBRANE DEVICE

The jet nozzle-collector tube assembly can be manufactured in several ways. Two ways are presented here. The first is indicated in Figure 2a; the second in Figure 2b. The first builds the nozzle-collector tube assembly from aluminum extrusions, cut and then assembled between two pipes. These pipes supply the necessary fluorocarbon gas flow. This entire assembly forms the division between the vacuum chamber and the discharge of the enriched heads flow. The extruded nozzle-collector tube parts are cut to 2-cm lengths and then assembled with the spacing balls into the space between the pipes. The pipes have openings to fit the space where the fluorocarbon enters the nozzle assembly. The number of nozzle assemblies required is determined by the flow requirements. According to calculations presented by Grumman and supported by test results, one nozzle assembly 2 cm long will produce 1.988 x 10^{-9} lb/sec flow of enriched UF_6. This means that the smallest flow (product) module "B" needs 37 nozzles each 2 cm long. Since the nozzles are 3 mm apart in the assembly, the 37 nozzles take up 11.12 cm length. The largest module, "D", needs 6968 nozzles. Table 5 shows the minimum and maximum numbers of nozzles in each module. Such a large number of nozzles cannot be assembled in one row between two pipes. A cross network of FC-43 ducts is needed to properly distirubte the jet gas among the nozzle-collector tube assemblies. Figure 2a shows such a cross network.

The total number of nozzles is 7,138,544.

Figure 2b indicates the second way the nozzle-collector tube assemblies can be manufactured. The total nozzle cross-section is etched into a metal foil then the foils are put on top of each other to form the assembly. Pins through the holes provided could be used for proper alignment. The jet gas enters and the headsflow leaves on the sides of the assembly. This fact makes necessary the use of somewhat complicated side tubing to distribute the fluorocarbon and collect the headsflow. The overall arrangement, the number of assemblies, and total number of nozzles can be very similar to those described before.

STAGE PROCESSING MODULE DESIGN

Figure 3 is a flow diagram of the jet-membrane processing modules from the (i - 1)th stage to the (i + 1)th stage. Table 2 itemizes the major components. Figure 4, together with Table 3, gives the pressure and temperature levels at key points in the system for FC-43 carrier gas.

The system design is based on the assumption that each stage consists of one or more processing modules. Each module has the required number of jet-membrane devices consisting of jet nozzles and collector tubes of cross-sectional areas to match exactly the total flow across the stage. The number of jet-membrane devices in any stage is the ratio of the required stage separative capacity to the individual device separative capacity. Each jet-membrane device discharges 0.0001988 lb of UF_6 per sec to the heads stream. Each module has heat exchangers, compressors, and pumps of capacity sufficient for the flow through the module but not necessarily designed to the exact flow rate. The compressors have a surge bypass control device to facilitate startup and to permit the modules to operate at flows below the compressor surge limit. The pumps can operate at any flow rate below rated capacity, and need no bypass control; a simple throttle valve can adjust the flow rate.

The modules are selected to accommodate the required flow rates as follows. Module "A" is designed for twice the cascade product flow rate. Module "B" is designed for the cascade tails flow rate. Module "C" is designed for 5.9 times the "B" flow rate. Module "D" is designed for 5.9 times the "C" flow rate. The smaller "A" modules could be replaced by "B" modules with very little increase in power requirement. It is possible to assign a certain number of any combination of modules to each stage, without dropping below 50% of rated flow, except when a "B" module is replacing an "A" module. Table 4 shows the distribution of module sizes for the cascade stages.

The total module requirement is then as follows:

Size	Number Required
B	60
C	280
D	1177

The total number of each component, except individual jet-membrane devices can now be determined.

PROCESSING MODULE OPERATION

The layout of a typical cascade stage is shown in Figure 3. UF_6 feed gas enters the processing chamber of processing module 1 from aftercooler 4 through the intake valve. The fluorocarbon jet gas is evaporated in boiler 8 and enters the plenum of the processing module.* A mixture containing 0.666

*The jet gas then expands through the jet nozzles forming the jet membrane through which the UF_6 gas diffuses into the collector tubes with the fluorocarbon gas.

mole fraction of enriched UF_6 gas and 0.334 mole fraction of FC-43 gas are drawn from the module collector tubes. The FC-43 is separated from enriched mixture in the condenser-separator 2. UF_6 gas is drawn from the top and the condensed FC-43 liquid is removed at the bottom. This liquid FC-43 will still contain a neglectable amount of dissolved UF_6.*

This gas is compressed to vacuum-chamber pressure by compressor 3. The heads stream from stage i mixes with the tails stream from stage (i + 2) through circulator 5, and after which it is cooled prior to entering stage (i + 1).

The UF_6 tails stream and half of the FC-43 jet gas are cooled in the processing unit. This chamber is designed to provide cooling to condense only the jet gas and thereby separate the jet gas from the gaseous UF_6 tails stream. No appreciable amount of UF_6 is dissolved in the condensed FC-43. This liquefied jet gas is utilized in the preceding stage module so that all dissolved and gaseous UF_6 gas entering the stage has the same $U^{235}F_6$ concentration.**

The gaseous tails stream from stage i is compressed through the circulator 5 and then mixed with the heads stream from the (i - 2) stage below. The circulator pressure ratio is designed to match the resistance of the heat exchangers, pipes and fittings.***

The pressure of the liquid FC-43 from stage i condenser-separator 2 is increased by pump 6 to the boiler pressure pump above. These streams are then mixed and pumped by pump 7 to the pressure of boiler 8 where the liquid is evaporated and fed into the stage (i + 1) stagnation chambers.

FLUID MOTIVE POWER REQUIREMENTS

The total electric power requirements for the gaseous UF_6 streams are as follows:

Compressors	11.7 Megawatts
Circulators	0.63 Megawatts

*The separated gas fraction is mostly UF_6, but also contains 9.473 weight percent of FC-43.

**The gas portion of the tails contains 94.25 weight percent UF_6 and 5.75 weight percent FC-43.

***The liquid fluorocarbon leaving the heat exchangers is pressurized by two pumps: pump 6 is handling the liquid from the condenser 2 while pump 7 is pressurizing the fluid from the processing unit 1. To reduce the heat required for cooling and heating, the fluid is returned into the recuperator portion of each component. The liquid heads stream from the condenser of stage i and the liquid tails stream from the processing unit of stage (i + 2) are mixed and fed into the boiler of stage (i + 1) where it is evaporated and fed into the processing unit of the same stage.

The pumping of condensed FC-43 and dissolved UF_6 requires very little power. Pumps 6 and 7 can be run at the two ends of one motor as described later on. The total electric power requirement for all liquid pumping is about 57 kilowatt for FC-43 (see also Table 11).

THERMAL MANAGEMENT REQUIREMENTS

The total heat input required to evaporate 2468.79 lb/sec total flow of FC-43 is 4.023×10^8 Btu/hr. This power can be electrical, waste heat, or even a heat pump, since the required temperature is only 311.3°F. The heat could be pumped directly from the condensers and aftercoolers by an R-114 coolant-heater system.

The total heat rejection for the condensers and gas intercoolers needed is 4.373×10^8 Btu/hr.

PROCESSING MODULE WITH THE JET MEMBRANE DEVICE

Figure 5 shows the principal sketch of the jet-membrane device as presented in Reference 4 by Grumman Energy Systems. The device is incorporating the process chamber, the stagnation chamber, the jet orifice, the collector probe, and the jet-gas (fluorocarbon) condenser.

The size and basic form of the jet nozzles and the collector tube has been determined by Reference 1. They are longitudinal slots, the jet nozzle surrounding the collector tube. The width of the collector tube is 0.009 cm while the jet nozzle width is 0.010 cm overall. The length of the slots were not defined.

Figure 2 shows a cross section of the nozzle. A length of 2.0 cm has been assumed for each orifice. Reference 5 specifies the minimum distance, S, between orifices to be calculated by the equation:

$$S = 0.8\ D_j\sqrt{\frac{Ps}{Pb}} = 0.98\ D_j = 0.0098\ \text{cm}$$

This value is not practical, the actual distance has to be much larger. The practical value of it has to be determined by the flow of the jet gas to the nozzles to ensure good flow and velocity distribution along the length of the nozzle. This gives a density of one nozzle per centimeter.

The minimum theoretical depth, X_m, of the reaction chamber is also given by Reference 5:

$$X_m = 0.67\ D_j\sqrt{\frac{Ps}{Pb}} = 0.8206\ D_j = 0.025\ \text{cm}$$

The practical value is much larger than this.

The question came up whether an improvement of the separation performance of the device could be achieved by a crossflow arrangement of the nozzles as described in Reference 7 (pages 493 to 495). It shows, in connection with the gaseous-diffusion separator, that if the quality of the gas is not uniform across the surface of the membrane but flows across, thus continously depleting from one end to the other, the integral of the qualities will become higher than that of the original uniform quality. Thus the stage separation factor is improved. A similar system could be employed in connection with the jet membrane device; but the outcome is quite questionable for several reasons:

1. The jet membrane is not a uniform membrane but a series of jet flows. The proper distribution of gas flows is very difficult here. The efficiency of the separation does depend on another (called "Z") factor, which is unknown in the case of the jet membrane. The presently assumed 100 percent efficiency figure and the assumption of the perfect flow distribution is very optimistic.

2. The derivation of the cross-flow analysis has been developed for UF_6 gas alone. In the case of the jet membrane there is the other gas, a condensible fluorocarbon present. In the case of cross-flow system this gas would continuously dilute the UF_6 stream, thus reducing the effectiveness of the diffusion process. It is our opinion that the good distribution of the UF_6- FC-43 gas atmosphere is very important for proper operation of this device to reach the 100% efficiency level as assumed.

The jet nozzle-collector tube assembly can be arranged in many combinations. The total flow across the nozzles must be equal to the theoretical value for the operation of the separation stage. The whole assembly is built according to the modular principle using three module sizes to fit the machinery but the total area of the jet nozzles and collector tubes vary according to the flow requirement of the separation stage. The assumed 1-cm-long jet nozzle orifices having 0.01 cm width and 0.02 cm^2 total area will pass 0.0012507 lb/sec of FC-43 gas expanding from 420 torr to 280 torr pressure. With 33.4 mole percent FC-43 and 66.6 mole percent UF_6 in the reaction chamber, the collector tube will transmit 0.0007173 lb/sec of UF_6 head flow per tube. The minimum head flow is the product output, 0.007368 lb/sec of UF_6. Therefore 10.3 nozzle assemblies are needed in the last jet membrane device in a B size module. Table 5 gives the maximum and minimum numbers of nozzle assemblies in each module jet membrane device.

The arrangement of the processing unit will include the jet membrane device and the condenser for the tails flow of the gases. Many variations are possible in the geometry, generally the processing chamber with the jet membrane is arranged in one end and the condenser-recuperator on the other. The position can be horizontal, vertical, or folded. The unit can be separated into the jet membrane and the condenser or it can be integral. The folded-vertical integral arrangement has been selected as the best for several reasons.

The UF_6 gas will remain on the top in the processing chamber longer, thus giving better distribution across the jets and longer time to diffuse.

The descending part followed by an ascending portion gives better separation to the UF_6 and FC-43 fractions.

The recuperation coils are set in the descending section and the cooling coils in the ascending section.

The sketch of the processing unit is shown in Figure 1. The description of the heat exchanging arrangement and performance is given in the second part of this report.

SELECTION OF JET GAS

Jet gas is the medium which forms the jet membrane by expanding through the nozzle surrounding the heads collection probe. The ideal jet gas should be compatible with UF_6, easily separable from UF_6, and should require low interstage power for boiling and circulating. Two fluorocarbons, FC-43 and FC-75, have been investigated for this purpose.

FC-43 fluorocarbon has been selected for this study because of the relative ease of separation from UF gas by means of simple equipment. Figure 6 shows the calculated phase curves of UF_6-FC-43 and UF_6-FC-75 mixtures at 85 torr pressure. The diagram clearly shows that the FC-43 can be separated by simply cooling and flushing the phases while FC-75 needs distillation. A complication with FC-75 could be caused by the fact that the UF_6 separates into gas and solid phases which must be dissolved by the liquid fluorocarbon. This reduces the allowable percentage of UF_6 in the liquid fluorocarbon phase. The diagram has been calculated for ideal solutions.

COMPRESSORS

The flow diagram of the separation stage, Figure 3, shows the position of compressor 3 in the system. The compressor is placed after condenser 2 and it should recompress the gaseous portion of the low-pressure heads stream up to the pressure needed to feed the gas into the next jet membrane stage.

The composition of the gas mixture leaving the condenser is determined by the temperature, and it is calculated as 94.789 mole percent UF_6 and 5.211 mole percent of FC-43. The temperature is $330.55^{\circ}K$ at 83.64 torr pressure. The gas mixture is assumed to behave as ideal gas having a calculated gas constant of $R = 4.19273$ ft-lb/lb$^{\circ}$R and a gas exponent of $\gamma = 1.056285$.

The pressure limits for the compression were calculated allowing reasonable minimal pressure drops through the heat exchangers, pipes, and fittings. These pressures are as listed in Table 3 for positions 3 and 4 as 83.64 torr for the compressor inlet and 292.74 torr for the discharge. The overall total to static pressure ratio is then 3.5.

Table 1 shows the UF_6 mole fraction of the heads flow for each separation stage. The flow through the compressor should be 1.10464 times this value due to the additional amount of FC-43 fluorocarbon still remaining in the gas.

The ideal compressor would be one which has the best performance exactly at the required stage flow. This means that an individual design would be made and built for every one of the 551 stages. A more practical solution is to utilize modular units thus minimizing design and development effort just as well as manufacturing expenses. The unit compressor will operate at partial flow when lower than design flow is required by the separation stage and multiple units will be used when the flow requirement is higher than the compressor design flow.*

If only one kind of compressor module is used within one separation stage, the minimum partial flow rate of the compressor should be half of the design flow rate. A compressor producing such a high pressure ratio has a narrow operating range: maximum to surge flow ratio. Figure 7 shows the typical compressor performance map at constant speed. It shows that the surge flow is only 90 percent of the maximum flow at 3.5 pressure ratio. Surge control is needed then to operate at flows lower surge flow. A surge Control Device provides automatic recirculation below the surge point. The power required in bypass operation is just as high as the total flow determines useful flow plus the recirculated flow. The average power of compressors operating at various flow rates is calculated as 0.9673 times the power at design point.

Three compressor modules are to be designed, handling flows equivalent to the requirement of the cascade tails flow (B module), 5.9025 times that of the B module (C module) and again 5.9025 times that of the C module (D module). The maximum number of modules used in one separation stage is four. The source of the flows handled by four D module compressors represents the maximum heads flow requirement in the whole system.

The sizing and efficiency calculations of the compressors are performed by an AiResearch computer program well proven by the performance of compressors built by AiResearch. This program optimizes the geometric design of the compressor and then predicts its performance. Table 6 shows the input-output printout of the computation made for the three compressor modules. The rotational speed is the parameter. The speed can be selected to maximize efficiency and to select one which is achievable by an electric motor. In case of the module "D" compressor, the speed of best performance is exactly the speed of a 4-pole, 400-cycle electric motor, 11,600 rpm.

The dimensions and performances of the machinery used in this separation plant are summarized in Tables 8, 9, and 10 for the modules B, C and D, respectively. The first column gives the values for the compressors.

The layout of the compressor modules is visualized as a hermetic design containing the rotor with the impeller and electric motor-rotor running on process fluid foil bearings. The bearing lubricant can be either the surrounding UF_6-FC-43 gas mixture or, much better, the pressurized FC-43 liquid from the pumps. Figure 8 shows a similar compressor assembly built by AiResearch for solar power application showing the hermetic design principle.

* Table 4 shows the system of modules used for each separation stage.

CIRCULATORS

Transferring the gas portion of the tails stream from the jet membrane device to the previous separator stage inlet is the job of the circulator compressor. Item 5 represents the circulator on the system layout in Figure 3.

The circulator handles a gas mixture separated from the liquid FC-43 portion by cooling the tails stream. This gas mixture contains 96.8948 mole percent of UF_6 and 3.1052 mole percent of FC-43 vapor, at 341.67 Kelvin temperature and 275.0 torr pressure. For the circulator design and performance calculations, we assume that it is an ideal gas mixture having a calculated gas constant of $R = 4.27032$ ft-lb/lb°R and a gas exponent $j = 1.0600$.

The working pressures of the circulator are determined by the pressure drop through the heat exchanger portion of the jet-membrane device and the resistance of the pipes and fittings. The discharge flow from the circulator joins the compressor discharge flow. The intake pressure is taken as 270.0 torr and the discharge as 292.74 torr which is equal to the compressor discharge pressure. The overall pressure ratio is then 1.08423.

The flow through the circulator is determined by the tails flow of each stage containing almost all of the UF_6 portion and some FC-43 vapors. The total weight of the flow is 1.061 times the weight flow of the UF_6 head flow of the stage.

The circulator modules are designed the same way as the compressor modules. The three module sizes are then as follows: B module is the smallest, handling a flow equivalent to the waist flow; C module is designed for 5.9025 times more flow than B; and D module is designed for 5.9025 times more than C.

The design configuration of the circulator could be either axial or radial since the pressure ratio is low. The radial or mixed flow design would have an advantage over the axial due to its wider flow range, therefore it is assumed for this investigation. Figure 9 shows the performance of a typical AiResearch circulator compressor at low pressure ratio output. The diagram shows the excellent stability of the output even below half the full flow rate. The power consumption of many compressors operating between full and half flow rate is indicated as 0.782 times that of the power at full flow.

Sizing and efficiency calculations are made by the AiResearch computer program, the same as used for the compressor design. Optimization is made for speed selection also, as shown in the computer output sheet for module D circulator in Table 7.

The dimensions and performances of the circulator modules are given in the second column of Tables 8, 9, and 10.

The layout of the machines are similar to the compressor design shown in Figure 8. It is a hermetic unit running on gas bearings or fluid bearings lubricated by FC-43 liquid.

PUMPS

There are two pumps needed per processing module. Both are feeding the boiler at 430 torr pressure after driving the fluid across the recuperator as seen in system sketch in Figure 3. The fluid handled by the pumps is almost pure FC-43 liquid containing only a small amount of UF_6.

Pump 6 serves the heads stream and is located after condenser 2. The suction pressure of this pump is 83.64 torr and the discharge is 435.0 torr, allowing 5 torr of pressure drop through the condenser pipes. The temperature of the fluid is 135°F at inlet. The flow is dependent on this requirement and changes from module to module.

Pump 7 is located in the tails stream of the jet membrane device. The inlet conditions are 275 torr pressure and 155°F temperature. The discharge pressure is 435 torr allowing 5 torr pressure drop across the recuperator piping.

The maximum flow requirements and the characteristic operational values of both pumps are given in Tables 8, 9, and 10 for modules B, C and D pumps respectively.

Since the pumps need very little power, the two pumps of each module could be combined into one unit. The two impellers of each pump could be mounted one on each end of the shaft of the electric motor.

Figure 10 shows a sketch of such an arrangement. The maximum electric power requirement of each unit is as follows:

Module B - 6.67 watts
Module C - 24.01 watts
Module D - 61.04 watts

Since high specific speed pumps need constant power at part flow operation, the total electric power requirement is calculated to be 57.111 kw of electric current, as it is shown in Table 11 which gives a summary of the power required by each component.

COSTS

The following calculation provides a cost estimate for one 2000-jet cluster assembly for the processing module using aluminum extrusions for the jet clusters.

					Qty.		
Jet (2) Pieces	Each cost		\$ 3.50	x	2000	=	\$ 7,000
Top Plate (1) Piece	Cost per hole		1.75	x	2000	=	3,500
Bottom Plate (1) Piece	Cost per hole		2.75	x	2000	=	5,500
Assembly	100 hrs	x	20.00			=	2,000
Inspect	30 hrs	x	25.00			=	750
							\$18,750
			Contingency (25%)				4,700
			Cost per jet cluster				\$23,450

The cost estimate for tooling (electric-discharge and lathe machines) is calculated as:

Jet tooling	$ 3,500
Top plate tooling	5,000
Bottom plate tooling	8,000
Assembly tooling	2,500
Subtotal	$19,000
Contingency (25%)	4,750
Tooling cost	$23,750

Grumman Energy Systems suggests (reference 9) that the cost of a nozzle built by the photochemical machining technique is 15 cents per cm or 15 cents per nozzle. To achieve such costs, the photoetching process would be completely automated. Sheet nickel would be fed from a roll. It would be cut into 18 cm by 20 cm plates. These plates would be photoetched to produce strips such as shown in Figure 2b. These strips would be stacked and diffusion welded under pressure.

The distributors would be built by some sort of casting process. Analysis of the aultomated process suggests per nozzle costs of roughly one dollar.

REFERENCES

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3. Phone conversation with J. W. Brook of Grumman, 8-18-77.

4. Grumman Staff, "Jet Membrane Uranium Enrichment Process," Mid Term Program Review #2208.

5. J. W. Brook, "The Physical Basis of the Jet Membrane Enrichment Process," Grumman #UE-TR-1, June 1976.

6. J. W. Brook, "Jet Membrane Process for Uranium Enrichment, Economic Analysis," Grumman #RM-611, January 1976.

7. Benedict and Pigford, "Nuclear Chemical Engineering," McGraw-Hill, 1957.

8. R. deWitt, "Uranium Hexafluoride: A Survey of the Physico-Chemical Properties," Goodyear Atomic, GAT-280, August 1960.

9. J. W. Brook, letter of March 1, 1978.

Table 1

IDEAL SYMMETRIC CASCADE WITH JET-MEMBRANE SEPARATION UNIT

α	β	n	m	Feed, lbs/sec	Product, lbs/sec	Waste, lbs/sec	X_F	X_P	X_W
1.009402	1.004690	551	225	.04709678	.00736800	.03972878	.00717000	.03227650	.00251381

n — TOP STAGE NO.; m — FEED STAGE NO.

$\sum_{i=1}^{n} L_i$

2838.285126

i	x_i	x_i'	x_i''	L_i	L_i'	L_i''	$\theta_i = L_i'/L_i$
551	.03213067	.03227650	.03198548	.01476833	.00736800	.00740033	.49890541
550	.03198548	.03213067	.03184092	.02960148	.01476833	.01483315	.49890507
549	.03184092	.03198548	.03169700	.04449978	.02220115	.02229863	.49890474
548	.03169700	.03184092	.03155370	.05946356	.02966663	.02979693	.49890440
547	.03155370	.03169700	.03141103	.07449314	.03716493	.03732821	.49890406
546	.03141103	.03155370	.03126899	.08958884	.04469621	.04489264	.49890373
545	.03126899	.03141103	.03112756	.10475101	.05226064	.05249038	.49890339
544	.03112756	.03126899	.03098676	.11997997	.05985838	.06012160	.49890307
543	.03098676	.03112756	.03084657	.13527606	.06748960	.06778646	.49890274
542	.03084657	.03098676	.03070700	.15063961	.07515446	.07548515	.49890241
541	.03070700	.03084657	.03056804	.16607096	.08285315	.08321781	.49890208
540	.03056804	.03070700	.03042968	.18157044	.09058581	.09098463	.49890175
539	.03042968	.03056804	.03029194	.19713840	.09835263	.09878577	.49890143
538	.03029194	.03042968	.03015480	.21277517	.10615377	.10662140	.49890111
537	.03015480	.03029194	.03001825	.22848110	.11398940	.11449170	.49890079
536	.03001825	.03015480	.02988231	.24425653	.12185970	.12239683	.49890047
535	.02988231	.03001825	.02974697	.26010181	.12976483	.13033698	.49890016
534	.02974697	.02988231	.02961222	.27601729	.13770498	.13831231	.49889984
533	.02961222	.02974697	.02947806	.29200330	.14568031	.14632300	.49889952
532	.02947806	.02961222	.02934449	.30806021	.15369100	.15436922	.49889921
531	.02934449	.02947806	.02921151	.32418837	.16173722	.16245115	.49889889
530	.02921151	.02934449	.02907911	.34038812	.16981915	.17056897	.49889858
529	.02907911	.02921151	.02894730	.35665982	.17793697	.17872285	.49889827
528	.02894730	.02907911	.02881606	.37300383	.18609085	.18691298	.49889797
527	.02881606	.02894730	.02868540	.38942051	.19428098	.19513953	.49889766
526	.02868540	.02881606	.02855532	.40591021	.20250753	.20340268	.49889735
525	.02855532	.02868540	.02842581	.42247330	.21077068	.21170262	.49889705
524	.02842581	.02855532	.02829687	.43911013	.21907062	.22003952	.49889675
523	.02829687	.02842581	.02816850	.45582109	.22740752	.22841357	.49889644
522	.02816850	.02829687	.02804069	.47260652	.23578157	.23682495	.49889614
521	.02804069	.02816850	.02791345	.48946679	.24419295	.24527385	.49889584
520	.02791345	.02804069	.02778677	.50640228	.25264185	.25376044	.49889555
519	.02778677	.02791345	.02766064	.52341337	.26112844	.26228493	.49889525
518	.02766064	.02778677	.02753507	.54050040	.26965293	.27084748	.49889496
517	.02753507	.02766064	.02741006	.55766378	.27821548	.27944830	.49889466
516	.02741006	.02753507	.02728560	.57490385	.28681630	.28808756	.49889437
515	.02728560	.02741006	.02716169	.59222102	.29545556	.29676546	.49889408
514	.02716169	.02728560	.02703832	.60961565	.30413346	.30548219	.49889379
513	.02703832	.02716169	.02691550	.62708813	.31285019	.31423794	.49889350
512	.02691550	.02703832	.02679322	.64463884	.32160594	.32303290	.49889321
511	.02679322	.02691550	.02667148	.66226816	.33040090	.33186726	.49889292
510	.02667148	.02679322	.02655028	.67997648	.33923526	.34074122	.49889264
509	.02655028	.02667148	.02642962	.69776418	.34810922	.34965497	.49889236
508	.02642962	.02655028	.02630949	.71563166	.35702297	.35860870	.49889208
507	.02630949	.02642962	.02618989	.73357932	.36597670	.36760262	.49889179
506	.02618989	.02630949	.02607082	.75160752	.37497062	.37663691	.49889151

Table 1 (continued)

505	.02607082	.02618989	.02595228	.76971669	.38400491	.38571178	.49889123
504	.02595228	.02607082	.02583426	.78790721	.39307978	.39482743	.49889096
503	.02583426	.02595228	.02571676	.80617947	.40219543	.40398405	.49889068
502	.02571676	.02583426	.02559979	.82453389	.41135205	.41318184	.49889041
501	.02559979	.02571676	.02548333	.84297086	.42054984	.42242101	.49889013
500	.02548333	.02559979	.02536739	.86149077	.42978901	.43170176	.49888986
499	.02536739	.02548333	.02525196	.88009406	.43906976	.44102430	.49888959
498	.02525196	.02536739	.02513705	.89878111	.44839230	.45038882	.49888932
497	.02513705	.02525196	.02502264	.91755234	.45775682	.45979552	.49888905
496	.02502264	.02513705	.02490874	.93640815	.46716352	.46924463	.49888878
495	.02490874	.02502264	.02479535	.95534897	.47661263	.47873634	.49888851
494	.02479535	.02490874	.02468246	.97437520	.48610434	.48827086	.49888825
493	.02468246	.02479535	.02457007	.99348727	.49563886	.49784841	.49888799
492	.02457007	.02468246	.02445818	1.01268558	.50521641	.50746918	.49888772
491	.02445818	.02457007	.02434678	1.03197056	.51483718	.51713339	.49888746
490	.02434678	.02445818	.02423588	1.05134264	.52450139	.52684126	.49888721
489	.02423588	.02434678	.02412548	1.07080224	.53420926	.53659299	.49888694
488	.02412548	.02423588	.02401556	1.09034978	.54396099	.54638880	.49888669
487	.02401556	.02412548	.02390613	1.10998569	.55375680	.55622890	.49888643
486	.02390613	.02401556	.02379719	1.12971041	.56359690	.56611351	.49888617
485	.02379719	.02390613	.02368874	1.14952435	.57348151	.57604284	.49888591
484	.02368874	.02379719	.02358076	1.16942796	.58341084	.58601712	.49888566
483	.02358076	.02368874	.02347327	1.18942167	.59338512	.59603656	.49888541
482	.02347327	.02358076	.02336625	1.20950593	.60340456	.60610137	.49888515
481	.02336625	.02347327	.02325971	1.22968116	.61346937	.61621179	.49888491
480	.02325971	.02336625	.02315365	1.24994782	.62357979	.62636803	.49888466
479	.02315365	.02325971	.02304806	1.27030633	.63373603	.63657031	.49888441
478	.02304806	.02315365	.02294293	1.29075716	.64393831	.64681886	.49888416
477	.02294293	.02304806	.02283828	1.31130075	.65418686	.65711390	.49888392
476	.02283828	.02294293	.02273409	1.33193755	.66448190	.66745566	.49888368
475	.02273409	.02283828	.02263037	1.35266802	.67482366	.67784436	.49888343
474	.02263037	.02273409	.02252711	1.37349260	.68521236	.68828024	.49888318
473	.02252711	.02263037	.02242431	1.39441174	.69564824	.69876351	.49888294
472	.02242431	.02252711	.02232196	1.41542591	.70613151	.70929441	.49888270
471	.02232196	.02242431	.02222008	1.43653557	.71666241	.71987317	.49888247
470	.02222008	.02232196	.02211865	1.45774119	.72724117	.73050002	.49888223
469	.02211865	.02222008	.02201767	1.47904320	.73786802	.74117520	.49888199
468	.02201767	.02211865	.02191714	1.50044212	.74854320	.75189893	.49888175
467	.02191714	.02201767	.02181706	1.52193837	.75926693	.76267145	.49888152
466	.02181706	.02191714	.02171743	1.54353245	.77003945	.77349300	.49888128
465	.02171743	.02181706	.02161824	1.56522481	.78086100	.78436382	.49888105
464	.02161824	.02171743	.02151949	1.58701596	.79173182	.79528414	.49888082
463	.02151949	.02161824	.02142119	1.60890634	.80265214	.80625420	.49888058
462	.02142119	.02151949	.02132333	1.63089645	.81362220	.81727425	.49888036
461	.02132333	.02142119	.02122590	1.65298675	.82464225	.82834452	.49888013
460	.02122590	.02132333	.02112891	1.67517775	.83571252	.83946525	.49887990
459	.02112891	.02122590	.02103235	1.69746993	.84683325	.85063669	.49887967
458	.02103235	.02112891	.02093622	1.71986377	.85800469	.86185909	.49887945
457	.02093622	.02103235	.02084053	1.74235977	.86922709	.87313269	.49887922
456	.02084053	.02093622	.02074526	1.76495841	.88050069	.88445773	.49887900
455	.02074526	.02084053	.02065042	1.78766018	.89182573	.89583447	.49887878
454	.02065042	.02074526	.02055600	1.81046560	.90320247	.90726315	.49887855
453	.02055600	.02065042	.02046201	1.83337516	.91463115	.91874402	.49887833
452	.02046201	.02055600	.02036843	1.85638936	.92611202	.93027734	.49887811
451	.02036843	.02046201	.02027528	1.87950869	.93764534	.94186336	.49887789
450	.02027528	.02036843	.02018254	1.90273367	.94923136	.95350233	.49887768
449	.02018254	.02027528	.02009022	1.92606482	.96087033	.96519450	.49887746
448	.02009022	.02018254	.01999831	1.94950263	.97256250	.97694014	.49887724
447	.01999831	.02009022	.01990682	1.97304761	.98430814	.98873949	.49887703
446	.01990682	.01999831	.01981573	1.99670030	.99610749	1.00059282	.49887681

Table 1 (continued)

445	.01981573	.01990682	.01972505	2.02046120	1.00796082	1.01250039	.49887660
444	.01972505	.01981573	.01963478	2.04433084	1.01986839	1.02446246	.49887639
443	.01963478	.01972505	.01954492	2.06830972	1.03183046	1.03647929	.49887618
442	.01954492	.01963478	.01945545	2.09239841	1.04384729	1.04855113	.49887597
441	.01945545	.01954492	.01936639	2.11659738	1.05591913	1.06067827	.49887576
440	.01936639	.01945545	.01927773	2.14090723	1.06804627	1.07286096	.49887555
439	.01927773	.01936639	.01918947	2.16532841	1.08022896	1.08509947	.49887534
438	.01918947	.01927773	.01910160	2.18986151	1.09246747	1.09739406	.49887514
437	.01910160	.01918947	.01901413	2.21450704	1.10476206	1.10974501	.49887494
436	.01901413	.01910160	.01892705	2.23926559	1.11711301	1.12215259	.49887472
435	.01892705	.01901413	.01884036	2.26413763	1.12952059	1.13461707	.49887453
434	.01884036	.01892705	.01875406	2.28912377	1.14198507	1.14713871	.49887432
433	.01875406	.01884036	.01866815	2.31422451	1.15450671	1.15971780	.49887412
432	.01866815	.01875406	.01858262	2.33944041	1.16708580	1.17235462	.49887392
431	.01858262	.01866815	.01849748	2.36477202	1.17972262	1.18504943	.49887372
430	.01849748	.01858262	.01841272	2.39021993	1.19241743	1.19780251	.49887352
429	.01841272	.01849748	.01832834	2.41578466	1.20517051	1.21061415	.49887332
428	.01832834	.01841272	.01824435	2.44146678	1.21798215	1.22348463	.49887312
427	.01824435	.01832834	.01816073	2.46726683	1.23085263	1.23641422	.49887293
426	.01816073	.01824435	.01807748	2.49318543	1.24378222	1.24940321	.49887273
425	.01807748	.01816073	.01799461	2.51922309	1.25677121	1.26245189	.49887253
424	.01799461	.01807748	.01791212	2.54538041	1.26981989	1.27556054	.49887234
423	.01791212	.01799461	.01782999	2.57165796	1.28292854	1.28872944	.49887215
422	.01782999	.01791212	.01774824	2.59805632	1.29609744	1.30195889	.49887196
421	.01774824	.01782999	.01766685	2.62457603	1.30932689	1.31524917	.49887177
420	.01766685	.01774824	.01758583	2.65121773	1.32261717	1.32860058	.49887158
419	.01758583	.01766685	.01750517	2.67798197	1.33596858	1.34201341	.49887139
418	.01750517	.01758583	.01742488	2.70486933	1.34938141	1.35548795	.49887120
417	.01742488	.01750517	.01734495	2.73188043	1.36285595	1.36902449	.49887101
416	.01734495	.01742488	.01726538	2.75901583	1.37639249	1.38262334	.49887082
415	.01726538	.01734495	.01718617	2.78627613	1.38999134	1.39628479	.49887063
414	.01718617	.01726538	.01710731	2.81366193	1.40365279	1.41000914	.49887045
413	.01710731	.01718617	.01702882	2.84117383	1.41737714	1.42379670	.49887026
412	.01702882	.01710731	.01695067	2.86881244	1.43116470	1.43764775	.49887008
411	.01695067	.01702882	.01687288	2.89657834	1.44501575	1.45156261	.49886990
410	.01687288	.01695067	.01679544	2.92447218	1.45893061	1.46554158	.49886971
409	.01679544	.01687288	.01671834	2.95249453	1.47290958	1.47958496	.49886953
408	.01671834	.01679544	.01664160	2.98064601	1.48695296	1.49369307	.49886936
407	.01664160	.01671834	.01656520	3.00892726	1.50106107	1.50786621	.49886918
406	.01656520	.01664160	.01648915	3.03733888	1.51523421	1.52210470	.49886900
405	.01648915	.01656520	.01641344	3.06588152	1.52947270	1.53640884	.49886882
404	.01641344	.01648915	.01633807	3.09455577	1.54377684	1.55077894	.49886864
403	.01633807	.01641344	.01626304	3.12336227	1.55814694	1.56521533	.49886846
402	.01626304	.01633807	.01618835	3.15230164	1.57258333	1.57971832	.49886829
401	.01618835	.01626304	.01611400	3.18137452	1.58708632	1.59428822	.49886812
400	.01611400	.01618835	.01603999	3.21058157	1.60165622	1.60892536	.49886794
399	.01603999	.01611400	.01596631	3.23992342	1.61629336	1.62363006	.49886777
398	.01596631	.01603999	.01589296	3.26940069	1.63099806	1.63840263	.49886759
397	.01589296	.01596631	.01581994	3.29901400	1.64577063	1.65324340	.49886743
396	.01581994	.01589296	.01574726	3.32876408	1.66061140	1.66815270	.49886725
395	.01574726	.01581994	.01567490	3.35865155	1.67552070	1.68313085	.49886708
394	.01567490	.01574726	.01560287	3.38867703	1.69049885	1.69817818	.49886691
393	.01560287	.01567490	.01553116	3.41884118	1.70554618	1.71329502	.49886674
392	.01553116	.01560287	.01545978	3.44914472	1.72066302	1.72848170	.49886658
391	.01545978	.01553116	.01538873	3.47958824	1.73584970	1.74373855	.49886641
390	.01538873	.01545978	.01531799	3.51017246	1.75110655	1.75906592	.49886625
389	.01531799	.01538873	.01524757	3.54089803	1.76643392	1.77446412	.49886608
388	.01524757	.01531799	.01517748	3.57176560	1.78183212	1.78993350	.49886591
387	.01517748	.01524757	.01510770	3.60277590	1.79730150	1.80547440	.49886575
386	.01510770	.01517748	.01503823	3.63392955	1.81284240	1.82108716	.49886559

Table 1 (continued)

385	.01503823	.01510770	.01496909	3.66522726	1.82845516	1.83677212	.49886543
384	.01496908	.01503823	.01490025	3.69666973	1.84414012	1.85252963	.49886526
383	.01490025	.01496908	.01483172	3.72825763	1.85989763	1.86836002	.49886510
382	.01483172	.01490025	.01476351	3.75999165	1.87572802	1.88426365	.49886494
381	.01476351	.01483172	.01469560	3.79187250	1.89163165	1.90024086	.49886478
380	.01469560	.01476351	.01462801	3.82390085	1.90760886	1.91629200	.49886462
379	.01462801	.01469560	.01456072	3.85607743	1.92366000	1.93241743	.49886446
378	.01456072	.01462801	.01449373	3.88840291	1.93978543	1.94861750	.49886431
377	.01449373	.01456072	.01442705	3.92087805	1.95598550	1.96489256	.49886415
376	.01442705	.01449373	.01436067	3.95350352	1.97226056	1.98124297	.49886400
375	.01436067	.01442705	.01429459	3.98628005	1.98861097	1.99766908	.49886383
374	.01429459	.01436067	.01422881	4.01920831	2.00503708	2.01417127	.49886369
373	.01422881	.01429459	.01416333	4.05228913	2.02153927	2.03074988	.49886353
372	.01416333	.01422881	.01409814	4.08552313	2.03811788	2.04740528	.49886338
371	.01409814	.01416333	.01403326	4.11891109	2.05477328	2.06413783	.49886322
370	.01403326	.01409814	.01396866	4.15245372	2.07150583	2.08094791	.49886307
369	.01396866	.01403326	.01390436	4.18615174	2.08831591	2.09783588	.49886293
368	.01390436	.01396866	.01384035	4.22000593	2.10520388	2.11480210	.49886278
367	.01384035	.01390436	.01377664	4.25401706	2.12217010	2.13184696	.49886262
366	.01377664	.01384035	.01371321	4.28818578	2.13921496	2.14897082	.49886247
365	.01371321	.01377664	.01365007	4.32251287	2.15633882	2.16617406	.49886233
364	.01365007	.01371321	.01358721	4.35699910	2.17354206	2.18345706	.49886218
363	.01358721	.01365007	.01352464	4.39164519	2.19082506	2.20082019	.49886203
362	.01352464	.01358721	.01346236	4.42645198	2.20818819	2.21826383	.49886189
361	.01346236	.01352464	.01340036	4.46142018	2.22563183	2.23578837	.49886174
360	.01340036	.01346236	.01333864	4.49655056	2.24315637	2.25339419	.49886159
359	.01333864	.01340036	.01327720	4.53184384	2.26076219	2.27108168	.49886145
358	.01327720	.01333864	.01321604	4.56730086	2.27844968	2.28885121	.49886131
357	.01321604	.01327720	.01315515	4.60292238	2.29621921	2.30670319	.49886116
356	.01315515	.01321604	.01309455	4.63870919	2.31407119	2.32463800	.49886102
355	.01309455	.01315515	.01303422	4.67466199	2.33200600	2.34265604	.49886088
354	.01303422	.01309455	.01297416	4.71078169	2.35002404	2.36075769	.49886074
353	.01297416	.01303422	.01291438	4.74706900	2.36812569	2.37894336	.49886060
352	.01291438	.01297416	.01285487	4.78352481	2.38631136	2.39721345	.49886045
351	.01285487	.01291438	.01279563	4.82014978	2.40458145	2.41556835	.49886031
350	.01279563	.01285487	.01273666	4.85694480	2.42293635	2.43400846	.49886018
349	.01273666	.01279563	.01267796	4.89391065	2.44137646	2.45253419	.49886004
348	.01267796	.01273666	.01261952	4.93104810	2.45990219	2.47114595	.49885990
347	.01261952	.01267796	.01256135	4.96835804	2.47851395	2.48984414	.49885977
346	.01256135	.01261952	.01250345	5.00584131	2.49721214	2.50862918	.49885963
345	.01250345	.01256135	.01244581	5.04349864	2.51599718	2.52750146	.49885949
344	.01244581	.01250345	.01238843	5.08133084	2.53486946	2.54646141	.49885936
343	.01238843	.01244581	.01233131	5.11933881	2.55382941	2.56550945	.49885923
342	.01233131	.01238843	.01227445	5.15752339	2.57287745	2.58464598	.49885909
341	.01227445	.01233131	.01221785	5.19588536	2.59201398	2.60387143	.49885896
340	.01221785	.01227445	.01216151	5.23442560	2.61123943	2.62318622	.49885883
339	.01216151	.01221785	.01210543	5.27314496	2.63055422	2.64259076	.49885869
338	.01210543	.01216151	.01204960	5.31204426	2.64995876	2.66208550	.49885856
337	.01204960	.01210543	.01199403	5.35112429	2.66945350	2.68167085	.49885844
336	.01199403	.01204960	.01193870	5.39038604	2.68903885	2.70134724	.49885830
335	.01193870	.01199403	.01188364	5.42983031	2.70871524	2.72111510	.49885817
334	.01188364	.01193870	.01182882	5.46945792	2.72848310	2.74097486	.49885805
333	.01182882	.01188364	.01177425	5.50926983	2.74834286	2.76092697	.49885791
332	.01177425	.01182882	.01171993	5.54926682	2.76829497	2.78097185	.49885779
331	.01171993	.01177425	.01166586	5.58944976	2.78833985	2.80110995	.49885766
330	.01166586	.01171993	.01161203	5.62981963	2.80847795	2.82134171	.49885754
329	.01161203	.01166586	.01155845	5.67037725	2.82870971	2.84166756	.49885741
328	.01155845	.01161203	.01150512	5.71112347	2.84903556	2.86208796	.49885729
327	.01150512	.01155845	.01145203	5.75205928	2.86945596	2.88260335	.49885716
326	.01145203	.01150512	.01139918	5.79318553	2.88997135	2.90321418	.49885703

Table 1 (continued)

325	.01139918	.01145203	.01134657	5.83450305	2.91058218	2.92392091	.49885691
324	.01134657	.01139918	.01129420	5.87601286	2.93128891	2.94472398	.49885679
323	.01129420	.01134657	.01124207	5.91771579	2.95209198	2.96562305	.49885667
322	.01124207	.01129420	.01119018	5.95961279	2.97299185	2.98662097	.49885654
321	.01119018	.01124207	.01113852	6.00170475	2.99398897	3.00771582	.49885642
320	.01113852	.01119018	.01108710	6.04399264	3.01508382	3.02890885	.49885630
319	.01108710	.01113852	.01103592	6.08647734	3.03627685	3.05020052	.49885618
318	.01103592	.01108710	.01098497	6.12915981	3.05756852	3.07159130	.49885606
317	.01098497	.01103592	.01093425	6.17204094	3.07895930	3.09308165	.49885594
316	.01093425	.01098497	.01088376	6.21512169	3.10044965	3.11467206	.49885582
315	.01088376	.01093425	.01083351	6.25840300	3.12204006	3.13636299	.49885571
314	.01083351	.01088376	.01078348	6.30188584	3.14373099	3.15815491	.49885559
313	.01078348	.01083351	.01073368	6.34557122	3.16552291	3.18004831	.49885547
312	.01073368	.01078348	.01068411	6.38945997	3.18741631	3.20204366	.49885535
311	.01068411	.01073368	.01063477	6.43355310	3.20941166	3.22414145	.49885524
310	.01063477	.01068411	.01058565	6.47785157	3.23150945	3.24634215	.49885512
309	.01058565	.01063477	.01053675	6.52235639	3.25371015	3.26864626	.49885501
308	.01053675	.01058565	.01048808	6.56706846	3.27601426	3.29105426	.49885489
307	.01048808	.01053675	.01043963	6.61198884	3.29842226	3.31356664	.49885478
306	.01043963	.01048808	.01039141	6.65711850	3.32093464	3.33618370	.49885467
305	.01039141	.01043963	.01034340	6.70245838	3.34355190	3.35890653	.49885456
304	.01034340	.01039141	.01029561	6.74800950	3.36627453	3.38173503	.49885444
303	.01029561	.01034340	.01024804	6.79377288	3.38910303	3.40466990	.49885433
302	.01024804	.01029561	.01020069	6.83974952	3.41203790	3.42771163	.49885422
301	.01020069	.01024804	.01015356	6.88594037	3.43507963	3.45086075	.49885410
300	.01015356	.01020069	.01010664	6.93234646	3.45822875	3.47411774	.49885400
299	.01010664	.01015356	.01005994	6.97896886	3.48148574	3.49748313	.49885388
298	.01005993	.01010664	.01001344	7.02580851	3.50485113	3.52095742	.49885378
297	.01001344	.01005994	.00996717	7.07286650	3.52832542	3.54454112	.49885367
296	.00996717	.01001344	.00992110	7.12014383	3.55190912	3.56823476	.49885356
295	.00992110	.00996717	.00987524	7.16764158	3.57560276	3.59203885	.49885345
294	.00987524	.00992110	.00982960	7.21536070	3.59940685	3.61595391	.49885335
293	.00982960	.00987524	.00978416	7.26330233	3.62332191	3.63998047	.49885324
292	.00978416	.00982960	.00973893	7.31146747	3.64734847	3.66411905	.49885313
291	.00973893	.00978416	.00969391	7.35985720	3.67148705	3.68837018	.49885302
290	.00969391	.00973893	.00964910	7.40847254	3.69573818	3.71273439	.49885292
289	.00964910	.00969391	.00960449	7.45731461	3.72010239	3.73721222	.49885282
288	.00960449	.00964910	.00956008	7.50638437	3.74458022	3.76180420	.49885271
287	.00956008	.00960449	.00951588	7.55568302	3.76917220	3.78651087	.49885261
286	.00951588	.00956008	.00947188	7.60521162	3.79387887	3.81133277	.49885250
285	.00947188	.00951588	.00942808	7.65497118	3.81870077	3.83627044	.49885240
284	.00942808	.00947188	.00938448	7.70496285	3.84363844	3.86132443	.49885230
283	.00938448	.00942808	.00934108	7.75518769	3.86869243	3.88649530	.49885220
282	.00934108	.00938448	.00929788	7.80564684	3.89386330	3.91178358	.49885210
281	.00929788	.00934108	.00925488	7.85634136	3.91915158	3.93718983	.49885200
280	.00925488	.00929788	.00921207	7.90727240	3.94455783	3.96271461	.49885190
279	.00921207	.00925488	.00916947	7.95844108	3.97008261	3.98835848	.49885179
278	.00916947	.00921207	.00912705	8.00984848	3.99572648	4.01412200	.49885169
277	.00912705	.00916947	.00908483	8.06149566	4.02149000	4.04000574	.49885160
276	.00908483	.00912705	.00904281	8.11338389	4.04737374	4.06601025	.49885150
275	.00904281	.00908483	.00900097	8.16551435	4.07337825	4.09213612	.49885140
274	.00900097	.00904281	.00895933	8.21788800	4.09950412	4.11838398	.49885130
273	.00895933	.00900097	.00891788	8.27050602	4.12575190	4.14475418	.49885120
272	.00891788	.00895933	.00887662	8.32336962	4.15212218	4.17124754	.49885111
271	.00887662	.00891788	.00883555	8.37647998	4.17861554	4.19786455	.49885101
270	.00883555	.00887662	.00879467	8.42983830	4.20523255	4.22460579	.49885091
269	.00879467	.00883555	.00875397	8.48344564	4.23197379	4.25147186	.49885081
268	.00875397	.00879467	.00871347	8.53730309	4.25883986	4.27846334	.49885073
267	.00871347	.00875397	.00867314	8.59141207	4.28583134	4.30558081	.49885063
266	.00867314	.00871347	.00863301	8.64577365	4.31294881	4.33282489	.49885053

Table 1 (continued)

265	.00863301	.00867314	.00859305	8.70038903	4.34019289	4.36019615	.49885044
264	.00859305	.00863301	.00855328	8.75525928	4.36756415	4.38769520	.49885035
263	.00855328	.00859305	.00851369	8.81038582	4.39506320	4.41532265	.49885025
262	.00851369	.00855328	.00847429	8.86576962	4.42269065	4.44307909	.49885016
261	.00847429	.00851369	.00843506	8.92141223	4.45044709	4.47096514	.49885007
260	.00843506	.00847429	.00839602	8.97731447	4.47833314	4.49898141	.49884998
259	.00839602	.00843506	.00835715	9.03347790	4.50634941	4.52712850	.49884988
258	.00835715	.00839602	.00831846	9.08990347	4.53449650	4.55540704	.49884979
257	.00831846	.00835715	.00827995	9.14659262	4.56277504	4.58381764	.49884970
256	.00827995	.00831846	.00824162	9.20354652	4.59118564	4.61236093	.49884961
255	.00824162	.00827995	.00820346	9.26076639	4.61972893	4.64103753	.49884953
254	.00820346	.00824167	.00816548	9.31825352	4.64840553	4.66984806	.49884944
253	.00816548	.00820346	.00812767	9.37600923	4.67721606	4.69879317	.49884934
252	.00812767	.00816548	.00809004	9.43403459	4.70616117	4.72787348	.49884926
251	.00809004	.00812767	.00805258	9.49233103	4.73524148	4.75708963	.49884917
250	.00805258	.00809004	.00801529	9.55089986	4.76445763	4.78644227	.49884908
249	.00801529	.00805258	.00797817	9.60974228	4.79381027	4.81593202	.49884899
248	.00797817	.00801529	.00794122	9.66885948	4.82330002	4.84555954	.49884891
247	.00794122	.00797817	.00790445	9.72825301	4.85292754	4.87532548	.49884882
246	.00790445	.00794122	.00786784	9.78792393	4.88269348	4.90523049	.49884873
245	.00786784	.00790445	.00783140	9.84787369	4.91259849	4.93527522	.49884865
244	.00783140	.00786784	.00779513	9.90810347	4.94264322	4.96546033	.49884856
243	.00779513	.00783140	.00775902	9.96861470	4.97282833	4.99578648	.49884848
242	.00775902	.00779513	.00772308	10.02940881	5.00315448	5.02625434	.49884839
241	.00772308	.00775902	.00768730	10.09048688	5.03362234	5.05686457	.49884831
240	.00768730	.00772308	.00765169	10.15185034	5.06423257	5.08761784	.49884823
239	.00765169	.00768730	.00761625	10.21350062	5.09498584	5.11851483	.49884814
238	.00761625	.00765169	.00758096	10.27543902	5.12588283	5.14955621	.49884806
237	.00758096	.00761625	.00754584	10.33766687	5.15692421	5.18074266	.49884798
236	.00754584	.00758096	.00751088	10.40018547	5.18811066	5.21207487	.49884790
235	.00751088	.00754584	.00747608	10.46299636	5.21944287	5.24355352	.49884781
234	.00747608	.00751088	.00744144	10.52610075	5.25092152	5.27517930	.49884773
233	.00744144	.00747608	.00740696	10.58950019	5.28254730	5.30695291	.49884765
232	.00740696	.00744144	.00737264	10.65319586	5.31432091	5.33887503	.49884757
231	.00737264	.00740696	.00733848	10.71718931	5.34624303	5.37094637	.49884749
230	.00733848	.00737264	.00730447	10.78148198	5.37831437	5.40316762	.49884741
229	.00730447	.00733848	.00727062	10.84607506	5.41053562	5.43553950	.49884733
228	.00727062	.00730447	.00723692	10.91097021	5.44290750	5.46806272	.49884725
227	.00723692	.00727062	.00720339	10.97616863	5.47543072	5.50073798	.49884718
226	.00720339	.00723692	.00717000	11.04167187	5.50810598	5.53356600	.49884710
225	.00717000	.00720339	.00713677	11.10748136	5.54093400	5.56654746	.49884702
224	.00713677	.00717000	.00710369	11.07918727	5.52681868	5.55236866	.49884694
223	.00710369	.00713677	.00707076	11.05076587	5.51263988	5.53812602	.49884686
222	.00707076	.00710369	.00703799	11.02221644	5.49839724	5.52381924	.49884678
221	.00703799	.00707076	.00700536	10.99353838	5.48409046	5.50944800	.49884671
220	.00700536	.00703799	.00697289	10.96473110	5.46971922	5.49501199	.49884664
219	.00697289	.00700536	.00694057	10.93579400	5.45528320	5.48051089	.49884656
218	.00694057	.00697289	.00690839	10.90672648	5.44078210	5.46594438	.49884648
217	.00690839	.00694057	.00687636	10.87752771	5.42621560	5.45131215	.49884640
216	.00687636	.00690839	.00684448	10.84819722	5.41158336	5.43661387	.49884633
215	.00684448	.00687636	.00681275	10.81873429	5.39688509	5.42184922	.49884625
214	.00681275	.00684448	.00678116	10.78913832	5.38212044	5.40701789	.49884618
213	.00678116	.00681275	.00674972	10.75940859	5.36728910	5.39211954	.49884611
212	.00674972	.00678116	.00671843	10.72954452	5.35239075	5.37715384	.49884604
211	.00671843	.00674972	.00668727	10.69954550	5.33742506	5.36212048	.49884596
210	.00668727	.00671843	.00665626	10.66941071	5.32239170	5.34701912	.49884589
209	.00665626	.00668727	.00662540	10.63913977	5.30729034	5.33184943	.49884581
208	.00662540	.00665626	.00659467	10.60873163	5.29212065	5.31661109	.49884574
207	.00659467	.00662540	.00656409	10.57818604	5.27688230	5.30130374	.49884567
206	.00656409	.00659467	.00653365	10.54750192	5.26157496	5.28592707	.49884560

Table 1 (continued)

205	.00653365	.00656409	.00650335	10.51667893	5.24619829	5.27048073	.49884553
204	.00650335	.00653365	.00647319	10.48571622	5.23075195	5.25496438	.49884546
203	.00647319	.00650335	.00644316	10.45461321	5.21523560	5.23937770	.49884539
202	.00644316	.00647319	.00641328	10.42336917	5.19964891	5.22372032	.49884532
201	.00641328	.00644316	.00638353	10.39198339	5.18399154	5.20799192	.49884525
200	.00638353	.00641328	.00635392	10.36045527	5.16826314	5.19219215	.49884517
199	.00635392	.00638353	.00632445	10.32878399	5.15246336	5.17632065	.49884511
198	.00632445	.00635392	.00629511	10.29696894	5.13659187	5.16037709	.49884504
197	.00629511	.00632445	.00626591	10.26500940	5.12064831	5.14436112	.49884497
196	.00626591	.00629511	.00623684	10.23290467	5.10463234	5.12827238	.49884490
195	.00623684	.00626591	.00620791	10.20065403	5.08854360	5.11211052	.49884484
194	.00620791	.00623684	.00617911	10.16825688	5.07238174	5.09587519	.49884477
193	.00617911	.00620791	.00615044	10.13571239	5.05614641	5.07956604	.49884470
192	.00615044	.00617911	.00612190	10.10301983	5.03983726	5.06318270	.49884463
191	.00612190	.00615044	.00609350	10.07017863	5.02345391	5.04672481	.49884457
190	.00609350	.00612190	.00606523	10.03718805	5.00699603	5.03019203	.49884450
189	.00606523	.00609350	.00603709	10.00404716	4.99046324	5.01358397	.49884443
188	.00603709	.00606523	.00600907	9.97075546	4.97385519	4.99690029	.49884437
187	.00600907	.00603709	.00598119	9.93731213	4.95717151	4.98014062	.49884430
186	.00598119	.00600907	.00595344	9.90371633	4.94041183	4.96330458	.49884424
185	.00595344	.00598119	.00592581	9.86996758	4.92357580	4.94639181	.49884417
184	.00592581	.00595344	.00589831	9.83606493	4.90666303	4.92940195	.49884411
183	.00589831	.00592581	.00587094	9.80200768	4.88967317	4.91233461	.49884404
182	.00587094	.00589831	.00584369	9.76779521	4.87260583	4.89518943	.49884398
181	.00584369	.00587094	.00581657	9.73342657	4.85546065	4.87796602	.49884392
180	.00581657	.00584369	.00578958	9.69890118	4.83823724	4.86066402	.49884385
179	.00578958	.00581657	.00576271	9.66421819	4.82093524	4.84328304	.49884379
178	.00576271	.00578958	.00573596	9.62937689	4.80355426	4.82582271	.49884373
177	.00573596	.00576271	.00570934	9.59437644	4.78609392	4.80828263	.49884367
176	.00570934	.00573596	.00568284	9.55921626	4.76855385	4.79066243	.49884360
175	.00568284	.00570934	.00565646	9.52389526	4.75093365	4.77296172	.49884354
174	.00565646	.00568284	.00563020	9.48841298	4.73323294	4.75518012	.49884348
173	.00563020	.00565646	.00560407	9.45276845	4.71545133	4.73731722	.49884342
172	.00560407	.00563020	.00557805	9.41696107	4.69758844	4.71937266	.49884335
171	.00557805	.00560407	.00555216	9.38098979	4.67964387	4.70134602	.49884329
170	.00555216	.00557805	.00552638	9.34485412	4.66161723	4.68323691	.49884323
169	.00552638	.00555216	.00550073	9.30855298	4.64350813	4.66504495	.49884317
168	.00550073	.00552638	.00547519	9.27208579	4.62531616	4.64676972	.49884311
167	.00547519	.00550073	.00544977	9.23545170	4.60704094	4.62841084	.49884305
166	.00544977	.00547519	.00542447	9.19864988	4.58868205	4.60996789	.49884299
165	.00542447	.00544977	.00539928	9.16167951	4.57023911	4.59144048	.49884294
164	.00539928	.00542447	.00537421	9.12453985	4.55171170	4.57282820	.49884287
163	.00537421	.00539928	.00534926	9.08722997	4.53309941	4.55413063	.49884282
162	.00534926	.00537421	.00532442	9.04974914	4.51440185	4.53534739	.49884276
161	.00532442	.00534926	.00529970	9.01209652	4.49561860	4.51647804	.49884270
160	.00529970	.00532442	.00527509	8.97427142	4.47674925	4.49752218	.49884264
159	.00527509	.00529970	.00525059	8.93627274	4.45779339	4.47847939	.49884258
158	.00525059	.00527509	.00522621	8.89809978	4.43875061	4.45934926	.49884253
157	.00522621	.00525059	.00520194	8.85975182	4.41962047	4.44013136	.49884247
156	.00520194	.00522621	.00517778	8.82122779	4.40040258	4.42082528	.49884241
155	.00517778	.00520194	.00515374	8.78252709	4.38109650	4.40143060	.49884235
154	.00515374	.00517778	.00512980	8.74364865	4.36170182	4.38194688	.49884230
153	.00512980	.00515374	.00510598	8.70459175	4.34221810	4.36237371	.49884224
152	.00510598	.00512980	.00508227	8.66535556	4.32264493	4.34271065	.49884219
151	.00508227	.00510598	.00505866	8.62593913	4.30298187	4.32295727	.49884213
150	.00505866	.00508227	.00503517	8.58634162	4.28322849	4.30311315	.49884208
149	.00503517	.00505866	.00501178	8.54656219	4.26338437	4.28317784	.49884202
148	.00501178	.00503517	.00498850	8.50659990	4.24344906	4.26315091	.49884197
147	.00498850	.00501178	.00496533	8.46645403	4.22342213	4.24303192	.49884191
146	.00496533	.00498850	.00494226	8.42612350	4.20330314	4.22282044	.49884186

Table 1 (continued)

145	.00494226	.00496531	.00491931	8.38560760	4.18309165	4.20251601	.49884181
144	.00491931	.00494226	.00489646	8.34490538	4.16278723	4.18211820	.49884175
143	.00489646	.00491931	.00487371	8.30401587	4.14238941	4.16162655	.49884170
142	.00487371	.00489646	.00485107	8.26293838	4.12189777	4.14104062	.49884164
141	.00485107	.00487371	.00482853	8.22167170	4.10131184	4.12035996	.49884159
140	.00482853	.00485107	.00480610	8.18021524	4.08063118	4.09958412	.49884154
139	.00480610	.00482853	.00478377	8.13856792	4.05985534	4.07871264	.49884149
138	.00478377	.00480610	.00476155	8.09672880	4.03898385	4.05774506	.49884144
137	.00476155	.00478377	.00473943	8.05469716	4.01801628	4.03668092	.49884138
136	.00473943	.00476155	.00471741	8.01247180	3.99695214	4.01551977	.49884133
135	.00471741	.00473943	.00469549	7.97005212	3.97579099	3.99426114	.49884127
134	.00469549	.00471741	.00467367	7.92743689	3.95453236	3.97290456	.49884123
133	.00467367	.00469549	.00465196	7.88462532	3.93317578	3.95144957	.49884118
132	.00465196	.00467367	.00463034	7.84161645	3.91172079	3.92989570	.49884113
131	.00463034	.00465196	.00460883	7.79840934	3.89016692	3.90824247	.49884108
130	.00460883	.00463034	.00458741	7.75500309	3.86851369	3.88648942	.49884102
129	.00458741	.00460883	.00456609	7.71139663	3.84676063	3.86463606	.49884098
128	.00456609	.00458741	.00454487	7.66758913	3.82490727	3.84268191	.49884092
127	.00454487	.00456609	.00452375	7.62357962	3.80295313	3.82062650	.49884087
126	.00452375	.00454487	.00450273	7.57936704	3.78089772	3.79846935	.49884082
125	.00450273	.00452375	.00448181	7.53495049	3.75874057	3.77620996	.49884078
124	.00448181	.00450273	.00446098	7.49032903	3.73648118	3.75384786	.49884073
123	.00446098	.00448181	.00444025	7.44550157	3.71411907	3.73138254	.49884068
122	.00444025	.00446098	.00441961	7.40046728	3.69165376	3.70881353	.49884063
121	.00441961	.00444025	.00439907	7.35522503	3.66908474	3.68614032	.49884058
120	.00439907	.00441961	.00437862	7.30977392	3.64641153	3.66336241	.49884053
119	.00437862	.00439907	.00435827	7.26411295	3.62363363	3.64047932	.49884048
118	.00435827	.00437862	.00433802	7.21824104	3.60075054	3.61749054	.49884044
117	.00433802	.00435827	.00431785	7.17215729	3.57776176	3.59439556	.49884039
116	.00431785	.00433802	.00429778	7.12586063	3.55466678	3.57119389	.49884034
115	.00429778	.00431785	.00427781	7.07935005	3.53146511	3.54788500	.49884030
114	.00427781	.00429778	.00425792	7.03262460	3.50815622	3.52446840	.49884025
113	.00425792	.00427781	.00423813	6.98568314	3.48473962	3.50094357	.49884021
112	.00423813	.00425792	.00421843	6.93852472	3.46121479	3.47730999	.49884016
111	.00421843	.00423813	.00419882	6.89114833	3.43758121	3.45356715	.49884011
110	.00419882	.00421843	.00417930	6.84355289	3.41383837	3.42971452	.49884006
109	.00417930	.00419882	.00415987	6.79573733	3.38998574	3.40575159	.49884002
108	.00415987	.00417930	.00414054	6.74770063	3.36602281	3.38167783	.49883997
107	.00414054	.00415987	.00412129	6.69944173	3.34194905	3.35749272	.49883993
106	.00412129	.00414054	.00410213	6.65095961	3.31776393	3.33319571	.49883988
105	.00410213	.00412129	.00408306	6.60225320	3.29346693	3.30878629	.49883984
104	.00408306	.00410213	.00406407	6.55332142	3.26905751	3.28426392	.49883979
103	.00406407	.00408306	.00404518	6.50416315	3.24453513	3.25962805	.49883975
102	.00404518	.00406407	.00402637	6.45477742	3.21989927	3.23487816	.49883970
101	.00402637	.00404518	.00400765	6.40516305	3.19514938	3.21001369	.49883966
100	.00400765	.00402637	.00398902	6.35531902	3.17028491	3.18503412	.49883962
99	.00398902	.00400765	.00397047	6.30524415	3.14530533	3.15993887	.49883958
98	.00397047	.00398902	.00395201	6.25493747	3.12021009	3.13472742	.49883953
97	.00395201	.00397047	.00393363	6.20439780	3.09499864	3.10939920	.49883949
96	.00393363	.00395201	.00391534	6.15362406	3.06967042	3.08395367	.49883945
95	.00391534	.00393363	.00389714	6.10261512	3.04422489	3.05839026	.49883940
94	.00389714	.00391534	.00387902	6.05136985	3.01866148	3.03270841	.49883936
93	.00387902	.00389714	.00386098	5.99988717	2.99297963	3.00690757	.49883932
92	.00386098	.00387902	.00384302	5.94816595	2.96717879	2.98098717	.49883927
91	.00384302	.00386098	.00382515	5.89620501	2.94125839	2.95494663	.49883923
90	.00382515	.00384302	.00380736	5.84400320	2.91521785	2.92878540	.49883919
89	.00380736	.00382515	.00378966	5.79155946	2.88905662	2.90250290	.49883915
88	.00378966	.00380736	.00377203	5.73887265	2.86277411	2.87609854	.49883911
87	.00377203	.00378966	.00375449	5.68594152	2.83636976	2.84957176	.49883907
86	.00375449	.00377203	.00373703	5.63276494	2.80984298	2.82292198	.49883902

Table 1 (continued)

85	.00373703	.00375449	.00371965	5.57934177	2.78319320	2.79614860	.49883898
84	.00371965	.00373703	.00370235	5.52567083	2.75641982	2.76925105	.49883895
83	.00370235	.00371965	.00368513	5.47175097	2.72952227	2.74222873	.49883891
82	.00368513	.00370235	.00366799	5.41758096	2.70249995	2.71508106	.49883886
81	.00366799	.00368513	.00365093	5.36315966	2.67535228	2.68780744	.49883883
80	.00365093	.00366799	.00363395	5.30848587	2.64807865	2.66040726	.49883879
79	.00363395	.00365093	.00361705	5.25355840	2.62067848	2.63287994	.49883875
78	.00361705	.00363395	.00360023	5.19837600	2.59315116	2.60522487	.49883870
77	.00360023	.00361705	.00358348	5.14293748	2.56549609	2.57744144	.49883867
76	.00358348	.00360023	.00356681	5.08724171	2.53771266	2.54952905	.49883862
75	.00356681	.00358348	.00355022	5.03128731	2.50980027	2.52148708	.49883859
74	.00355022	.00356681	.00353371	4.97507322	2.48175830	2.49331492	.49883855
73	.00353371	.00355022	.00351727	4.91859806	2.45350614	2.46501196	.49883851
72	.00351727	.00353371	.00350091	4.86186069	2.42528318	2.43657757	.49883847
71	.00350091	.00351727	.00348462	4.80485988	2.39684879	2.40801113	.49883844
70	.00348462	.00350091	.00346841	4.74759436	2.36828235	2.37931202	.49883839
69	.00346841	.00348462	.00345228	4.69006282	2.33958324	2.35047961	.49883836
68	.00345228	.00346841	.00343622	4.63226408	2.31075082	2.32151326	.49883832
67	.00343622	.00345228	.00342023	4.57419682	2.28178448	2.29241234	.49883828
66	.00342023	.00343622	.00340432	4.51585978	2.25268356	2.26317622	.49883824
65	.00340432	.00342023	.00338848	4.45725167	2.22344744	2.23380426	.49883821
64	.00338848	.00340432	.00337272	4.39837128	2.19407548	2.20429581	.49883817
63	.00337272	.00338848	.00335702	4.33921719	2.16456702	2.17465022	.49883814
62	.00335702	.00337272	.00334141	4.27978826	2.13492144	2.14486685	.49883810
61	.00334141	.00335702	.00332586	4.22008306	2.10513807	2.11494504	.49883806
60	.00332586	.00334141	.00331039	4.16010040	2.07521626	2.08488415	.49883802
59	.00331039	.00332586	.00329498	4.09983885	2.04515537	2.05468351	.49883799
58	.00329498	.00331039	.00327965	4.03929716	2.01495472	2.02434245	.49883795
57	.00327965	.00329498	.00326439	3.97847399	1.98461367	1.99386033	.49883791
56	.00326439	.00327965	.00324920	3.91736799	1.95413154	1.96323646	.49883788
55	.00324920	.00326439	.00323408	3.85597783	1.92350768	1.93247018	.49883784
54	.00323408	.00324920	.00321904	3.79430220	1.89274140	1.90156082	.49883781
53	.00321904	.00323408	.00320406	3.73233971	1.86183203	1.87050769	.49883777
52	.00320406	.00321904	.00318915	3.67008901	1.83077891	1.83931012	.49883774
51	.00318915	.00320406	.00317431	3.60754874	1.79958134	1.80796743	.49883771
50	.00317431	.00318915	.00315954	3.54471755	1.76823865	1.77647893	.49883767
49	.00315954	.00317431	.00314483	3.48159406	1.73675014	1.74484392	.49883763
48	.00314483	.00315954	.00313020	3.41817686	1.70511514	1.71306172	.49883760
47	.00313020	.00314483	.00311563	3.35446456	1.67333294	1.68113164	.49883756
46	.00311563	.00313020	.00310113	3.29045582	1.64140286	1.64905297	.49883753
45	.00310113	.00311563	.00308670	3.22614917	1.60932418	1.61682500	.49883750
44	.00308670	.00310113	.00307234	3.16154325	1.57709622	1.58444704	.49883746
43	.00307234	.00308670	.00305804	3.09663662	1.54471826	1.55191838	.49883743
42	.00305804	.00307234	.00304381	3.03142789	1.51218960	1.51923830	.49883740
41	.00304381	.00305804	.00302964	2.96591559	1.47950952	1.48640609	.49883736
40	.00302964	.00304381	.00301554	2.90009832	1.44667730	1.45342102	.49883733
39	.00301554	.00302964	.00300151	2.83397460	1.41369224	1.42028239	.49883730
38	.00300151	.00301554	.00298754	2.76754305	1.38055360	1.38698945	.49883726
37	.00298754	.00300151	.00297363	2.70080215	1.34726067	1.35354149	.49883723
36	.00297363	.00298754	.00295979	2.63375044	1.31381270	1.31993776	.49883720
35	.00295979	.00297363	.00294602	2.56638652	1.28020898	1.28617754	.49883717
34	.00294602	.00295979	.00293230	2.49870884	1.24644876	1.25226009	.49883713
33	.00293230	.00294602	.00291866	2.43071595	1.21253131	1.21818466	.49883710
32	.00291866	.00293230	.00290507	2.36240637	1.17845588	1.18395051	.49883707
31	.00290507	.00291866	.00289155	2.29377860	1.14422172	1.14955688	.49883704
30	.00289155	.00290507	.00287809	2.22483110	1.10982810	1.11500303	.49883701
29	.00287809	.00289155	.00286469	2.15556243	1.07527424	1.08028819	.49883697
28	.00286469	.00287809	.00285136	2.08597100	1.04055941	1.04541161	.49883695
27	.00285136	.00286469	.00283809	2.01605535	1.00568283	1.01037253	.49883691
26	.00283809	.00285136	.00282487	1.94581391	.97064375	.97517017	.49883688

Table 1 (continued)

25	.00282487	.00283809	.00281173	1.87524515	.93544139	.93980377	.49883685
24	.00281173	.00282487	.00279864	1.80434753	.90007499	.90427255	.49883682
23	.00279864	.00281173	.00278561	1.73311950	.86454377	.86857574	.49883679
22	.00278561	.00279864	.00277264	1.66155949	.82884696	.83271255	.49883676
21	.00277264	.00278561	.00275973	1.58966595	.79298376	.79668219	.49883673
20	.00275973	.00277264	.00274689	1.51743729	.75695341	.76048389	.49883670
19	.00274689	.00275973	.00273410	1.44487193	.72075510	.72411684	.49883667
18	.00273410	.00274689	.00272137	1.37196830	.68438805	.68758025	.49883664
17	.00272137	.00273410	.00270870	1.29872477	.64785146	.65087332	.49883661
16	.00270870	.00272137	.00269609	1.22513977	.61114453	.61399524	.49883658
15	.00269609	.00270870	.00268354	1.15121166	.57426646	.57694522	.49883655
14	.00268354	.00269609	.00267105	1.07693885	.53721643	.53972243	.49883652
13	.00267105	.00268354	.00265861	1.00231971	.49999365	.50232606	.49883649
12	.00265861	.00267105	.00264623	.92735258	.46259728	.46475530	.49883646
11	.00264623	.00265861	.00263391	.85203586	.42502652	.42700932	.49883643
10	.00263391	.00264623	.00262165	.77636784	.38728054	.38908730	.49883641
9	.00262165	.00263391	.00260944	.70034691	.34935852	.35098840	.49883638
8	.00260944	.00262165	.00259729	.62397140	.31125962	.31271179	.49883635
7	.00259729	.00260944	.00258520	.54723964	.27298301	.27425663	.49883632
6	.00258520	.00259729	.00257316	.47014994	.23452785	.23562209	.49883629
5	.00257316	.00258520	.00256118	.39270062	.19589331	.19680731	.49883626
4	.00256118	.00257316	.00254926	.31488997	.15707853	.15781144	.49883624
3	.00254926	.00256118	.00253739	.23671630	.11808266	.11863364	.49883621
2	.00253739	.00254926	.00252557	.15817790	.07890486	.07927304	.49883618
1	.00252557	.00253739	.00251381	.07927304	.03954426	.03972878	.49883615

TABLE 2

FLOW SYSTEM

1. Processing Module containing Jet-Membrane Device
2. Condenser-Separator
3. Compressor (Pressure Ratio = 3.5)
4. Aftercooler
5. Circulator (Pressure Ratio = 1.085)
6. Pump (FC-Fluid)
7. Pump (Boiler Feed - FC-Fluid)
8. Boiler
9. Valves

TABLE 3

PRESSURES AND TEMPERATURES

A. Collector Tube Circuit (UF_6 Circuit)

Position	P (torr)	T (Kelvin)
0	P = 280* torr	T = 398.6519 Kelvin
1	88.5*	397.0 (1)
2	85.64	397.0
3	83.64	330.556
4	292.74	358.8131 (2)
5	291.78	351.22
6	285.88	351.22
7	275.0	341.667
8	270.0	341.667
9	420.0*	428.5

B. FC-43 Circuit

Position	P (torr)	T (Kelvin)
10	85.64	330.556
11	275.0	341.667
12	435.0	330.556
13	435.0	398.890
14	422.0	430.0
9	420.0*	428.5

Notes: *As specified.

(1) Assumed Joule-Thompson expansion total temperature.

(2) For the largest modules.

TABLE 4

DISTRIBUTION OF MODULES FOR SEPARATION STAGES

STAGES	MODULE	NUMBER OF MODULES IN PARALLEL
<u>Enriching</u>		
547 - 551	B	1
542 - 546	B	2
537 - 541	B	3
532 - 536	B	4
523 - 531	C	1
496 - 522	C	2
473 - 495	C	3
451 - 472	C	4
416 - 450	D	1
332 - 415	D	2
272 - 331	D	3
225 - 271	D	4
<u>Stripping</u>		
144 - 224	D	4
85 - 143	D	3
39 - 84	D	2
26 - 38	D	1
19 - 25	C	4
13 - 18	C	3
7 - 12	C	2
5 - 6	C	1
4	B	4
3	B	3
2	B	2
1	B	1

TABLE 5

NUMBER OF NOZZLE ASSEMBLIES REQUIRED
IN THE JET-MEMBRANE DEVICE

MODULE SIZE	NUMBER OF NOZZLE ASSEMBLIES MINIMUM	MAXIMUM
B	37.0	200.00
C	590.28	1180.52
D	3484.02	6968.00

TABLE 6

COMPRESSOR CHARACTERISTICS

UF6 COMPRESSOR - R-MODULE

COMPRESSOR PRESSURE RATIO = 3.500

GAMMA = 1.056
TO = 595.00 DEG. R
QAD = .5000

GAS CONSTANT = 4.193
PO = 1.62 PSIA
IMP. EFFICIENCY = .8300
U2 = 456.03

VISCOSITY = 9.050 * 0.000001 LB/SEC-FT
FLOW = .044 LBS/SEC
HO = 3231.9 FT-LB/LB

RPM	NS	D2	RE	DI	C2M	B2	E-MWI	HP	MI
50000.	.0987	2.0903	819455.	.9017	90.37	.0487	.7088	.3642	.7818
60000.	.1185	1.7419	682879.	.8379	103.24	.0519	.6986	.3695	.8723
70000.	.1382	1.4931	585325.	.7860	116.10	.0547	.6819	.3786	.9551

FOR RPM = 80000. THE SPECIFIC SPEED IS .1580 CASE NOT CALCULATED.

RPM	Revolutions per minute
NS	Specific speed
D2	Impeller tip diameter, inches
RE	Reynolds number
DI	Inlet diameter, inches
C2M	Radial velocity at impeller tip, ft/sec
B2	Impeller tip width, inches
E-MWI	Estimate of compressor efficiency
HP	Horsepower
MI	Actual Mach number at impeller inlet
TO	Inlet total temperature, °R
QAD	Adiabatic head coefficient
PO	Inlet total pressure, psia
U2	Rotational tip speed, ft/sec
HO	Adiabatic heat, ft

TABLE 6 (Continued)

UF6 COMPRESSOR - C-MODULE

COMPRESSOR PRESSURE RATIO = 3.500

GAMMA = 1.056
TO = 595.00 DEG. R
OAD = .5000

GAS CONSTANT = 4.193
PO = 1.62 PSIA
IMP. EFFICIENCY = .8600
U2 = 456.03

VISCOSITY = 9.050 * 0.000001 LB/SEC-FT
FLOW = .259 LBS/SEC
HO = 3231.9 FT-LB/LB

RPM	NS	D2	RE	DI	C2M	B2	E-MWI	HP	MI
15000.	.0720	6.9677	2731516.	2.4746	72.93	.1015	.7522	2.0257	.6432
20000.	.0959	5.2258	2048637.	2.2155	88.56	.1131	.7731	1.9709	.7683
23300.	.1118	4.4856	1758486.	2.0846	98.87	.1194	.7779	1.9588	.8426
30000.	.1439	3.4838	1365758.	1.8773	119.81	.1304	.7725	1.9724	.9778

E2-28

UF6 COMPRESSOR - D-MODULE

COMPRESSOR PRESSURE RATIO = 3.500

GAMMA = 1.056
TO = 595.00 DEG. R
OAD = .5000

GAS CONSTANT = 4.193
PO = 1.62 PSIA
IMP. EFFICIENCY = .8800
U2 = 456.03

VISCOSITY = 9.050 * 0.000001 LB/SEC-FT
FLOW = 1.531 LBS/SEC
HO = 3231.9 FT-LB/LB

RPM	NS	D2	RE	DI	C2M	B2	E-MWI	HP	MI
7800.	.0909	13.3994	5252915.	5.4974	85.28	.2633	.7938	11.3304	.7434
10000.	.1165	10.4515	4097273.	4.9795	101.98	.2877	.8057	11.1626	.8639
11600.	.1352	9.0099	3532132.	4.6829	114.13	.3031	.8074	11.1388	.9429
12750.	.1486	8.1973	3213548.	4.4990	122.86	.3135	.8057	11.1629	.9960

TABLE 7

CIRCULATOR CHARACTERISTICS

UF6 CIRCULATOR - B-MODULE.

COMPRESSOR PRESSURE RATIO = 1.084

GAMMA = 1.060
TO = 615.00 DEG. R
OAD = .4600

GAS CONSTANT = 4.270 ft/°R
PO = 5.32 PSIA
IMP. EFFICIENCY = .8400
U2 = 122.06

VISCOSITY = 9.250 * 0.000001 LB/SEC-FT
FLOW = .042 LBS/SEC
HO = 213.0 FT-LB/LB

RPM	NS	D2	RE	DI	C2M	B2	E-MWI	HP	MI
10000.	.0842	2.7973	896857.	1.0921	21.65	.1103	.8361	.0195	.1839
11600.	.0977	2.4115	773152.	1.0387	24.00	.1155	.8303	.0197	.2029
14000.	.1179	1.9981	640612.	.9747	27.52	.1217	.8162	.0200	.2298
17500.	.1473	1.5985	512489.	.9034	32.66	.1284	.7908	.0207	.2662

UF6 CIRCULATOR - C-MODULE.

COMPRESSOR PRESSURE RATIO = 1.084

GAMMA = 1.060
TO = 615.00 DEG. R
OAD = .4600

GAS CONSTANT = 4.270 ft/°R
PO = 5.32 PSIA
IMP. EFFICIENCY = .8700
U2 = 122.06

VISCOSITY = 9.250 * 0.000001 LB/SEC-FT
FLOW = .249 LBS/SEC
HO = 213.0 FT-LB/LB

RPM	NS	D2	RE	DI	C2M	B2	E-MWI	HP	MI
4000.	.0818	6.9933	2242141.	2.6789	21.24	.2647	.8766	.1100	.1804
5000.	.1023	5.5946	1793713.	2.4845	24.81	.2836	.8824	.1093	.2092
6000.	.1227	4.6622	1494761.	2.3357	28.37	.2979	.8823	.1093	.2360
7000.	.1432	3.9962	1281224.	2.2163	31.94	.3092	.8790	.1097	.2613

TABLE 7 (Continued)

UF6 CIRCULATOR - D-MODULE.

COMPRESSOR PRESSURE RATIO = 1.084

GAMMA = 1.060
TO = 615.00 DEG. R
QAD = .4600

GAS CONSTANT = 6.270 ft/°R
PO = 5.32 PSIA
IMP. EFFICIENCY = .8900
U2 = 122.06

VISCOSITY = 9.250 * 0.000001 LB/SEC-FT
FLOW = 1.470 LBS/SEC
HQ = 213.0 FT-LB/LB

RPM	NS	D2	RE	D1	C2M	B2	E-MW1	HP	M1
2000.	.0994	13.9866	4484283.	6.0947	24.30	.6823	.8961	.6354	.2052
2500.	.1242	11.1893	3587426.	5.6510	28.63	.7249	.9004	.6323	.2379
2800.	.1391	9.9904	3203059.	5.4373	31.23	.7451	.9015	.6316	.2564
3000.	.1491	9.3244	2989522.	5.3109	32.97	.7569	.9018	.6313	.2683

TABLE 8

SUMMARY OF C SIZE MACHINERY

	COMPRESSOR	CIRCULATOR	PUMP 1	PUMP 2	DIMENSIONS
Weight flow	0.2593	0.24907	0.19953	0.20976	lb/sec
Volume flow	2.7775	0.85431	-	-	CFS
	-	-	0.7955	0.8482	GPM
Inlet pressure	83.62	269.92	83.64	275.0	Torr
Discharge pressure	292.67	292.67	435.0	435.0	Torr
Inlet temperature	330.56	341.67	330.56	341.67	Kelvin
Pressure ratio	3.5	1.0843	-	-	
Pressure rise	-	-	6.796	3.095	Psid
Head	3231.9	213.0	8.6982	4.015	ft lb/lb
Speed	23,300	5000	7800	7800	RPM
Specification speed	0.1118	0.1023	1377	2533	
Impeller diameter	4.486	5.595	0.696	0.512	Inch
Reynolds number	1.76×10^6	1.794×10^6	0.1022×10^6	0.070×10^6	
Efficiency	77.8	88.2	60.0	54.6	Percent
Power**	1.959	0.1093	0.00677	0.00281	Horsepower
Electric power**	1.810	0.1384	-	24.01*	Kilowatts

*Both pumps on one motor, watts
**At design point

TABLE 9

SUMMARY OF D SIZE MACHINERY

	COMPRESSOR	CIRCULATOR	PUMP 1	PUMP 2	DIMENSIONS
Weight flow	1.53059	1.47012	1.1777	1.2381	Lb/sec
Volume flow	16.395	5.0425	-	-	CFS
	-	-	4.6955	5.006	GPM
Inlet pressure	83.62	269.92	83.64	275	Torr
Discharge pressure	292.67	292.67	435.0	435.0	Torr
Inlet temperature	330.56	341.67	330.56	341.67	Kelvin
Pressure ratio	3.5	1.0843	-	-	
Pressure rise	-	-	6.796	3.095	Psid
Head	3231.9	213.0	8.6982	4.015	Ft lb/lb
Speed	11,600	2800	3500	3500	RPM
Specification speed	0.1352	0.1391	1497.4	2761.0	
Impeller diameter	9.010	9.991	1.582	1.158	Inch
Reynolds number	3.532×10^6	3.20×10^6	0.237×10^6	0.1605×10^6	
Efficiency	80.74	90.1	76.0	70.8	Percent
Power**	11.139	0.6316	0.0314	0.0128	Horsepower
Electric power**	9.830	0.6440	-	61.04*	Kilowatts

*Both pumps on one motor, watts
**At design point

TABLE 10

SUMMARY OF B SIZE MACHINERY

	COMPRESSOR	CIRCULATOR	PUMP 1	PUMP 2	DIMENSIONS
Weight flow	0.04393	0.042201	0.3380	0.03554	Lb/sec
Volume flow	0.47056	0.14474	-	-	CFS
	-	-	0.13476	0.14371	GPM
Inlet pressure	83.62	275.0	83.64	275.0	Torr
Discharge pressure	292.67	298.20	435.0	435.0	Torr
Inlet temperature	330.56	341.67	330.56	341.67	Kelvin
Pressure ratio	3.5	1.0843	-	-	
Pressure rise	-	-	6.796	3.095	Psid
Head	3231.9	213.0	8.6982	4.015	Ft lb/lb
Speed	50,000	11,600	23,000	23,000	RPM
Specification speed	0.987	0.977	1666.6	3047.1	
Impeller diameter	2.091	2.412	0.244	0.180	Inch
Reynolds number	0.8195×10^6	0.773×10^6	0.37×10^6	0.0254×10^6	
Efficiency	70.88	83.0	47.0	32.7	Percent
Power**	0.3642	0.020	0.00114	0.00065	Horsepower
Electric power	0.3812	0.060	-	6.67*	Kilowatts

*Both pumps on one motor, watts
**At design point

TABLE 11

MACHINERY POWER

SIZE	D	C	B	
Number of Modules	1177	280	60	
Power at Design Point				
Compressor	9.830	1.810	0.3812	
Circulator	0.644	0.1384	0.060	
Pumps	0.06104	0.0024	0.0067	
Part Load Power				Overall:
Compressor	9.5068	1.7510	0.3688	11,704.03
Circulator	0.5037	0.1083	0.0470	626.00
Pumps	0.0478	0.0019	0.0053	57.111
Total part load power	10.0601	1.8612	0.4211	
Total power for plant	11,840.74	521.136	25.266	

Overall power required = 12,387.14 kW

All values are in kW of electric power.

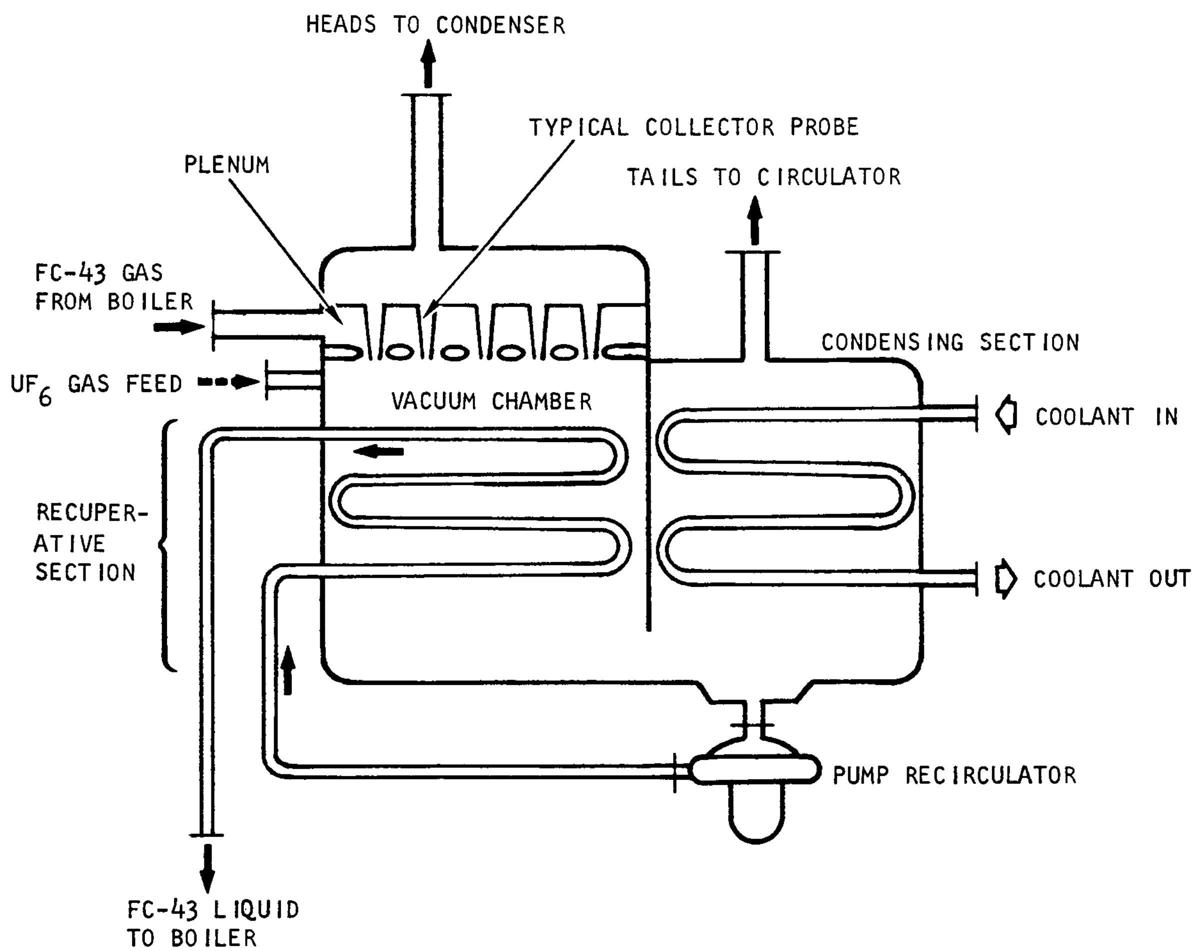


FIGURE 1. JET-MEMBRANE DEVICE PROCESSING MODULE

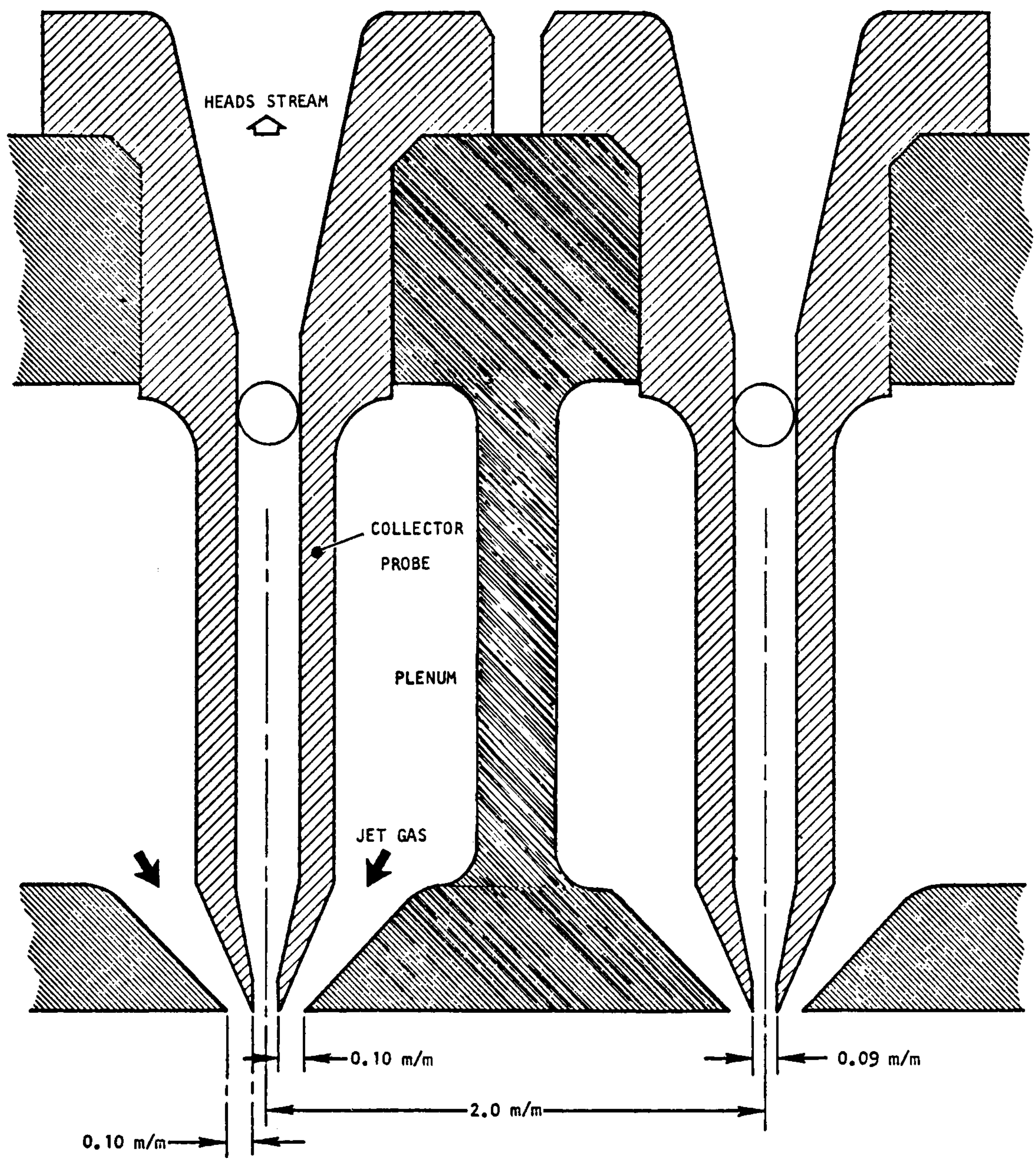


FIGURE 2a. JET-MEMBRANE DEVICE

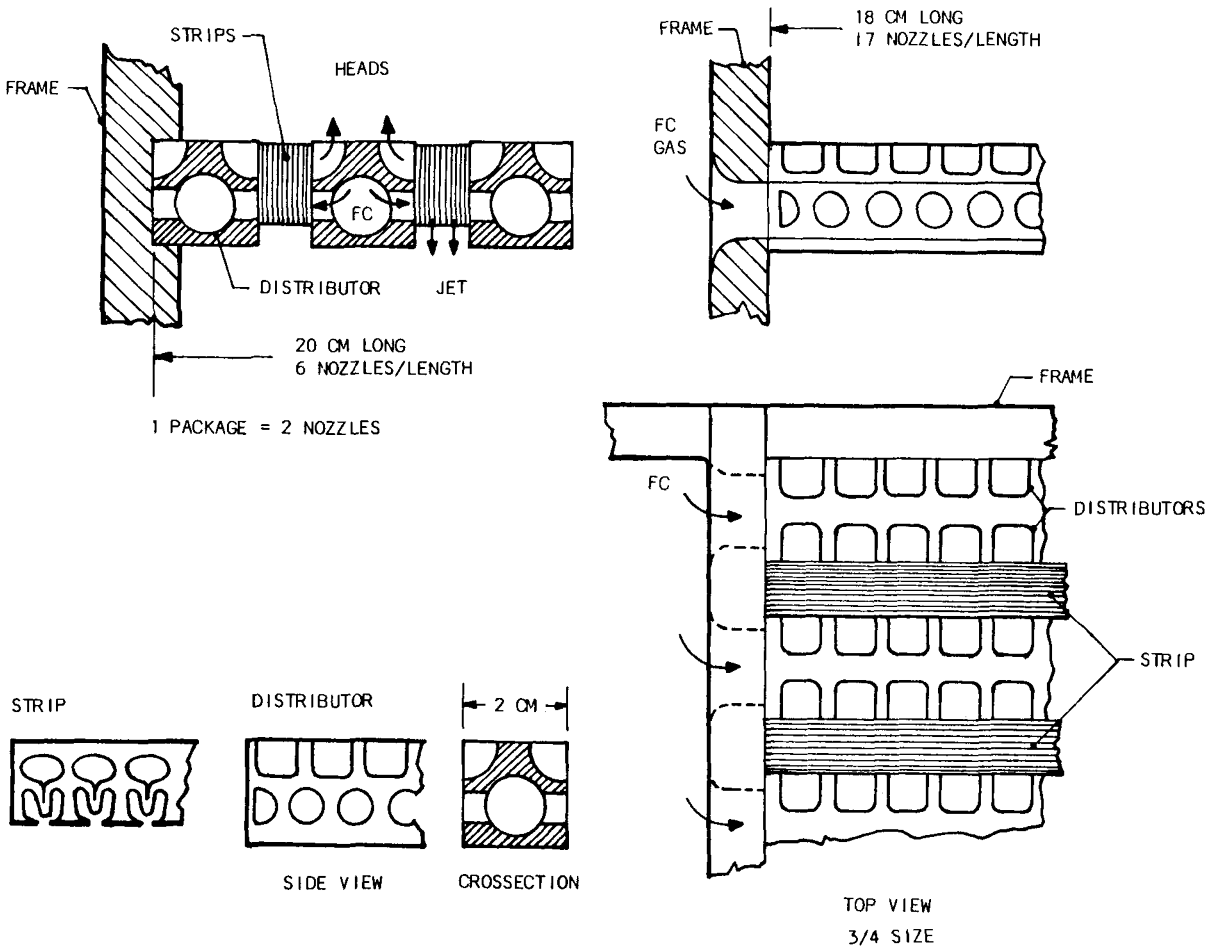


Exhibit 2b. JET MEMBRANE DEVICE SKETCH

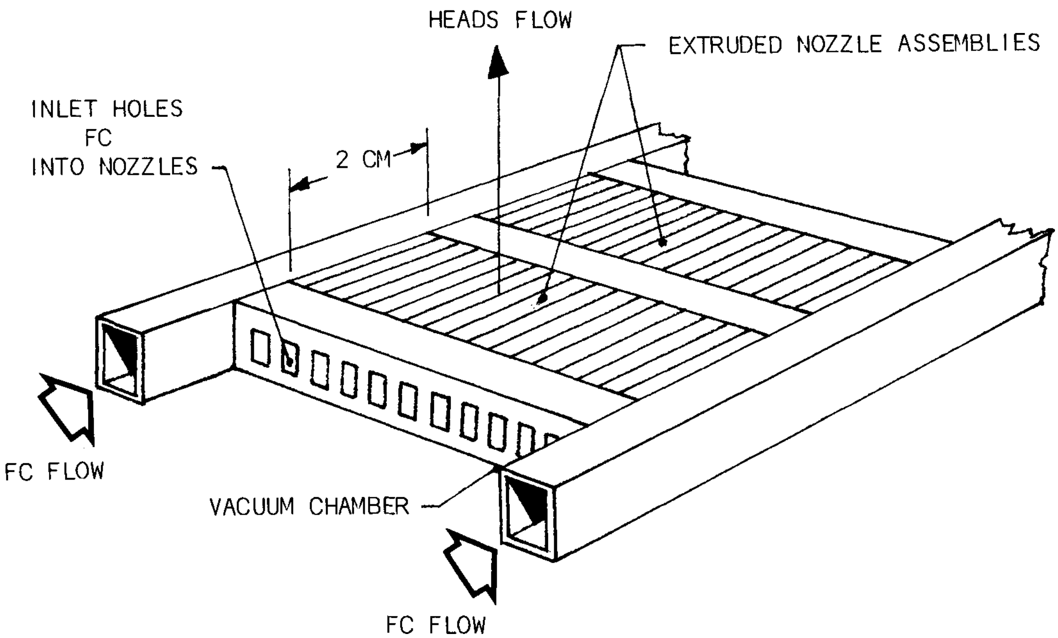


FIGURE 2c. PRINCIPLE OF THE JET-MEMBRANE ASSEMBLY CROSS NETWORK

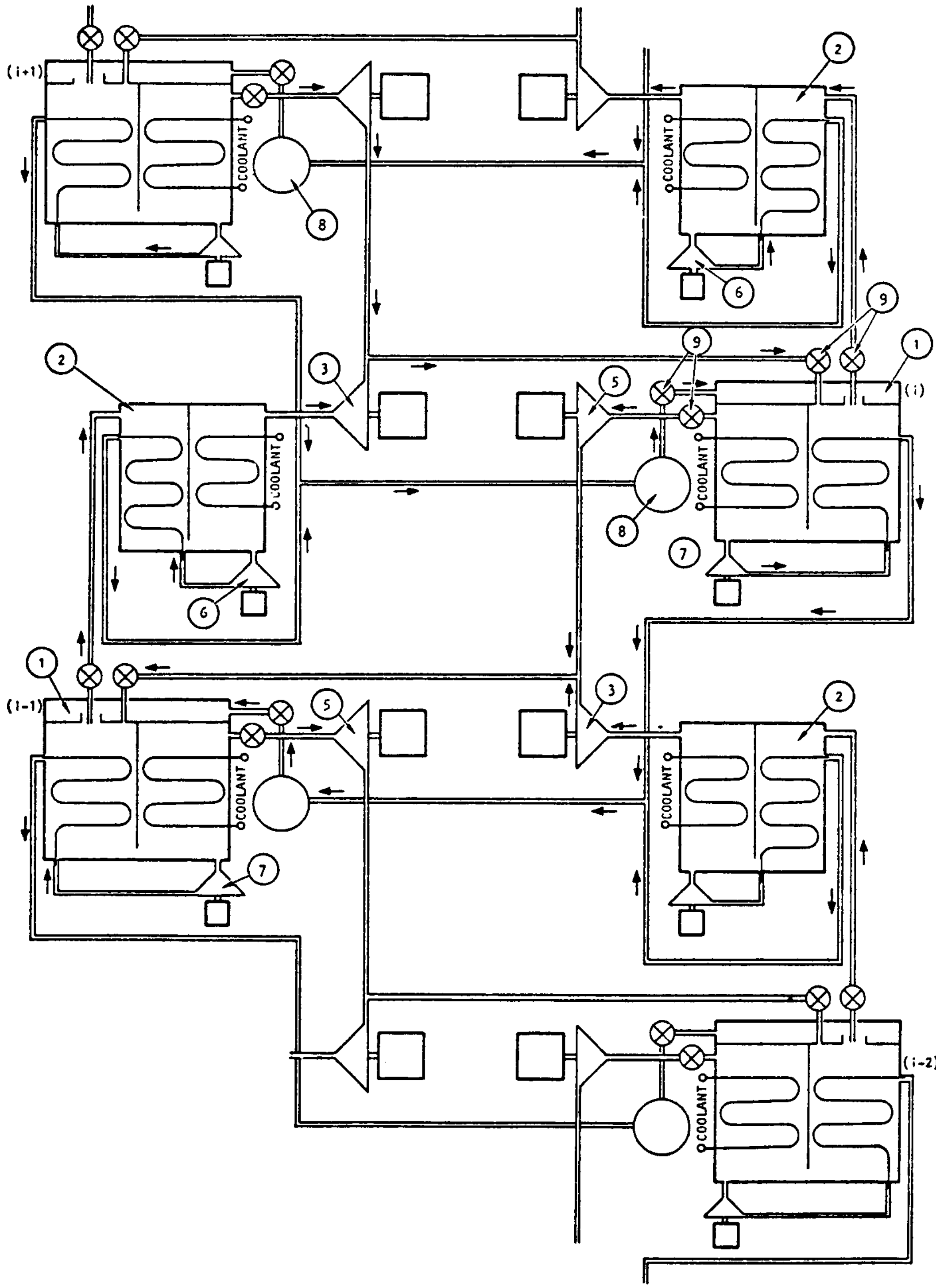


FIGURE 3. JET-MEMBRANE SEPARATION FLOW DIAGRAM

(SEE TABLE 2)

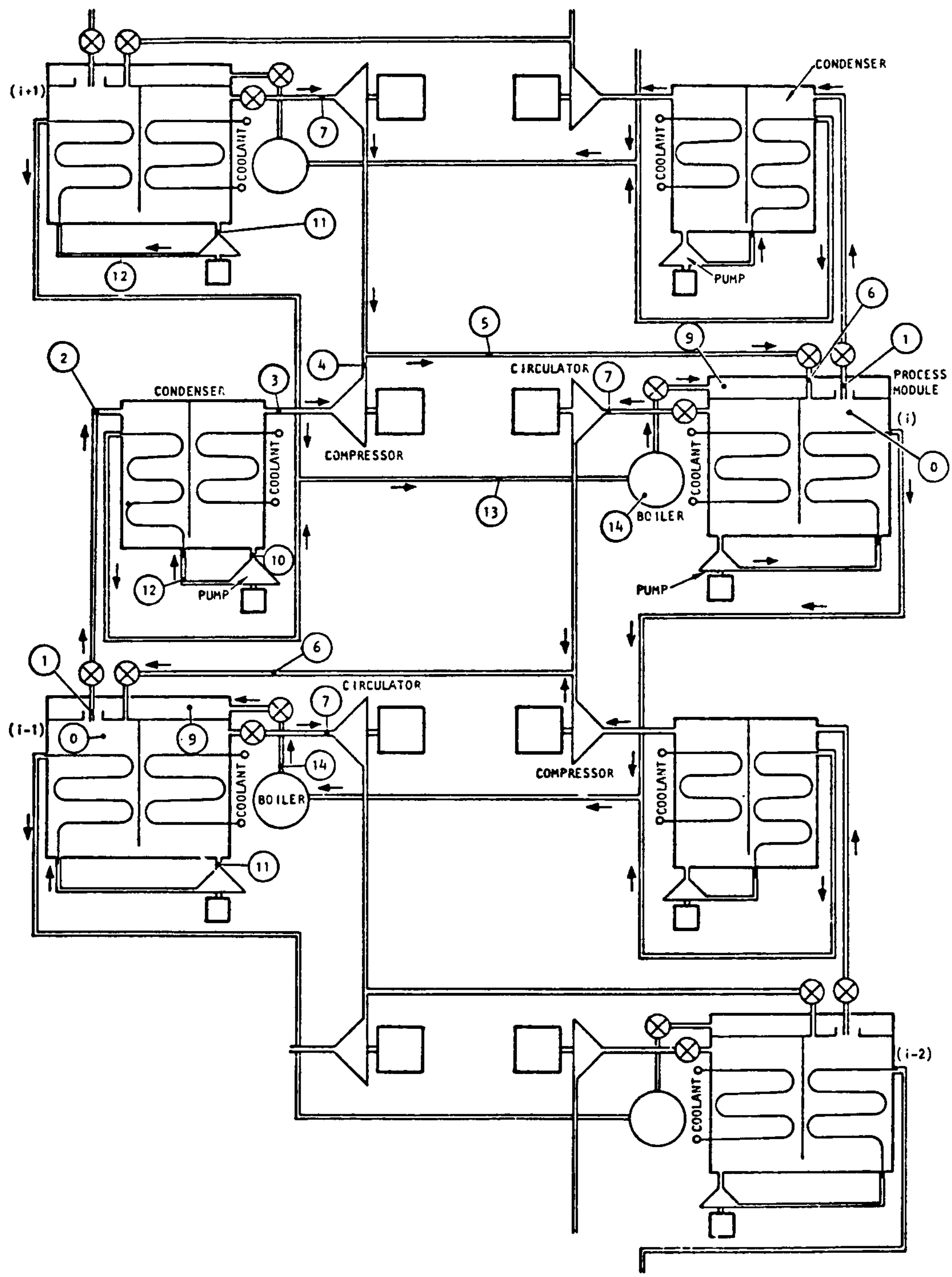


FIGURE 4. JET-MEMBRANE SEPARATION SYSTEM PRESSURES AND TEMPERATURES

(SEE TABLE 3)

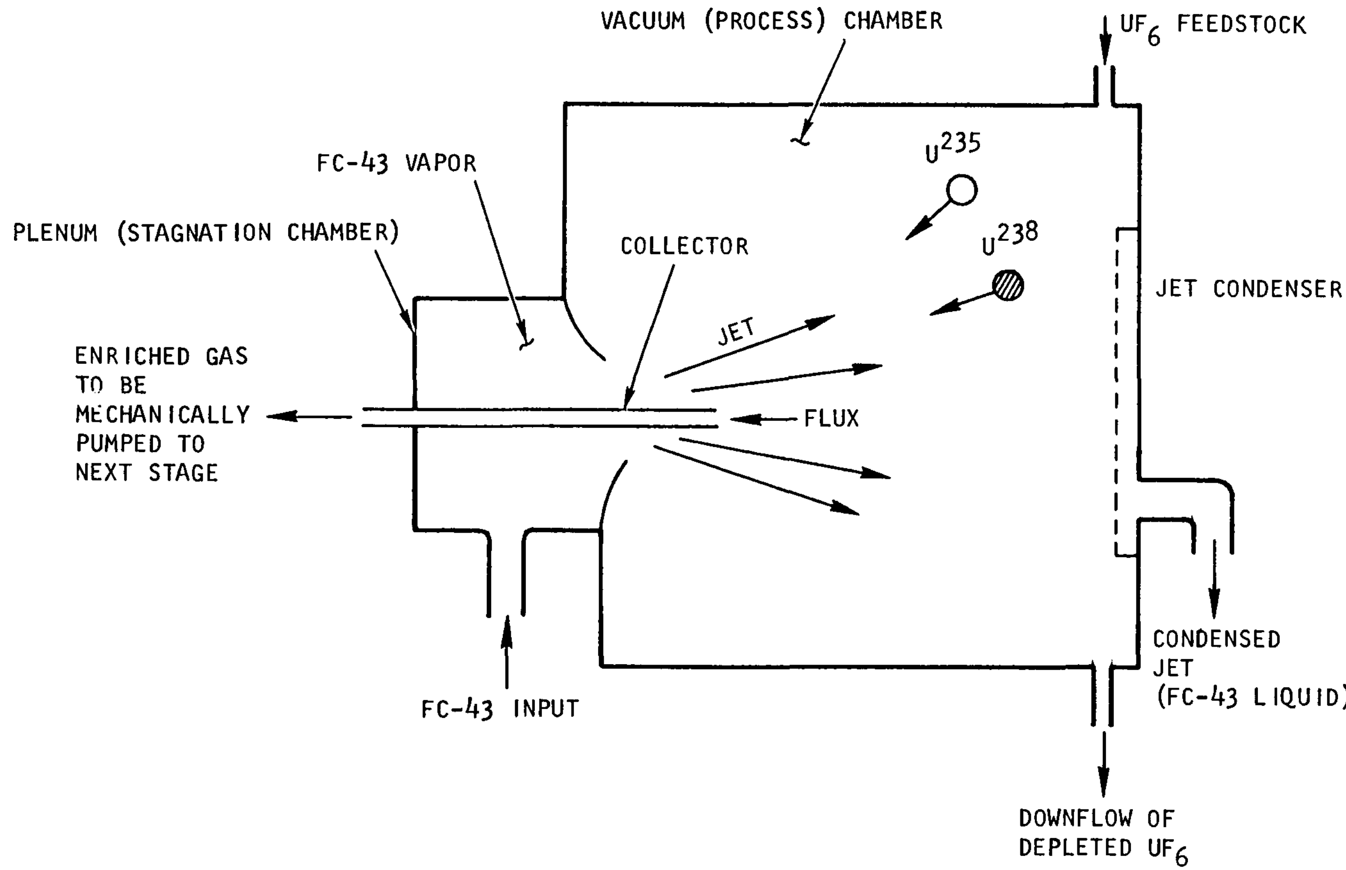


FIGURE 5. JET-MEMBRANE PROCESSING MODULE

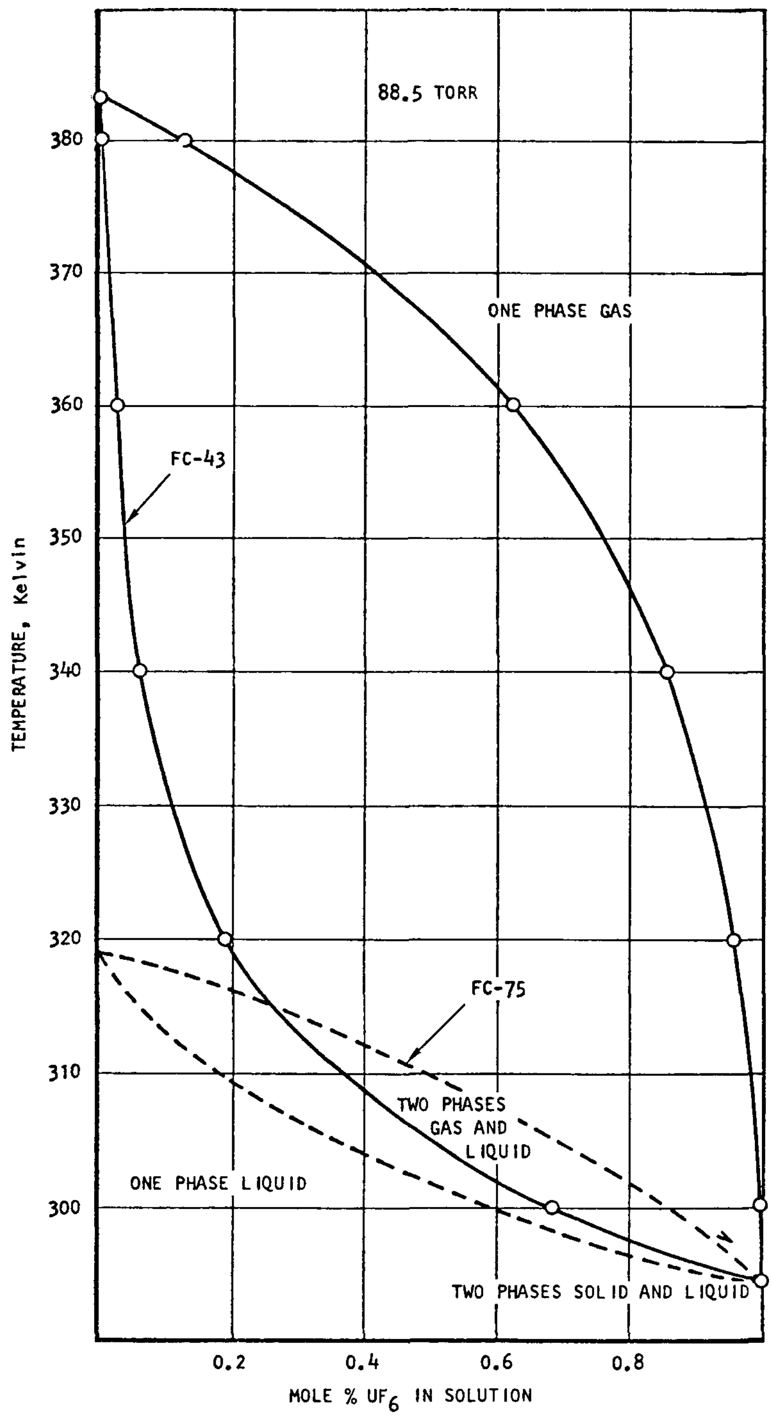


FIGURE 6. PHASE DIAGRAMS FOR FC-43 AND FC-75

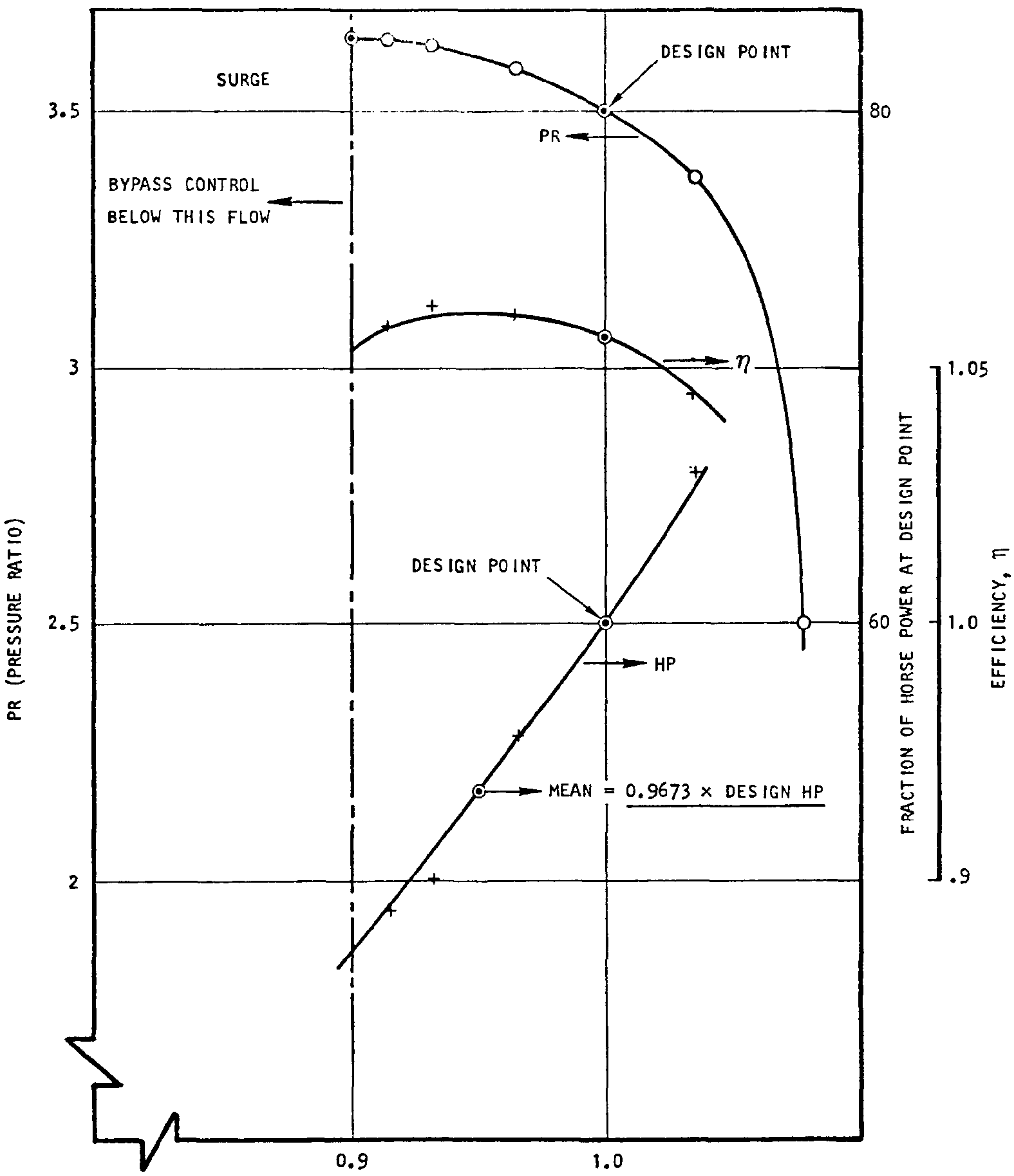


FIGURE 7. TYPICAL PERFORMANCE MAP FOR HIGH PRESSURE - RATIO COMPRESSORS

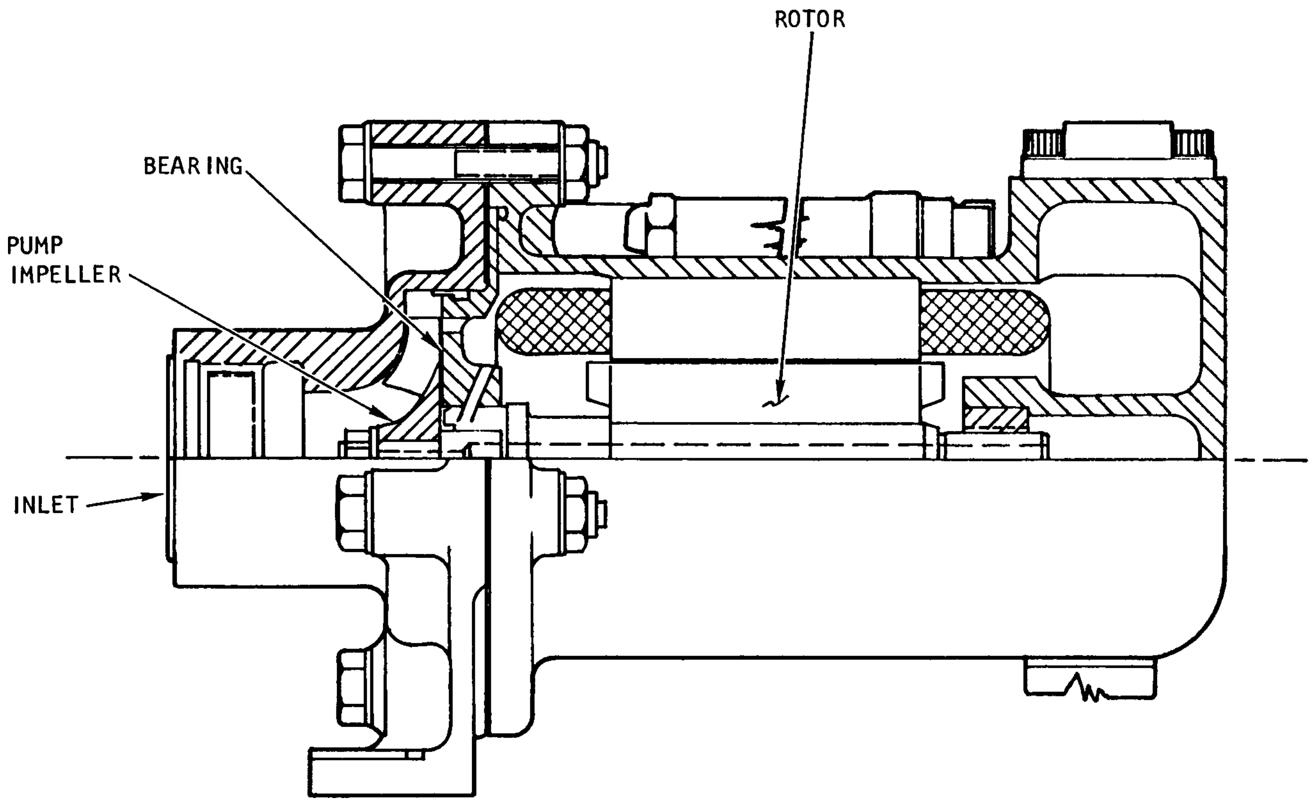


FIGURE 8. TYPICAL HERMETIC PUMP

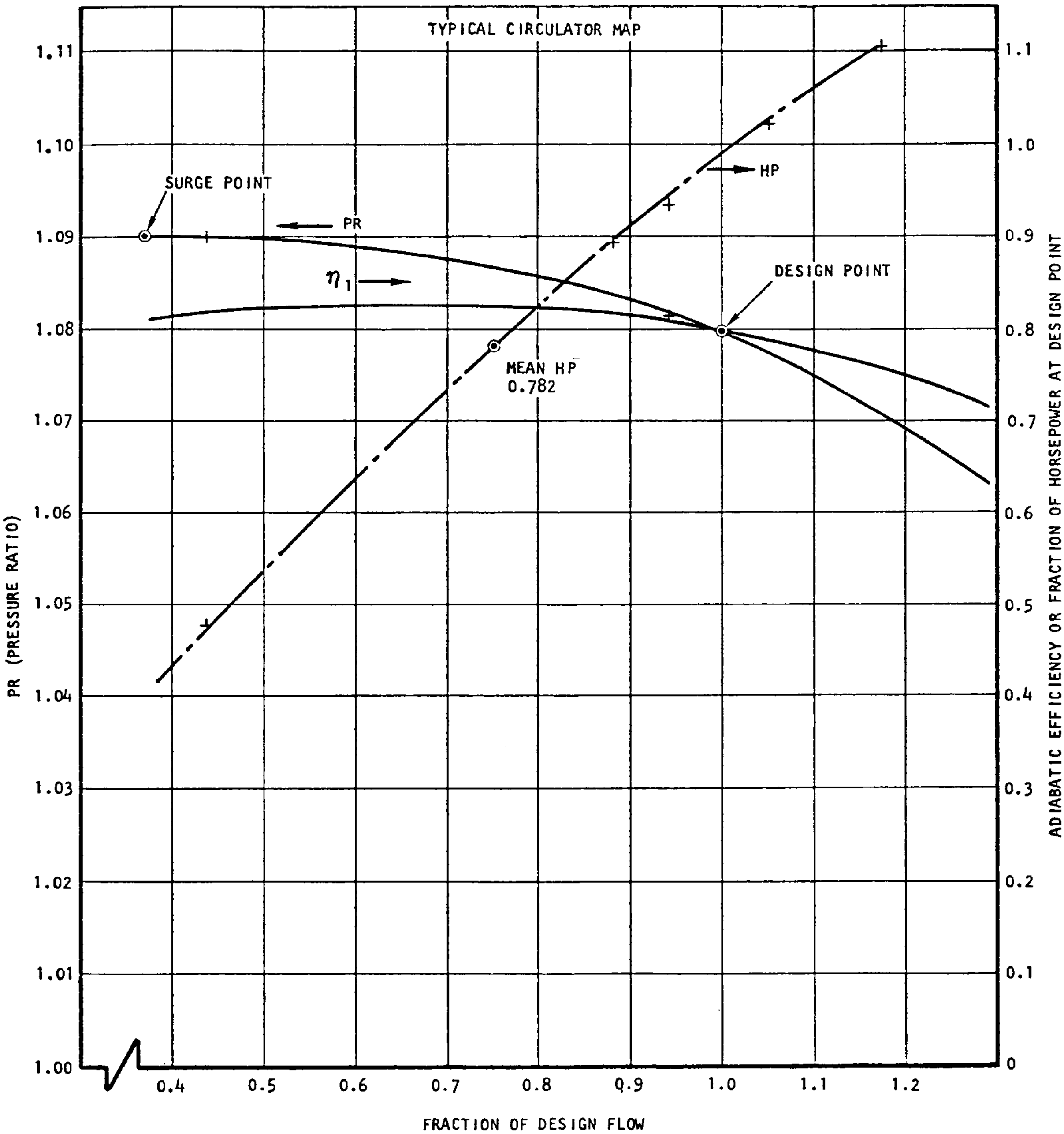


FIGURE 9. TYPICAL CIRCULATOR MAP

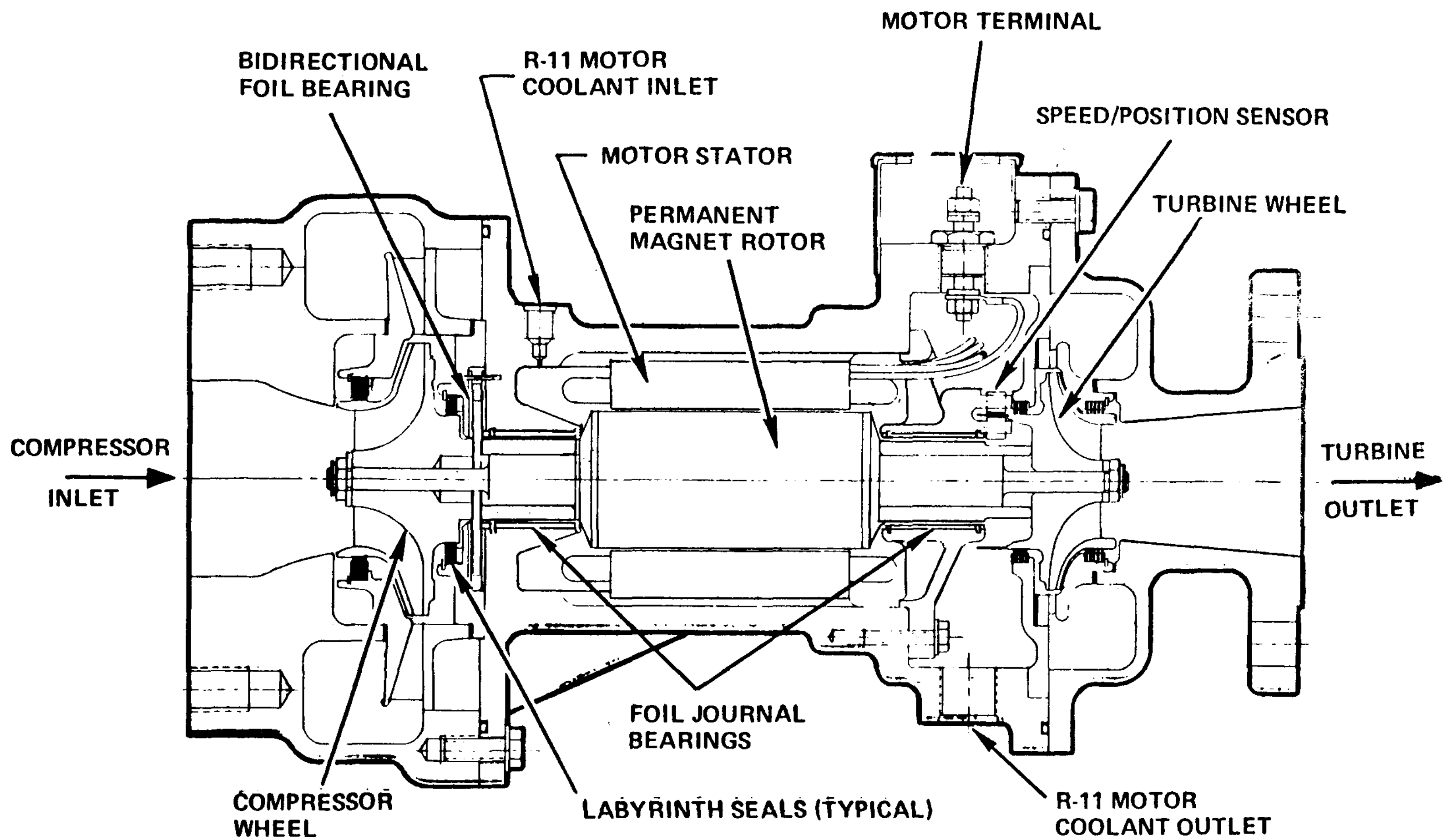


FIGURE 10. COMPRESSOR WITH IMPELLERS ON BOTH ENDS OF THE SHAFT

PART 2

JET MEMBRANE ISOTOPE SEPARATION PLANT - ENERGY CONSUMPTION OF FC-43 CARRIER GAS LOOP AND CAPITAL COST FOR HEAT EXCHANGERS

The objective of this present study is to determine the energy consumption and capital cost of heat exchangers for the carrier gas loop of a 300,000 SWU/yr uranium enrichment plant using jet-membrane isotope separation process 4 . The process as conceived by Grumman Energy Systems utilizes FC-43 (perfluorotributylamine, $[C_4F_9]_3N$) as the carrier gas, and as a result of using condensation and evaporation process to recirculate the carrier gas (see Figure 1), the process requires a larger sum of energy and heat transfer surface area in its carrier gas loop. The present study was conducted in three steps in order to estimate in a reasonable accuracy the energy consumption and the cost of heat exchangers:

(1) Evaluation of thermophysical properties of FC-43 vapor

(2) A thermohydraulic design of the FC-43 carrier gas loop

(3) Heat exchangers sizing and cost estimate

The results obtained for each of the tasks are briefly described below. Further details may be found in the referenced calculation file.

The calculations contained in this memo are based on the stage separation factor, $\alpha = 1.009402$, and the modular concept described in the first part of this report. The 300,000 SWU/yr plant has 551 cascade stages; the entire cascade consists of 1177 size D module separation units, 280 size C separation units and 60 size B separation units. Each separation unit or module may contain up to seven heat exchangers as shown in Figure 6. The design flow rates of UF_6 and FC-43 for each module were given in Part 1. They are included in Table 1.

THERMODYNAMIC AND THERMOPHYSICAL PROPERTIES OF UF_6, FC-43, AND THEIR MIXTURES

Thermodynamic and thermophysical properties of UF_6 were taken from Ref. 3. The properties of FC-43, which have a significant effect on the heat load and heat exchanger size, were not available in the existing literatures (unclassified) except for a few basic data at liquid state published by its manufacturer. The FC-43 properties used in the present study were calculated by extrapolating the manufacturer's data for the liquid regions and by using the available theoretical models for the vapor region. The saturation lines were determined. Figures 2 through 4 show the calculated transport properties for FC-43 vapor and its mixture with UF_6. They are approximate and may be used only for preliminary calculations in the absence of more accurate data.

PRELIMINARY THERMOHYDRAULIC DESIGN OF THE FC-43 CARRIER GAS LOOP

Evaluation of System Concepts: Heat Pump or Direct Heating

Two different approaches were considered for boiling of FC-43 as shown in Figure 5. The first is a heat pump approach which utilizes the heat rejected from the FC-43 condenser to evaporate FC-43 at a higher pressure. The second is a direct heating of FC-43 using solar energy or waste heat. Three different working fluids were considered for the heat pump approach: FC-75, R-114, and F-85. The F-85 resulted in the highest COP (coefficient of performance) among the fluids considered, but still the large amount of compression work required multistaging of the FC-43 condensers. Figure 5a shows the power consumption of the F-85 compressors as a function of the final condensing temperature of FC-43. Despite the multistaging and recuperation, the power required to drive the compressors is too high to make this approach attractive. Figure 5b shows the thermal energy input required for the direct heating of FC-43. The values represent theoretical minimum; the energy requirement is very large and this approach is worth considering only when waste heat can be utilized with a relatively low capital investment. Between the two approaches, the direct heating concept was adopted in the present study because of the lower capital cost anticipated, and because of the fact that it requires thermal energy, not electrical energy.

Selection of the Design Condensing Temperatures for FC-43

The condensing temperature of FC-43 has two important consequences: the higher the condensing temperature is, the lower the system heat load and the heat exchanger size. At the same time, a higher condensing temperature results in a lower rate of separation of FC-43. This in turn increases the UF_6 compressor work load and more importantly, may tend to reduce the stage separation factor of the jet-membrane process. Figure 4 shows the FC-43 condenser-separator performance as a function of the condensing temperature. The performance of the heads stream FC-43 separator varies sharply with the condensing temperature. This suggests that the FC-43 condensing temperature is one of the primary design parameters that will affect both the system performance and the cost of the plant.

The design condensing temperatures selected for the present study is 135°F for the heat stream and 155°F for the tails stream. The selection is based on a trade-off study on heat exchangers and assumptions that a 5 percent mole fraction of FC-43 in UF_6 stream has no degrading effect on the jet membrane unit performance. A condensing temperature below 135°F for the head stream was found to increase drastically the size of FC-43 condenser and the corresponding heat removal equipment to the heat sink.

Recuperation of the Rejected Energy from Desuperheating and Condensing

Figure 6b shows the large amount of thermal energy that is required to preheat and boil FC-43 for a 300,000 SWU/yr plant. This is based on a 100 percent recuperation. Without the recuperation, energy required would have increased approximately by 70 percent. It is essential, therefore, to use a high degree of recuperation of energy rejected by desuperheating and condensation of FC-43 in order to minimize the boiler heat load. The only problem anticipated is the fact that a high effectiveness recuperation is often prohibitively expensive for very low-pressure, low-speed gas heat exchangers (e.g., heads stream recuperator).

The design conditions for the recuperators are based on a 10°F approach temperature. This requires a 96 percent effectiveness for the head stream and a 91 percent effectiveness for the tail stream recuperators. The effect of such high effectivenesses on the cost of heat exchangers is discussed later.

Preliminary Definition of Thermohydraulic Design Conditions of the Carrier Gas Loop

The considerations described above were implemented in a system design to define the thermohydraulic design conditions of the carrier gas loop. Figure 8 illustrates schematically the carrier gas loop and the state variables at each station. The design utilizes R-114 as an intermediate working medium to absorb the sensible and latent heat from the UF_6/FC-43 stream and then to reject it to cooling tower water. The water inlet temperature is chosen to be 90°F, which is 10° to 15°F higher than the wet bulb temperature at the locations of the existing gaseous diffusion plants. A 10°F approach temperature was used for the R-114 condensers in consideration of the heat exchanger size and water flow rate. The FC-43 boiler uses caloria HT-43 as the heating medium. The selection is based on its relatively low cost, high heating capacity and relatively high thermal stability. The inlet temperature is chosen to be 450°F to allow a medium grade waste heat or solar energy to be used to heat the working medium.

The maximum flow rates and heat loads for each heat exchanger are summarized in Tables 1 and 2 for the three modules and for the entire plant. They were calculated on the basis of the condenser/separator performance at the design point shown on Figure 7.

HEAT EXCHANGER SIZING AND COST ESTIMATE

Heat Exchanger Design Conditions

Heat exchanger design conditions were determined based on the system operating conditions in Figure 8 and the flow rates and heat loads in Tables 1 and 2. The design conditions for size D module heat exchangers are summarized in Figures 9 through 14. The same design conditions can be used for size C and Size B module heat exchangers except for the flow rates and heat load.

Selection of Heat Transfer Surface and Material

The heat transfer surfaces selected are either internally or externally finned surfaces which are commercially available in large quantity at a relatively low cost. They are specified in Table 3. Aluminum is used as the tube and fin materials for the recuperators and the FC-43 condensers because of its high thermal conductivity, low cost, ease of fabrication, and compatibility with FC-43, UF_6, and R-114. A copper alloy is used for the tube material for the R-114 condensers because of its high serviceability with industrial water. The inner fin tubing which is used for the FC-43 boiler has stainless steel tube and copper fins.

Heat Exchanger Sizing and Cost Estimate

Heat exchanger sizing programs available at AiResearch have been used to size the heat exchangers except for the condensing portion of the recuperators and the FC-43 condensers. The heat transfer in the condensing regime of FC-43 is very complicated because of the presence of a noncondensable gas (UF_6) and should be calculated in a finite difference manner, using a forward marching scheme, to calculate the local mass transfer potential and sensible heat transfer potential along the mixture flow direction. The procedure requires a large number of calculations, however, and was not attempted in the present study. Rather, in view of the fact that both the FC-43 saturation line and the mass diffusion coefficient available at present are very approximate, the condensing heat transfer was calculated using the FC-43 vapor concentration gradient at a point where two-thirds of the condensing heat load is transferred. Sensible heat transfer was superposed to the above condensing heat transfer to form the overall heat transfer in the condensing section.

Table 3 summarizes the core size, weight, and an expected cost of the heat exchangers. The cost was estimated by assuming that the installed cost of a heat exchanger can be computed using $8.00 per pound of its core weight for aluminum and $6.00 for other materials. The estimate is very approximate and should be used only in an absence of better information. It is noted that the heads stream recuperator takes approximately 40 percent of the total cost of the heat exchangers. This is a result of a low gas-side heat transfer coefficient and a very high recuperator effectiveness (92 percent) discussed earlier.

Table 4 summarizes the total heat load, flow rates and the cost of heat exchangers for the FC-43 carrier gas loop of the 300,000 SWU/yr plant: the total installed cost of the heat exchangers amounts to $13,444,000 and the plant requires 123.136 MW (4.203×10^8 Btu/hr) of thermal energy to evaporate 2475 lb/sec of FC-43.

CONCLUSIONS

1. The large thermal energy required to operate FC-43 carrier gas loop (approximately 125 MW for a 300,000 SWU/yr enrichment plant) clouds the prospect of the jet membrane process as an energy-saving alternative to the gaseous diffusion process. Within the framework of the present concept and the stage separation factor, the process may not be economically viable unless a large quantity of waste heat (600°F or higher) can be utilized with a relatively low capital investment.

2. The thermal energy requirement above will vary somewhat with the carrier gas loop system design conditions. No drastic reduction is anticipated, however, by system optimization because the heat load per unit flow rate of FC-43 should change relatively little.

3. The total cost of the heat exchangers for the carrier gas loop is very large at approximately $13,500,000. The cost can be reduced substantially be lowering the recuperator effectiveness and by refining heat exchanger design. The low recuperator effectiveness will increase further the thermal energy requirement above. The heat exchanger design refinement should take extensive trade-off studies.

4. The following studies are recommended if the work is to be continued to refine the carrier gas loop of the jet membrane process:

   (a) Evaluation of alternative concepts to evaporate FC-43, including re-examination of heat pump concept and, possibly, a combination of heat pump concept and direct heating.

   (b) Establish accurate thermodynamic and thermophysical data for the carrier gas.

   (c) System level trade-off studies to determine the minimum energy design within the acceptable capital cost.

   (d) Heat exchanger trade-off studies to minimize the cost of the heat exchangers.

TABLE 1

SUMMARY OF FLOW RATES AND HEAT LOAD

(a) UF_6 and FC-43 Flow Rates at Condenser Exit (lb/sec)

	HEADS STREAM			TAILS STREAM		
	UF_6	FC-43 VAPOR	FC-43 LIQUID	UF_6	FC-43 VAPOR	FC-43 LIQUID
Module D	1.38560	0.14499	1.17771	1.38560	0.08452	1.23812
Module C	0.23475	0.02455	0.19953	0.23475	0.01432	0.20976
Module B	0.039771	0.00416	0.03380	0.039771	0.00243	0.03554
Plant Total	1419.14	148.44	1206.24	1419.14	86.57	1268.11

(b) R-114, Water, and HT-43 Flow Rates (lb/sec)

	R-114		WATER		CALORIA HT-43
	HEADS R-114 CONDENSER	TAILS R-114 CONDENSER	HEADS R-114 CONDENSER	TAILS R-114 CONDENSER	FC-43 BOILER
Module D	1.2183	1.2432	2.2514	1.2253	1.2243
Module C	0.2064	0.2106	0.3815	0.2076	0.2074
Module B	0.0350	0.0357	0.0647	0.0352	0.0351
Plant Total	1247.80	1273.32	2305.89	1255.00	1253.91

TABLE 2

SUMMARY OF HEAT EXCHANGER HEAT LOAD
(BTU/SEC)

	HEADS STREAM		TAILS STREAM		
	FC-43 CONDENSER	FC-43 REGENERATOR	FC-43 CONDENSER	FC-43 REGENERATOR	FC-43 BOILER
Module D	56.2858	38.159	55.137	35.435	113.980
Module C	9.536	6.465	9.341	6.159	19.311
Module B	1.6156	1.0953	1.5826	1.0171	3.2716
Plant Total (Btu/sec)	57,648	39,083	56,471	36,243	116,739
Plant Total (MW)	60.81	41.223	59.566	38.282	123.136

NOTE: R-114 condenser heat loads are equal to those of their respective condensers.

Table 3

SUMMARY OF HEAT EXCHANGERS, SIZE D MODULE

	FC-43 RECUPERATOR HEADS	FC-43 CONDENSER HEADS	FC-43 RECUPERATOR TAILS	FC-43 CONDENSER TAILS	FC-43 BOILER	R-114 CONDENSER HEADS	R-114 CONDENSER HEADS	TOTAL FOR D-MODULE
Heat exchanger type	Finned-tube-bank hx in rectangular array				Shelf-and-tube heat exchanger (hx)			
Fluid inside tube	Liquid FC-43	F-114	Liquid FC-43	R-114	FC-43	Water	Water	
Fluid outside tube	FC-43/UF_6	FC-43/UF_6	FC-43/UF_6	FC-43/UF_6	HT-43	R-114	R-114	
Heat transfer surface	Wolverine Type H/A high fin tube No. 61-1106035-41	Wolverine type S/T low-fin tube, No. 60-193032-41			1/2-in. OD Dunham/Bush inner fin tube	Dunham/Bush 5/8-in. square finned tube		
Material, tube	Aluminum	Aluminum	Aluminum	Aluminum	Stainless steel	Copper		
Material, fin	Aluminum	Aluminum	Aluminum	Aluminum	Copper	Aluminum		
Shell size or no-flow length, in.	25.0	11.6875	19.25	11.6875	11.0	10.0	8.0	
Number of tubes per pass (number of pass)	20 (36)	68 (12)	29 (41)	68 (12)	258 (1)	20 (4)	10 (4)	
Baffle spacing, in.	-	-	-		4.0	-	-	
Tube flow length, in.	48.0	48.0	36.0	36.0	24.0	42.0	60.0	
Outflow length, in.	38.25	28.5788	24.50	28.5788	-	-	-	
Core volume, ft^3	26.56	9.28	9.83	6.96	1.20	1.72	1.53	57.08
Core weight, lb	515	233	243	175	118	78	56	1418
Heat exchanger cost, $	4120	1864	1944	1400	708	468	336	10,940

TABLE 4

SUMMARY OF HEAT EXCHANGERS
(300,000 SWU/YR PLANT)

Total Heat Exchange Rate:	443.39 MW
Total External Heat Supply (Waste Heat or Solar Energy)	123.136 MW
Total Heat Rejection (to Cooling Water):	120.376 MW
Total UF_6 Flow Rate: (Sum of the Stage Inlet Flow Rates)	2,838.285 lb/sec
Total FC-43 Flow Rate: (Sum of the Stage Inlet Flow Rates)	2,713.364 lb/sec
Total R-114 Flow Rate:	2,521.120 lb/sec
Total Cooling Water Flow Rate:	3,560.89 lb/sec = 25,627 gpm
Total HT-43 Flow Rate:	1,253.91 lb/sec
Total Heat Exchanger Core Volume:	70,143 ft^3
Total Heat Exchanger Core Weight:	1,742,500 lb
Estimated Heat Exchanger Cost:	$13,444,000.00

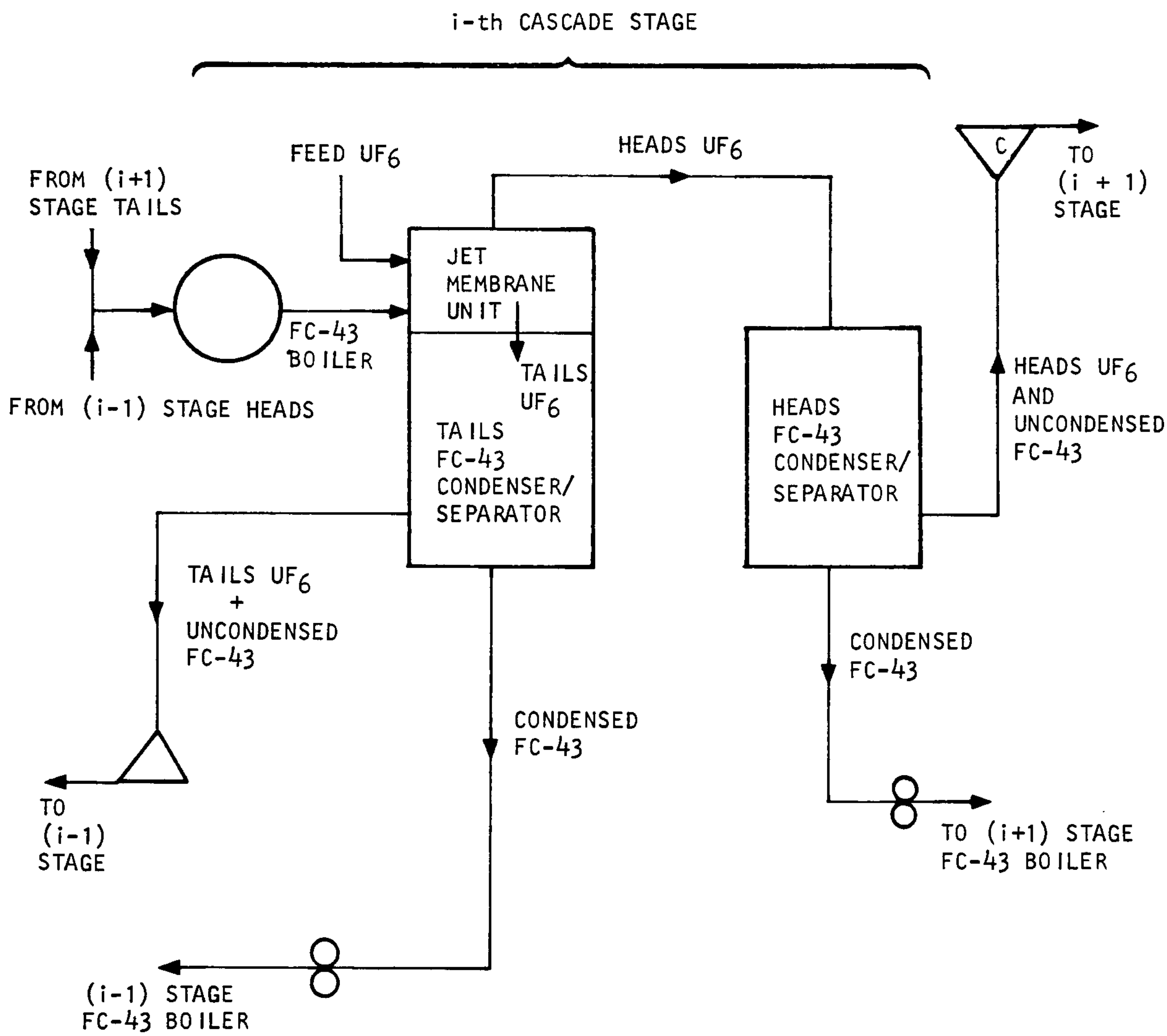


FIGURE 1. SCHEMATIC DIAGRAM OF FC-43 CARRIER GAS LOOP

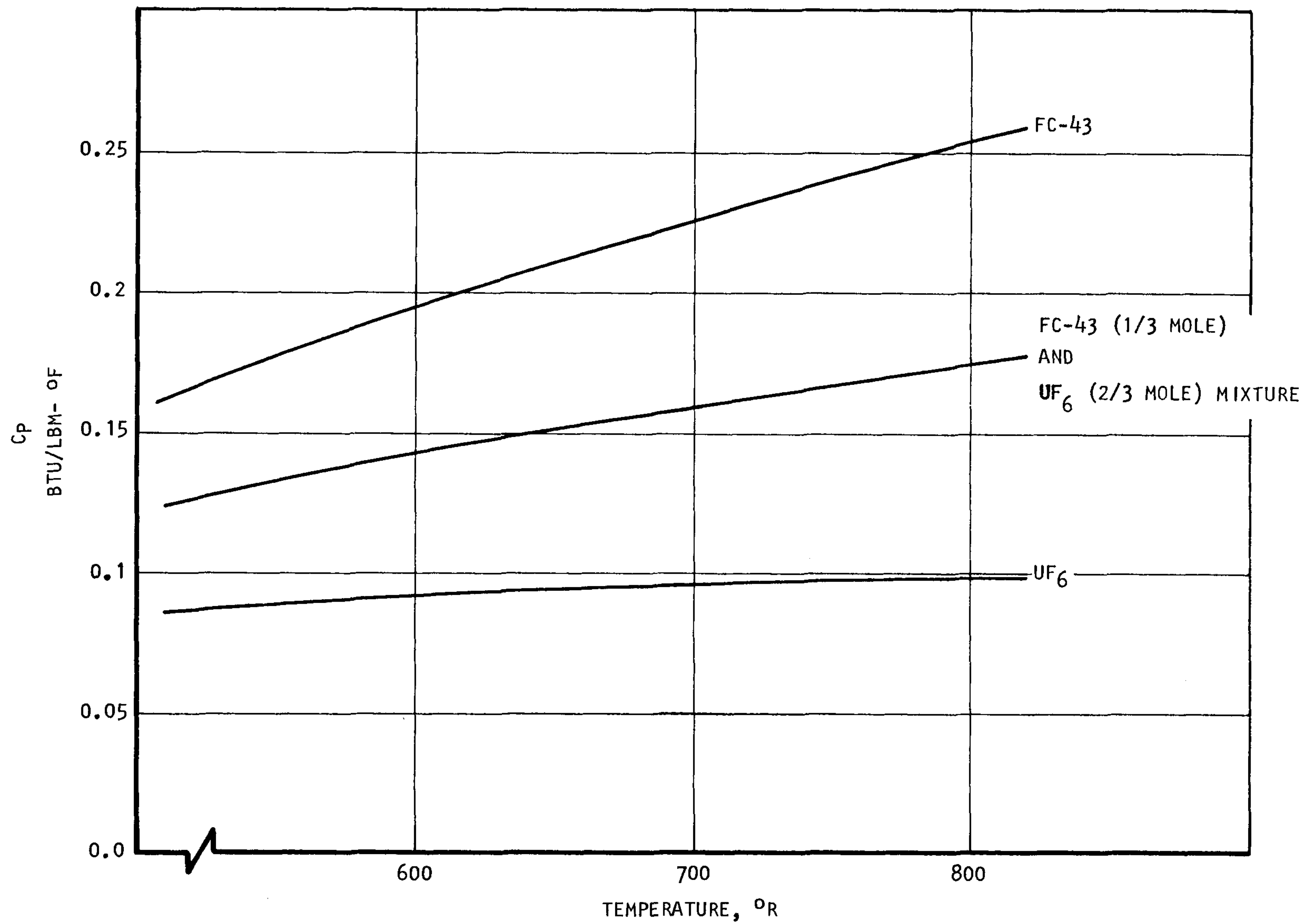


FIGURE 2. SPECIFIC HEAT (C_p) OF FC-43 AND UF_6 IN VAPOR PHASE

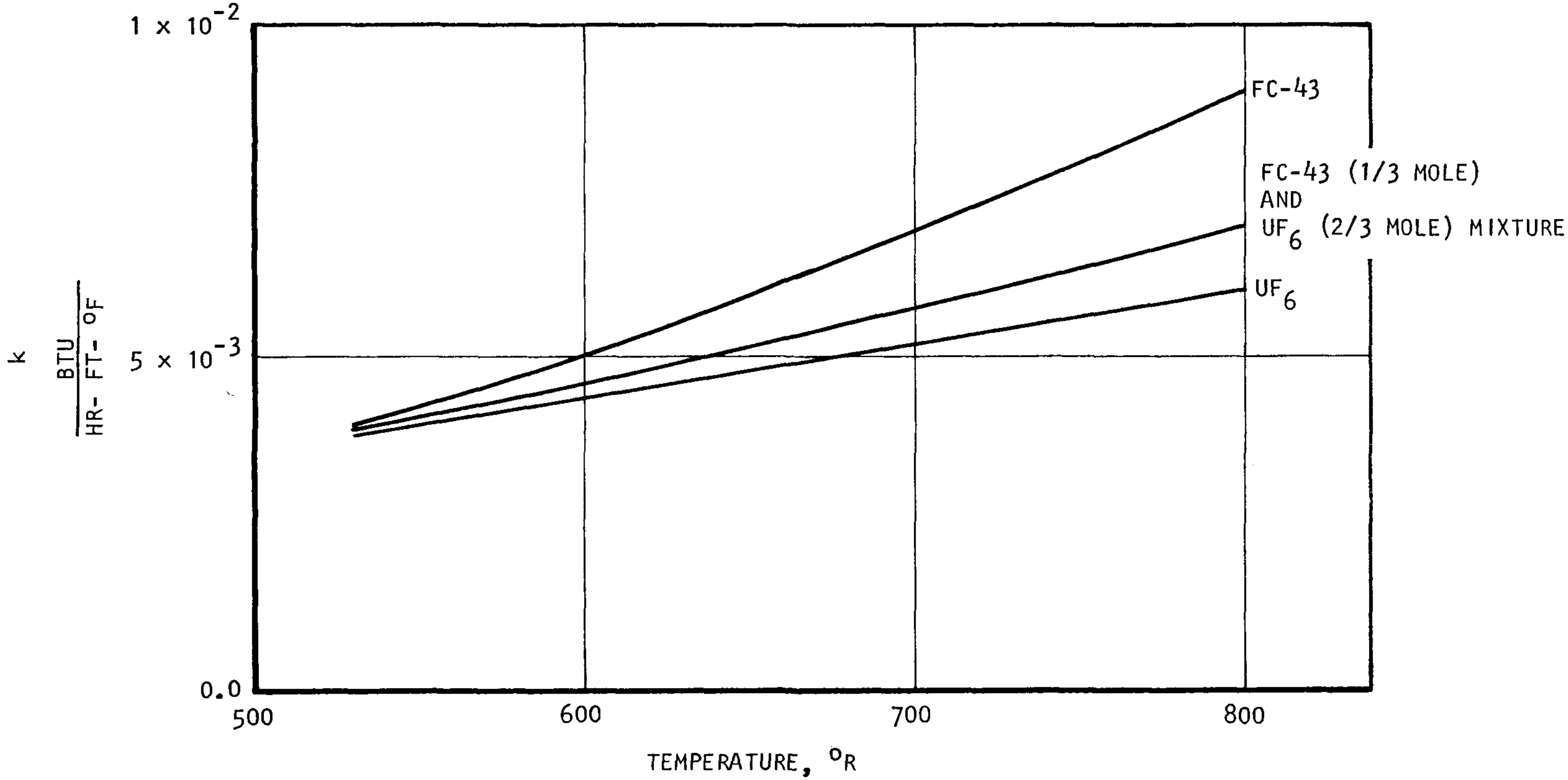


FIGURE 3. THERMAL CONDUCTIVITY OF FC-43 AND UF_6 IN VAPOR PHASE

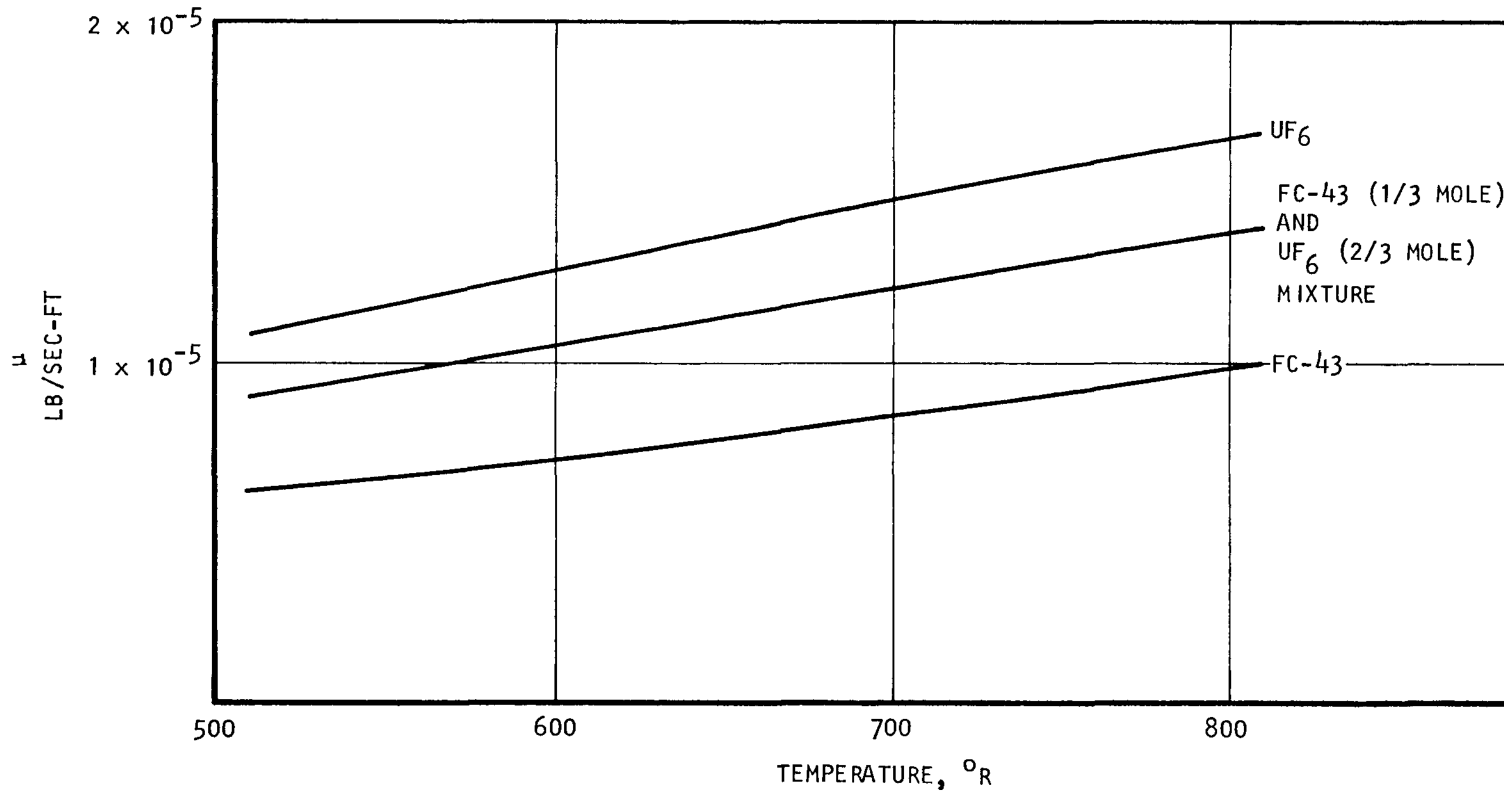
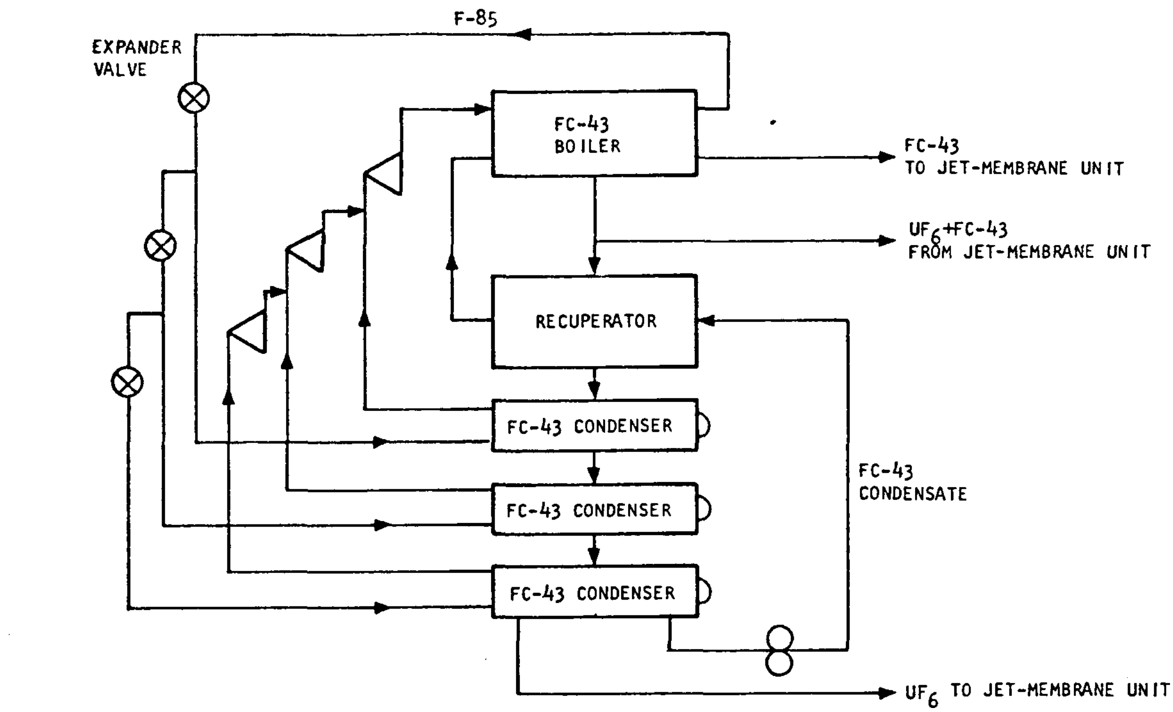
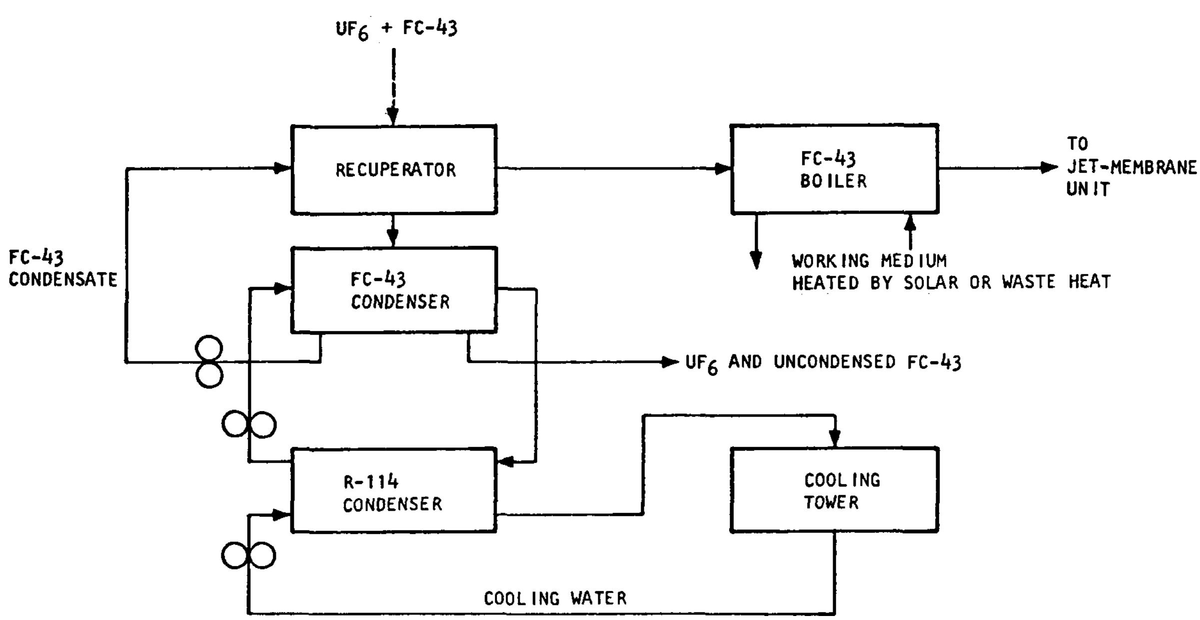


FIGURE 4. ABSOLUTE (DYNAMIC) VISCOSITY OF FC-43 AND UF_6 IN VAPOR PHASE



a. A HEAT PUMP CONCEPT WITH THREE-STAGE CONDENSATION (F-85 AS WORKING FLUID)



b. WASTE HEAT UTILIZATION WITH RECUPERATION - DIRECT HEATING

FIGURE 5. CONCEPTS FOR BOILING FC-43

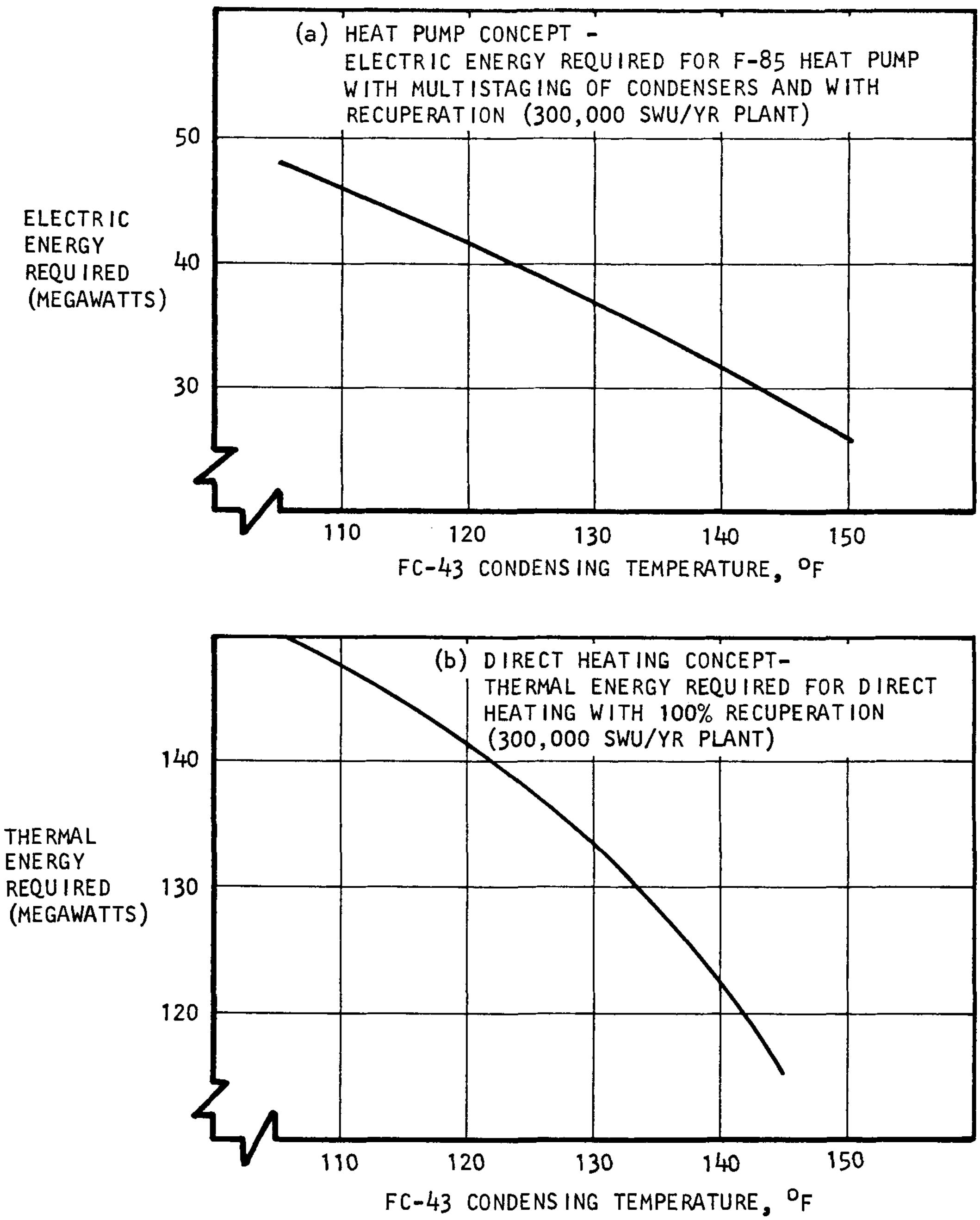


FIGURE 6. POWER REQUIRED FOR PREHEATING AND BOILING FC-43

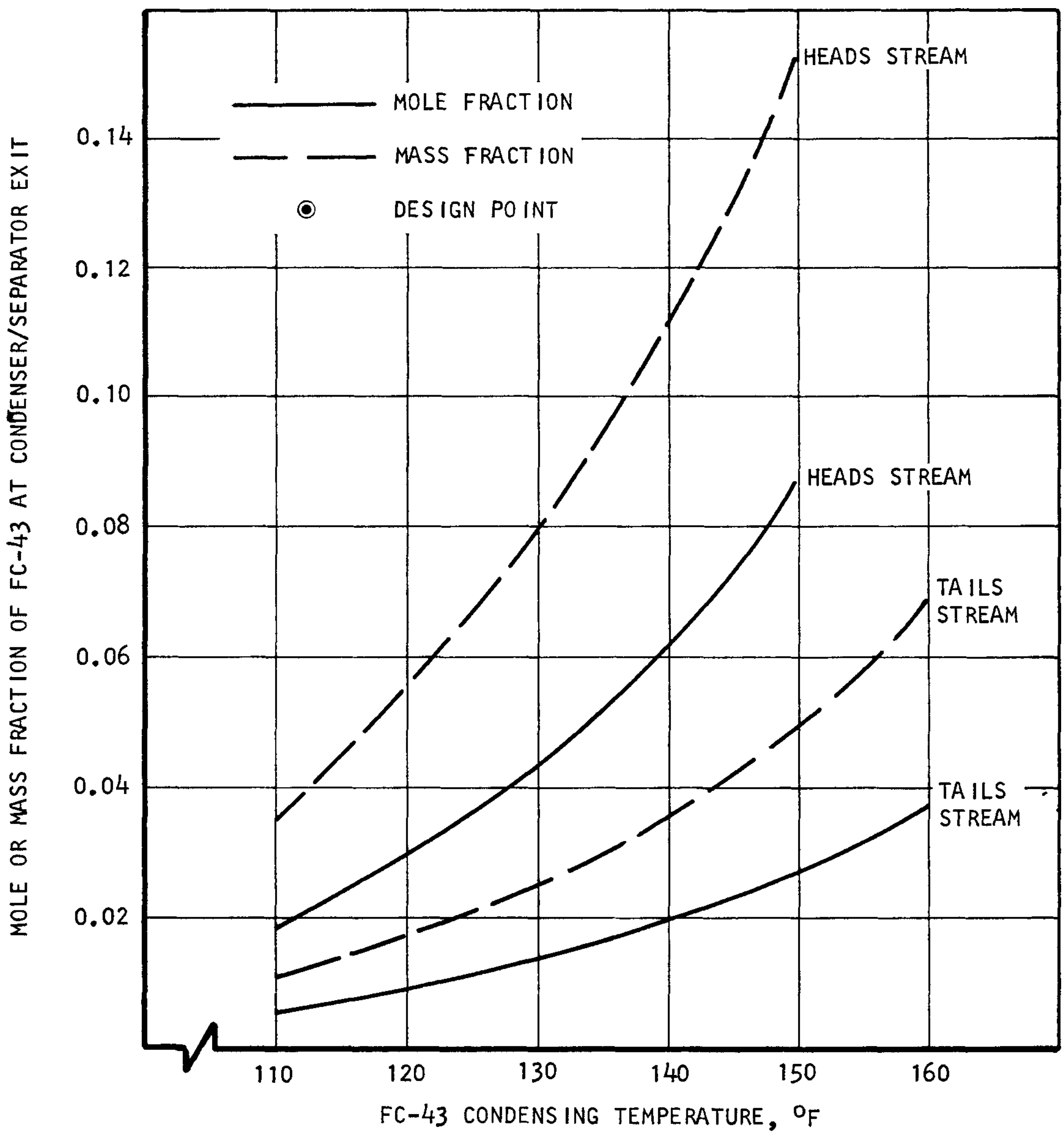


FIGURE 7. VAPOR COMPOSITION AT CONDENSER/SEPARATOR EXIT

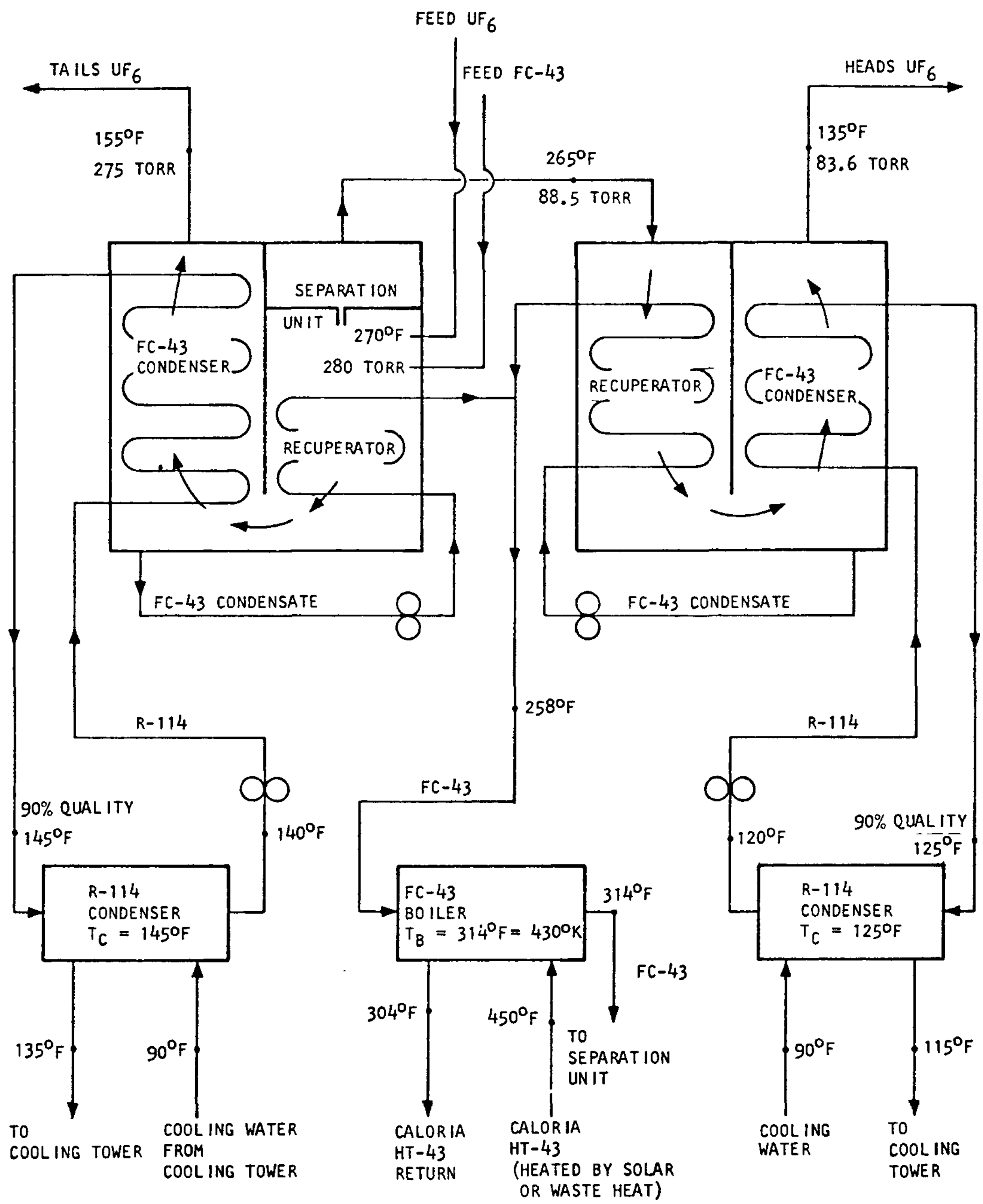


FIGURE 8. SCHEMATIC DIAGRAM OF THE CARRIER-GAS LOOP

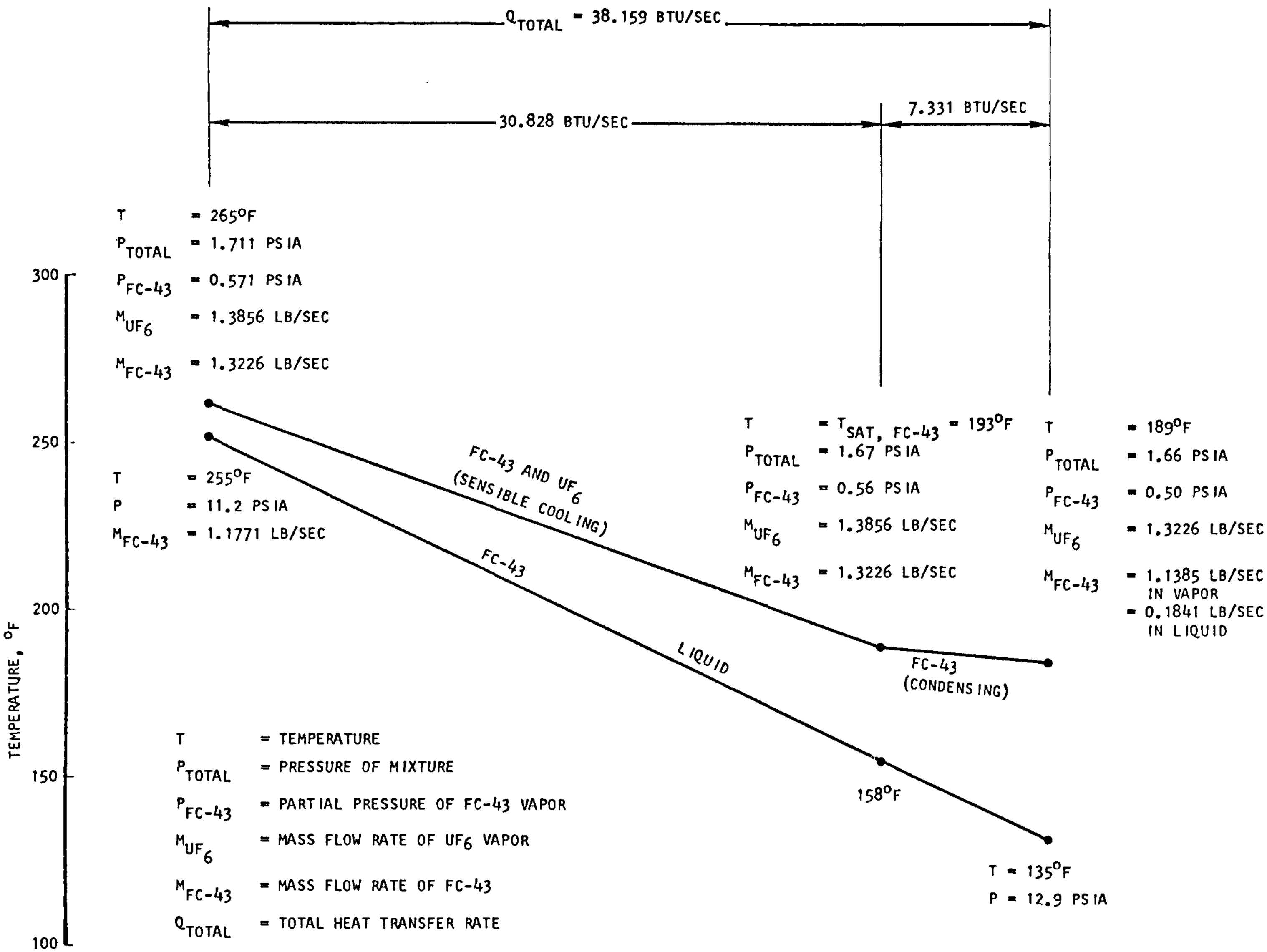


FIGURE 9. RECUPERATOR DESIGN CONDITIONS - HEADS STREAM, SIZE D MODULE

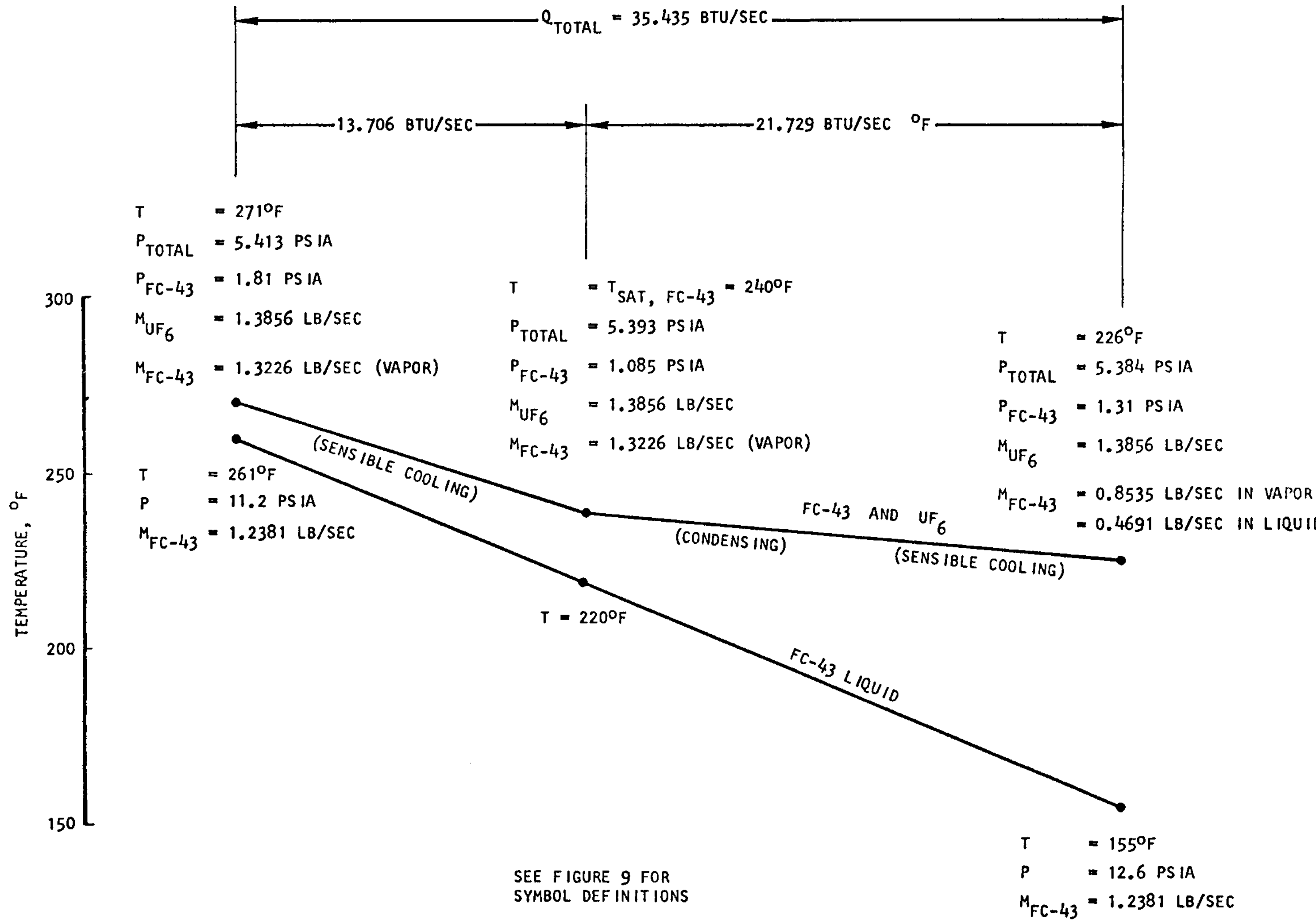
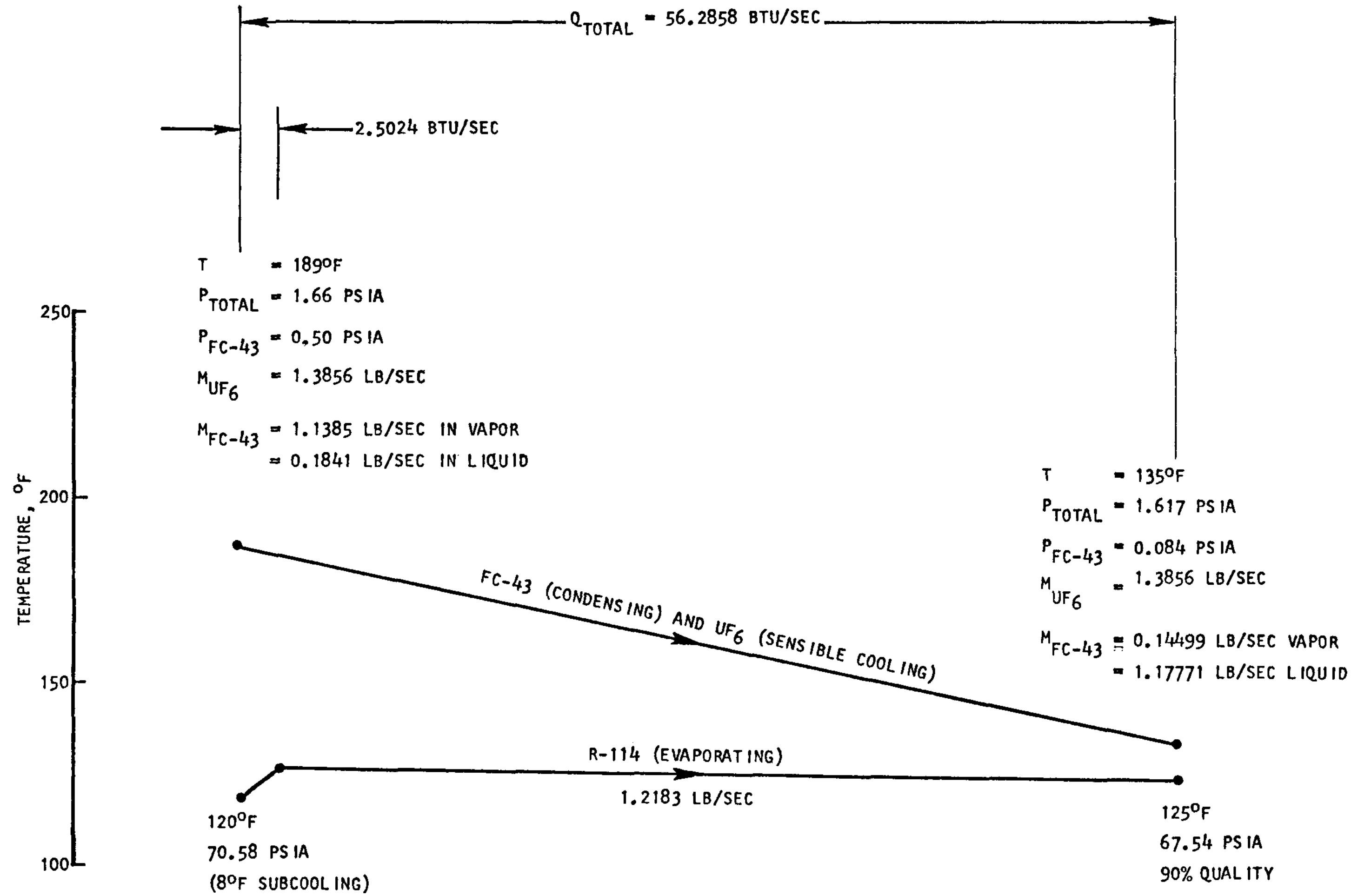


FIGURE 10. RECUPERATOR DESIGN CONDITIONS - TAILS STREAM, SIZE D MODULE



SEE FIGURE 9 FOR SYMBOL DEFINITIONS

FIGURE 11. CONDENSER DESIGN CONDITIONS - HEADS STREAM, SIZE D MODULE

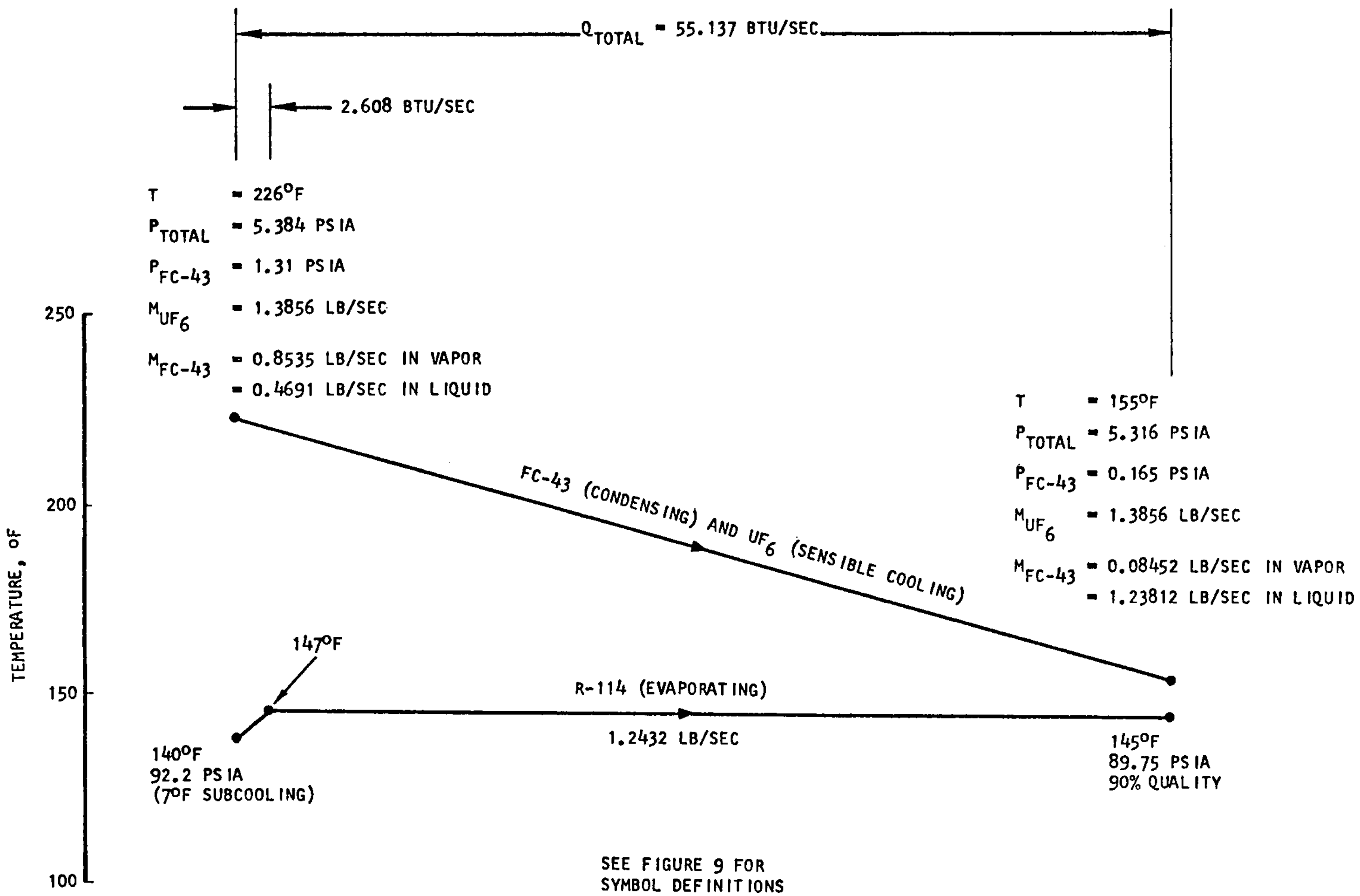


FIGURE 12. CONDENSER DESIGN CONDITIONS - TAILS STREAM, SIZE D MODULE

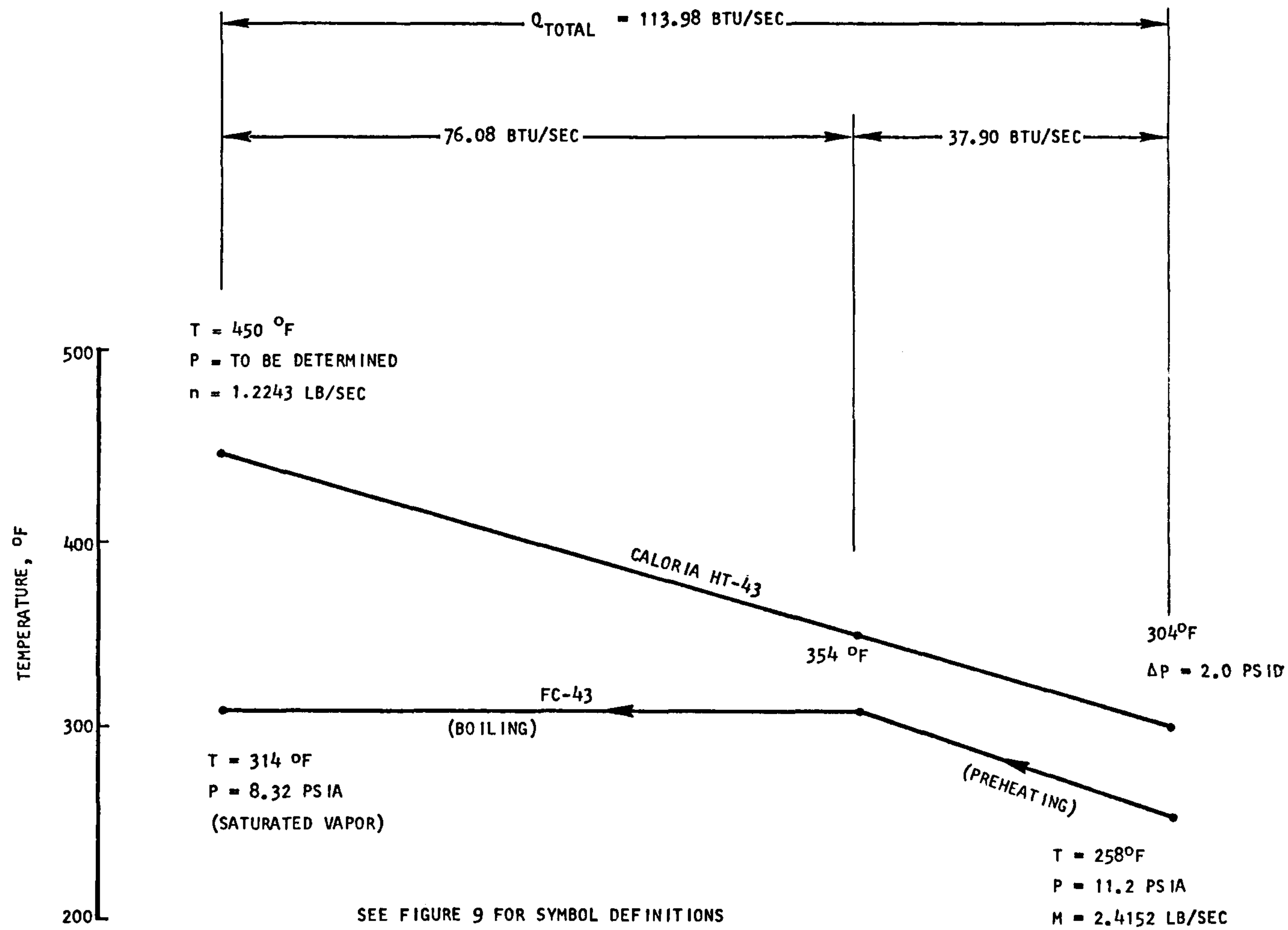


FIGURE 13. FC-43 BOILER DESIGN CONDITIONS - SIZE D MODULE

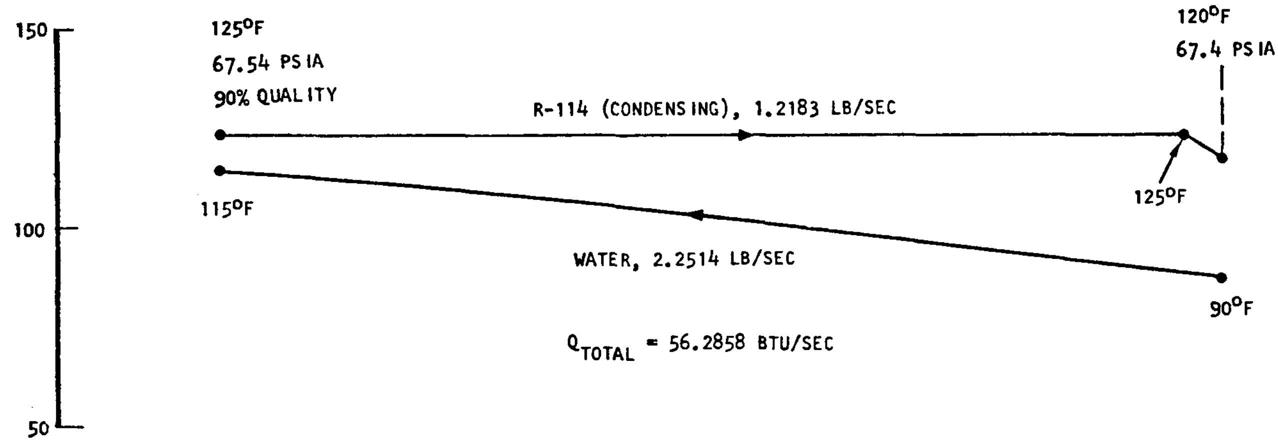


FIGURE 14. R-114 CONDENSER DESIGN CONDITION - HEADS STREAM (SIZE D MODULE)

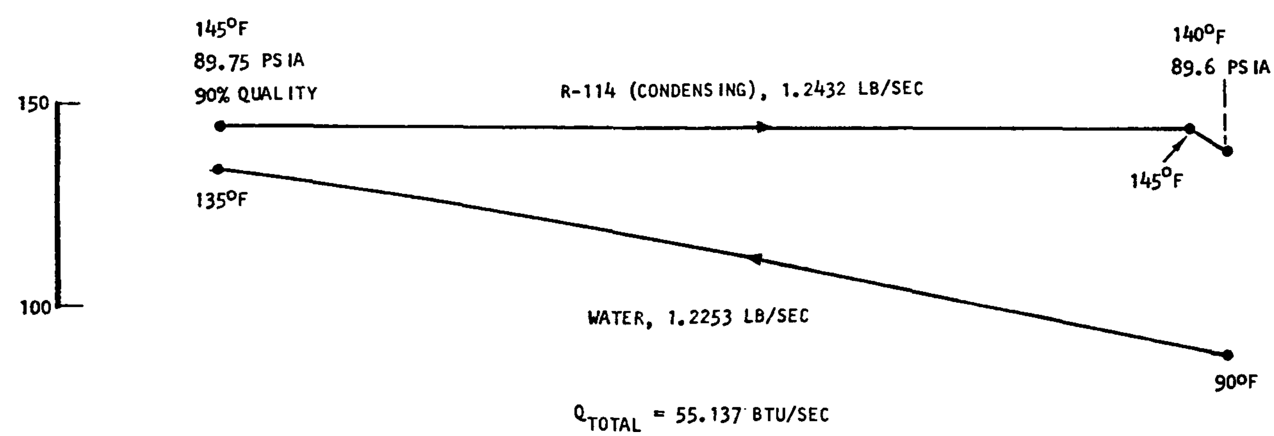


FIGURE 15. R-114 CONDENSER DESIGN CONDITIONS - TAILS STREAM

ENCLOSURE 3

TO PART I

TECHNICAL ANALYSIS OF VELOCITY-SLIP PROCESS

INTRODUCTION AND SUMMARY

This report describes the design of a 300,000 SWU/yr uranium enrichment plant utilizing the velocity-slip isotope separation process. The plant design involves three advanced technology areas: (1) design of high flow capacity separation units, (2) layout of the plant for a multistream countercurrent cascade, with a three-component mixture of two heavy molecular species and a light carrier gas, and (3) design of compressor modules for a 100:1 pressure ratio with an inlet pressure of 0.25 Torr for compressing a gas mixture of helium (95 mole percent) and uranium hexafluoride (5 mole percent).

The velocity-slip process is an aerodynamic phenomenon, which occurs when a low molecular weight carrier gas is seeded with heavier isotope molecules and expanded from stagnation through a converging nozzle into an expansion chamber maintained at low pressure. Downstream of the nozzle exit, in the transition region between continuum and free-molecular flow, a difference between the velocity distributions of the heavy and light isotope species will develop due to collisions with the high velocity carrier gas. A relatively large value of the Knudsen number is required to produce the velocity-slip phenomenon. If a velocity selector is located at an appropriate distance from the nozzle exit, it is possible to transmit only molecules which have velocities within a restricted bandwidth and thereby increase the concentration of the desired isotope molecular species, which is $^{235}UF_6$ in this study. The analytical basis of this process is described by Anderson, Davidovits, and Raghuraman in References 1, 3, and 7.

It turns out that the velocity slip process may be capable of achieving a stage heads-to-tails separation factor, α, in the cascade, such that $\alpha - 1$ is 20 times greater than the ideal separation factor for a gaseous diffusion membrane (see Reference 6 for cascade theory and nomenclature). However, the requirement of a large Knudsen number at the nozzle exit tends to limit the process to very low pressures. The low pressures in turn limit the throughput of the individual separation units.

A preliminary plant design has been prepared on the basis of theoretical performance estimates for the velocity-slip separation unit. For a 5 percent seeding of uranium hexafluoride in helium, a total cascade flow of 76.09 lbm/sec of UF_6 + He mixture is required to produce 3.2 percent enriched product with a 0.25 percent waste concentration. The cascade design is based on an ideal asymmetric, countercurrent recycle cascade with two heads and one tails stream. The cascade was designed for a stage heads-to-tails separation factor of 1.07 and a stage cut of 0.326. The cascade relations were developed for a single gas with two isotope constituents. While the cascade equations are developed on a molal basis, final flowrates in each stage were converted to mass flow rate of uranium hexafluoride, lbm UF_6/sec, by matching the cascade product to the product required for 300,000 SWU/yr. An inherent assumption in the cascade analysis is that the seed fraction is constant for each cascade stage feed. This is valid if the carrier gas and UF_6 stage cuts are equal. Otherwise, the seed fraction must be reconstituted in the stage feed by suitable separation or addition of carrier gas and UF_6. A certain amount of care must be taken to keep track of each of the constituents in a cascade with a three-component mixture.

The cascade power consumption is based on power required to compress the gas and the work done by the velocity selector vanes. The power consumption of the compressors is 41.87 MW, which includes an estimate of pressure loss in manifolding and the intercoolers. Power losses due to bearings and electric motor inefficiency were not included in the cascade power consumption estimate. The velocity selector power was computed to be 10.40 MW for the plant. Velocity selector power was estimated from the work done by the blades on the molecular beam, utilizing Euler's equation, which relates the change in angular momentum to energy across a turbomachine. The assumption was made that the fraction of flow in the beam, which impacts on the rotating blades, leaves the blade passage with the full wheel peripheral velocity. Power required for heat removal loops and plant maintenance was found to be relatively small and is neglected. Most of the plant power requirements and corresponding capital investment cost will be required for the separation units, compressors, electric drive motors, and interconnecting process piping. The total power requirement is 52.27 MW, which compares favorably with the 83.3 MW of power required for an equivalent amount of separative work output from a large gaseous diffusion plant (Reference 9).

A total of 114 cascade stages with 42,423 individual separation units are required for the plant. Three sizes of compressor modules, each of which consists of four centrifugal compressor stages with intercoolers and an aftercooler were sized for the plant. A total of 2184 compressors and heat exchangers are required. It turns out that some of the first stage compressors are so large that the assumed impeller tip speed of 1925 ft/sec might not be acceptable for a wheel which is built up instead of cast as a single piece. In this case, a fifth compressor stage may be required.

During the course of this study, the value of the stage heads-to-tails separation factor was changed from 1.037 implied in Reference 1 to 1.07 as a result of the meeting of Reference 2. The value of stage heads to feed mass ratio for UF_6, the cut, has varied from 0.23 from Reference 1 to 0.45 from Reference 2. No work has been done on the cut for the carrier gas, which is also important in plant design. Additionally, the separation unit throughput is not well established because no experimental work has been done to date wherein two isotopes have been actually separated in a multinozzle selector. Therefore, it is reasonable at this time to fabricate and test a prototype velocity slip separation unit prior to any further plant design work.

As a part of this study, it was proposed to investigate the use of a condensable carrier gas, as an alternative to the helium carrier gas utilized for the earlier analytical work. The objective of this approach was to reduce the work input required to pressurize the process gas by condensing, pumping, and boiling the process fluid instead of compressing it as a low density gas. This approach does not appear feasible, beccause at the pressures required in the process gas, neither the UF_6 nor HF can exist as liquid. Condensed process gas would be solid unless compressed. In either case, substantial costs are incurred in solids handling equipment or additional high-compression ratio compressors.

VELOCITY-SLIP SEPARATION PERFORMANCE

The available literature on the velocity-slip isotope separation process was reviewed and a nominal design point for the separation unit was selected. The helium carrier gas, with 1 and 5 percent seeding of UF_6 has been examined quantitatively. Reference 3 shows that a fivefold increase in UF_6 concentration results in only a 14 percent reduction of $(\alpha - 1)$, where α is the stage separation factor. For this reason, the 5 percent seeding was utilized for the design.

Although additional theoretical and experimental work is required to verify the separating unit performance, the following design parameters were selected from Reference 1 for the purpose of this study:

Number of downstream collisions	$i = 72$
Stage heads-to-tails separation factor	$\alpha = 1.07$
Reduction in $\alpha - 1$ due to collisions with background gas	-15%
Reduction in $\alpha - 1$ due to collisions with heavy isotope molecules	-20%
Reduction in $\alpha - 1$ due to transmission function in velocity selector	-11%
Increase in $\alpha - 1$ due to unequal velocity of isotope species at nozzle sonic throat (from Reference 2)	+40%
Net stage separation factor	$\alpha = 1.0658$

Early velocity slip studies (Reference 3) were directed toward evaluating the differences in velocities between heavy isotope molecular species with different masses in a molecular beam formed by expansion of a mixture with light carrier gas from a nozzle source. A tacit assumption was made that at any distance from the source nozzle, where velocity slip is a maximum, all molecules with velocities to the right of the midpoint between the two Gaussian distributions of the heavy species could be separated from all molecules to the left of the midpoint. This led to the definition of the stage separation factor as

$$\alpha \cong 1 + \frac{4}{\pi^{1/2}} S \frac{\Delta\bar{U}}{\bar{U}}$$

The transmission function $B(\xi)$ is defined as the fraction of molecules of velocity ξ, which pass through the velocity selector and therefore comprise the heads stream. The transmission function in the early work of Reference 1 was a step function, equal to zero where $\xi < \bar{U}$ and equal to 1 for $\xi \geq \bar{U}$.

The stage separation factor α is the ratio of the ratios of the isotope molecular fluxes in the two flows which either pass through or do not pass through the velocity selector:

$$\alpha = \frac{n_{1L}\ n_{2R}}{n_{1R}\ n_{2L}}$$

The stage cut is the ratio of the molecular flux transmitted to the total molecular flux in the feed:

$$\theta = \frac{n_{1R} + n_{2R}}{n_{1R} + n_{1L} + n_{2R} + n_{2L}}$$

where 1 and 2 refer to the heavy and light isotope species and the terms R and L refer to molecules which are transmitted or not transmitted by the velocity selector. The fraction of each transmitted species can readily be found by integrating the product of the species velocity distribution function and the transmission function of the velocity selector:

$$n_R = \int_0^\infty B(\xi)U(\xi)d\xi$$

The step function of Reference 3 was clearly an idealized model for a bladed rotating velocity selector.

Reference 1 utilized a simplified, triangular model of the transmission function to calculate the cut, θ, of the separating unit as 0.23. This analysis does not include the contribution of the "trapped molecules" from within the velocity selector blades. A more realistic value of θ should be from 0.4 to 0.45 according to Reference 4. The cut has a profound effect on the layout and separative work mixing loss of the separating cascade. Ideal, nonmixing cascades for small α and low isotope concentrations should have discrete values of θ as illustrated by Figure 3 of Reference 5. The design value of θ for the present consideration should be approximately 1/2, 1/3, or 1/4, corresponding to separation cascades with 1, 2, or 3 heads streams and a single tails stream. The approximate effect of the cut on the total cascade flow can be deduced from the expression for separative work of an optimized stage:

$$\delta U = \frac{1}{2} L(\alpha - 1)^2 \theta (1 - \theta)$$

where L is the stage molar feed rate. For very small values of θ, the cascade total flow is inversely proportional to θ. For a change of θ from $\theta \approx 1/2$ to $\theta \approx 1/3$, it will be shown that the flow increases by 9.1 percent for ideal cascades with $\alpha = 1.07$. It appears, therefore, to be desirable to maximize θ up to 0.5, provided there is no decrease in α.

Before a velocity-slip separation plant is actually built, it will be necessary to define experimentally the design values of α and θ for a separation unit with adequate throughput. Experiments to date have been limited to a single velocity-slip generating nozzle and have not included a practical velocity selector downstream. It appears that, because the flow downstream of the nozzles in the collecting chambers is near free-molecular, it may not be feasible to control the cut by changing the pressure ratio across the separating unit without an excessive reduction in α or increase in pressure ratio. It is therefore desirable to investigate the performance of a velocity-slip separation unit at off-design conditions for variations in feed rate, pressure ratio, and velocity selector speed.

For the present, the separation factor is taken as $\alpha = 1.07$ and the cut is taken as $\theta \approx 1/3$. Any refinements of these numbers will require more elaborate flow models and experimental data, which are beyond the scope of the present study. It should be noted that the velocity-slip process could be enhanced by a parametric optimization to define the effect of separation factor, cut, nozzle stagnation pressure, background pressure, and seed fraction on total flow and power requirements.

SEPARATION UNIT DESIGN

The design of a single velocity selector for a separating unit is sketched in Figures 1 and 2 and relevant parameters are tabulated. The design follows the recommended nozzle size and spacing of Reference 1. It was desirable to reduce the velocity selector solidity (ratio of blade chord to blade spacing ℓ/a in Figure 2) from the levels implied in Reference 1. By utilizing an axial velocity selector similar to a turbine wheel with thin, tapered blades, an increased wheel speed of 2000 ft/sec (610 m/sec) can be achieved. This reduces the blade solidity from 100:1 assumed in Reference 1 to a producible 20:1. By way of comparison, typical axial compressor and turbine solidities range from 0.5 to 2. This implies that the blades must be made extremely thin in order to avoid excessive blockage of the nozzle flow. One method of reducing the blade blockage is to increase the size of the velocity selector blade cascade by increasing the axial chord of the blades. Thus the axial chord of the blades in Figure 2 is 5 cm, while the blade spacing or pitch is 0.32 cm. Blade blockage is only 11 percent of the annular area.

The size limit of the velocity selector blades is determined by the interaction between blade passages and successive nozzles. The blade passage must be emptied of "trapped molecules" prior to intercepting the molecular beam from the next nozzle. The trapped molecules are defined as molecules which make one or more collisions with the blade surfaces. Reference 7 gives some guidance in this respect. The density buildup in the blade passages is calculated for solidities of $\ell/a = 5$ and 10 and time constants of $\frac{t_f\sqrt{2RT_w}}{a} = 2$ and 4, respectively, where t_f is the time during which the blade passage is exposed to the molecular beam. It would be desirable to repeat this analysis to verify the proposed separation unit design, where $\ell/a = 20$ and $\frac{t_f\sqrt{2RT_w}}{a} = 1.65$ for helium.

The flow capacity of the separating unit can be calculated on the basis of the total nozzle area at the sonic throat, which is 120 mm^2.

$$\dot{m}_{UF_6} = A\ P_T \left(\frac{\dot{m}_{UF_6}}{\dot{m}_{UF_6+He}}\right)\sqrt{\frac{\gamma g_c}{RT_T}}\ \left[\frac{1+\gamma}{2}\right]^{-\frac{(\gamma+1)}{2(\gamma-1)}} = 1.475 \times 10^{-3}\ \text{lbm } UF_6/\text{sec}$$

where for 5% seeding,

$\gamma = 1.457$, ratio of specific heats

$R = 72.21$ ft-lbf/lbm-°R

$\dot{m}_{UF_6}/\dot{m}_{UF_6+He} = 0.8224$ lbm UF_6/lbm(UF_6 + He)

$T_T = 540°R$

$P_T = 25$ Torr = 3333 Pa

The above relationship for flow through a choked nozzle from Reference 13 has, as an inherent assumption, a flow coefficient of unity, where the flow coefficient is the ratio of effective area to actual nozzle throat area. In practice, the flow through very slender nozzle slits may exhibit a flow coefficient appreciably less than 1. The flowrate can be adjusted to match the design stage flows by minor changes to nozzle height and/or the number of nozzles. A typical arrangement of separating units and associated hardware is illustrated in the flow diagram of Figure 3.

An estimate of the power required to drive the velocity selector units was made from the change in angular momentum of the beam impinging on the rotating blades. It is assumed that the UF_6 tails stream and all of the helium molecules strike the blade surface at least once and subsequently discharge from the blade passages with the full peripheral velocity component of the velocity selector. The UF_6 heads stream is assumed to pass through the velocity selector with no collisions with the blade surfaces. The Euler turbine equation of Reference 12 can be used to relate the ideal power input to the velocity selector with the change in angular momentum of the fluid and the mass flow as follows

$$P_{vi} = U^2\left[(1-\theta) + \frac{\dot{m}_{He}}{\dot{m}_{UF_6}}\right] = 0.1662\ \frac{\text{MW}}{\text{lbm } UF_6/\text{sec}}$$

for

$$\theta = 1/3$$

$$\dot{m}_{He}/\dot{m}_{UF_6} = 0.31933$$

$$U = 2000 \text{ ft/sec}$$

The power requirements for a cascade stage include the work done to recompress the gas as well as work done in the velocity selector. The ideal, isentropic compressor work is given by

$$P_{c_i} = \left(\frac{\dot{m}_{UF_6+He}}{\dot{m}_{UF_6}}\right) \frac{R\gamma}{\gamma - 1} T_T \left[\left(P_1/P_2\right)^{\frac{\gamma-1}{\gamma}} - 1\right] = 0.6641 \frac{MW}{\text{lbm } UF_6/\text{sec}}$$

where the overall pressure ratio P_1/P_2 is 100. The final compressor design will probably consist of multistaged radial compressors with four stages and intercoolers between each stage. As the number of stages increases, the process approaches an isothermal one. A large number of compressor stages will also result in higher interstage pressure losses in the intercoolers and a corresponding increase in overall compression ratio.

CASCADE DESIGN

The plant design is based on the cascade stage flowrates. An ideal, asymmetric cascade with two heads streams and a single tails stream was used as a model. This configuration resulted in a nearly constant value of stage cut of 0.326. The plant is arranged as a countercurrent recycle cascade, wherein the heads stream is fed into the second stage above and the tails stream is fed into the stage below, as shown in Figure 4. A total of 114 stages were required with 67 enriching and 46 stripping stages above and below the feed stage, respectively.

The cascade analysis is based on cascade theory of References 5 and 6. By definition, the ideal cascade produces no mixing losses, so that the isotope concentration in mixing streams is equal. It is assumed that the stage separation factor is independent of composition. The relationship between stage feed abundance ratios, heads to feed abundance ratios, and tails to feed abundance ratios for the asymmetric cascade can be shown to be

$$\frac{\xi_i}{\xi_j} = \epsilon^{i-j}$$

$$\frac{\xi_i'}{\xi_i} = \epsilon^2$$

$$\frac{\xi_i''}{\xi_i} = \epsilon^{-1}$$

where $\epsilon = \alpha^{1/3}$ for two heads and one tails stream and the abundance ratio ξ is defined in terms of concentration X as $\xi = \frac{X}{1 - X}$. In this manner, all stage isotope concentrations can be computed. Stages are numbered consecutively, from waste stage 1 to the last product stage n. The feed stage number is m. The number of stages to the feed and the total number of stages are

$$m \geq \frac{\ell n(\xi_F/\xi_W)}{\ell n \epsilon}$$

$$n \geq \frac{\ell n(\xi_{P1}/\xi_F)}{\ell n \epsilon} + m - 2$$

The product is composed of two heads streams $P_1 = L'_n$ and $P_2 = L'_{n-1}$, so that

$$P = P_1 + P_2$$

$$PX_P = P_1X_{P1} + P_2X_{P2}$$

where $X_{P1} = \dfrac{1}{1 + \dfrac{\epsilon^{m-n-2}}{\xi_F}}$

$$X_{P2} = \frac{1}{1 + \dfrac{\epsilon^{m-n-1}}{\xi_F}}$$

The ratio of product flows $\frac{P_1}{P}$ is determined by calculating through the entire cascade and iterating until the P_2 product flow calculations match. Recursion relations are based on conservation of mass and species around the cascade from the jth stage to the waste stage and around the jth stage:

$$L'_{j-1} + L'_j - L''_{j+1} = C$$

$$L'_{j-1}X'_{j-1} + L'_jX'_j - L''_{j+1}X''_{j+1} = CX_C$$

$$-L'_j + L''_{j+1} = (L''_j - L'_{j-2}) - D$$

$$-L'_jX'_j + L''_{j+1}X''_{j+1} = (L''_jX''_j - L'_{j-2}X'_{j-2}) - DX_D$$

where

$$\left.\begin{aligned} C &= -W \\ CX_C &= -WX_W \\ D &= 0 \\ DX_D &= 0 \end{aligned}\right\} \text{ for } j = 3 \text{ to } m - 1$$

$$\left.\begin{aligned} C &= P \\ CX_C &= PX_P \\ D &= F \\ DX_D &= FX_F \end{aligned}\right\} \text{ for } j = m$$

$$\left.\begin{aligned} C &= P \\ CX_C &= PX_P \\ D &= 0 \\ DX_D &= 0 \end{aligned}\right\} \text{ for } j = m \text{ to } n - 1$$

For the two heads case, the fourth conservation equation is not required and the L'_j and L''_{j+1} can be evaluated from the remaining three equations, where the lower stage values of L'_{j-2} and L''_j are known. Starting values of L'_i, L'_2, L''_2, and L''_3 can be calculated by solving the same four equations where $j = 2$ and $L''_1 = W$, the waste flow. The term L'_{j-2} does not exist at the waste end of the cascade when $j = 2$.

The net cascade flows can be determined by applying mass and species conservation around the entire cascade as follows

$$F = P + W$$

$$FX_F = PX_P + WX_W$$

where P and X_F are fixed and X_P and X_W are determined, by the requirement of integer stage numbers, to be greater than and less than the respective design requirements. The ratio of kilograms of uranium product flow to SWU's is derived from the relation from Reference 8, where mole fractions of UF_6 are used for the assay values X.

$$\frac{\Delta}{P} = \left[V(X_P) - V(X_W)\right] - (F/P)\left[V(X_F) - V(X_W)\right]$$

where $V(X) = (2X - 1)\ \ell n\left(\frac{X}{1 - X}\right)$, the value function

X_F = 0.00717, feed mole fraction UF_6

X_P = 0.03227, product mole fraction for 0.032 mass fraction UF_6

X_W = 0.00252, waste mole fraction for 0.0025 mass fraction UF_6

where Δ = 300,000 SWU/yr plant design

P = 71262.5 kg U/yr

or P = 0.007368 lbm UF_6/sec

The resultant values of cascade flow and concentration are tabulated below along with the corresponding values for the symmetric, single heads cascade:

	Ideal Symmetric Cascade	Ideal Asymmetric Cascade
Number of stages (n)	77	114
Feed stage (m)	32	47
Concentrations (mole fraction)		
X_F	.007170	.007170
X_W	.002440	.002496
X_P	.033102	.032624
Flow rates, lbm UF_6/sec		
F	.047765	.047491
W	.040397	.040123
P	.007368	.007368
P_1	---	.002439
P_2	---	.004929
Total cascade flow $\left(\sum_{i=1}^{n} L_i\right)$, lbm/sec	57.3465	62.5693

The stage number; concentration of the feed, heads, and tails streams; flow in the feed, heads, and tails streams; and stage cut for the design asymmetric cascade are given in Table 1. Stage flow rates are plotted in Figure 5.

The ideal power consumption of the cascade is then

$$P_i = 0.8303 \frac{\text{MW}}{\text{lbm UF}_6/\text{sec}} \times 62.5693 \frac{\text{lbm UF}_6}{\text{sec}} = 51.95 \text{ MW}$$

This does not include the power consumption due to compressor inefficiency, seals and bearings, electric motor drives, line losses, intercooler losses, and cooling circuit power consumption. The total power consumption of an 8.75 million SWU/yr gaseous diffusion plant based on 1970 technology is 2430 MW from Table 2 of Reference 9. This scales to 83.3 MW power required for the 300,000 SWU/yr fraction. Thus, a small velocity-slip plant could in theory have a lower power consumption per SWU than a large gaseous diffusion plant.

A simplified flow diagram for a cascade stage is illustrated schematically in Figure 3. Tails flow from the upper stage is mixed with heads flow from a lower stage prior to being compressed. A multistage compressor module with intercoolers and aftercooler is used to recompress the process gas. Up to 9 compressor modules and 798 separation units are manifolded together in any one cascade stage. Some of the process gas must be withdrawn so that the helium carrier gas can be separated from the UF_6. This may be done by liquifaction of the UF_6 as indicated or by a centrifuge separation process. The separated helium gas is used to makeup the desired seed fraction into the velocity separation unit.

It should be noted that the cut of the helium carrier gas has an important effect on cascade operation. No effort has been made to determine what fraction of the carrier gas flow passes into the heads stream of the velocity selector. This must probably be determined by actual experiment with a development model of the separation unit. It is assumed for the present that the two mixing feed streams reconstitute the required seed fraction closely enough, so that the helium separation unit has no impact on cascade design or cost and the compressor inlet flow is always at the same mole fraction of helium as the feed to the separation units.

NUMBER AND SIZE OF SEPARATION UNITS AND COMPRESSORS

A total of 42,423 separation units is required in the velocity slip isotope separation cascade. The large number of units is a consequence of the low feed capacity of only 0.001475 lbm UF_6/sec for the individual separation unit. This low capacity in turn is a result of the very low operating pressures of the feed gas, the intermittent nature of the velocity selector (which requires a large spacing between nozzles), and the very small width of the nozzle slots. In this context, a separation unit as shown in Figure 1 is a single annulus of nozzles and rotating selector blades. It may be possible to mount more than one set of blades on a single shaft.

A detailed tabulation of cascade stage requirements is given in Table 2. Stage number i, stage feed Li (lbm UF_6/sec), number of separation units, n_u, and ratio of total nominal flow of the separation units to the required stage flow, f_u, are itemized. The flow deviates from nominal design by no more than +3.0 and -2.2 percent, in any stage.

The compressor modules were sized for a minimum number of compressor designs and a maximum flow through each compressor stage. Three sizes of compressor modules were selected. Size C_3 is designed for 1/9th the flow in stage 106:

$$\dot{m}_{c3} = \frac{L_{n-8}}{9} = 0.00815 \text{ lbm } UF_6/\text{sec}$$

$$= 0.00991 \text{ lbm } UF_6 + \text{He/sec}$$

Size C_2 is 5 times the flow of C_3 and size C_1 is 25 times the flow of C_3. No more than two compressor sizes were utilized in any cascade stage. The total design flow of the compressors in any stage was required to be greater than or equal to the required stage flow. The excess flow is recirculated through the compressor module. The power consumed to recirculate the flow is offset by the use of fewer module sizes of larger flow capacity. It is desirable to increase the flow through the larger compressor modules because these modules exhibit a higher efficiency.

The numbers of each compressor module size are given in Table 2 as n_{c_1}, n_{c_2}, and n_{c_3}. The term fc is the error term in compressor flow matching

$$fc_i = \frac{\sum_{k=1}^{3} n_{c_{k,i}} \dot{m}_{c_k} - L_i}{L_i} \quad \text{for each stage}$$

This term indicates the amount of excess compressor flow capacity and varies between 1.0 and 1.176. The net excess compressor flow capacity for the entire cascade is less than 3 percent:

$$\frac{\sum_{i=1}^{n} \left(\sum_{k=1}^{3} n_{c_{k,i}} \dot{m}_{c_k} - L_i \right)}{\sum_{i=1}^{n} L_i} = 0.0298$$

The total number of compressors of each module size is:

$N_{c1} = 269.$

$N_{c2} = 226.$

$N_{c3} = 51.$

The percentage of the total compressor flow in each module size is then 84.07, 15.17, and 0.76, corresponding to modules C_1, C_2, and C_3.

COMPRESSOR MODULE DESIGN

Several different methods were considered for compressing the process gas from 0.25 to 25 Torr, a pressure ratio of 100:1. The design pressure levels fall into the region between so-called "rough" or fore pump and the typical high vacuum pumps which operate down to 10^{-6} mm Hg. Mechanical pumps such as the roots-type and the piston type were rejected because they require oil lubrication at these pressure levels and because they do not have the required volumetric flow capacity for a plant of this size. The volumetric flow is 590 ft^3/sec for the small compressor and 14,760 ft^3/sec the largest compressor module. Piston pumps were also eliminated from consideration because of mechanical complexity and because of the intermittent, pulsating nature of the compression process.

Vapor stream pumps, such as ejectors and "diffusion" pumps were not satisfactory because of contamination of the process gas with the high momentum stream. Ejector pumps tend to have low efficiencies for such large pressure ratios and they would have a very low entrainment ratio, so that the high pressure gas would be composed largely of the injected, primary gas. Diffusion pumps typically operate at exhaust pressures below those required for the velocity slip stagnation chamber.

The selected compression system consists of multistaged centrifugal compressors with intercooling between stages and aftercooling of the flow between last stage and the velocity selector. The compressors are to be hermetically sealed and can be driven by electric motors within the sealed volume. The bearings can be either gas foil bearings lubricated by helium or conventional bearings lubricated by fluorocarbons. The small amount of injected lubricant must be separated from the process gas.

A major technical uncertainty in the compressor design is performance at low inlet Reynolds number because of low process gas pressure. It is well known that centrifugal compressor efficiency falls rapidly at $Re < 10^5$. For this reason, the compressors were designed to be as large as possible, so as to increase the Reynolds number.

A second area of design limitation is the validity of continuum flow relations, which were used in the compressor designs. The mean free molecular path at the inlet to the first compressor stage was computed as follows from

Reference 14. The mean free path for constituant A of a binary gas mixture of A and B is approximately

$$\frac{1}{\lambda_A} = \sqrt{2}\,\pi\, n_A\, \delta_A^2 + \pi\, n_B\, \delta_{AB}^2 \left(1 + \frac{m_A}{m_B}\right)^{1/2}$$

where $\delta_{AB} = \frac{1}{2}(\delta_A + \delta_B)$

$n_A = \frac{P_A}{kT}$

λ = mean free path

n = molecular density

m = mass of molecule

δ = collision cross section

P = partial pressure

T = absolute temperature

k = Boltzman constant

For a 5 percent seed fraction, a pressure of 0.004544 lbf/in.^{2}, and a temperature of 540°R,

$$\lambda_{He} = 0.02408 \text{ in.}$$

$$\lambda_{UF_6} = 0.00579 \text{ in.}$$

The smallest flow dimension on the first stage of the smallest compressor module is the wheel exit width, b_2 = 1.22 inch. The largest Knudsen number is then $\frac{\lambda_{He}}{b_2} = 0.019$. This is just sufficiently small so that continuum flow can be assumed to model the compressor.

The 12 compressor stages were designed utilizing a proprietary AiResearch program for sizing and design point performance of centrifugal compressors, identified as CYNTHIA/41777. This program utilizes statistical correlations to estimate the performance based on specific speed, wheel tip Mach number, inlet Mach number, Reynolds number, and size effect.

The number of stages required was determined by the stress limitations on wheel speed and the aerodynamic loading of the rotor and diffuser vaned passages for good performance. Four compressor stages are required with a wheel tip speed of 1925 ft/sec. The overall pressure ratio for the four stages is 162:1, not including interstage losses. The following losses in total pressure were assumed in the design:

Line loss from separation unit to compressor	8%
Intercooler between first and second stages	12%
Intercooler between second and third stages	10%
Intercooler between third and fourth stages	8%
Aftercooler between fourth stage and separation unit	8%
Line loss from aftercooler to separation unit	2%

The net pressure ratio, from separation unit to separation unit, including interstage losses, is then 100:1.

It was assumed that all intercoolers utilize R114 secondary coolant loops, which, in turn, reject heat to the atmosphere via a water loop and cooling towers. Therefore, the intercooler outlet temperature was chosen as 640°R to allow for a minimum of 100 degree temperature difference between the process gas and heat sink. Because the velocity slip process is assumed to start with a 540°R stagnation chamber temperature, an aftercooler is utilized between the last compressor stage and the velocity slip units.

The process gas is expanded in the velocity slip module from 540°R stagnation temperature over a 100:1 pressure ratio. For an isentropic process, the exit temperature would be

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 127°R$$

However, the process will not be isentropic because of pressure losses through the selector blades, disk friction, and heat transfer through the walls of the velocity selector and manifold plumbing. For this reason, the compressor module inlet temperature was assumed to be at room temperature or 540°R.

The design parameters for the 12 compressors are listed in Table 3. Initial sizing was made for constant specific speed and adiabatic head for each stage with maximum overall compressor efficiency. Subsequently, the compressor speeds were adjusted so that only six different shaft speeds are utilized in the compressor modules.

The final design Reynolds number of the different stages is plotted on Figure 6, along with the curve of efficiency correction. The well established region is shown as a solid curve, while the dashed curve indicates a tentative correlation based on pump test data. All but one of the compressor designs are within an order of magnitude of the well defined region.

The only dimensions listed for the compressor are wheel diameter and wheel exit width. Either a vaned or a conical pipe diffuser will be used with the impeller, which will increase the diameter by approximately 70%. The compressor length, along the axis of rotation, will be approximately equal to its wheel diameter, including an upstream inlet section. Thus, the total volume of a compressor stage is approximately $2D_2^3$.

The total compressor power requirement can be determined from the total horsepower for each module times the number of modules as 56,153.5 hp or 41.87 MW. This is close to the ideal power for an isentropic compression process. A summary of the module number, flowrate, number of modules, module power, and net efficiency, including line losses, is given below:

Module Number	Flow, $\left(\frac{\text{lbm } UF_6 + He}{\text{sec}}\right)$	Number of Modules	Module Power (hp)	Net Efficiency
C1	0.24775	269	175.48	1.034
C2	0.04955	226	37.70	0.962
C3	0.00991	51	8.41	0.863

The compressor module efficiency is based on the ideal, isentropic compression work for a perfect gas for an overall pressure ratio of 100. and an inlet temperature of 540°R (see page A-7). This efficiency may be greater than one because of the heat removed by the intercoolers.

PROCESS HEAT REMOVAL SYSTEM

There are four heat exchangers in each compressor module: three intercoolers and one aftercooler, which are located downstream of each of the centrifugal compressors. The rate of heat removal from the cascade is 41.87 MW, which is the compressor work input. The energy added in the separation unit is neglected, as it is assumed that the process gas will reach room temperature by the time it reaches the inlet to the first compressor stage.

Table 4 summarizes the heat exchanger inlet and outlet temperatures and pressures on the primary side. The difference between the three modules is the inlet temperature, which is dependent on the compressor stage efficiency, and the flowrate.

CONDENSABLE CARRIER GAS

One of the goals of this plant design study was to utilize a condensable carrier gas, such as hydrogen fluoride, to reduce the compressor power requirements. The carrier gas would be condensed, pumped as a liquid, boiled, and remixed with the UF_6 isotopes. This would overcome a major drawback of the velocity slip process, which is the large work required to compress a low molecular weight, low pressure gas to a high pressure ratio.

Candidate condensable carrier gases must (1) be chemically compatible with UF_6 and available materials for pipe, pump, and heat exchanger equipment; (2) the gas must have a low molecular weight (nominally 40 or less); and (3) the gas must condense out at temperatures which do not require excessive investment in cryogenic equipment (typically above 140°R). The best available gas appeared to be hydrogen fluoride, with a molecular weight of 20.01. With this gas, the stage heads to tails separation factor, $\alpha - 1$, was reduced by 27 percent, compared with the value for helium (Reference 10).

The vapor pressure curves of hydrogen fluoride and uranium hexafluoride are presented in Figure 7 to illustrate the following discussion. At the background pressure of 0.15 Torr, assumed for the velocity selector, both gases will condense as a solid (Reference 15). In fact, the UF_6 will condense out first, as a solid, at partial pressures below the triple point of 1148 Torr for uranium hexafluoride. The heavier UF_6 molecules will probably condense before any conceivable lightweight carrier gas. Therefore, additional requirements for a condensable carrier gas might be (4) the gas should have a triple point below the background pressure in the velocity selector and (5) high solubility of the solid uranium hexafluoride in the liquid carrier gas is required for liquid pumps.

The condensed gases could be transported and pumped as solids, instead of liquids. It is possible to utilize a cyclical process, whereby the gas is condensed, the volume is reduced, and the gas is vaporized again. However, the volumetric flow capacity of the required tanks may be prohibitively expansive.

The total flow in the cascade for a hydrogen fluoride carrier gas has been computed for an ideal, asymmetric cascade with two heads and one tails streams with a stage heads-to-tails separation factor of 1.051 corresponding to a 5 percent seeding of uranium hexafluoride. The separation factor was estimated from the net values of $\alpha - 1$ of References 1 and 10. The helium $\alpha - 1$ of 0.07 was multiplied by the ratio of the net $\alpha - 1$ for hydrogen fluoride to the net $\alpha - 1$ for helium carrier gas. A total cascade flow of 114.01 lbm UF_6/sec is required in 155 stages. The average stage cut, θ, was 0.328 for the UF_6.

The volumetric flow of the cascade is found by multiplying the UF_6 flow by the ratio of UF_6 + HF flow to UF_6 flow and dividing by the density of the mixture at 0.15 Torr pressure and 540°R temperature. The cascade volumetric flow was computed as 776×10^6 ft^3/min.

The tank volume required for the process is the product of volumetric flow rate and cycle time. During a cycle, a valve is opened, the tank fills, a surface in the tank is cooled to 150°K, the volume is reduced, the tank is heated to 300°K, a valve is opened, and the tank is emptied of process gas. For a 10 minute time cycle, approximately 8 billion cubic feet of tank capacity is required.

CONCLUSIONS

The utility of the velocity-slip separation process depends on the level of stage separation factor, the interstage compression work, and the feed throughput of the individual separation unit. To paraphrase Comparque (Reference 11), the uncertainty in the separative work and the energy requirements is such that an optimistic choice of all parameters results in an extremely attractive estimate of the process, while a pessimistic choice of all parameters results in an extremely unattractive estimate of the process.

The important questions relate to the performance of an optimized velocity separation unit. What value of α can be achieved in a practical velocity selector with multipie slit nozzles and a rotating, bladed velocity selector? What is the cut of the seed and carrier gases corresponding to this α? What feed throughput can be achieved? Can the cut be controlled by varying the pressure ratio across the selector blades? What is the off-design performance of the velocity selector? Can the background pressure be raised, so as to reduce compressor work and increase separation unit throughput? What is the effect of higher seed fractions on performance? The final answers will require experimental verification wherein the heads and tails streams are actually separated in a multi-nozzle unit.

The present study has generally taken an optimistic evaluation of the velocity slip process, which results in performance better than that of a large gaseous diffusion plant. However, because of the low pressures in the process and the transient nature of the velocity-slip separation, a very large number of velocity selectors is required. An increase in diameter of the velocity selector wheel would make the nozzle clearance of 0.5 mm difficult to maintain. An increase of the nozzle and blade heights in the velocity selector is limited by considerations of blade stress and three-dimensional flow phenomena.

The turbomachinery used in the velocity slip process is unique because of the extremely low mass of fluid being processed for a given machine volume. For this reason, the power consumed in the bearings may be appreciable. Also, the manifolding of piping between process machinery could be very expensive. The piping must withstand buckling loads due to ambient external pressure and vacuum level internal pressure.

The use of a condensable gas, such as hydrogen fluoride, as the carrier gas was studied in an attempt to reduce the compression work. At the low background pressure of the velocity-slip process, both uranium hexafluoride and hydrogen fluoride condense as solids, so that conventional liquid pumps cannot be employed. Compression of the condensed solids requires an innovative method to efficiently separate and transport the condensate from the large volumetric flow exhausted from the velocity-separation units.

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TABLE 1 CASCADE CONCENTRATION AND FLOW RATE *

i	X_i	X'	X_i''	L_i	L_i'	L_i''	θ_i
114	.03168817	.03310181	.03100341	.007473	.002439	.005035	.326321
113	.03100341	.03238754	.03033300	.015106	.004929	.010177	.326311
112	.03033300	.03168617	.02967663	.022903	.007473	.016430	.326301
111	.02967663	.03100341	.02903404	.030867	.010072	.020796	.326291
110	.02903404	.03033300	.02840496	.039003	.012726	.026277	.326281
109	.02840496	.02967663	.02778912	.047315	.015438	.031877	.326272
108	.02778912	.02903404	.02718626	.055807	.018208	.037599	.326262
107	.02718626	.02840496	.02659612	.064483	.021038	.043445	.326253
106	.02659612	.02778912	.02601844	.073348	.023929	.049419	.326244
105	.02601844	.02718626	.02545299	.082406	.026884	.055522	.326236
104	.02545299	.02659612	.02489951	.091662	.029903	.061760	.326227
103	.02489951	.02601844	.02435776	.101121	.032988	.068133	.326219
102	.02435776	.02545299	.02382751	.110787	.036140	.074647	.326211
101	.02382751	.02489951	.02330853	.120666	.039361	.081304	.326203
100	.02330854	.02435776	.02280060	.130761	.042654	.088108	.326195
99	.02280060	.02382751	.02230347	.141080	.046018	.095061	.326187
98	.02230347	.02330853	.02181695	.151626	.049457	.102168	.326180
97	.02181695	.02280060	.02134080	.162405	.052972	.109433	.326173
96	.02134080	.02230347	.02087483	.173423	.056564	.116858	.326165
95	.02087483	.02181695	.02041881	.184684	.060236	.124448	.326158
94	.02041881	.02134080	.01997256	.196196	.063990	.132207	.326152
93	.01997256	.02087483	.01953586	.207964	.067826	.140137	.326145
92	.01953586	.02041881	.01910853	.219993	.071748	.148245	.326138
91	.01910853	.01997256	.01869036	.232290	.075757	.156533	.326132
90	.01869036	.01953586	.01828118	.244862	.079856	.165006	.326126
89	.01828118	.01910853	.01788079	.257714	.084045	.173668	.326119
88	.01788079	.01869036	.01748901	.270852	.088329	.182524	.326113
87	.01748901	.01828118	.01710567	.284285	.092708	.191578	.326108
86	.01710567	.01788079	.01673059	.298018	.097184	.200834	.326102
85	.01673059	.01748901	.01636360	.312059	.101761	.210298	.326096
84	.01636359	.01710567	.01600452	.326415	.106441	.219974	.326091
83	.01600452	.01673059	.01565320	.341092	.111225	.229867	.326085
82	.01565320	.01636360	.01530947	.356099	.116117	.239982	.326080
81	.01530947	.01600452	.01497317	.371443	.121118	.250325	.326075
80	.01497317	.01565320	.01464415	.387132	.126232	.260900	.326070
79	.01464415	.01530947	.01432226	.403174	.131461	.271713	.326065
78	.01432226	.01497317	.01400734	.419577	.136807	.282770	.326060
77	.01400734	.01464415	.01369925	.436350	.142274	.294076	.326055
76	.01369925	.01432226	.01339784	.453500	.147864	.305636	.326051
75	.01339784	.01400734	.01310298	.471037	.153580	.317457	.326046
74	.01310298	.01369925	.01281452	.488969	.159424	.329545	.326042
73	.01281452	.01339784	.01253233	.507306	.165401	.341906	.326037
72	.01253233	.01310298	.01225628	.526058	.171512	.354545	.326033
71	.01225628	.01281452	.01198624	.545232	.177761	.367471	.326029
70	.01198624	.01253233	.01172207	.564840	.184152	.380688	.326025
69	.01172207	.01225628	.01146366	.584892	.190687	.394205	.326021
68	.01146366	.01198624	.01121088	.605397	.197370	.408027	.326017
67	.01121088	.01172207	.01096361	.626365	.204203	.422162	.326013
66	.01096361	.01146366	.01072174	.647809	.211192	.436617	.326009
65	.01072174	.01121088	.01048515	.669737	.218338	.451399	.326006
64	.01048515	.01096361	.01025372	.692163	.225647	.466516	.326002
63	.01025372	.01072174	.01002735	.715096	.233121	.481976	.325999
62	.01002735	.01048515	.00980593	.738549	.240764	.497785	.325995
61	.00980593	.01025372	.00958935	.762535	.248580	.513955	.325992
60	.00958935	.01002735	.00937751	.787061	.256573	.530488	.325989
59	.00937751	.00980593	.00917030	.812151	.264750	.547402	.325986
58	.00917030	.00958935	.00896764	.837795	.273107	.564689	.325982
57	.00896764	[illegible]	.00876941	.864052	.281663	.582389	.325979
					[illegible]	.600448	.325976

* All flows are expressed in units of 16m UF6 /sec

TABLE 1 - CONTINUED

i	X_i	X_i'	X_i''	L_i	L_i'	L_i''	θ_i
55	.00857552	.00896764	.00838589	.918367	.299363	.619004	.325974
54	.00838589	.00876941	.00820041	.946260	.308453	.637807	.325971
53	.00820041	.00857552	.00801901	.975307	.317919	.657388	.325968
52	.00801901	.00838589	.00784158	1.003961	.327256	.676705	.325965
51	.00784158	.00820041	.00766805	1.035395	.337500	.697895	.325962
50	.00766805	.00801901	.00749833	1.063237	.346573	.716665	.325960
49	.00749833	.00784158	.00733234	1.100421	.358690	.741731	.325957
48	.00733234	.00766805	.00717000	1.120837	.365342	.755495	.325955
47	.00717000	.00749833	.00701123	1.177340	.383757	.793583	.325952
46	.00701123	.00733234	.00685595	1.163080	.379106	.783974	.325950
45	.00685594	.00717000	.00670408	1.148508	.374354	.774155	.325948
44	.00670408	.00701123	.00655556	1.133616	.369497	.764119	.325945
43	.00655556	.00685595	.00641030	1.118397	.364534	.753863	.325943
42	.00641030	.00670408	.00626824	1.102843	.359462	.743382	.325941
41	.00626824	.00655556	.00612932	1.086946	.354278	.732668	.325939
40	.00612932	.00641030	.00599345	1.070698	.348980	.721718	.325937
39	.00599345	.00626824	.00586058	1.054091	.343565	.710526	.325935
38	.00586058	.00612932	.00573063	1.037116	.338030	.699086	.325933
37	.00573063	.00599345	.00560355	1.019765	.332373	.687392	.325931
36	.00560355	.00586058	.00547927	1.002028	.326590	.675438	.325929
35	.00547927	.00573063	.00535774	.983897	.320679	.663219	.325927
34	.00535774	.00560355	.00523888	.965363	.314636	.650727	.325925
33	.00523888	.00547927	.00512265	.946416	.308459	.637957	.325923
32	.00512265	.00535774	.00500899	.927046	.302144	.624902	.325922
31	.00500899	.00523888	.00489783	.907244	.295689	.611555	.325920
30	.00489783	.00512265	.00478913	.886999	.289089	.597910	.325918
29	.00478913	.00500899	.00468283	.866302	.282342	.583960	.325917
28	.00468283	.00489783	.00457888	.845141	.275444	.569697	.325915
27	.00457888	.00478913	.00447723	.823507	.268392	.555115	.325913
26	.00447723	.00468283	.00437782	.801387	.261182	.540206	.325912
25	.00437782	.00457888	.00428061	.778771	.253810	.524962	.325910
24	.00428061	.00447723	.00418555	.755648	.246272	.509375	.325909
23	.00418555	.00437782	.00409259	.732005	.238566	.493439	.325908
22	.00409259	.00428061	.00400169	.707830	.230686	.477144	.325906
21	.00400169	.00418555	.00391280	.683111	.222629	.460482	.325905
20	.00391280	.00409259	.00382588	.657836	.214391	.443445	.325903
19	.00382588	.00400169	.00374088	.631992	.205967	.426024	.325902
18	.00374088	.00391280	.00365776	.605565	.197354	.408211	.325901
17	.00365776	.00382588	.00357648	.578542	.188547	.389995	.325900
16	.00357648	.00374088	.00349700	.550909	.179540	.371369	.325898
15	.00349700	.00365776	.00341928	.522654	.170331	.352322	.325897
14	.00341928	.00357648	.00334329	.493759	.160914	.332845	.325896
13	.00334329	.00349700	.00326897	.464214	.151285	.312929	.325895
12	.00326897	.00341928	.00319631	.433995	.141436	.292559	.325894
11	.00319631	.00334329	.00312525	.403106	.131369	.271737	.325893
10	.00312525	.00326897	.00305577	.371492	.121066	.250426	.325892
9	.00305577	.00319631	.00298783	.339215	.110547	.228668	.325891
8	.00298783	.00312525	.00292139	.306101	.099755	.206346	.325890
7	.00292139	.00305577	.00285643	.272454	.088790	.183664	.325889
6	.00285643	.00298783	.00279291	.237605	.077433	.160173	.325888
5	.00279291	.00292139	.00273080	.202856	.066108	.136748	.325887
4	.00273080	.00285643	.00267006	.165522	.053941	.111580	.325886
3	.00267006	.00279291	.00261067	.130977	.042683	.088294	.325885
2	.00261067	.00273080	.00255260	.088294	.028773	.059520	.325884
1	.00255260	.00267006	.00249582	.059520	.019397	.040124	.325883

TABLE 2 NUMBER OF INDIVIDUAL SEPARATION UNITS AND COMPRESSOR MODULES

i	L_i	n_u	f_u	n_{c1}	n_{c2}	n_{c3}	f_c
114	.00747323	5.	.98686	0.	0.	1.	1.09056
113	.01510624	10.	.97642	0.	0.	2.	1.07902
112	.02290290	16.	1.03044	0.	0.	3.	1.06755
111	.03086719	21.	1.00349	0.	0.	4.	1.05614
110	.03900316	26.	.98325	0.	1.	0.	1.04479
109	.04731493	32.	.99757	0.	1.	1.	1.03350
108	.05580675	38.	1.00436	0.	1.	2.	1.02228
107	.06448293	44.	1.00647	0.	1.	3.	1.01112
106	.07334788	50.	1.00548	0.	1.	4.	1.00003
105	.08240611	56.	1.00235	0.	2.	1.	1.08790
104	.09166224	62.	.99768	0.	2.	2.	1.06696
103	.10112096	69.	1.00647	0.	2.	3.	1.04776
102	.11078709	75.	.99854	0.	2.	4.	1.02990
101	.12066555	82.	1.00236	0.	3.	0.	1.01313
100	.13076136	89.	1.00393	0.	3.	2.	1.05956
99	.14107965	96.	1.00369	0.	3.	3.	1.03984
98	.15162569	103.	1.00197	0.	3.	4.	1.02126
97	.16240481	110.	.99905	0.	4.	0.	1.00366
96	.17342253	118.	1.00362	0.	4.	2.	1.03389
95	.18468442	125.	.99832	0.	4.	3.	1.01497
94	.19619624	133.	.99989	1.	0.	0.	1.03850
93	.20796382	141.	1.00005	1.	1.	0.	1.17569
92	.21999316	149.	.99901	1.	1.	0.	1.11140
91	.23229037	157.	.99692	1.	1.	0.	1.05256
90	.24486171	166.	.99995	1.	2.	0.	1.16494
89	.25771357	175.	1.00160	1.	2.	0.	1.10685
88	.27085250	184.	1.00202	1.	2.	0.	1.05316
87	.28428517	193.	1.00137	1.	2.	0.	1.00339
86	.29801841	202.	.99977	1.	3.	0.	1.09389
85	.31205922	212.	1.00205	1.	3.	0.	1.04467
84	.32641474	221.	.99865	1.	4.	0.	1.12357
83	.34109226	231.	.99892	1.	4.	0.	1.07522
82	.35609925	241.	.99825	1.	4.	0.	1.02991
81	.37144335	252.	1.00069	2.	0.	0.	1.09707
80	.38713235	262.	.99824	2.	0.	0.	1.05261
79	.40317425	273.	.99876	2.	0.	0.	1.01073
78	.41957720	284.	.99839	2.	1.	0.	1.06834
77	.43634954	296.	1.00057	2.	1.	0.	1.02727
76	.45349981	307.	.99851	2.	2.	0.	1.07828
75	.47103672	319.	.99891	2.	2.	0.	1.03814
74	.48896920	332.	1.00149	2.	2.	0.	1.00006
73	.50730637	344.	1.00018	2.	3.	0.	1.04424
72	.52605756	357.	1.00098	2.	3.	0.	1.00702
71	.54523231	370.	1.00095	2.	4.	0.	1.04634
70	.56484036	383.	1.00015	2.	4.	0.	1.01002
69	.58489171	397.	1.00117	3.	0.	0.	1.04507
68	.60539652	410.	.99893	3.	0.	0.	1.00967
67	.62636526	425.	1.00081	3.	1.	0.	1.04093
66	.64780853	439.	.99956	3.	1.	0.	1.00647
65	.66973740	454.	.99987	3.	2.	0.	1.03436
64	.69216268	469.	.99944	3.	2.	0.	1.00085
63	.71509645	485.	1.00039	3.	3.	0.	1.02574
62	.73854903	501.	1.00058	3.	4.	0.	1.04834
61	.76253509	517.	1.00005	3.	4.	0.	1.01536
60	.78706126	534.	1.00075	4.	0.	0.	1.03550
59	.81215129	551.	1.00071	4.	0.	0.	1.00351
58	.83779513	568.	1.00001	4.	1.	0.	1.02143
57	.86405198	586.	1.00034	4.	2.	0.	1.03755
56	.89084184	604.	[illegible]	[illegible]	2.	[illegible]	[illegible]

TABLE 2 – CONTINUED

i	L_i	n_u	f_u	n_{c_1}	n_{c_2}	n_{c_3}	f_c
55	.91036713	623.	1.00061	4.	3.	0.	1.02056
54	.94626004	642.	1.00073	4.	4.	0.	1.03354
53	.97530696	661.	.99966	4.	4.	0.	1.00276
52	1.00396091	681.	1.00051	5.	0.	0.	1.01473
51	1.03539503	702.	1.00005	5.	1.	0.	1.02328
50	1.06323729	721.	1.00022	5.	2.	0.	1.03481
49	1.10042131	746.	.99994	5.	3.	0.	1.03688
48	1.12083688	760.	1.00015	5.	3.	0.	1.01799
47	1.17733979	798.	.99975	5.	4.	0.	1.00375
46	1.16308011	789.	1.00060	5.	4.	0.	1.01605
45	1.14850813	779.	1.00045	5.	4.	0.	1.02894
44	1.13361643	769.	1.00058	5.	3.	0.	1.00651
43	1.11839744	758.	.99969	5.	3.	0.	1.02021
42	1.10284340	748.	1.00041	5.	3.	0.	1.03460
41	1.08694643	737.	1.00012	5.	2.	0.	1.01224
40	1.07069843	726.	1.00014	5.	2.	0.	1.02760
39	1.05409111	715.	1.00051	5.	1.	0.	1.00513
38	1.03711605	703.	.99982	5.	1.	0.	1.02158
37	1.01976462	691.	.99947	5.	1.	0.	1.03897
36	1.00202797	679.	.99950	5.	0.	0.	1.01669
35	.98389710	667.	.99993	5.	0.	0.	1.03542
34	.96536279	654.	.99926	4.	4.	0.	1.01309
33	.94641559	642.	1.00056	4.	4.	0.	1.03337
32	.92704587	629.	1.00079	4.	3.	0.	1.01101
31	.90724379	615.	.99987	4.	3.	0.	1.03307
30	.88699926	601.	.99941	4.	2.	0.	1.01071
29	.86630201	587.	.99945	4.	2.	0.	1.03486
28	.84514148	573.	1.00004	4.	1.	0.	1.01255
27	.82350693	558.	.99945	4.	1.	0.	1.03915
26	.80138734	543.	.99942	4.	0.	0.	1.01699
25	.77877147	528.	1.00004	4.	0.	0.	1.04652
24	.75564780	512.	.99941	3.	4.	0.	1.02462
23	.73200459	496.	.99945	3.	3.	0.	1.00204
22	.70782980	480.	1.00024	3.	3.	0.	1.03627
21	.68311115	463.	.99973	3.	2.	0.	1.01411
20	.65783602	446.	1.00002	3.	2.	0.	1.05307
19	.63199165	428.	.99891	3.	1.	0.	1.03166
18	.60556472	411.	1.00109	3.	0.	0.	1.00939
17	.57854210	392.	.99941	3.	0.	0.	1.05654
16	.55090946	373.	.99867	2.	4.	0.	1.03556
15	.52265390	354.	.99904	2.	3.	0.	1.01358
14	.49375872	335.	1.00074	2.	3.	0.	1.07289
13	.46421393	315.	1.00089	2.	2.	0.	1.05339
12	.43399497	294.	.99921	2.	1.	0.	1.03285
11	.40310574	273.	.99893	2.	0.	0.	1.01090
10	.37149158	252.	1.00056	2.	0.	0.	1.09693
9	.33921518	230.	1.00010	1.	4.	0.	1.08117
8	.30610079	208.	1.00228	1.	3.	0.	1.06501
7	.27245384	185.	1.00155	1.	2.	0.	1.04697
6	.23760535	161.	.99945	1.	1.	0.	1.02902
5	.20285614	138.	1.00342	1.	0.	0.	1.00441
4	.16552151	112.	.99806	0.	4.	1.	1.03400
3	.13097703	89.	1.00227	0.	3.	2.	1.05782
2	.06829361	60.	1.00234	0.	2.	1.	1.01536
1	.05952015	40.	.99126	0.	1.	3.	1.09543

TABLE 3 SUMMARY OF COMPRESSOR STAGE DESIGNS FOR VELOCITY SLIP CASCADE

C	N_c	W	ST	RPM	P_o	T_o	PR	U_2	D_2	b_2	N_s	$Re \times 10^{-6}$	M_i	η	HP
1	661	0.24775	1	3600.	0.004544	540.	4.092	1925.	122.5	7.15	0.126	0.0275	0.921	0.6529	47.67
			2	6000.	0.016365	640.	3.408	1925.	73.5	4.31	0.121	0.0501	0.828	0.7044	44.18
			3	12000.	0.050190	640.	3.408	1925.	36.8	2.56	0.138	0.0769	0.899	0.7299	42.64
			4	18000.	0.157349	640.	3.408	1925.	24.5	1.37	0.117	0.1606	0.811	0.7595	40.98
2	226	0.04155	1	6000.	0.004544	540.	4.092	1925	73.5	2.84	0.094	0.0165	0.768	0.5950	10.46
			2	12000.	0.016365	640	3.408	1925.	36.8	1.86	0.108	0.0251	0.773	0.6506	9.57
			3	18000.	0.050190	640.	3.408	1925.	24.5	1.01	0.093	0.0512	0.701	0.6892	9.03
			4	36000.	0.157349	640.	3.408	1925	12.3	0.59	0.105	0.0831	0.757	0.7208	8.64
3	51	0.00991	1	12000.	0.004544	540.	4.092	1925	36.8	1.22	0.084	0.0082	0.716	0.5093	2.49
			2	18000.	0.016365	640.	3.408	1925	24.5	0.73	0.073	0.0167	0.600	0.5824	2.14
			3	36000.	0.050190	640.	3.408	1925.	12.3	0.43	0.083	0.0256	0.653	0.6326	1.97
			4	66000.	0.157349	640.	3.408	1925.	6.7	0.25	0.086	0.0438	0.668	0.6707	1.86

LEGEND

- C — COMPRESSOR MODULE DESIGNATION
- N_c — TOTAL NUMBER OF MODULES IN CASCADE
- W — FLOW RATE (lbm UF_6 + He/sec)
- ST — STAGE NUMBER
- RPM — SHAFT SPEED (REV/MIN)
- P_o — COMPRESSOR INLET STAGNATION PRESSURE (lbf/in²)
- T_o — COMPRESSOR INLET STAGNATION TEMPERATURE (°R)
- PR — COMPRESSOR TOTAL-TO-STATIC PRESSURE RATIO
- U_2 — IMPELLER TIP SPEED (ft/sec)
- D_2 — IMPELLER TIP DIAMETER (in)
- b_2 — IMPELLER TIP FLOW WIDTH (in)
- N_s — COMPRESSOR SPECIFIC SPEED (DIMENSIONLESS)
- Re — COMPRESSOR TIP REYNOLDS NUMBER
- M_i — COMPRESSOR EYE RELATIVE MACH NUMBER
- η — COMPRESSOR EFFICIENCY (TOTAL-TO-STATIC)
- HP — STAGE COMPRESSOR POWER REQUIRED (LESS BEARINGS & SEALS

TABLE 4 PRIMARY HEAT EXCHANGER DESIGN VALUES

MODULE	FLOW lbm UF6+He / sec	STAGE	PTHXIN PSIA	TTHXIN °R	PTHXEX PSIA	TTHXEX °R
C1	0.24775	1	.018597	999.72	.016365	640.00
		2	.055767	1066.06	.050190	640.00
		3	.171032	1051.18	.157349	640.00
		4	.536195	1035.20	.493299	540.00
C2	0.04955	1	.018597	1044.44	.016365	640.00
		2	.055767	1101.29	.050190	640.00
		3	.171032	1075.49	.157349	640.00
		4	.536195	1056.42	.493299	540.00
C3	0.00991	1	.018597	1129.32	.016365	640.00
		2	.055767	1155.30	.050190	640.00
		3	.171032	1114.48	.157349	640.00
		4	.536195	1087.52	.493299	540.00

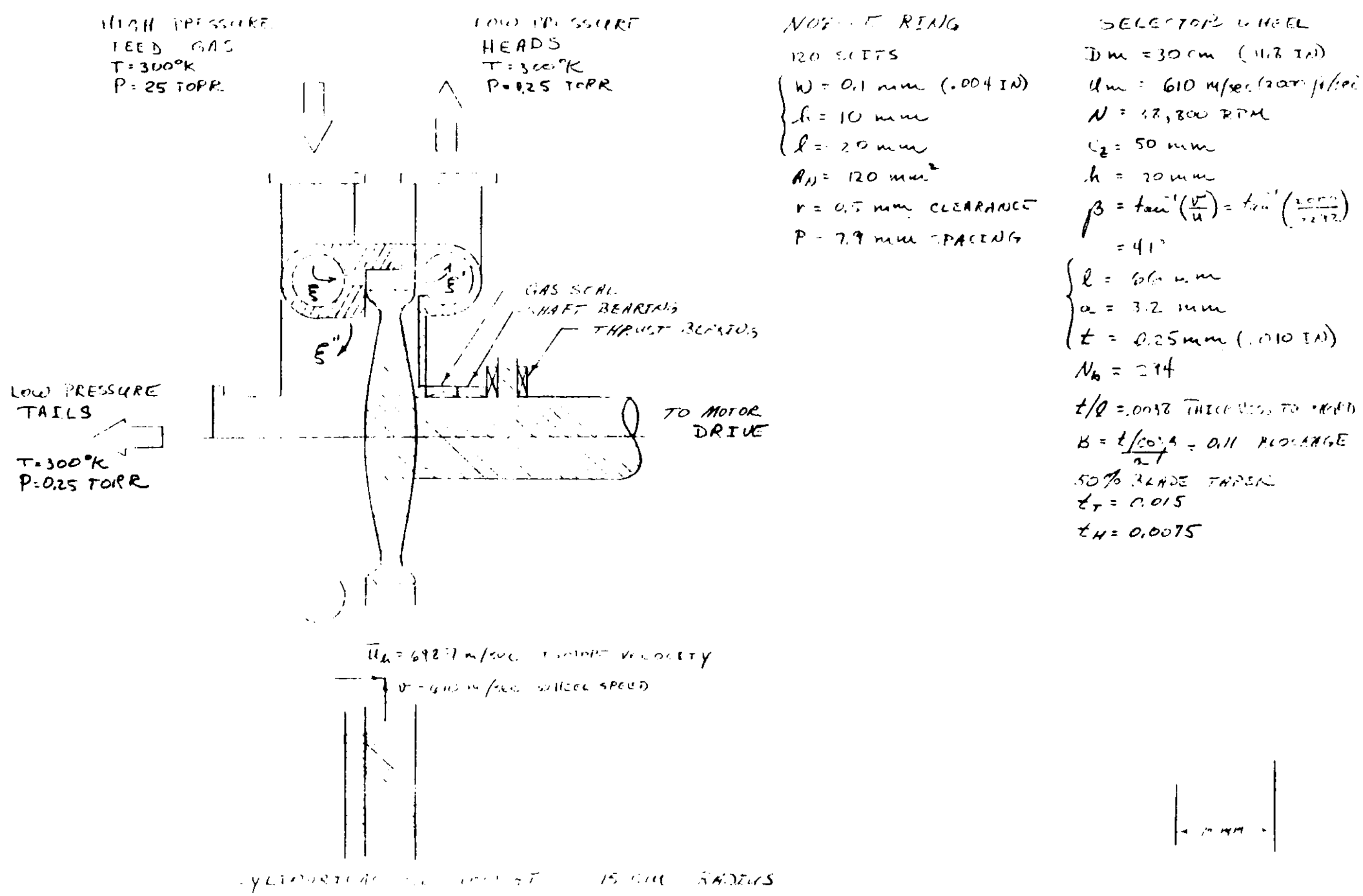


FIGURE 1 INDIVIDUAL VELOCITY-SLIP SEPARATION UNIT

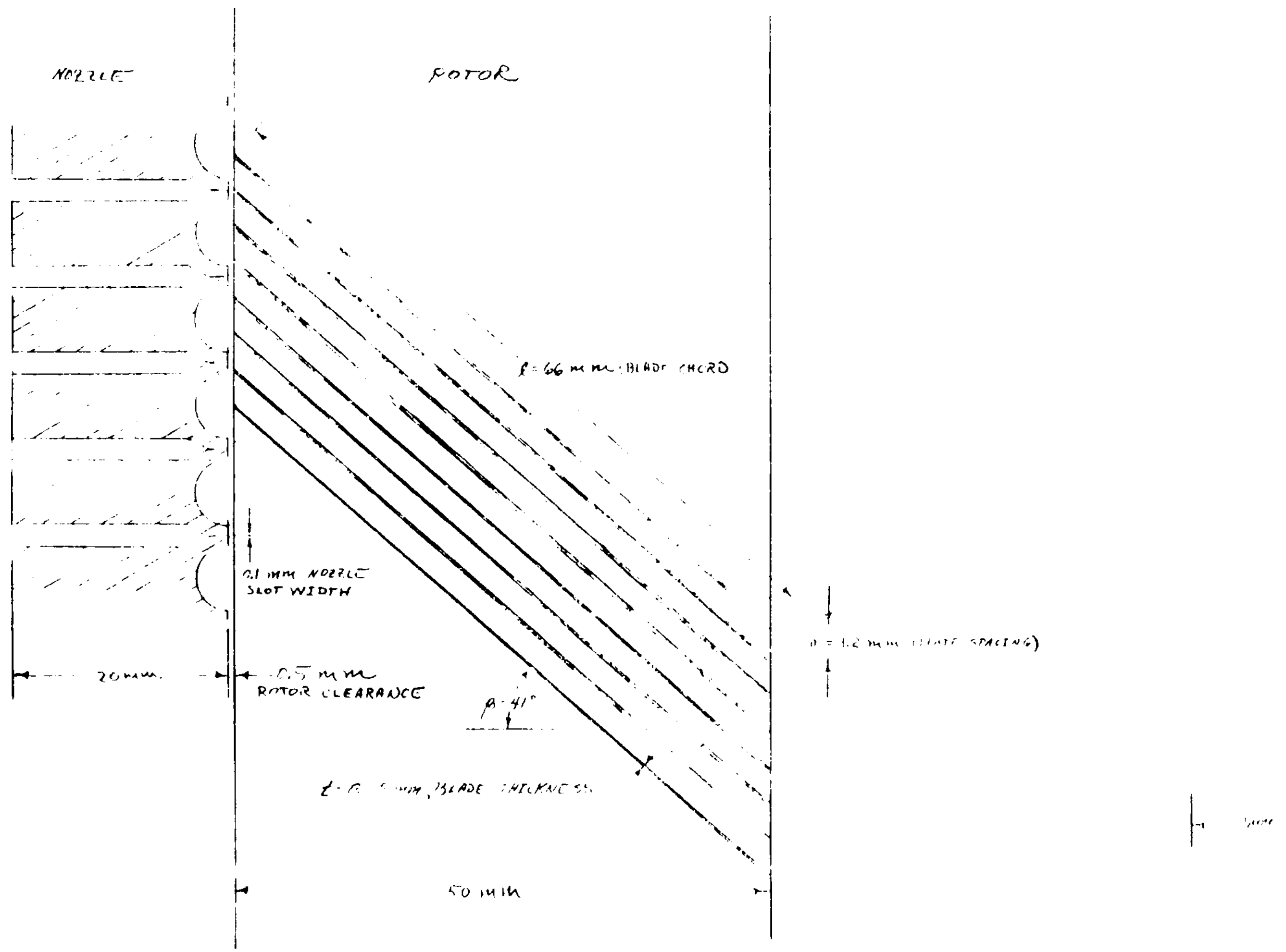


FIGURE 2 VELOCITY SELECTOR GEOMETRY FOR 5% UF_6 IN He CYLINDRICAL SECTION, 15 CM RADIUS

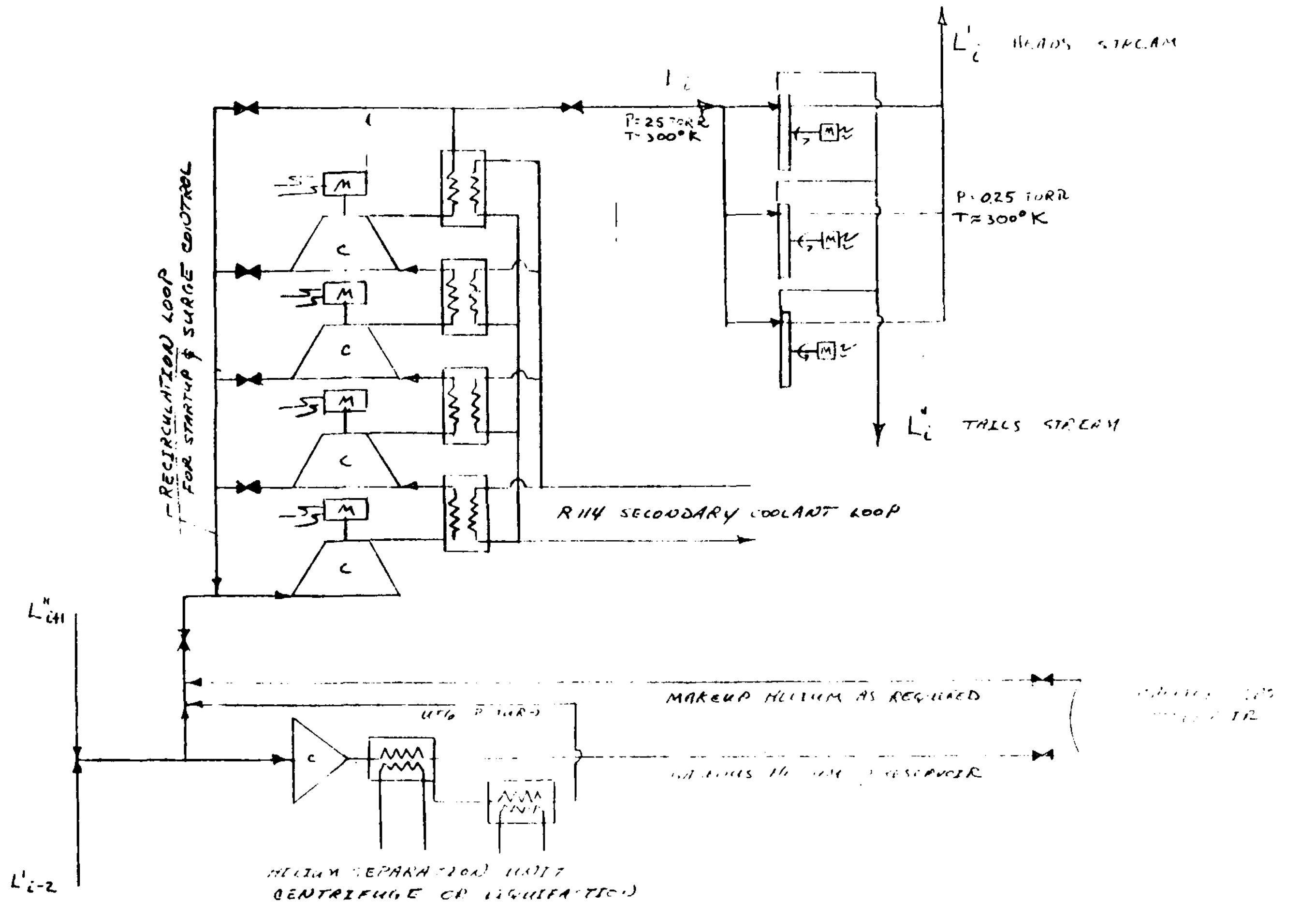


FIGURE 3 FLOW SCHEMATIC FOR CASCADE STAGE

- SINGLE COMPRESSOR MODULE FEEDS SEVERAL INDIVIDUAL VELOCITY SEPARATION UNITS IN PARALLEL
- FOUR IN LINE RADIAL COMPRESSOR STAGES WITH INTERCOOLING & AFTERCOOLING
- MIXING OF HEADS AND TAILS IN CASCADE REESTABLISHES THE SEED FRACTION. SMALL AMOUNTS OF CARRIER GAS CAN BE ADDED FOR FINE TUNING [illegible] THE STAGE

FIGURE 4
ASYMMETRIC CASCADE FLOW DIAGRAM
FOR 2 HEADS AND 1 TAILS STREAM

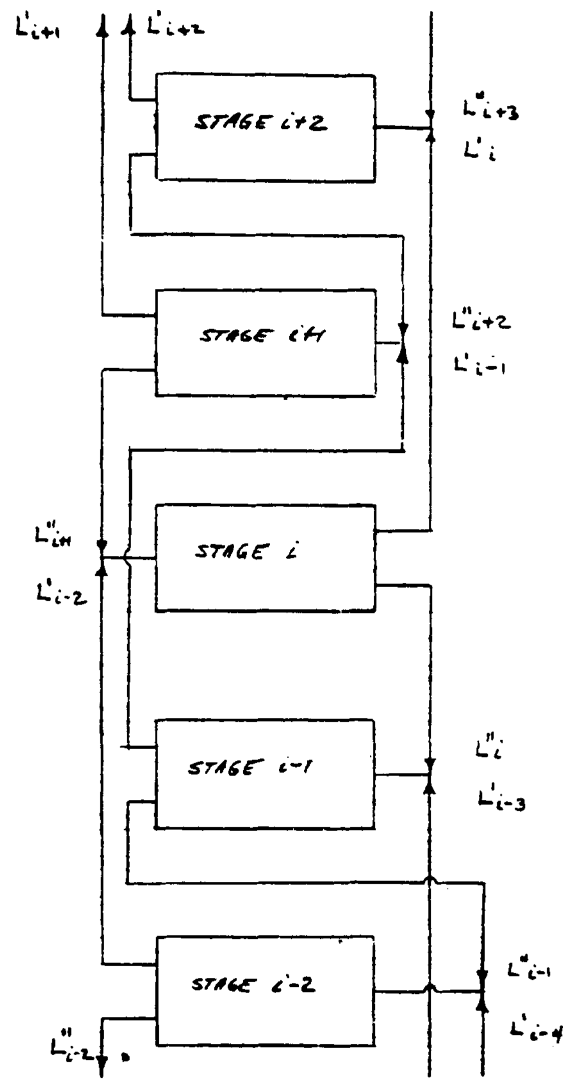
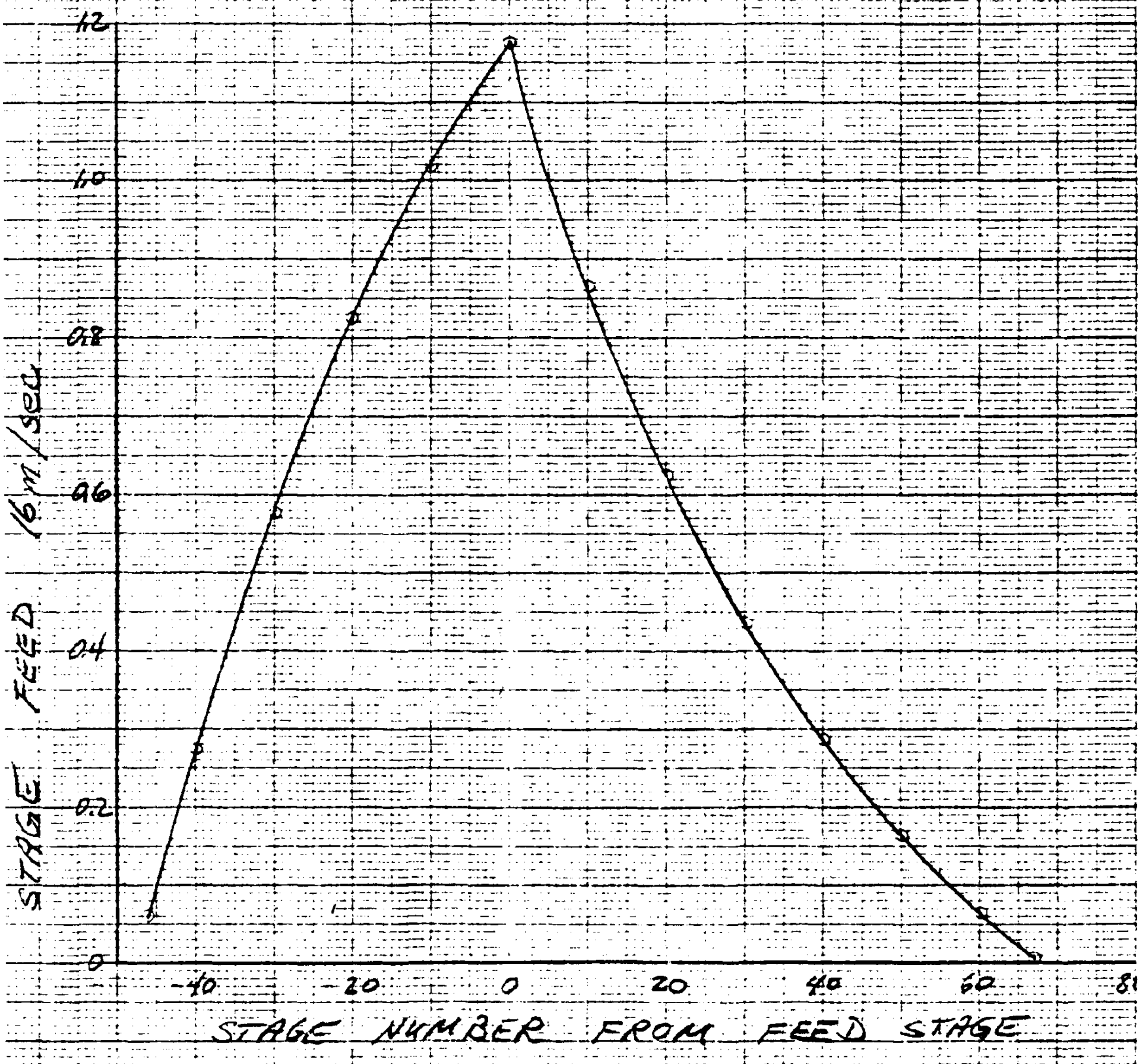


FIGURE 5

IDEAL ASYMMETRIC CASCADE FLOW RATE

- 2 HEADS, 1 TAILS STREAM
- VELOCITY SLIP SEPARATION UNIT
- $\alpha = 1.07$, $\theta = 0.326$
- $x_F = 0.00717$, $x_P = 0.03262$, $x_W = 0.00250$
- $P = 0.007368$ lbm/sec UF_6
- TOTAL NUMBER OF STAGES = 114



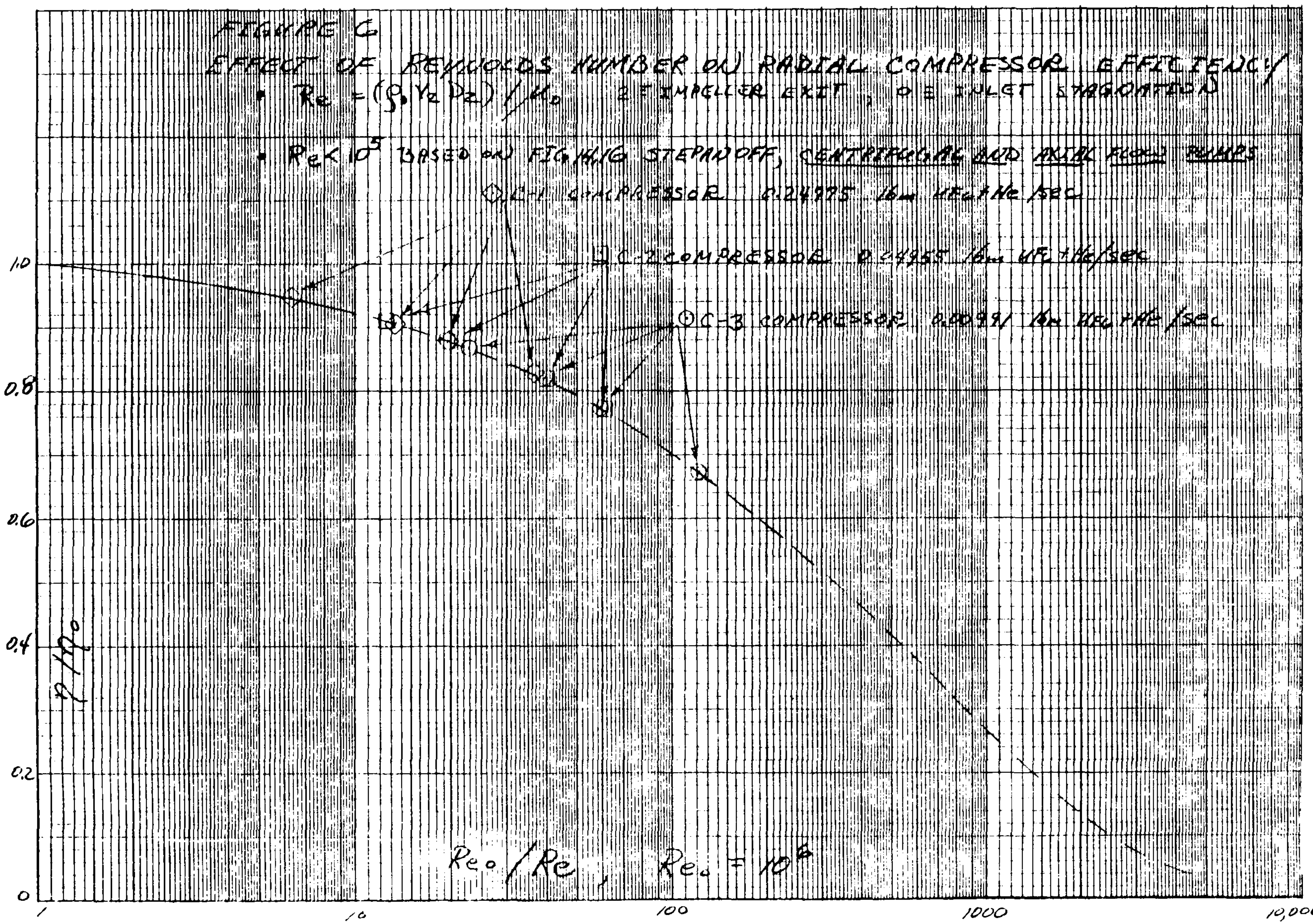


FIGURE 6
EFFECT OF REYNOLDS NUMBER ON RADIAL COMPRESSOR EFFICIENCY
Re = (ρ₀ V₂ D₂) / μ₀   2 = IMPELLER EXIT , 0 = INLET STAGNATION
Re < 10⁵ BASED ON FIG. STEPANOFF, CENTRIFUGAL AND AXIAL FLOW PUMPS
C-1 COMPRESSOR 0.24975 lbm HEL + He / SEC
C-2 COMPRESSOR 0.4955 lbm HEL + He / SEC
C-3 COMPRESSOR 0.0991 lbm HEL + He / SEC
1.0
0.8
0.6
0.4
0.2
0
1
10
100
1000
10,000
Re₀ / Re , Re₀ = 10⁶

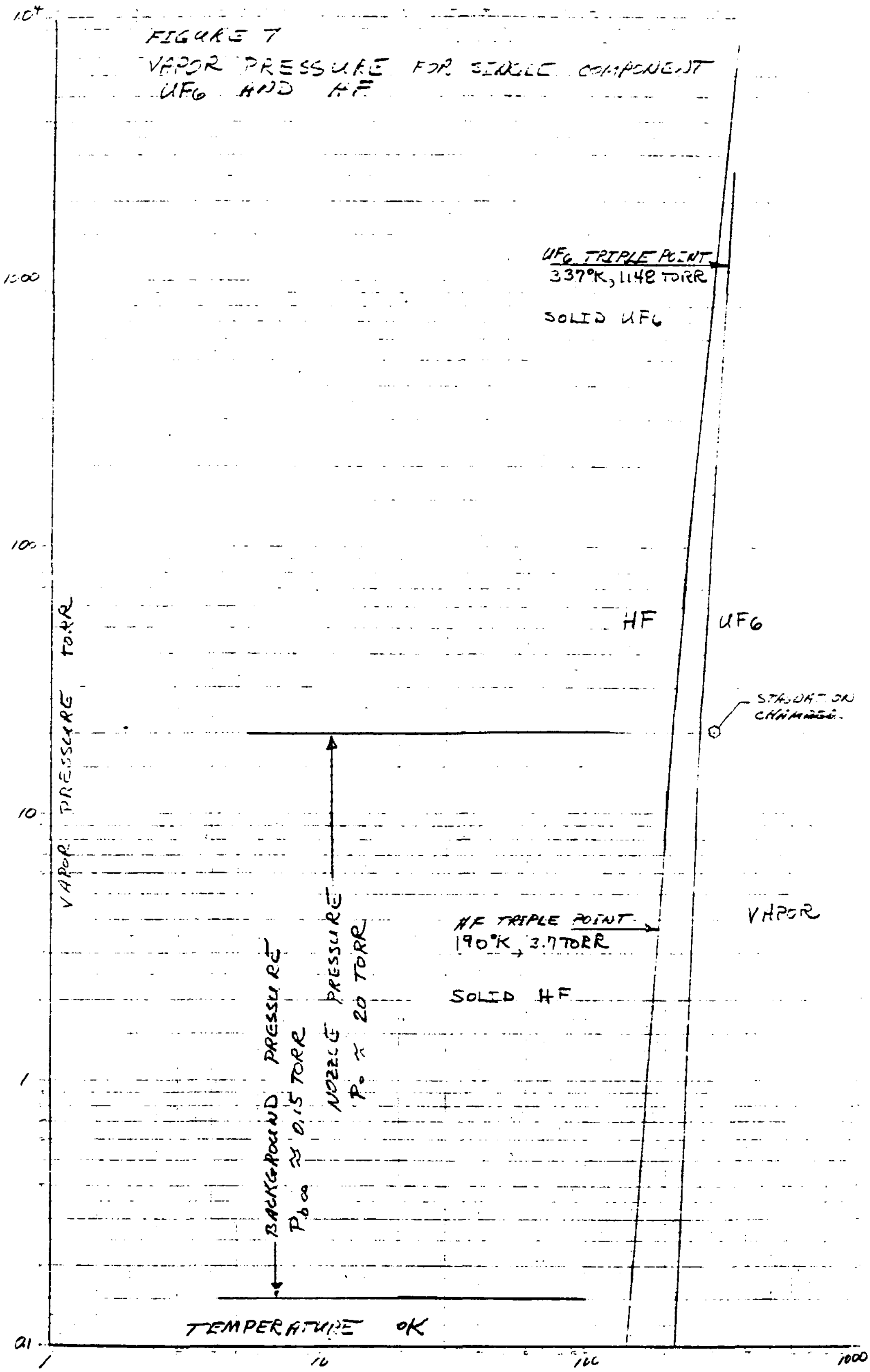


FIGURE 7
VAPOR PRESSURE FOR SINGLE COMPONENT
UF6 AND HF
UF6 TRIPLE POINT
337°K, 1148 TORR
SOLID UF6
HF
UF6
VAPOR
HF TRIPLE POINT
190°K, 3.7 TORR
SOLID HF
BACKGROUND PRESSURE
Pb∞ ≈ 0.15 TORR
NOZZLE PRESSURE
P0 ≈ 20 TORR
VAPOR PRESSURE TORR
TEMPERATURE °K
10⁴
1000
100
10
1
.01
1
10
100
1000

TABLE OF NOMENCLATURE

Symbol	Pages	Meaning
A	A-6	total nozzle area per separating unit, mm^2
A	A-14	designator for first gas constituent
A_N	A-26	total throat area of nozzle slits
a	A-5, A-27	blade spacing, inches
a	A-26	pitch of velocity selector blades
B	A-14	designator for second gas constituent
B	A-26	fraction of available area blocked by blades
$B(\xi)$	A-4	transmission function: fraction of molecules of velocity which pass through selector to become heads stream
b_2	A-14	compressor wheel exit width, inches
C	A-28	compressor
C	A-8	a surrogate for P and -W
C_z	A-26	axial chord of velocity selector blade
C_3	A-12	designator for compressor module size
D	A-8	a surrogate for F
D	A-16	compressor wheel diameter
D_m	A-26	selector wheel diameter
D_2	A-31	duct diameter
F	A-8	cascade feed flux, lbmoles UF_6/sec or SWU/year required stage flow
f_U	A-12	ratio of total nominal flow through separation units to required stage flow
f_C	A-12	compressor flow error
f_{ci}	A-12	stage-i compressor flow error
g_c		lbm to lbf conversion factor: 32.174 lbm-ft/lbf-sec^2
h	A-26	height of nozzle slot
h	A-26	height of velocity selector blade
i	A-10	stage index number
j	A-10	stage index number
k	A-14	Boltzman constant
L	A-4	subscript denoting heads stream
L	A-4	stage feed rate, lbmoles UF_6/sec
L'	A-8	stage-i head flux, lbmoles UF_6/sec
L"	A-8	stage-i tails flux, lbmoles UF_6/sec
L	A-12	stage-i feed flux, lbm UF_6/sec
L	A-8	stage-i feed flux, lbmoles UF_6/sec
lbf		pounds force: 32.174 lbm-ft/sec^2
lbm		pounds mass
ℓ	A-5, A-27	blade chord length, inches
ℓ	A-26	length of nozzle slot
ℓn	A-8	natural logarithm

Symbol	Pages	Meaning
M	A-8	feed-stage index number
MW		megawatt
M	A-28	motor
m_A	A-14	mass of molecule A
m_B	A-14	mass of molecule B
$\dot{m}_{c3}$	A-12	flux capacity of C_3 compressor module, lbm UF_6/sec
$\dot{m}_k$	A-6	flow rate of substance or mixture k: lbmole/sec
$\dot{m}_u$	A-6	UF_6 flow capacity of separation units, lbm UF_6/sec
N	A-26	selector wheel frequency
N_b	A-26	number of blades
N_{c1}	A-13	total number of C_1 compressor modules
N_{c2}	A-13	total number of C_2 compressor modules
N_{c3}	A-13	total number of C_3 compressor modules
n	A-8	number of stages in cascade and topmost product stage index number
n_A	A-14	molecular density of A
n_B	A-14	molecular density of B
n_{C_1}	A-12	number of C_1 compressor modules required
n_{C_2}	A-12	number of C_2 compressor modules required
n_{C_3}	A-12	number of C_3 compressor modules required
$n_{C_{k,i}}$	A-12	number of C_k compressor modules in stage i
n_R	A-4	fraction of flux intercepted by selector
n_U	A-12	number of separation units
n_{1L}	A-4	flux of molecules containing light isotope which pass through selector
n_{2L}	A-4	flux of molecules containing heavy isotope which pass through selector
n_{1R}	A-4	flux of molecules containing light isotope which is intercepted by selector
n_{2R}	A-4	flux of molecules containing heavy isotope which is intercepted by selector
P	A-26	pitch of nozzle slits
P	A-14	partial pressure
P	A-8	cascade product flux, lbmoles UF_6/sec
PTHXEX	A-25	total pressure at heat exchanger exit
PTHXIN	A-25	total pressure at heat exchanger inlet
P_A	A-14	partial pressure of A
P_{b_∞}	A-32	background pressure in velocity selector
P_{C_i}	A-7	ideal specific isentropic compression work, $\frac{\text{MW-sec}}{\text{lbm } UF_6}$
P_i	A-11	cascade ideal power consumption, MW
P_0	A-32	stagnation chamber pressure in velocity selector
P_T	A-6	total pressure of stream in nozzle, torr
P_{vi}	A-6	ideal specific power input by gas, MW-sec/lbm UF_6
P_1	A-7	pressure at compressor inlet, torr
P_1	A-8	topmost stage heads flux, lbmoles UF_6/sec
P_2	A-7	pressure at compressor outlet, torr
P_2	A-8	next-to-topmost stage heads flux, lbmoles UF_6/sec

Symbol	Pages	Meaning
R	A-4	subscript denoting tails stream
R	A-5	universal gas constant: 72.21 ft-lbf/lbm-°R
Re	A-13	Reynolds number
R114	A-15	fluorocarbon refrigerant
r	A-26	clearance between rotor and nozzle ring
S	A-3	speed ratio: ratio of average velocity to thermal velocity
T	A-14	absolute temperature
TTHXEX	A-25	total pressure at heat exchanger exit
TTHXIN	A-25	total temperature at heat exchanger inlet
T_T	A-6	total temperatures of stream in nozzle, °R
T_w	A-5	temperature of velocity selector slot walls
T_1	A-15	absolute temperature of inlet stream
T_2	A-15	absolute temperature of outlet stream
t	A-26	blade thickness at midheight
t/ℓ	A-26	blade thickness to chord ratio
t_f	A-5	time interval during which passage between selector blades receives the molecular beam
t_H	A-26	blade thickness at hub
t_T	A-26	blade thickness at tip
U	A-6, A-7	bulk velocity of stream through nozzle, $\sqrt{\frac{\text{MW-sec}}{\text{lbm gas}}}$, ft/sec
$\underline{U}$ (ξ)	A-4	species velocity distribution function
$\overline{U}$	A-3	average velocity of heavy species in seeded molecular beam
$\overline{u}_h$	A-26	velocity of molecules leaving wheel radially
u_m	A-26	selector wheel peripheral speed
v	A-26	peripheral speed of wheel
V(X)	A-9	value function for mole fraction X
V_2	A-31	gas speed
W	A-8	cascade tails flux, lbmoles UF_6/sec
w	A-26	nozzle slit width
X	A-8	mole fraction of light-isotope molecules
X_C	A-8	a surrogate for X_P and X_W
X_D	A-8	a surrogate for X_F
X_i	A-20	mole fraction of light-isotope molecules in stage-i feed stream
X_i'	A-20	mole fraction of light-isotope molecules in stage-i heads stream
X_i''	A-20	mole fraction of light-isotope molecules in stage-i tails stream
X_P	A-8	mole fraction of light-isotope molecules in cascade product stream

Symbol	Page	Meaning
x_{P_1}	A-9	mole fraction of light-isotope molecules in heads of topmost stage
x_{P_2}	A-8	mole fraction of light-isotope molecules in heads of next-to-topmost stage

Greek Symbols

α	A-3	stage separation factor (X'(1-X"))/(X"(1-X'))
β	A-26	angle of incident molecules of selected velocity with respect to rotating blades
γ	A-6	ratio of specific heats for gas mixture
Δ	A-9	separative capacity, lbmoles UF_6 /sec, SWU/year
$\Delta\overline{U}$	A-3	difference in mean forward velocity of the heavy species in a seeded molecular beam
δU	A-4	stage separative capacity, lbmoles UF_6/sec
δ_A	A-14	collision cross section for A
δ_B	A-14	collision cross section for B
δ_{AB}	A-14	$(\delta_A + \delta_B)/2$
ϵ	A-8	cascade assay factor: ratio of feed abundance ratios for adjacent stages
θ	A-4	stage cut: ratio of heads flux to feed flux
θ_i	A-20	stage-i cut
η	A-31	efficiency
λ_A	A-14	mean free path for A
μ_0	A-31	gas absolute viscosity at inlet stagnation conditions
ξ	A-4	molecular velocity in stream direction
ξ_F	A-8	abundance ratio for cascade feed
ξ_i	A-7	abundance ratio for stage-i feed
ξ_i'	A-8	abundance ratio for stage-i heads
ξ_i''	A-8	abundance ratio for stage-i tails
ξ_j	A-7	abundance ratio for stage-j feed
ξ_W	A-8	abundance ratio for cascade tails
ρ_0	A-31	gas density at inlet stagnation condition

SUBJECT: Velocity-Slip Isotope Separation Plant - Compressor Intercooler Design Considerations and Cost Estimate

REF: Springer, G. S., "Heat Transfer in Rarefied Gases," in Advance in Heat Transfer (J. P. Hartnett and T. Irvine, eds.), Vol. 7, Academic Press, 1971.

This memo summarizes details of considerations which were given to the sizing and cost estimate for compressor intercoolers for a 300,000 SWU/yr uranium enrichment plant using a velocity-slip isotope separation process. The study was conducted as a part of a technical and economic feasibility study for the velocity-slip isotope separation process, and, accordingly has concerned itself with a workable design approach and a cost estimate rather than details of heat transfer and heat exchanger design. The following describes briefly the cooling scheme used, selection of the heat transfer surface for the purpose of cost estimate, a summary of heat transfer analysis, heat exchanger cost estimate, and the power consumption expected for the secondary coolant loop.

1. Compressor Inter- and Aftercooling Requirement and Cooling Scheme

Each cascade stage of the enrichment plant contains up to nine compressor modules each of which has a four-stage compressor, three intercoolers and an aftercooler. There are only three different sizes of compressor modules in the entire cascade and as such there are three different inter- or aftercooler modules for each compression stage. The entire plant has twelve different modules of heat exchangers. Table 1 summarizes the helium-uranium hexafluoride (He-UF_6 mixture) side design condition and the number of each heat exchanger module required for the entire plant. The design conditions were established by R. Keating of Dept. 93-32.

The cooling scheme is schematically illustrated in Figure 1. R-114 is used as the primary coolant and water the secondary coolant. The He-UF_6 mixture transfers its sensible energy to R-114 evaporating inside tubes of the intercoolers, which in turn rejects heat to cooling tower water by condensing in the R-114-to-water heat exchanger. It is assumed that the cooling tower is capable of cooling 9000 gpm of water from 130°F to 90°F. The aftercooler consists of two heat exchanger components: the He-UF_6 mixture entering the aftercooler cools down to 640°R in the first component then to 540°R in the second component. The second component utilizes a R-114 refrigeration cycle to accomplish the required cooling.

2. Selection of the Heat Transfer Surface for the Cost Estimate

A preliminary heat transfer analysis and a cost estimate indicate that

(1) The overall cost of the inter- and aftercoolers will be less than 5% of the total plant cost.

(2) C1 module heat exchangers, i.e., heat exchangers for the C1 compressor modules, take approximately 85% of the cost. Among those, the first stage intercoolers will be responsible for 35% of the cost.

(3) The first stage intercoolers will operate in a slip flow regime. The He-UF_6 side heat transfer coefficient is in the order of 1 Btu/hr-ft^2-°F while that of R-114 is in the order of 100 Btu/hr-ft^2-°F.

The above establishes that, for the purpose of a cost estimate, a heat transfer surface which best economizes the first stage intercooler of the C1 compressor module can be applied to all twelve heat exchanger modules without resulting in a significant error in the cost of the plant. Also, it is obvious that the surface selected should have a large outside fin surface area per unit inside surface area to offset the large difference in heat transfer coefficients between the He-UF_6 side (tube outside) and the R-114 side (tube inside). The He-UF_6 side pressure drop is another major item that was considered in the selection of the heat transfer surface.

Table 2 summarizes the physical characteristics of the heat transfer surface selected. It is an aluminum high fin tubing commercially available. The outside to inside surface area ratio is approximately 21, and the tubing has a relatively good pressure drop characteristic because of the use of high fins on a relatively large fin spacing. The effectiveness of the fin is close to unity in the operating ranges presently considered. The tube arrangement chosen, i.e., transverse pitch equal to 1.64 times the fin diameter and longitudinal pitch equal to 1.08 times the fin diameter with tubes arranged in a staggered fashion, is a result of a study which was conducted to minimize the core pressure drop while keeping the heat exchanger frontal area reasonably small. The aluminum fin tubing is believed to be compatible with both of the working fluids, He-UF_6 and R-114.

3. Cost Model

At present, Dept. 93-39 does not have a detailed cost model established for process heat exchangers. As a rule of thumb, however, F. Faulkner, Chief of Thermodynamics, has suggested that the installed cost of a heat exchanger be computed using $6.00 per pound of its core weight. This figure has been used lately for many process applications and were reported, in several programs, to yield a reasonably good agreement with the actual installed cost of heat exchangers.

The same rule of thumb was used in the present application in view of the fact that heat exchanger takes a very small fraction of the total cost of the plant and the error introduced by the rule of thumb, if any, will be negligible compared to the total cost of the enrichment plant. With this rule of thumb, the cost per linear foot of the finned tubing specified in Table 2 is $4.67 per foot. This figure was used as a basis of the cost estimate described in the subsequent sections.

4. Evaluation of the He-UF_6 Side Heat Transfer Coefficient

The heat transfer coefficient associated with evaporation of R-114 in 1.0 in. circular tube is in the order of 100 Btu/hr-ft^2-°F. At the same time, the convective heat transfer coefficient from the He-UF_6 mixture flow to the fin surface (outside) is in the order to 1 Btu/hr-ft^2-°F. The outside-to-inside surface area ratio is 21 and, therefore, the He-UF_6 side heat transfer coefficient controls the overall heat transfer.

The He-UF_6 flows in the inter- and aftercoolers are characterized by very low Reynolds numbers and low pressures. In fact, the first stage intercooler operates in a slip flow regime with Knudsen number of 0.02 based on the hydraulic diameter of the finned tube bank (Table 2). The corresponding Reynolds number is approximately 15. The other intercoolers operate in continuum but at Reynolds numbers considerably lower* than the lower limit of the existing heat transfer correlations. This presents a serious problem because of the fact that a heat transfer correlation developed for a moderate or high Reynolds number flow cannot be safely extrapolated** to a low Reynolds number flow and that the cost of the heat exchangers varies almost inversely proportional to the He-UF_6 side heat transfer coefficients as illustrated in Figure 2.

In order to determine a realistic design value, the He-UF_6 side heat transfer coefficient was calculated using all applicable continuum flow theories. The table below summarizes some of the values calculated in this way for the first stage intercooler.

---

*Reynolds number varies between 15 and 350 in the intercoolers. The lower limits of most of the finned tube bank correlations available are approximately 600.

**The Colburn j-factor for flow over finned tube banks may be expressed by $j \propto Re^{-f(Re)}$ where f(Re) is a continuous function of Re varying between 1.0 at a low Reynolds number and 0.3 at a high Reynolds number.

Heat Transfer Model	Heat Transfer Coefficient, Btu/hr-ft^2-°F
1. An AiResearch finned tube bank correlation	0.21
2. Laminar boundary layer theory (flat plate) - fins	0.52
3. Laminar flow over a circular cylinder	0.64
4. Fully developed laminar channel flow	2.82
5. Extrapolation of the AiResearch correlation above using $j \propto Re^{-0.6}$ for $Re < 800$	0.58

As expected, a direct extrapolation of the AiResearch correlation for flow over finned tube bank results in a much lower value than those of the laminar flow theories. This is a result of the extrapolation of $j \propto Re^{-0.35}$ to $Re = 15$, and may be considered as the lower bound for the He-UF_6 side heat transfer coefficient. The fully developed laminar channel flow assumption gives a fairly high value. Such a high heat transfer coefficient will not be realized, however, because the flow retardation in the finned section and subsequent mixing of heated and unheated fluids downstream will effectively reduce the heat transfer coefficient in the finned tube bank. The thermal entry length of the flow in the finned section is very short ($x/D_h \approx 1.0$) and as a result it is expected that the actual heat transfer coefficient will be slightly greater than that of the laminar boundary layer assumption (second value in the table).

The design heat transfer coefficients in the present study were evaluated by extrapolating the AiResearch correlation assuming a power law relation $j \propto Re^{-0.6}$ for $Re \leq 800$. This modification is based on observations that the AiResearch correlation is applicable down to $Re = 800$ and that the heat transfer phenomena in laminar flow regime involving flow separations can often be approximated by $Re^{-0.6}$ for a low Reynolds number region.

For a slip flow regime, the heat transfer coefficient based on the continuum theory was modified for the reduction of Nusselt number (Reference 1) as well as for the reduction of thermal conductivity in the slip flow regime. The combined effect amounts to approximately 14% for the first stage intercooler, reducing the He-UF_6 side heat transfer coefficient at the design point from 0.58 Btu/hr-ft^2-°F to 0.50 Btu/hr-ft^2-°F. The design point values for other stages are shown in Figure 2.

5. Heat Exchanger Characteristics and Secondary Loop Power Consumption

Table 3 summarizes the heat exchanger design characteristics and the resulting core volume, weight, and the cost. They are tabulated in terms of the plant total for each compression stage. The calculation is based on an average evaporation temperature of 140°F for R-114 for the intercoolers and 65°F for the fourth stage aftercoolers (i.e., the second component of the compressor aftercooler).

The inter- and aftercooler core length in the direction of the He-UF_6 flow varies approximately from 5.0-in. for the first stage intercoolers to 40-in. for the aftercooler. At the same time, the frontal area of heat exchangers varies from one module to another in the same intercooling stage. As a result, when the heat transfer surface specified in Table 2 is used, the core dimensions of the first stage intercooler for C1 compressor module will be 85-in. by 85-in. by 5-in. while that of the aftercooler for C3 compressor module will be 3-in. by 3-in. by 40-in. The core configurations for smaller heat exchangers, such as those for C3 compressor modules, can be improved by using an optimum heat transfer surface for their operating conditions; this will not affect the total cost of the heat exchangers to any significant extent as explained earlier in Section 2.

The cooling water flow rate required for condensing R-114 is 1010 lb/sec or 7300 gpm. The total power consumption for the R-114 pump and the water pump is expected to be 0.5 mw. The R-114 refrigeration cycle compressor (see Figure 1) requires approximately 1.0 mw for the operating conditions assumed in Figure 1. This compression work can be reduced by 40% by installing a separate R114-to-water condenser with R-114 condensing at 120°F.

6. Concluding Remarks

(1) The total cost of the compressor inter- and aftercoolers is expected to be anywhere between $700,000 and $2,400,000. The best estimate at present is $1,215,000. This does not include the cost of secondary coolant loop heat transfer equipment such as R-114-to-water heat exchanger and cooling tower.

(2) The present study was not concerned with a detailed sizing of heat exchangers. This requires a definition of the system operating conditions including those for the secondary loop, and an optimization of each of the twelve modules for its operating conditions and packaging requirements.

TABLE 1

PRIMARY LOOP HEAT EXCHANGER DESIGN CONDITIONS

Module	Flow, $\frac{\text{lbm } UF_6 + He}{\text{sec}}$	Stage	PTHXIN, psia	TTHXIN, °R	PTHXEX, psia	TTHXEX, °R	Total Number of Modules
C1	0.24775	1	.018597	999.72	.016365	640.00	269
		2	.055767	1066.06	.050190	640.00	269
		3	.171032	1051.18	.157349	640.00	269
		4	.536195	1035.20	.493299	540.00	269
C2	0.04955	1	.018597	1044.44	.016365	640.00	226
		2	.055767	1101.29	.050190	640.00	226
		3	.171032	1075.49	.157349	640.00	226
		4	.536195	1056.42	.493299	540.00	226
C3	0.00991	1	.018597	1129.32	.016365	640.00	51
		2	.055767	1155.30	.050190	640.00	51
		3	.171032	1114.48	.157349	640.00	51
		4	.536195	1087.52	.493299	540.00	51

TABLE 2

HEAT TRANSFER SURFACE SELECTED FOR COST ESTIMATE

Surface	
Manufacturer, cat. number	Wolverine, 69-5916049-41
Type	Circular finned tube
Material	Aluminum
Tube outside diameter	1.005-in.
Tube inside diameter	0.917-in.
Fin diameter	2.25-in.
Number of fins	9 fins/inch
Outside surface area per linear length	5.0189 ft^2/ft
Surface area ratio, outside to inside	21.13
Approx. weight per linear length	0.778 lb/ft
Surface (Finned Tube) Arrangement	
Pattern	Staggered tube bank
Transverse spacing	1.64 x (fin diameter)
Longitudinal spacing	1.08 x (fin diameter)
Hydraulic diameter	0.0347 ft
Outside surface area to volume ratio	80.6 ft^2/ft^3
Free flow area to frontal area ratio	0.665

TABLE 3

INTERCOOLER SIZE, WEIGHT AND COST

	1st St. Intercooler (Stage Total)	2nd St. Intercooler (Stage Total)	3rd St. Intercooler (Stage Total)	4th St. Intercooler (Stage Total)	4th St. Aftercooler (Stage Total)	System Total
Heat Flow, Btu/sec	8,638	10,154	9,778	9,378	2,353	40,301
LMTD, °F	157	174	170	166	49	
Design $h_{gas-side}$, Btu/hr-ft^2-°F	0.5	0.94	1.4	2.2	2.2	
HX Core Volume, ft^3	6,495	3,552	2,636	1,770	1,389	15,842
HX Core Weight, lb	81,141	47,713	32,927	22,112	18,649	202,542
HX Cost, $	486,844	286,280	197,562	132,669	111,891	1,215,246

*The fourth stage intercooler refers to the first component of the aftercooler in Figure 1 and the fourth stage aftercooler refers to the second component.

DATE 12-[illegible]-77 CALC. NO. SHEET NO.

PART NO. UF_6 Enrichment – Velocity Slip MODEL NO.

PREPARED BY [illegible] CHECKED BY

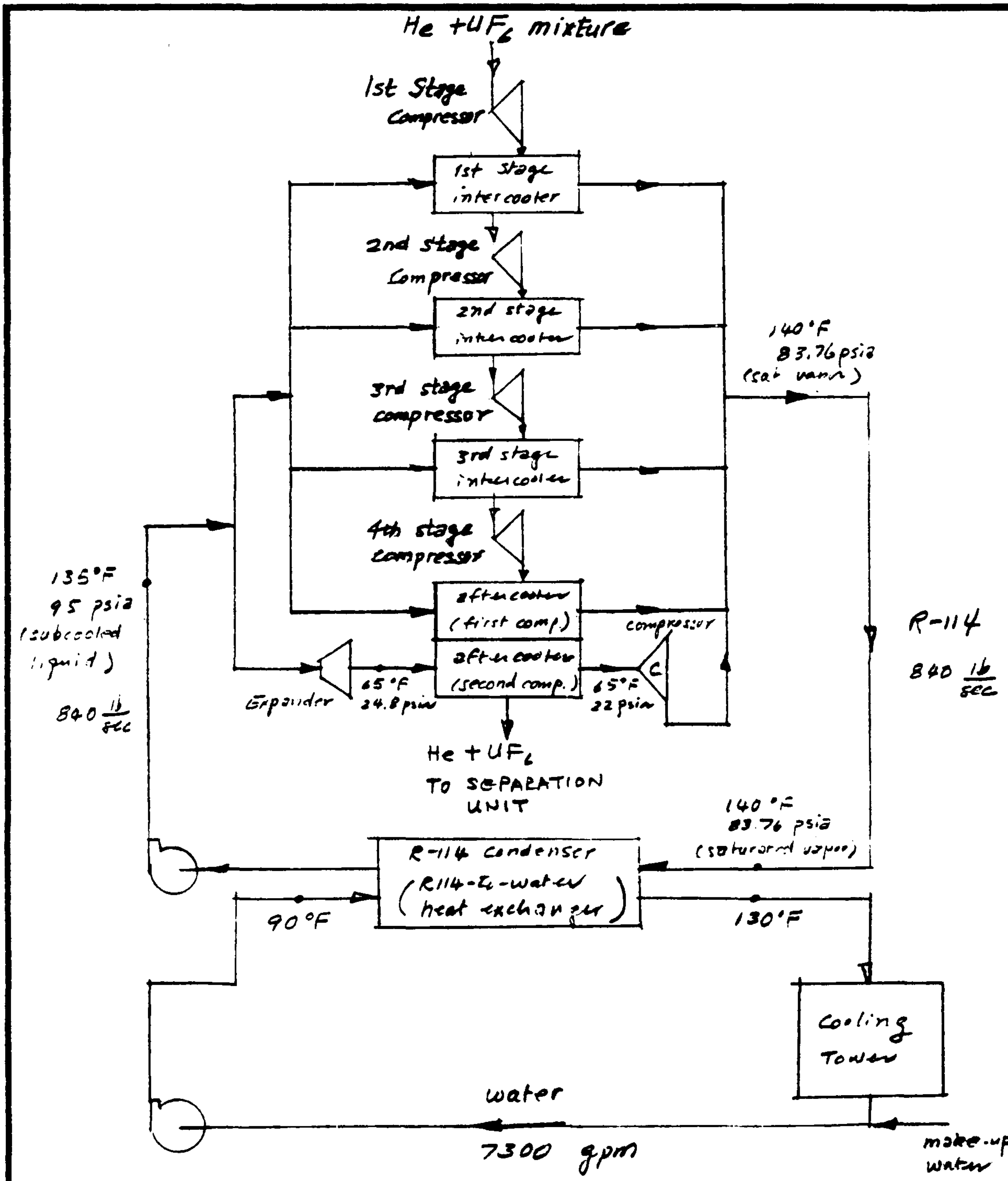


FIGURE 1 A Schematic of Cooling Loop

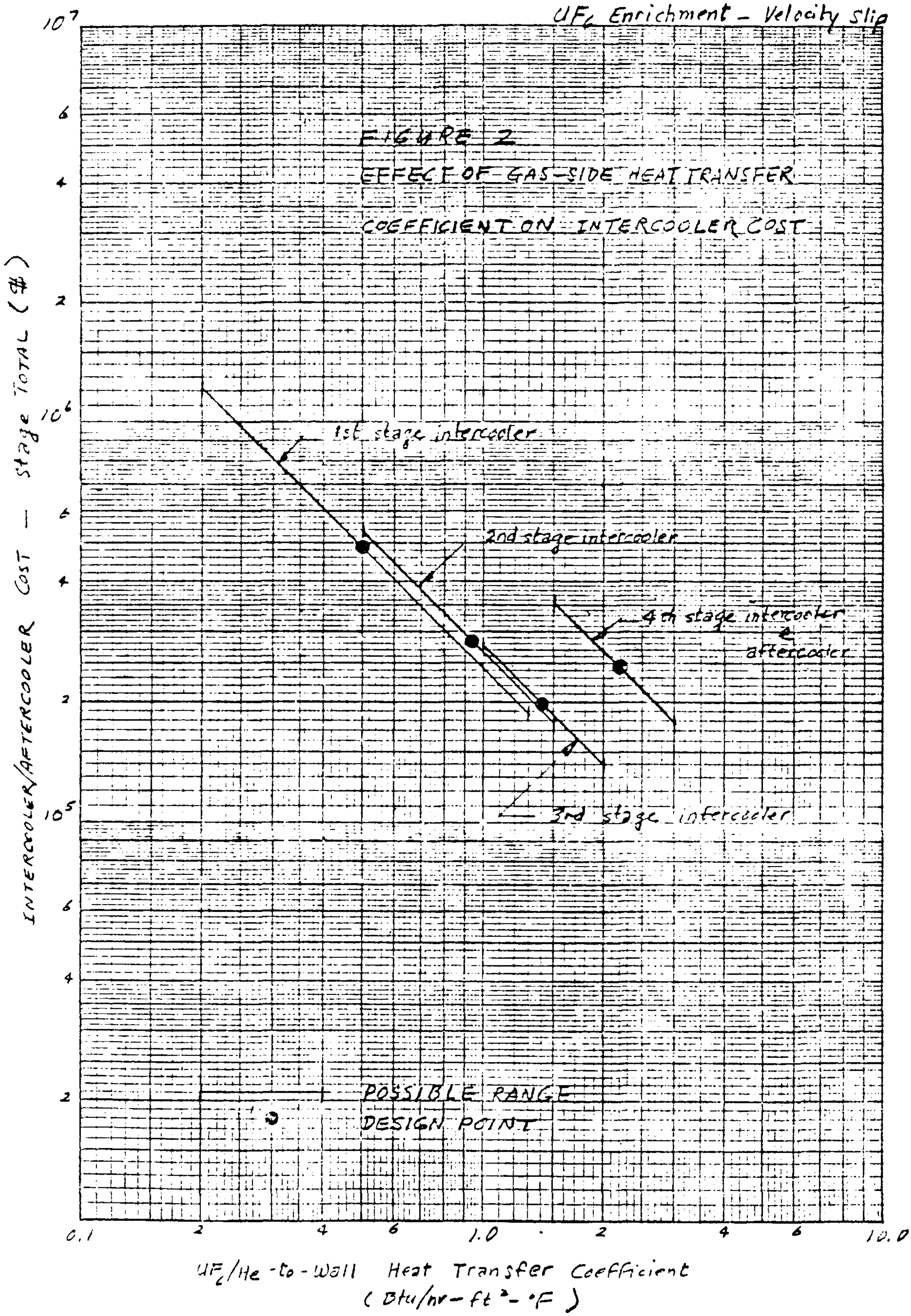


FIGURE 2
EFFECT OF GAS-SIDE HEAT TRANSFER
COEFFICIENT ON INTERCOOLER COST
1st stage intercooler
2nd stage intercooler
4th stage intercooler
&
aftercooler
3rd stage intercooler
POSSIBLE RANGE
DESIGN POINT
INTERCOOLER/AFTERCOOLER COST — stage TOTAL ($)
UF6/He-to-Wall Heat Transfer Coefficient
(Btu/hr-ft²-°F)

SECTION A

SUMMARY OF VELOCITY-SLIP URANIUM ENRICHMENT PLANT (VSUEP) EVALUATION

The evaluation of the velocity-slip uranium enrichment technique summarized here sought to:

- Perform a critical review of the technology and assess the feasibility of building an enterprise based on it as may be appropriate for a single utility system.
- Assess the economic characteristics of such an enterprise in a format which permits comparison with current standard options (e.g., gaseous diffusion and gas centrifuge).
- Apply the AiResearch privately-owned Uranium Enrichment Plant Economic Risk Model Computer Program to describe the uncertainty in the cost estimates. (Note: The economic risk model was not exercised because the capital cost of the VSUEP would render a SWU price far beyond acceptable limits.)

Exhibit A-1 shows a comparison of the projected unit costs of separative work from the velocity-slip and gas-centrifuge uranium enrichment plants. Exhibit A-2 compares the identifying key assumptions about these three plants.

The projected price of yellowcake (U_3O_8) determines the optimal $^{235}UF_6$ assay of the plant tails stream. The net value of the tails stream has been assumed to be zero. The Department of Energy (DOE) plan to strip tails from the gaseous diffusion and gas-centrifuge uranium enrichment plants indicates a value greater than zero for these tails in the appropriate form at the tails-stripping plant site. This value has not been estimated nor has the cost of conversion and transportation of the velocity-slip process tails in Texas to tails-stripping plant feed in Tennessee.

Exhibit A-3 shows the structure of the unit cost of separative work projection for the velocity-slip uranium enrichment enterprise. Clearly the capital charges associated with interest during construction, engineering, and contingency represent a substantial portion of the total. The total of these charges is roughly equal to the capital charges representing the cost of all the hardware and the buildings to house it.

Exhibit A-4 describes the calculation of the projected unit cost of separative work from the fixed-capital cost estimate, the operating cost estimate, and the capital recovery factor. Exhibit A-5 describes the calculation of the capital project and fixed-capital cost estimates from the base cost estimates developed by engineering evaluation of the hardware and labor costs involved in building the plant. The fixed-capital cost estimate for the VSUEP amounts to $6732 million. Exhibit A-6 compares the fixed-capital cost estimates for the two plants identified in Exhibits A-1 and A-2.

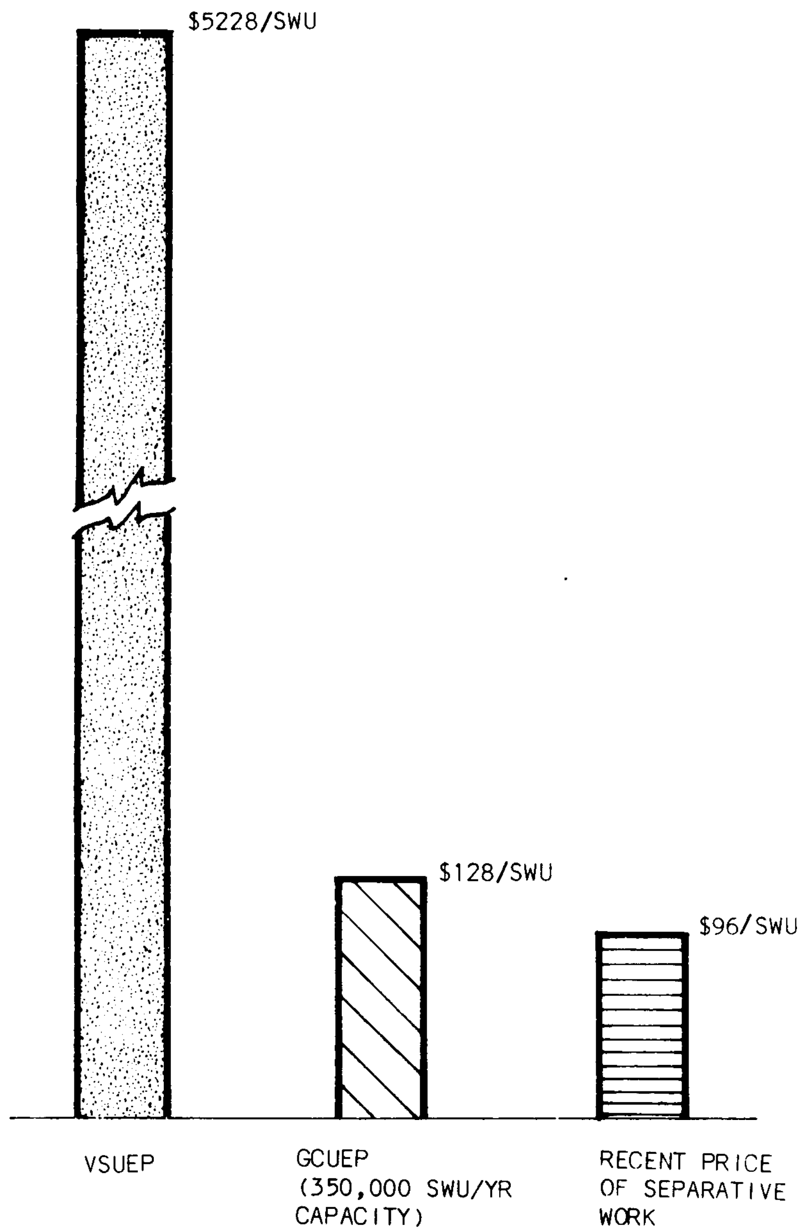


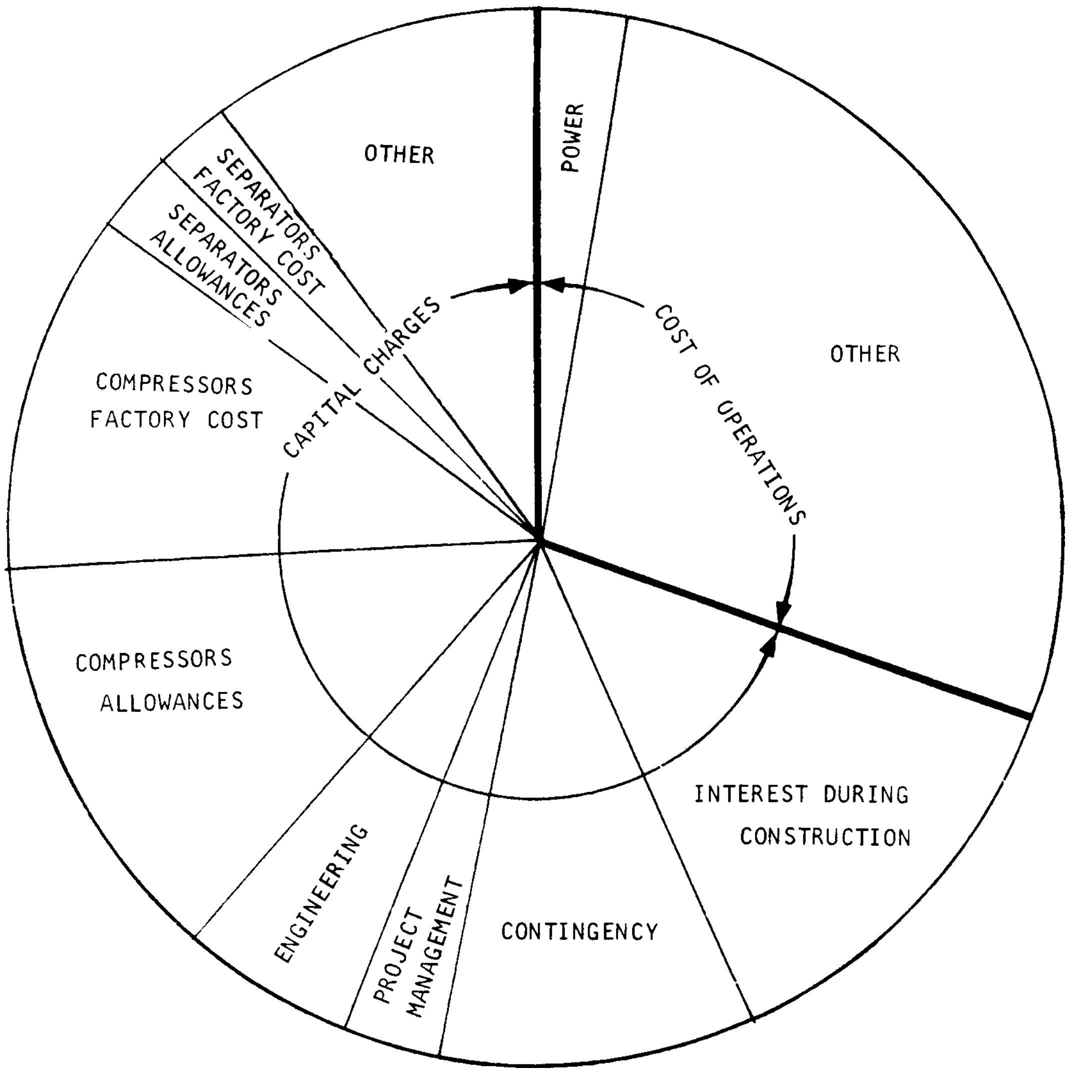
Exhibit A-1. Unit Cost or Price of Separative Work

EXHIBIT A-2

COMPARISON OF IDENTIFYING KEY ASSUMPTIONS FOR TWO ALTERNATIVE URANIUM ENRICHMENT PLANT CONCEPTS*

SITING	CASE A	CASE B
Process	Velocity-Slip	Gas-Centrifuge
Siting	Sharing a Texas power plant site	Stand-alone site in Texas
Ownership	Private	Private
Separative Capacity, SWU s/year	300,000	350,000
Product Assay, weight percent $^{235}UF_6$	3.2	3.2
Tails Assay, weight percent $^{235}UF_6$	0.25	0.25
Feed Assay, weight percent $^{235}UF_6$	0.711	0.711
New UF_6 Feed and Withdrawal Facilities (TESA)	Yes	Yes

*See Section B for more information about key assumptions.



Projected unit cost of separative work is $5228 per SWU

Exhibit A-3. Components of the Projected Unit Cost of Separative Work from the Velocity-Slip Uranium Enrichment Plant

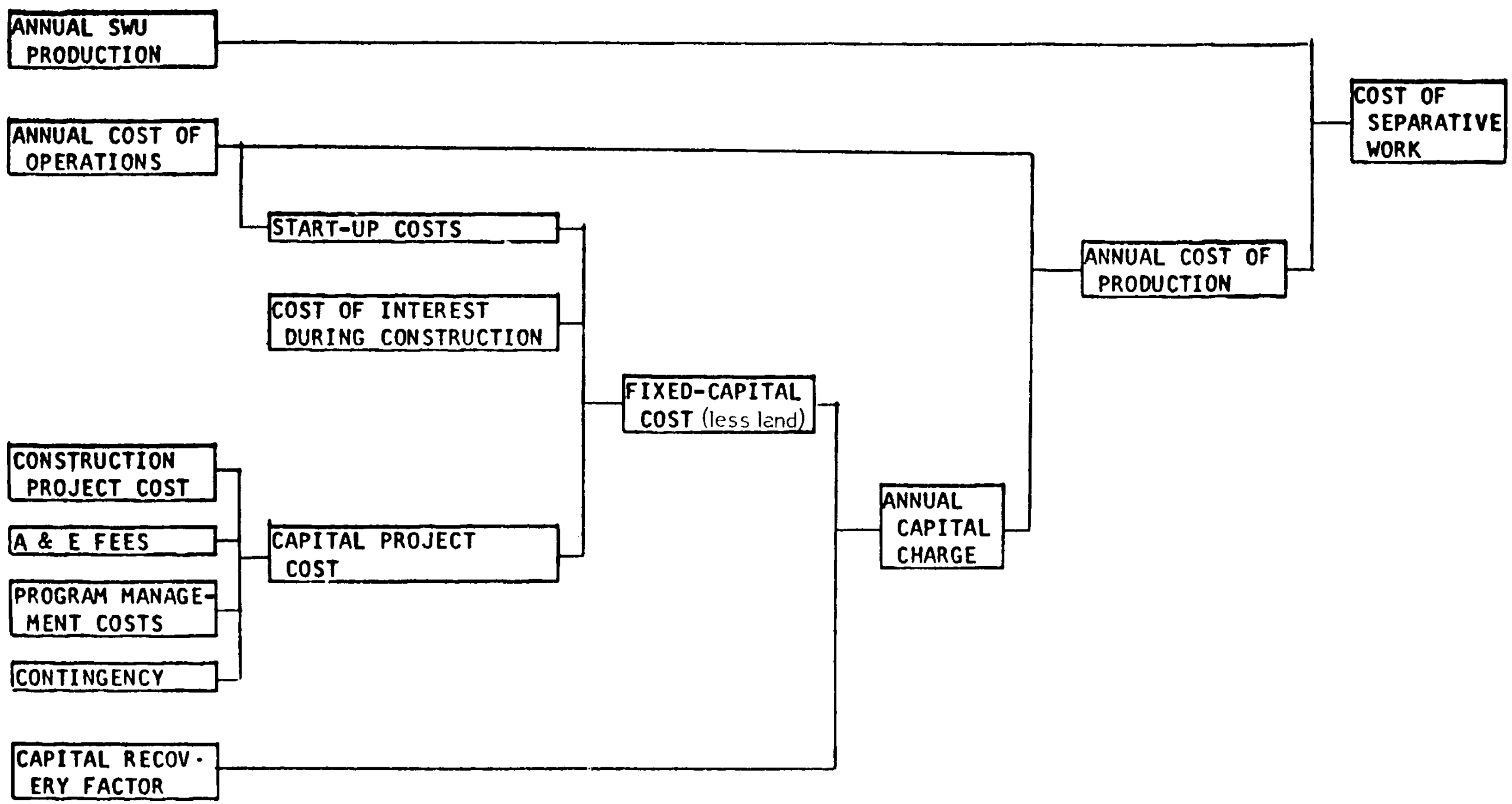


Exhibit A-4. Aggregate-Cost Model for the Cost of Separative Work

EXHIBIT A-5

FIXED-CAPITAL COSTS EXTENSION
millions of dollars

	Land	Other Architectural Systems	Structural Systems	Separator & Compressor Systems	Other Process Equipment	Mechanical Systems	Electrical Systems	Industrial Systems	Instrumentation	Totals
Base Cost Estimate	10.0	6.0	41.8	1417.0	272.0	9.0	30.9	5.1	168.9	1960.8
Freight in				42.5						42.5
Subtotal	10.0	6.0	41.8	1459.5	272.0	9.0	30.9	5.1	168.9	2003.3
Allowances for Indirect, Procurement, Insurance, FICA, State and Local Taxes, Small Tools, Scrappage and Overage, Premium Labor Rates Costs	0	1.7	11.7	729.8	76.2	2.5	8.7	1.4	47.3	879.3
Subtotal	10.0	7.7	53.5	2189.3	348.2	11.5	39.6	6.5	216.2	2882.5
Subcontractors' Markups and Fees	0	0	5.4	219.6	35.3	1.2	4.0	0.7	22.0	288.2
Subtotal	10.0	7.7	58.9	2408.9	383.5	12.7	43.6	7.2	238.2	3170.7
Construction Contractor's Indirect Costs	0	1.1	8.8	0	0	1.9	6.5	1.1	0	19.4
Operations Contractor's Overhead	0	0	0	354.3	57.1	0	0	0	35.4	446.8
Subtotal	10.0	8.8	67.7	2763.2	440.6	14.6	50.1	8.3	273.6	3636.9
Construction Project Cost (less land)										3626.9
Engineering (A&E) Fees Cost										507.8
Subtotal										4134.7
Project Management Costs										290.1
Subtotal										4424.8
Contingency for Oversight and Unidentified Miscellaneous										943.0
Subtotal										5367.8
Interest during Construction										1235.5
Land										10.0
Subtotal										6613.3
Start-up Costs										118.6
Total										6731.9

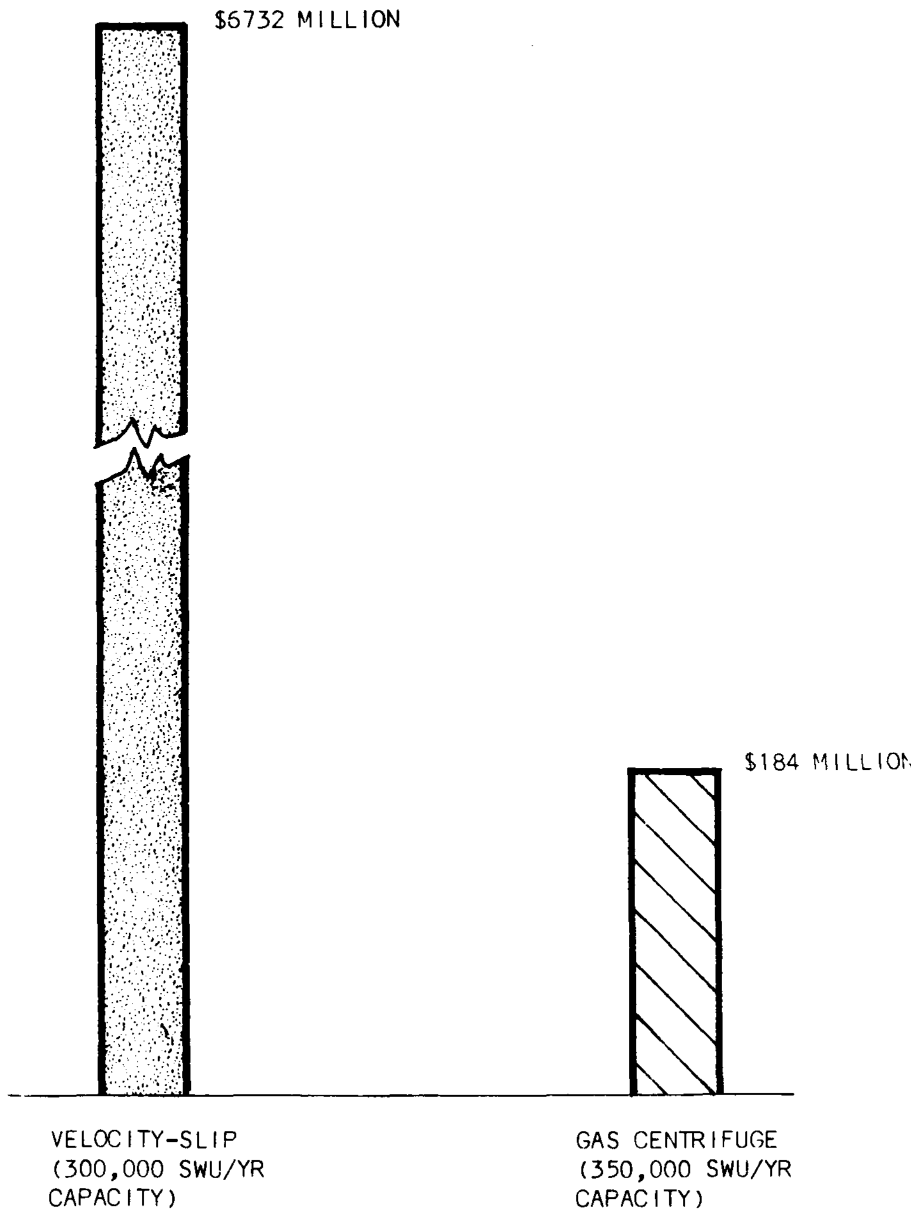


Exhibit A-6. Fixed-Capital Cost

The velocity slip uranium enrichment plant will incur operating costs of $474 million per year and require working capital amounting to $1.4 million.

The capital recovery factor has been assumed to be 0.16275 which represents the situation in which the average useful life of the hardware and buildings is 10 years and the cost of money to the enterprise is 10 percent per year. Clearly the buildings will last longer than 10 years but the velocity-slip modules and some of the UF_6 process equipment may last much less than 10 years. The value assumed is generally accepted, in the absence of better information, in the projection of the unit cost of separative work.

SECTION B

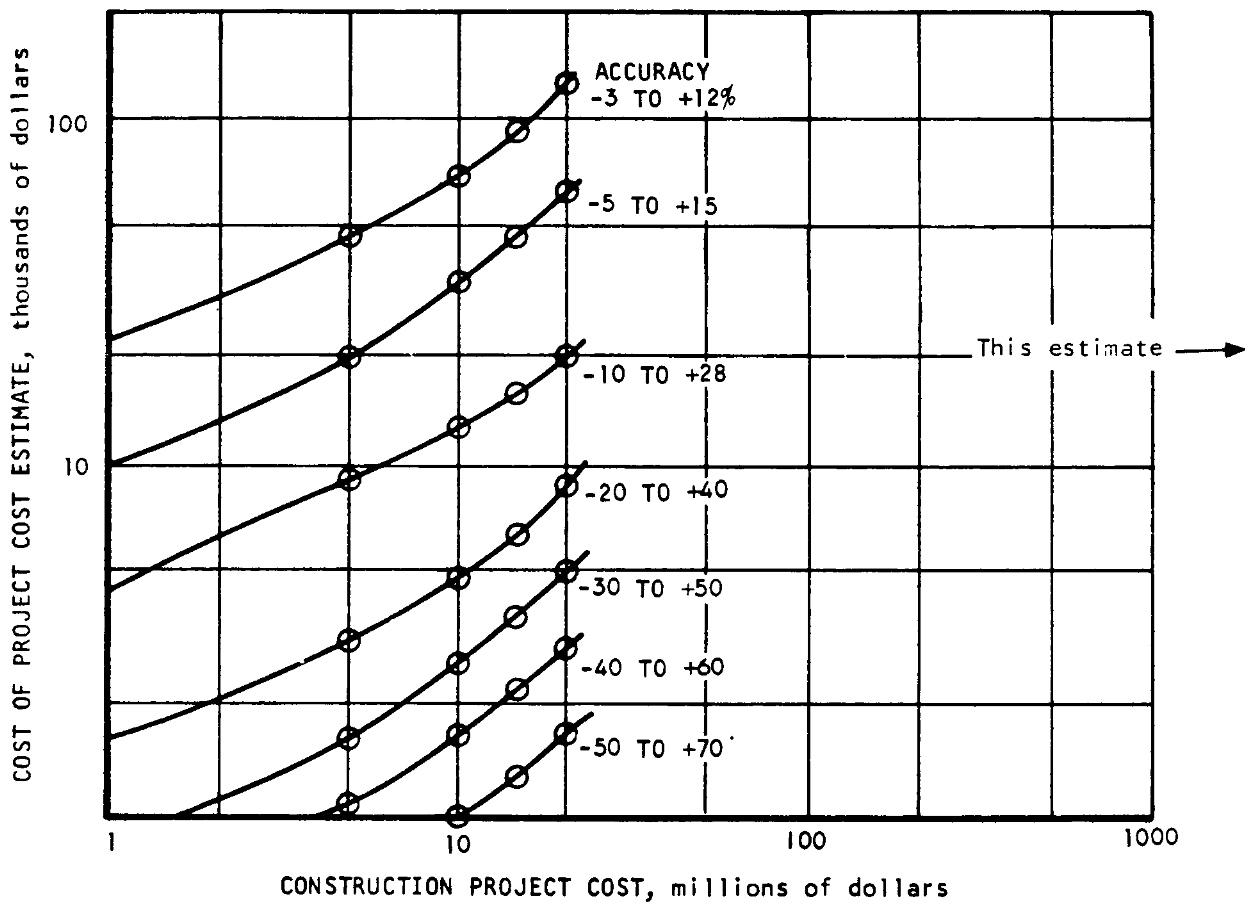
INTRODUCTION

A velocity-slip uranium enrichment plant (VSUEP) preliminary conceptual design and cost estimate are presented in this report. The highlights of this estimate have been summarized in Section A. The accuracy of this estimate is uncertain but Exhibit B-1 might be helpful in forming an opinion about it. The cost of this project-cost estimate is $20,000 and the projected construction project cost is $3,623 million. However, much of the information has been obtained from the AiResearch-funded studies of a 350,000 SWU/yr gas centrifuge enrichment plant. Some of this AiResearch-funded information was also included in a laser isotope separation economic study for LASL, which was a classified Secret - Restricted Data Study.

The preliminary conceptual design was developed by engineering discipline, e.g., architectural and electrical, the cost estimate summary aggregates cost by plant area e.g., process facilities area and UF feed and withdrawal area (TESA). The cost estimate is separately aggregated into categories of capital costs and operating costs.

The preliminary conceptual design assumes:

- Desired plant capacity is 300,000 SWU per year using natural-uranium hexafluoride as feed.
- The feed uranium hexafluoride can be purchased in the quantities required at an acceptable price.
- The tails UF_6 can be sent to the DOE tails stockpile at no net cost.
- The plant uses the velocity-slip process to separate the 235 and 238 isotopes of uranium and performs the functions described in Section C of this report.
- The plant is sited adjacent to a nuclear power plant located in Texas.
- The plant has a 100 percent duty factor.
- Successful demonstration of the process and key process equipment by the start of the construction project.
- All costs are adjusted to January 1978 values.
- Construction project starts in 1981 after all critical process components have been proved and proceeds along the timeline shown in Exhibit B-2.
- The capital costs are to be recovered by an annual charge against the product amounting to 0.16275 times the capital invested at the time startup is completed.



Source: Jelen, F. C. (1970). COST AND OPTIMIZATION ENGINEERING, New York: McGraw-Hill Book Company, page 303.

Exhibit B-1. Relationship of Accuracy to Cost of Estimate

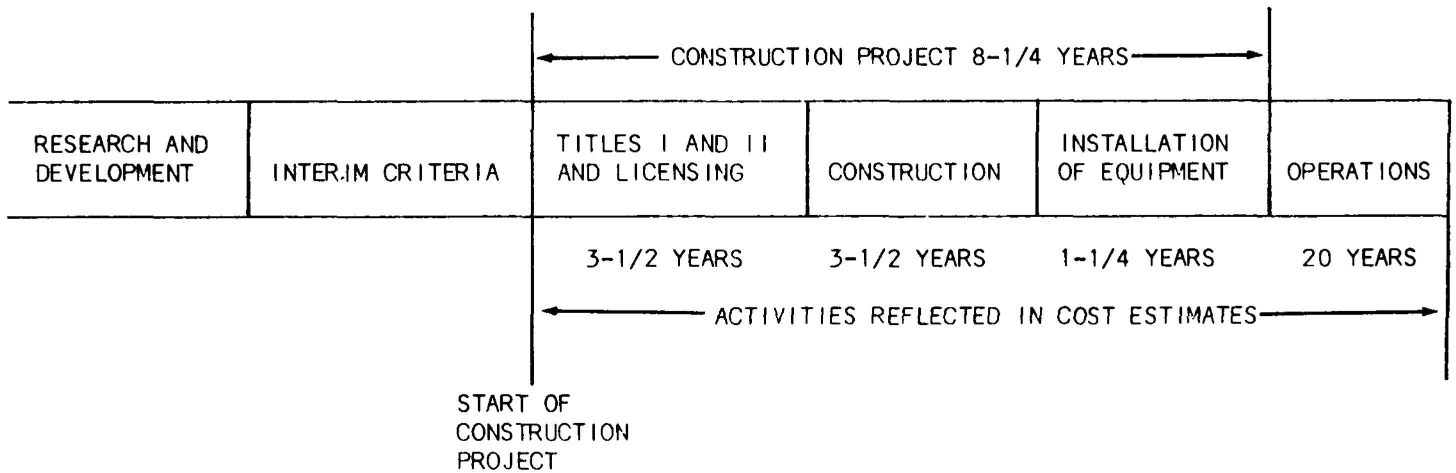


Exhibit B-2. Velocity-Slip Uranium Enrichment Plant Timelines

- Vendors' facilities capital costs assignable to the uranium enrichment plant capital costs are determined on the basis of no assured sales beyond the initial complement of process equipment. That is, the cost of highly specialized capital equipment will be completely recovered in the price of the initial complement of subsystems supplied by the vendor. Costs of other vendor capital facilities assignable to the velocity-slip capital costs are reduced by the fair market values at the time of completing the inital complement.

- Vendors and the uranium enrichment plant enterprise use the following depreciation rules for both capital recovery and tax purposes.

  (1) Land - No depreciation.

  (2) Buildings and Land Improvements - Depreciation for 45 years on straight-line basis. An additional 15 percent of the remaining book value is charged to the project to represent the costs of conversion to other uses.

  (3) Standard Equipment - Depreciation for 12 years using the sum-of-years digits method. An allowance of 50 percent of the remaining book value is charged to the project because of uncertain marketability of such equipment items offered in quantity.

  (4) Special Equipment - Same as for standard equipment except that 100 percent of remaining book value is charged to the project.

- Cost estimates are based on take-offs from the preliminary conceptual design drawings. Appropriate engineering cost indexes are used to update earlier price and cost information. Prices for materials and equipment are those obtained from industry wherever possible. Construction wage rates are those in effect in Texas in January 1978.

- All costs adjusted to the January 1978 value of the United States dollar.

The AiResearch Plant Engineering staff recently prepared a conceptual design and cost estimate for a 350,000-SWU-per-year gas-centrifuge uranium enrichment plant to be built, owned, and operated by Garrett Nuclear Corporation (GNC) in Texas. The extent of the effort on this gas-centrifuge plant conceptual design was severalfold that applied to VSUEP, and the conceptual design and cost estimate benefitted substantially from know-how developed by AiResearch engineers in their work for Garrett Nuclear Corporation. The design for the UF_6 feed and withdrawal area (TESA) for example, is essentially the same as the corresponding area for the GNC gas-centrifuge uranium enrichment plant.

The engineering estimates of cost are based on general experience with the more extensive conceptual designs of both Government and privately owned gas-centrifuge uranium enrichment plants to be located in Texas, Tennessee, and Ohio.

The cost estimates and construction plan presume the plant owner will delegate all work to one or the other of two prime CPFF contractors. The Operations Contractor will: (1) prepare the plant design criteria, (2) prepare procurement specifications, (3) design all specialized items of equipment for which there are no commercially available substitutes, (4) design all process systems, (5) review all the architect-engineering documents, (6) compile aggregate cost estimates for the construction project, (7) prepare and monitor construction project master schedules and budgets, and (8) operate and maintain the plant. The Operations Contractor will procure (1) items which require vendors to build special facilities in order to meet quantity-delivery requirements, (2) specialized items of equipment for which there are no commercially available substitutes, (3) velocity-slip isotope separation devices, and (4) other items of equipment and materials which involve long-lead time procurement and which might hold up construction if delivery schedule or quality slip.

Construction is performed by cost-plus-fixed-fee (CPFF) subcontractors. The prime Construction Contractor will administer subcontracts and will procure all items not assigned to the Operations Contractor. The primary suppliers will manufacture the most costly components of their respective subsystems on a fixed-priced basis. Each type of process subsystem will be supplied by two vendors. Each vendor will supply the complete subsystem ready for installation and demonstration in the process facility. The Operations Contractor will supervise the installation of all process equipment. Each vendor will have his own independent subtier of suppliers for the components he uses in his subsystem.

Because many of the subsystems are novel and unique to the VSUEP, no commercial price can be established. Cost estimates for these subsystems are based on aggregating engineering estimates of costs for labor, materials, and facilities required to manufacture and test them and estimates of the return inducements required to interest vendors and their investors. Primary subsystem suppliers are allowed a 10 percent administration fee applied to all subcontracts for subassemblies.

All capital costs are to be recovered in the price of the product. Because certain items of equipment are expected to fail before the completion of the plant startup, the vendor will be supplying units chargeable to capital costs and units chargeable to operating costs simultaneously. Costs chargeable to capital costs are allocated as the direct pro rata portion of total costs for these units. Costs are assumed to increase with capacity by the formula

$$\frac{\text{Cost at Capacity 1}}{\text{Cost at Capacity 2}} = \left(\frac{\text{Capacity 1}}{\text{Capacity 2}}\right)^{e}$$

The value of the exponent e depends on the item whose capacity is varied. In the absence of better information it is taken* to be 0.6.

*Peters, M. and K. D. Timmerhouse (1968). Plant Design and Economics for Chemical Engineers, New York, McGraw Book Company, p. 107.

Because of the very high value of the projected cost of separative work and the relatively smaller degree of uncertainty in the cost estimates, no risk analysis is warranted. Also it is not worth scaling to a 9,000,000 SWU/yr plant.

We anticipate the VSUEP uranium enrichment process details and facility would become classified "Secret - Restricted Data" when the process becomes economic and that the appropriate safeguards will be required.

SECTION C

FUNCTIONAL ANALYLSIS

Exhibit C-1 shows a functional analysis of the system for realizing the velocity-slip uranium enrichment concept. The system is described in this report in terms of the functions identified in the exhibit. The velocity-slip separation of isotopes represents new technology. The other functions are adaptations of technology established by predecessors of DOE for use in its gaseous-diffusion plant operations.

Exhibits C-2 through C-6 identify the key systems (or equipment items) required to perform the designated functions.

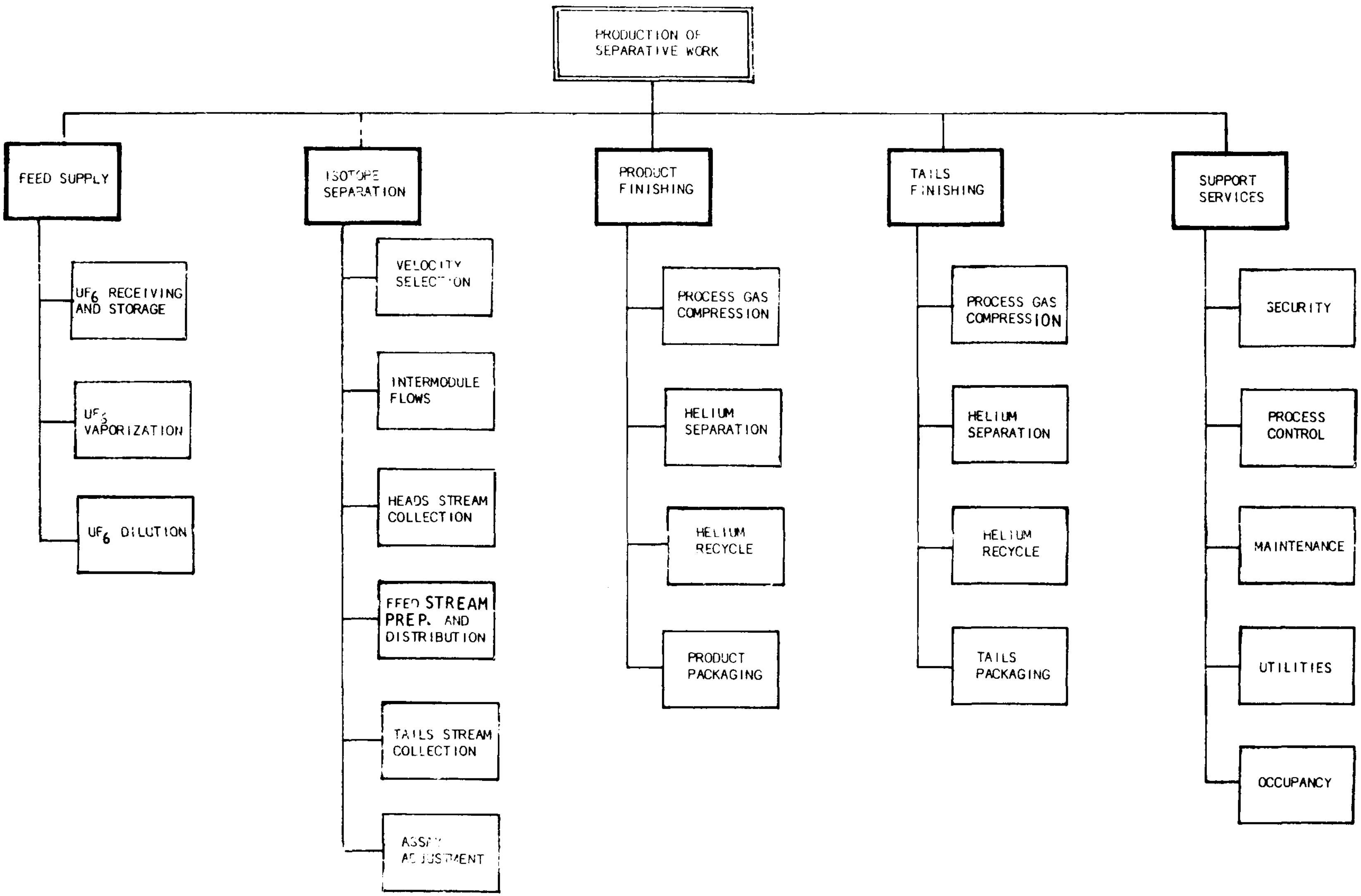


Exhibit C-1. Functional Analysis of the Velocity-Slip Uranium Enrichment Plant

EXHIBIT C-2

FEED SUPPLY FUNCTION (TESA)

UF_6 RECEIVING AND STORAGE

CASK HANDLING EQUIPMENT
SAMPLING EQUIPMENT
SCALES
SPECIAL NUCLEAR MATERIALS ACCOUNTABILITY SYSTEM

UF_6 VAPORIZATION

AUTOCLAVES
CASK HANDLING EQUIPMENT
ELECTRICAL DISTRIBUTION SYSTEM
INSTRUMENTATION
INSULATION
PIPING
SCALES

UF_6 DILUTION

CARRIER GAS ACCUMULATOR
CARRIER GAS RECYCLE SYSTEM
CARRIER GAS SUPPLY
INSTRUMENTATION
MIXER
PIPING

EXHIBIT C-3

ISOTOPE SEPARATION FUNCTION

VELOCITY SELECTION

SEPARATORS (VELOCITY SELECTORS)
VACUUM VALVES
POWER CONDITIONING EQUIPMENT

INTERMODULE FLOWS

COMPRESSORS
CASCADE PIPING
INSTRUMENTATION
CONTROL VALVES
VACUUM PUMPS

HEADS STREAM COLLECTION

HEADERS

FEED STREAM PREPARATION AND DISTRIBUTION

MIXING VALVE FOR HELIUM DILUENT
PIPING
HELIUM SUPPLY SYSTEM

TAILS STREAM COLLECTION

HEADERS

ASSAY ADJUSTMENT

INSTRUMENTATION
PIPING AND VALVING

EXHIBIT C-4

PRODUCT FINISHING FUNCTION

PROCESS GAS COMPRESSOR

- COMPRESSORS

HELIUM SEPARATION

- PARTIAL CONDENSERS
- RECUPERATIVE HEAT EXCHANGERS

HELIUM RECYLE

- HELIUM COMPRESSOR
- HELIUM ACCUMULATOR

PACKAGING

- UF_6 CYLINDERS
- SCALES
- CYLINDER HANDLING EQUIPMENT
- LABORATORY EQUIPMENT

EXHIBIT C-5

TAILS FINISHING FUNCTION

PROCESS GAS COMPRESSOR

- COMPRESSORS

HELIUM SEPARATION

- PARTIAL CONDENSERS
- RECUPERATIVE HEAT EXCHANGERS

HELIUM RECYLE

- HELIUM COMPRESSOR
- HELIUM ACCUMULATOR

PACKAGING

- UF_6 CYLINDERS
- CYLINDER HANDLING EQUIPMENT
- SCALES
- LABORATORY EQUIPMENT

EXHIBIT C-6

SUPPORT SERVICES FUNCTION

SECURITY

- FENCES
- FIRE PROTECTION SYSTEM
- PLANT SECURITY FACILITIES
- SAFEGUARDS FACILITIES
- SNM ACCOUNTABILITY FACILITIES

MAINTENANCE AND REPAIRS

- DECONTAMINATION FACILITY
- METROLOGY EQUIPMENT
- SHOP TOOLS
- SPARE PARTS AND ASSEMBLIES
- STANDBY SYSTEMS
- STORES

OTHER

- AIR HANDLERS FOR CRITICALITY CONTROL
- BUILDINGS, YARDS, ROADS, TRACKS, AND LANDSCAPING
- COMPUTER
- LABORATORIES
- MATERIALS AND EQUIPMENT HANDLING EQUIPMENT
- OFFICE EQUIPMENT AND PERSONNEL SUPPORT FACILITIES
- SHIPPING, RECEIVING, AND STORAGE FACILITIES

UTILITIES

- BOILER AND STEAM DISTRIBUTION SYSTEM
- COMMUNICATIONS SYSTEMS
- CONTAMINATED LIQUID COLLECTION SYSTEM
- CONTAMINATED LIQUID TREATMENT SYSTEM
- COOLING TOWER SYSTEM
- ELECTRICAL SUBSTATION AND DISTRIBUTION SYSTEM
- HEAT AND VENTILATING SYSTEMS
- INDUSTRIAL WASTE DISPOSAL SYSTEM
- LIGHTING
- LIQUID NITROGEN PLANT AND DISTRIBUTION SYSTEM
- SANITARY SYSTEM
- STORM SEWER
- WATER CHILLERS SYSTEM
- WATER TREATMENT FACILITIES

SECTION D

SUMMARY OF COST ESTIMATES

CAPITAL COSTS

The total fixed-capital requirements for the conceptual design velocity-slip uranium enrichment plant is $6732 million. The working capital requirement is $1.4 million. The estimated land costs which are included in the fixed-capital cost and are not recoverable through capital charges to separative work but rather through resale, amount to $10 million.

Exhibit D-1 shows the capital project costs (a portion of the total fixed-capital costs) allocated among nine categories (VARIABLES). The categories have differing amounts of uncertainty associated with them. They are chosen to reflect how a person might think about dividing the capital project costs so that he can deal with economic uncertainties.

The base cost of the installed process system for the conceptual design plant amounts to $3,204 million or about 88 percent of the capital project cost. In the chemical process industries, the installed process equipment cost ranges between 23 and 60 percent of the cost of the capital project. Peters and Timmerhaus* suggest that the average is about 36 percent.

Exhibit D-2 shows the direct capital project cost estimates divided among the variables and the engineering disciplines.

Finally, Exhibit D-3 shows estimated costs associated with each of the several variables divided among the sums of the direct costs on the one hand and Construction and Operations Contractors' indirect costs, allowances, and fees, on the other. These exhibits indicate the estimators' uncertainty in the estimated costs associated with each of the variables. Although much uncertainty lies in the contingency and interest-during-construction estimates due to uncertainty in the construction schedule, these uncertainties are not indicated in Exhibits D-3 These uncertainties are dependent on Variable 15.

OPERATIONS COSTS

The annual costs of operations for the conceptual design plant is estimated to be $474 million. The components of the cost estimates are presented in Exhibit D-4.

*Peters, M. and K. D. Timmerhaus (1968). Plant Designs and Economics for Chemical Engineers, New York; McGraw-Hill Book Company, p. 104.

EXHIBIT D-1

CAPITAL PROJECT COST* ESTIMATE SUMMARY
thousands of dollars

VARIABLE	COST	%
TOTAL	4,432,375	100
14 PROJECT MANAGEMENT	290,100	7
13 A&E	507,800	11
12 SEPARATORS AND COMPRESSORS (INCLUDING VARIABLES 1 AND 4)	2,763,162	62
11 INSTRUMENTATION	273,629	6
10 UF_6 FEED AND WITHDRAWAL AREA (TESA)	18,326	< 1
9 CASCADE AREA	543,065	12
8 REWORK, OVERHAUL, REPAIR AREA (RORA)	5,629	< 1
7 ADMINISTRATION BUILDING AND AUXILIARY BUILDINGS	14,103	<1
6 LAND AND SITE (SITEWORK AND OUTSIDE UTILITIES)	16,561	< 1

*DOES NOT INCLUDE CONTINGENCY, INTEREST DULRING CONSTRUCTION, START-UP, OR WORKING CAPITAL COSTS.

EXH T D-2

CAPITAL PROJECT COST* ESTIMATE SUMMARY
(thousands of dollars)

VARIABLE:
- 6 LAND AND SITE (SITEWORK AND OUTSIDE UTILITIES)
- 7 ADMINISTRATION BUILDING AND AUXILIARY BUILDINGS
- 8 REWORK, OVERHAUL, REPAIR AREA (RORA)
- 9 CASCADE AREA
- 10 UF_6 FEED AND WITHDRAWAL AREA (TESA)
- 11 INSTRUMENTATION
- 12 SEPARATORS AND COMPRESSORS (INCLUDING VARIABLES 1 AND 4)
- 13 ARCH. & ENG.
- 14 PROJECT MANAGEMENT

VARIABLE	TOTAL	14	13	12	11	10	9	8	7	6
ARCHITECTURAL	15,980	0	0	0	0	749	1,885	641	1,041	11,664
STRUCTURAL	41,763	0	0	0	0	4,957	33,600	1,482	1,724	0
PROCESS	1,731,563	0	0	1,459,500	0	3,420	266,891	70	1,236	446
MECHANICAL	9,031	0	0	0	0	70	5,339	70	2,883	669
ELECTRICAL	30,910	0	0	0	0	984	26,279	929	523	2,195
INSTRUMENTATION	168,907	0	0	0	168,907	0	0	0	0	0
INDUSTRIAL	5,150	0	0	0	0	1,202	1,406	342	1,395	805
OTHER**	2,429,040	290,100	507,800	1,303,631	104,722	6,944	207,665	2,095	5,301	782
TOTALS	4,432,344	290,100	507,800	2,763,131	273,629	18,326	543,065	5,629	14,103	16,561

*DOES NOT INCLUDE CONTINGENCY, INTEREST DURING CONSTRUCTION, START-UP, OR WORKING CAPITAL COSTS.
**ALLOWANCES, FEES, INTEREST, MARK-UPS, ETC.

EXHIBIT D-3

CONSTRUCTION VARIABLES

VARI-ABLE	DESCRIPTION	SUBCON-TRACTORS' DIRECT COSTS, $000,000	PRIME CON-TRACTORS' AND OWNER'S INDIRECT COSTS, ALLOWANCES AND FEES $000,000	TOTAL CAPITAL COST*, $000,000		
				NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
1	SEPARATOR AND COMPRESSOR SYSTEMS	1287.5	1150.0	2437.5	2000.0	4000.0
2						
3						
4	SEP. AND COMPRESSOR SYSTEMS FREIGHT-IN	42.5	38.0	80.5	80.0	120.0
5						
6	LAND AND SITE	15.8	0.8	16.6	16.0	18.0
7	ADMIN AND AUX BLDGS	8.8	5.3	14.1	14.0	15.5
8	RORA	3.5	2.1	5.6	5.0	7.0
9	CASCADE AREA	335.4	207.7	543.1	500.0	600.0
10	TESA	11.4	6.9	18.3	18.0	20.7
11	INSTRUMENTATION	168.9	104.7	273.6	250.0	300.0
12	SEPARATORS AND COM-PRESSORS INSTALLED	129.6	115.8	245.4	240.0	500.0
13	ARCH. AND ENG.	0	507.8	507.8	480.0	800.0
14	PROJECT MANAGEMENT	0	290.1	290.1	250.0	400.0
	TOTAL*	2003.1	2429.2	4432.3		

VARI-ABLE	DESCRIPTION	PROJECT PERIOD, YEARS		
		NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
15	CONSTRUCTION	8.25	7.00	9.25

*This total does not include costs of startup, interest during construction, contingency for miscellaneous unidentified small items, oversight, and uncertainty, nor cost of ɔrking capital. The minimum and maximum values are determined by Monte Carlo simulation,

EXHIBIT D-4

OPERATIONS VARIABLES

VARI-ABLE	DESCRIPTION	DIRECT COSTS, $000/YR	BURDEN COST, $000/YR	TOTAL OPERATIONS COST* $000,000/YEAR NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
16	LABOR	5,411	1,353	6,764	5,500	7,000
17	PROCESS EQUIPMENT UPKEEP	298,960	0	298,960	200,000	400,000
18	STANDARD EQUIPMENT AND BUILDING UPKEEP	22,907	0	22,907	20,000	25,000
19	UTILITIES	30,220	0	38,220	35,000	41,000
20	OVERHEAD AND MISCELLANEOUS	107,540	0	107,540	100,000	150,000
	TOTAL	473,038	1,353	474,391		
				CAPACITY, MILLION SWUS/YEAR		
VARI-ABLE	DESCRIPTION			NOMINAL VALUE	MINIMUM VALUE	MAXIMUM VALUE
21	PRODUCTION			0.3	0.25	0.31

*The minimum and maximum values for the total are determined by Monte Carlo simulation.

UNIT COST OF SEPARATIVE WORK

The projected unit cost of separative work from the conceptual design plant is $5233 per SWU. A recent price for separative work was $92 per SWU.

The computational model for calculating the projected unit cost of separative work from the various cost aggregates and the capital recovery factor is shown in Exhibit A-4.

SECTION E

CONSTRUCTION PROJECT PLAN

INTRODUCTION

This section discusses the approach assumed taken in accomplishing the design, construction, and startup of the Velocity-Slip Separation Process uranium enrichment (VSUEP) plant. This approach is discussed under the titles:

(a) Operations Contractor's Facilities Program

(b) Architectural and Engineering (A&E) Contractor

(c) Construction Contractor

(d) Site Selection

(e) Licensing and Safeguards

(f) Quality Assurance (QA)

(g) Manning

(h) Program Scheduling and Controls

The construction project plan affects the capital cost of VSUEP-produced separative work in a variety of ways and it addresses the principal uncertainties in capital cost projection, i.e., scheduling and resource availability.

OPERATIONS CONTRACTOR'S FACILITIES PROGRAM

As indicated in Exhibit E-1, the facilities design and construction program proceeds in parallel with, but separate from the on-going operations of the Owner or Operations Contractor. Both activities, however, are the responsibility of the Operations Contractor. Both the construction QA and licensing and facilities program management functions will phase out when the facility is completed, licensed, and started up. On-going facilities activities and QA and Nuclear Regulatory Commission (NRC) liaison activities will be handled by permanently assigned personnel within the Operation Contractor's organization.

FACILITIES PROGRAM MANAGEMENT

Exhibit E-2 outlines the facilities management program plan. It shows in simplified form the basic information and activity flow being implemented. This program is a first-of-a-kind plant construction program and hence the key process design technology does not currently reside in the architectural and engineering contractor (A&E) community. For this reason, a group will be used to supply key data to the group (referred to as the criteria development and control group) who actually will be the prime interface with the A&E function.

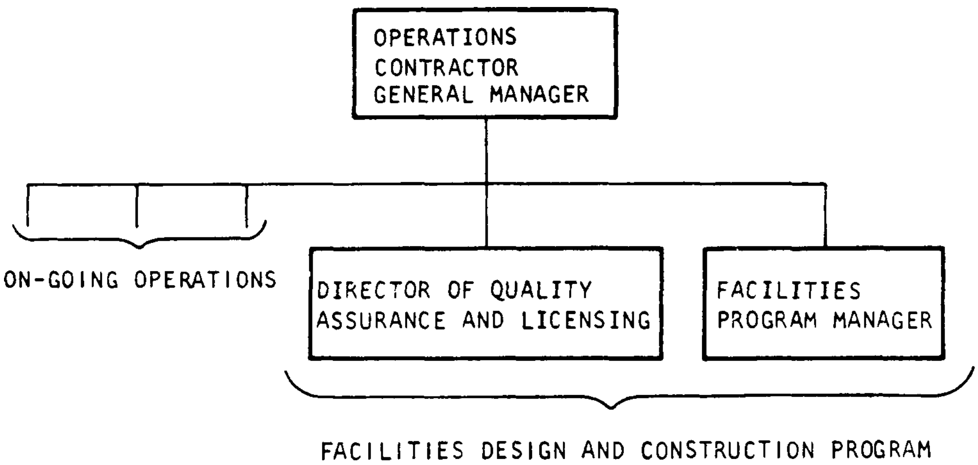


Exhibit E-1. Facilities Program Management

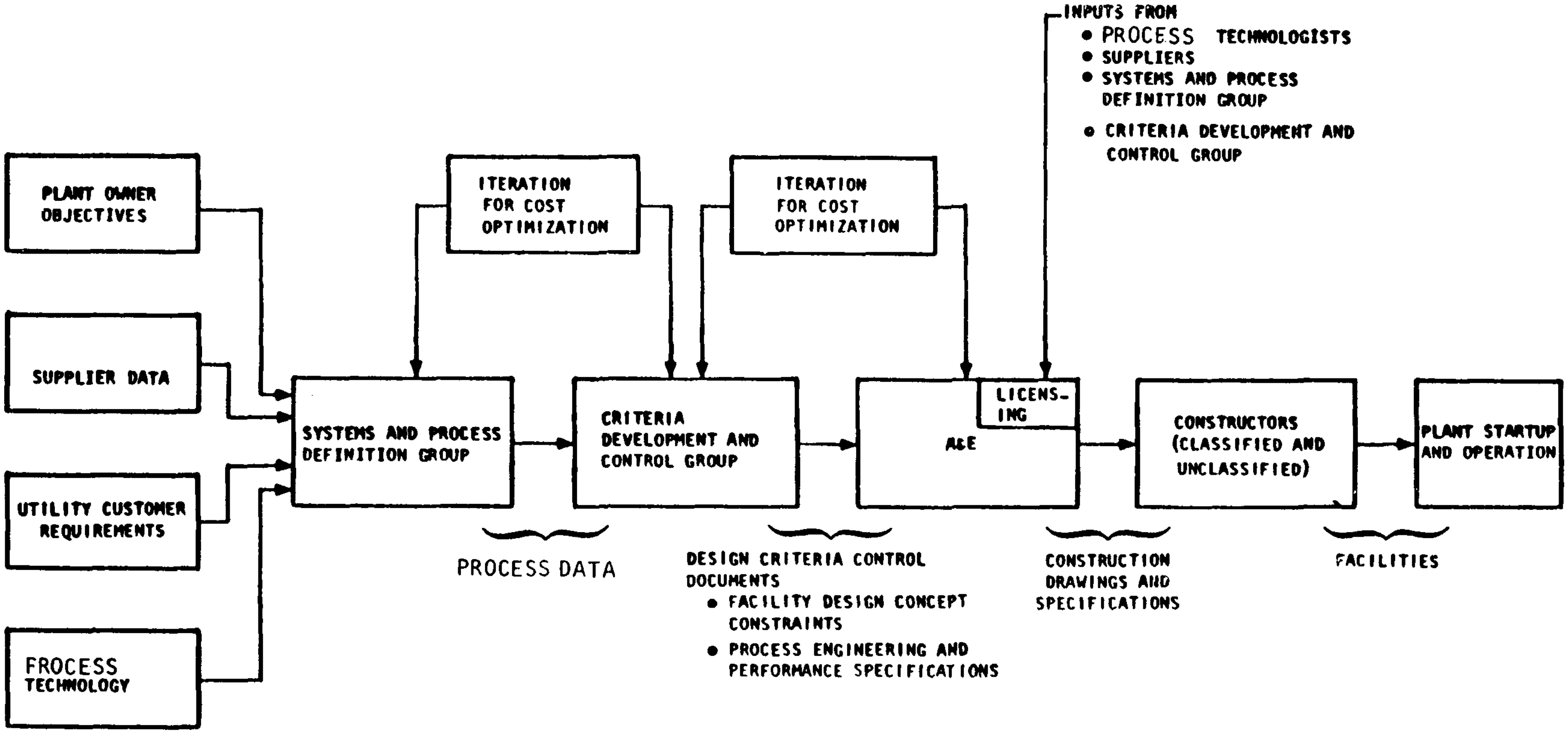


Exhibit E-2. Information and Activity Flow for Facilities Design and Construction

The only other uncommon feature of the proposed activity flow is in the area of licensing, which is shown as executed within the A&E function, receiving inputs from several functional levels.

The functional organizational structure for the Operations Contractor's facilities program management is shown in Exhibit E-3. The activities in each function are discussed briefly below.

SYSTEMS AND PROCESS DEFINITION

The group responsible for this function must define the basic system parameters and features of the process to be implemented. Typical responsibilities include:

(a) Descriptions of all process equipment and operating conditions.

(b) Values of all cascade design parameters and supplementary cascade design requirements to facilitate detailed design of the cascade and associated equipment.

(c) Provision of basic data to facilitate understanding of reliability characteristics of equipment and cascade.

(d) Definitions of instrumentation and control objectives and constraints.

(e) Definitions of interrelationships between UF_6 feed and withdrawal area (TESA) and the **cascade** areas and between TESA design and projected modes of doing business as an enricher.

(f) Definitions of rework and repair area requirements.

(g) Definitions of specific VSUEP and process-related hazards, process parameters, licensing criteria, systems reliability, and effluents accountability in support of licensing activities.

(h) Provision of basic data to support the special nuclear material accountability and other safeguards-related system design activities.

In general, this group provides the very specialized basic technology peculiar to the VSUEP process for use by the A&E contractor Title II in the detailed plant design. It also monitors the detailed design and the development of the formal criteria upon which the detailed design is to be based to ensure the correct interpretation and use of that technology.

CRITERIA DEVELOPMENT AND CONTROL

This function includes the preparation and coordination of the facility design criteria and supporting technical analyses, including interpretation (in the form of criteria) of the data generated by the systems and process definition group. Included in this function are:

(a) Definitions of facility design concepts and process engineering criteria, and control and coordination of criteria changes.

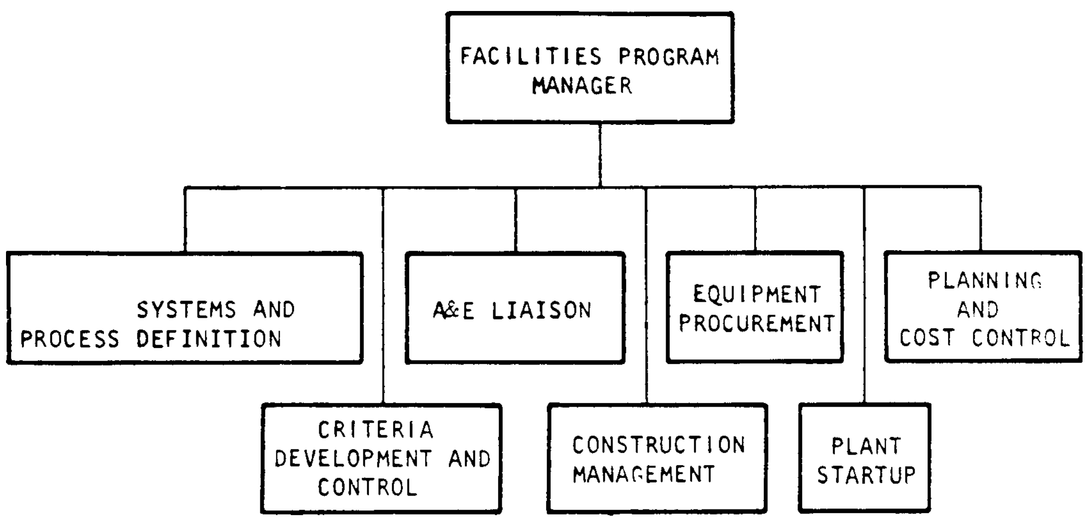


Exhibit E-3. Functional Organization for Facilities Program Management

(b) Participation in establishing licensing strategy.

(c) Participation in the task of analyzing A&E submittals relating to licensing documents including the Preliminary Safety Analysis Report (PSAR), the Environmental Impact Report (EIR), the Final Safety Analysis Report (FSAR), and safeguards.

(d) Establishment of commitments to Nuclear Regulatory Commission (NRC) and applicable codes and standards.

(e) Assistance in QA program.

(f) Contract technical review for engineering and construction.

(g) Preparation of NRC-required operations documents to support licensing submittals.

(h) Provision of project-level direction and approval of design engineering and construction phases.

(i) Direction at project-level for all matters of preoperational testing of equipment and systems startup.

(j) Obtaining necessary permits, waivers, and licenses (other than NRC-issued license) for the proposed facility from government regulatory agencies (federal, state, local).

A&E LIAISON

In essence, the A&E liaison task is to see that the necessary design engineering and supporting documentation (including licensing documentation as well as drawings) is generated in a timely, cost-effective manner, through a combination of in-house and subcontract effort. The controlling inputs to the A&E function are the design criteria developed by the criteria development and control function.

CONSTRUCTION MANAGEMENT

Construction management consists of project-level control of all construction field activity, as well as medium- and long-range planning. Responsibilities included in this function are:

(a) The coordination of the building contractors in the preconstruction startup of their assigned tasks.

(b) Maintaining overall familiarity with the design work as it progresses in order to minimize conflicts and interferences, and assisting in constructibility reviews and value engineering.

(c) Obtaining and assimilating up-to-date knowledge of the construction program, facility design, and material requirements, to assist with overall planning and scheduling.

(d) Receiving, distributing, and controlling all design documents.

(e) Approving or disapproving recommended solution or disposition of field nonconformances as identified by the quality control or quality assurance groups.

(f) Establishing and implementing procedures for the collection and consolidation of as-built information by the contractor.

EQUIPMENT PROCUREMENT

The equipment procurement group, functioning on behalf of the Operations Contractor, will procure the isotope separators , compressors, and other special process equipment, most standard equipment, and selected specially engineered equipment for the plant. It will be responsible for preparation of necessary specifications and bid packages, solicitation of bids, contract award and administration, and receiving inspection.

PLANT STARTUP

Overall direction and control of the plant start-up function is included as part of the Operations Contractor's facilities program management function, although it is intended that the construction subcontractors provide the personnel to perform the actual startup. Because of the specialized nature of the VSUEP process, assistance in the start-up process will be made available from the appropriate technologists. Vendor-supplied personnel will remain on site for a six- to twelve-month period after startup of the cascade. Some start-up craftsmen undoubtedly will be retained by the Operations Contractor as maintenance personnel.

PLANNING AND COST CONTROL

This function includes the coordination and implementation of the overall project cost and schedule control system, including project-level planning, scheduling, estimating, and cost engineering. Further discussion of project scheduling and controls is included later in this section.

ARCHITECTURAL AND ENGINEERING (A&E) CONTRACTOR

Exhibit E-4 is a functional analysis of the A&E portion of the facilities program. The A&E activities are performed, generally, by an A&E contractor and include the following normal design functions:

(a) Preparation and maintenance of design engineering schedules to meet projected milestone commitments for engineering activities.

(b) Provision of facilities, materials, and other resources necessary to provide release of technical specifications, engineering drawings, and bills of material, in accordance with established control procedures to requirements of schedule and budget.

(c) Preparation of technical analyses (including cost trade-offs), design engineering, and supporting data for licensing documents.

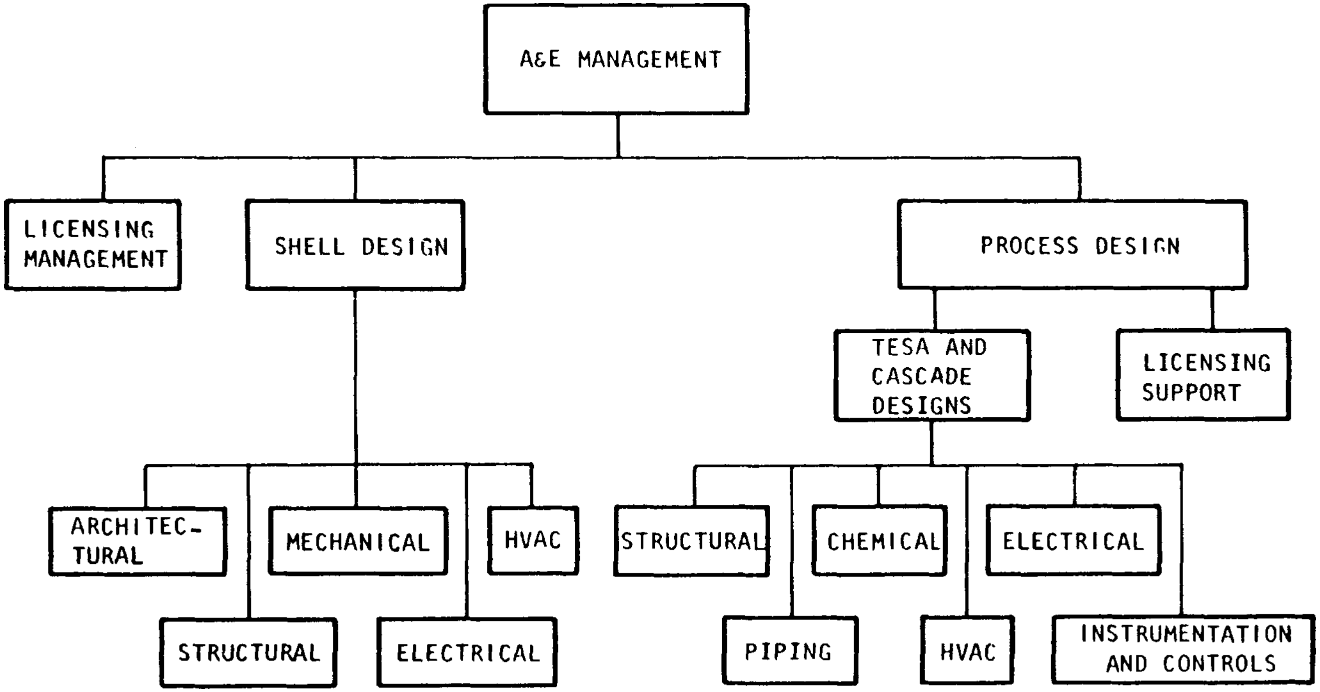


Exhibit E-4. A&E Functional Analysis

(d) Coordination of design engineering, shop, and certified equipment drawings, to ensure timely transmittal of drawings and technical specifications.

(e) Obtaining qualified consultants in areas of special technical expertise.

(f) Preparation of a scale model (3/4-in. to 1 ft) of one cascade piping layout.

(g) Preparation of a scale model (1/16-in. to a ft) of the entire plant.

(h) Provision of equipment and material estimates and detailed take-offs.

(i) Provision of other data for preparation of budget and definitive estimates.

(j) Preparation and maintenance of the program to implement required security provisions for control of classified information and documents as determined by the Government.

(k) Preparation and maintenance of a quality control program for design activities to comply with the project quality assurance program requirements.

All design drawings will be subject, as appropriate, to review by Nuclear Regulatory Commission (NRC), Department of Energy (DOE), and various other governmental regulatory bodies. In addition, they will be checked against owner or Operations Contractor approved design schematics and other criteria. Three drawing phases are identifiable:

1. Schematic Design Phase

   (a) Site plans

   (b) Building design

   (c) Process equipment layout and process and instrument diagrams

2. Preliminary Design Phase (Title I)

   (a) Preliminary drawings

   (b) Outline specifications

   (c) Preliminary cost estimates

3. Construction Documents Phase (Title II)

   (a) Site and building work (unclassified)--construction to the point of shell and building services

(b) Preparation for occupancy (classified and unclassified)--all building services for use of plant and process equipment

(c) Occupancy (classified and unclassified)--final hookup and installation of plant and process equipment

In addition to the normal design functions listed above, A&E will be responsible for managing the NRC-licensing function (see discussion on licensing later in this section).

CONSTRUCTION CONTRACTOR

Exhibit E-5 shows the functional analysis of the construction project. The items included in each of the functional areas called out in Exhibit E-5 are summarized in Exhibit E-6.

SITE SELECTION

Exhibits E-7 and E-8 illustrate the site selection process for the case of the stand-alone, privately owned plant. They show the major factors that must be weighed in the final selection. These factors are arranged in levels of importance, the first level being most important to the decision-making process.

The site selection process ensures that full environmental and safety regulations for this enrichment plant at the federal, state, and local government levels will be strictly observed. Environmental and safety requirements of an enrichment plant require that there are no significant health or safety hazards to employees or to the public. In addition, they stress that this plant will be an important addition to any community because (1) it will be the first plant constructed in the United States, (2) it will provide the community with a substantial number of new jobs, and (3) the physical plant will be clean, quiet, and architecturally acceptable. Exhibit E-9 presents (in required order of accomplishment) the major events in the site selection process.

Siting related costs are not expected to be a large part of the capital costs. As the plant is not Government owned, the Nuclear Regulatory Commission (NRC) will require that this plant be licensed under 10 CFR 50 Subpart F. For this reason, the choice of site could adversely impact the capital costs by imposing requirements on the plant design to solve potential licensing problems.

Even for a favorable site, however, there will be important constraints imposed on the facility design by licensing requirements (including safeguards considerations). For example, if a stage must produce an output at high enrichment levels, design for criticality control will be a more stringent requirement. The higher enrichment levels (if greater than 20 percent $^{235}U_6$ in UF_6) will upgrade the level of attention (with significant cost and licensing problem implications) that must be paid to safeguards provisions. It is assumed, however, that site size and general plant structural features will be dictated primarily by requirements to mitigate possible toxic effects at the site boundary arising from credible accidents invovling UF_6 spills.

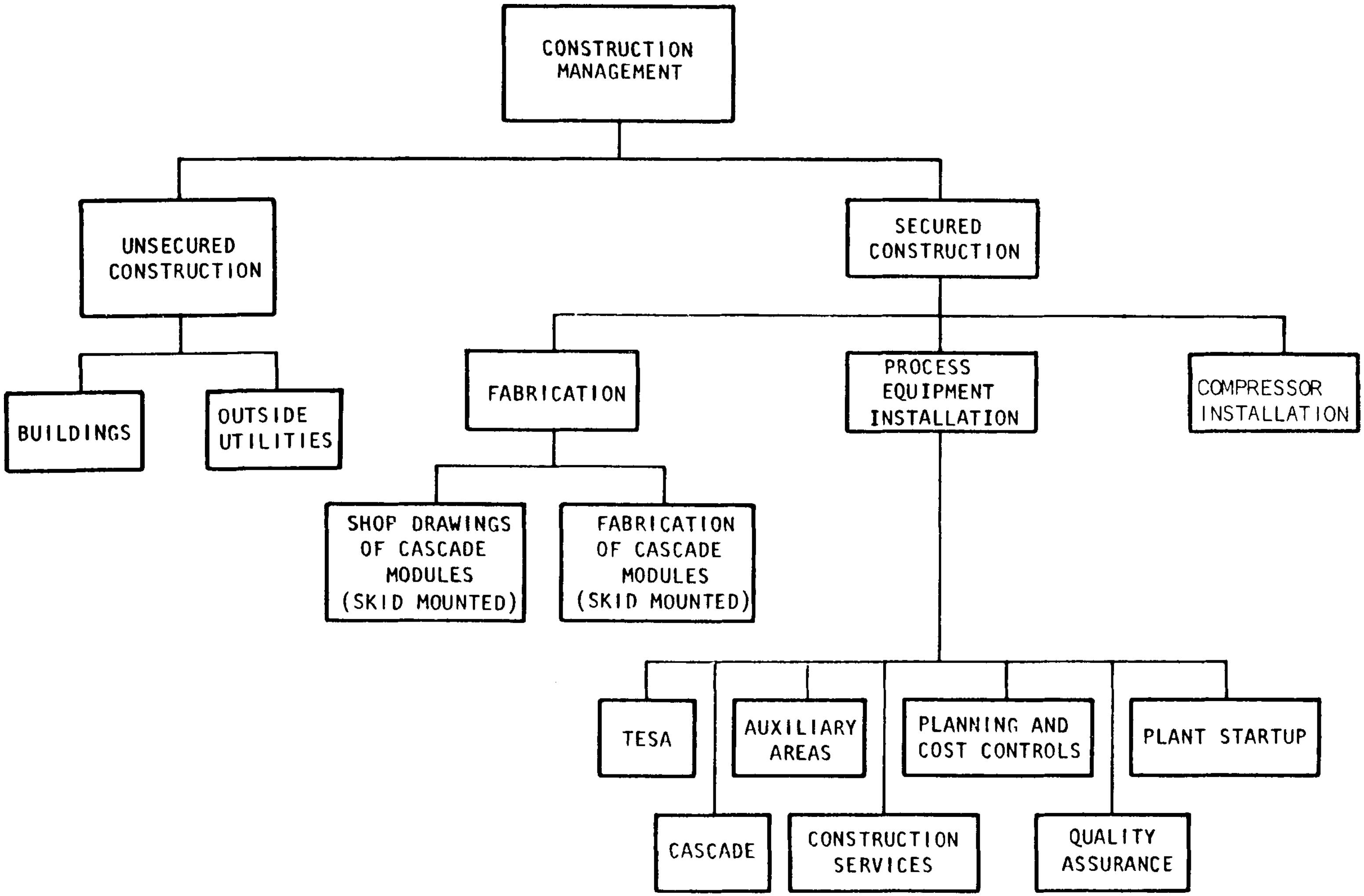


Exhibit E-5. Construction Functional Analysis

EXHIBIT E-6

CONSTRUCTION TASK BREAKDOWN

Unsecured Construction			Secured Construction									
			Fabrication		Installation							Process Equipment Installation
Buildings		Outside Utilities	Shop Drawings	Fabrication of Process Modules	TESA	CASCADE Area	Auxiliary Areas	Construction Services	Planning and Cost Control	Quality Assurance	Plant Startup	
Guard House (All) Administration Building (All) Land Bridges (All) TESA Bldg Bldg shell. Bridge Cranes. Platforms. Architectural finishes. 50 percent electrical. 90 percent piping. 30 percent lighting. Instrumentation. HVAC. Exhaust. Fire protection. Equipment installation. Scales. Chemical lab. TESA Cask Cleaning Building (All) Process Bldg Bldg shell. Bridge cranes. Monorails. HVAC. Architectural finishes. Lighting. Fire protection. Exhaust system. Power distribution. Mechanical bldg services.	Piping headers. Platforms. Control Rooms Walls and roof. Lighting. Architectural finishes. Fire protection. HVAC. Rework and Repair Area Bldg shell. Bridge cranes. Monorails. Lighting. HVAC. Fire protection. Architectural finishes. Mechanical bldg services. Power distribution. Shipping and Receiving Bldg shell. Bridge cranes. Monorails. Lighting. HVAC. Fire protection. Mechanical bldg services Power distribution. Machinery Rooms (All)	Storm drains. Settling ponds. Water tank. Water treatment plant. Underground piping/plumbing. Electric substation. Underground electrical. 138-kv high-line. Outside lighting. Outside security system. Roads. Landscaping. Scrap storage. Fencing. Cooling towers. Rail spur. Parking lot. N_2 supply He supply	Composite design. Bill of material. Prototype model.	1st article Piping. Electrical. Instrumentation tray. Skids. Fabricate remaining modules.	10 percent piping. 50 percent electrical. 70 percent instrumentation. Controls. Cryogenics storage. Support of startup/checkout.	Structural. Piping installation. HVAC, 40 percent. Electrical. Instrumentation. Controls. Cryogenics Equipment installation. Support of startup/checkout.	Control Rooms Electrical equipment. Instrumentation. Controls. Cabinet installation. Support of startup/checkout. Rework and Repair Area Structural platforms. Mechanical services. Electrical hookup. Instrumentation. Tooling. Equipment installation. Support of startup/checkout. Shipping and Receiving Structural platforms.	Material/equipment control. Accounting. Finance. Recruiting and training. Document control. Change orders. Estimation. Construction engineering Civil. Mechanical. Electrical. Instrumentation. Welding. As-builts.	Planning. Scheduling. Monitoring. Cost control. Budget. Audit. Data processing.	Civil. Mechanical. Electrical. Instrumentation. Welding.	Clean systems. Complete all hook-up. Pump down and leak check. Start process and TESA. Initiate other plant activities as appropriate.	Move into position and set in place on isolators. Plumb.

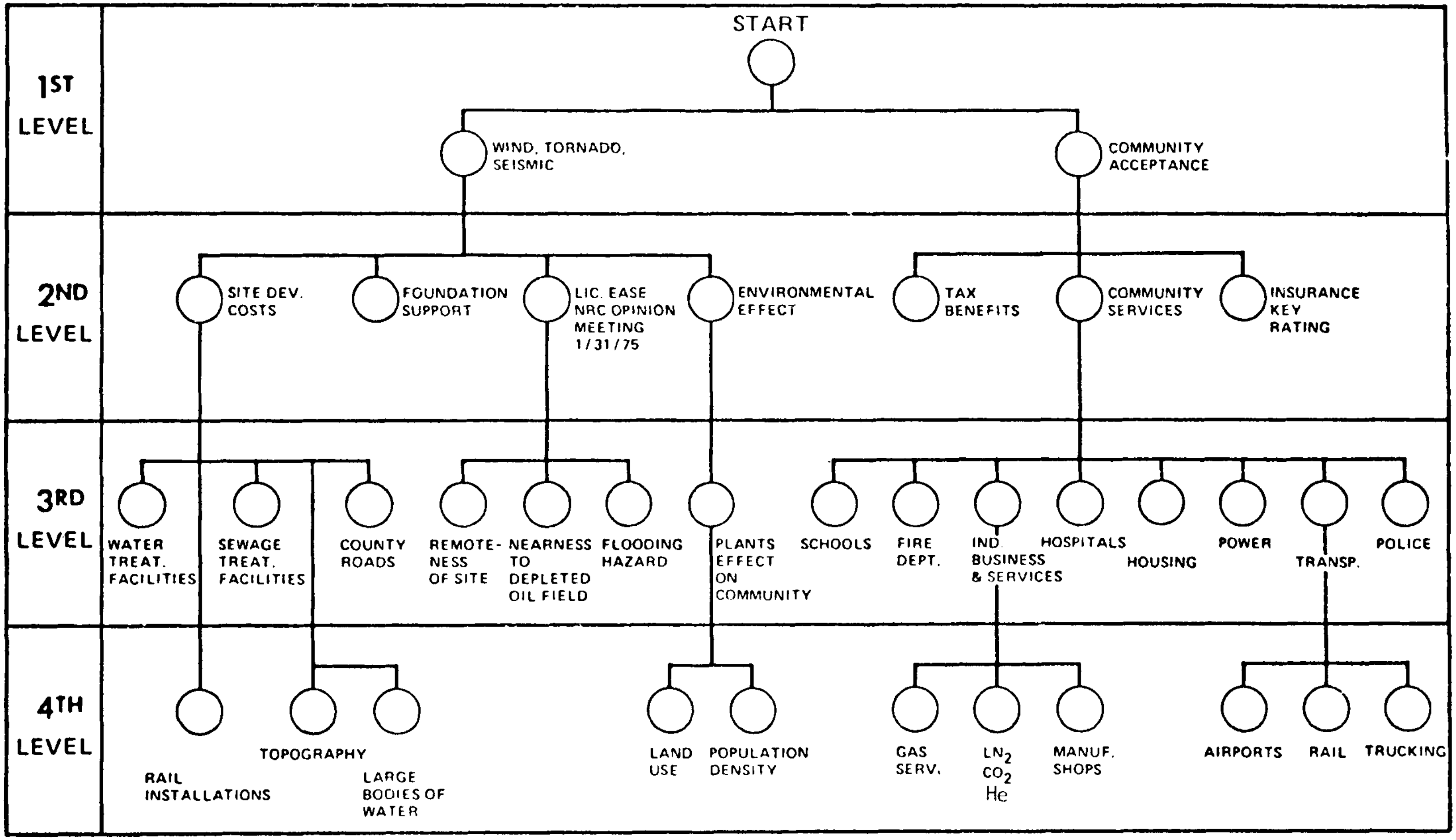


Exhibit E-7. Site Selection Decision Tree

HAZARD EVALUATION INPUTS	POTENTIAL HAZARD SOURCE						
	FLOODING	SEISMIC					HIGH WINDS
	INUNDATION	GROUND RUPTURE	LIQUEFACTION OR SETTLEMENT	SOIL INSTABILITY	TSUNAMIS AND SEICHES	DYNAMIC RESPONSE	STRUCTURAL LOADING
• TOPOGRAPHY	X			X	X	X	
• RAINFALL	X				X		
• RELATIONSHIP TO WATER COURSES	X						
• GROUNDWATER LEVEL	X	X	X	X		X	
• SUBSURFACE SOIL CONDITIONS		X	X	X		X	
• PROXIMITY OF ACTIVE FAULTS	X	X	X	X	X	X	
• SEISMIC HISTORY	X	X	X	X	X	X	
• TORNADO HISTORY							X
• WIND DATA							X

Exhibit E-8. Natural Phenomena Hazards to be Evaluated

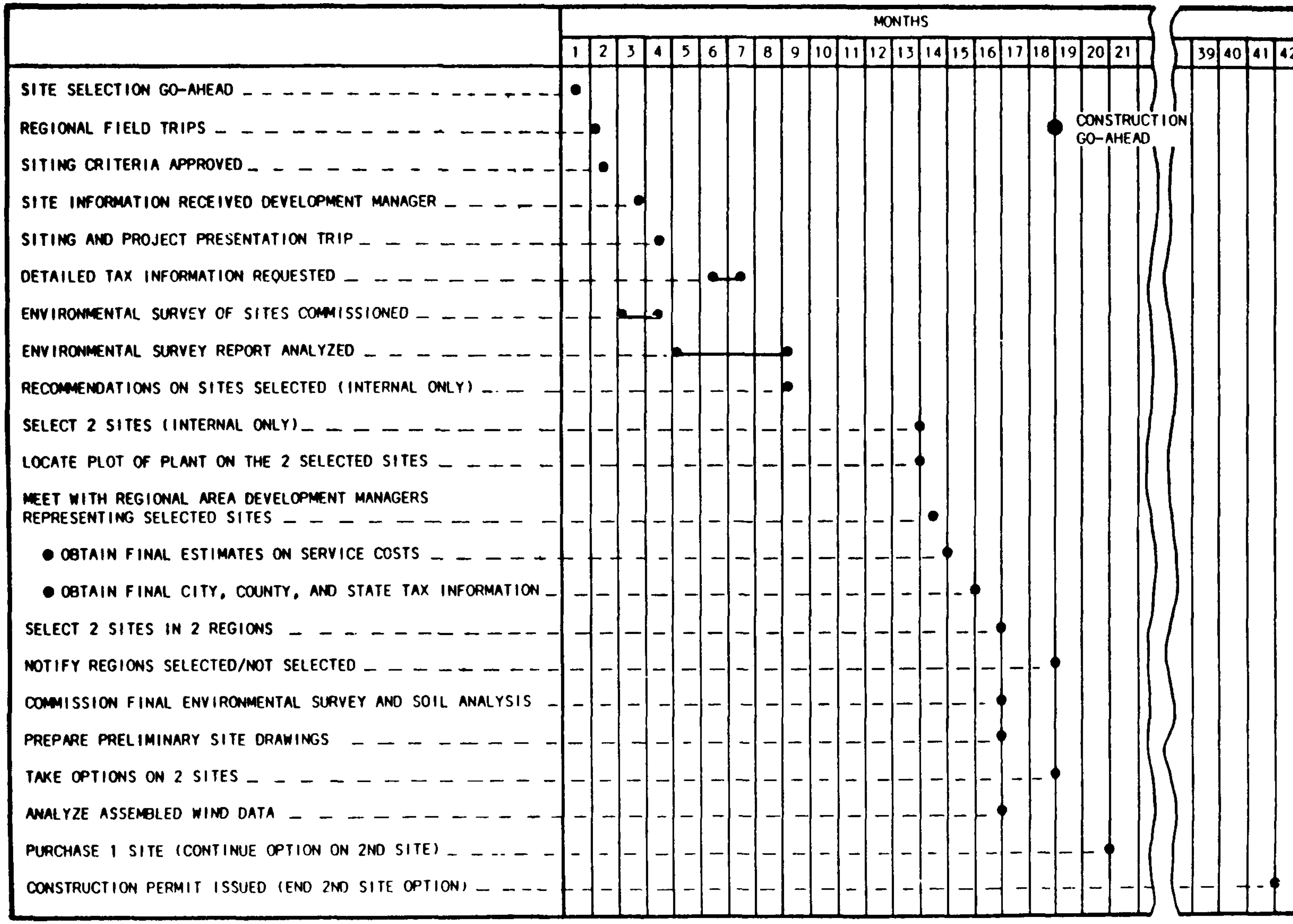


Exhibit E-9. Site Selection Plan

LICENSING AND SAFEGUARDS

INTRODUCTION

The 300,000 SWU/yr VSUEP Plant is classified as a uranium production facility and, under present federal law, commercial plants may be licensed by the NRC under regulatory document 10 CFR 50, Subpart F*, the governing regulation for enrichment plants.

This section deals with the general approach to accomplishing the large volume of work required to prepare and follow up the various licensing document submittals required by NRC in order to operate privately owned and operated plants. Similar work is required in accordance with DOE Manual Chapter 0531 for the Government owned plant. Although the paperwork is extensive the issues behind the paperwork must be dealt with.

To comply with DOE Manual Chapter 0531 the following items must be covered in the SAR report:

(a) A concise description of the type of facility site.

(b) The safety related design criteria.

(c) The quality assurance program applicable to the design, fabrication, construction, testing, operating, maintenance and modification phases of the facility.

(d) An evaluation of the nuclear facility site and the risk associated with accidents from a natural phenomena.

(e) An evaluation of the confinement and control of the radioactive material.

(f) The radiological impact associated with normal operations and/or abnormal operations, and accidents.

(g) An evaluation of radiation shielding.

(h) Projected effluent quantities and concentrations and an evaluation of an effluent treatment.

(i) An evaluation of the engineered safety related systems which assure continued safe operation or safe shutdown under accident conditions.

(j) Emergency plans.

*10CFR52 (Draft) regulations are applicable to enrichment plants, and government programs are following its requirements, however an Act of Congress would be required for it to be applied to the private sector by NRC.

The licensing plan has been formulated on the basis of (1) review of existing licensing documents for nuclear reactors and document 10 CFR 50, Subpart F; (2) review of enrichment plant-related regulatory guides issued by NRC, i.e., (a) Regulatory Guide 3.25, Standard Format and Content of Safety Analysis Reports for Uranium Enrichment Facilities; (b) Regulatory Guide 4.9, Preparation of Environmental Reports for Commercial Uranium Enrichment Facilities; and (c) Regulatory Guide 5.45, Standard Format and Content for the Special Nuclear Material Control and Accounting Section of a Special Nuclear Material License Application (including that for a Uranium Enrichment Facility).

The total contingency from the nominal licensing effort to the maximum licensing effort is 70 to 80 percent traceable to the uncertainty of the pending NRC regulations. Two uncertainties are:

(1) How much of the existing 10 CFR 50 will be imposed beyond the Subpart F.

(2) What effect might Subpart F have on costs.

The possible effects of 10 CFR 50 and Subpart F on costs can be classified into three levels:

A. Requirements not applicable to the VSUEP or its interpretation by NRC could have a serious dollar effect on project if imposed.

B. Requirements could apply to the VSUEP and could have some dollar effect on our project if imposed.

C. Requirements that do apply to the VSUEP and have effect on the project if imposed.

A detailed listing of these items in each level is:

- 10 CFR 50 -

LEVEL A

10 CFR 50.34 (1) (dealing with Part 100 and hypothetical accidents)
(3i and ii), 7
50.34b6vi
50.36a, b, and c

50.42
50.54 i through g
50.55a
50.55b
50.57a(1)
50.57a(5)
Part 100
Part 140

LEVEL A1

Parts of 10 CFR 50 that are clearly not applicable include:

50.21
50.34a (4ii)
50.34b (2i, 6ii and iii, 8 paragraph 4721)
50.43
50.44
50.46
50.55 e
50.60
50.65
Appendixes A and B
Appendix D Annex, F, G, H, I, J, K, N, O, P and Q.

LEVEL B

50.59
50.80
50.102
Appendix C
Appendix L

LEVEL C

10 CFR 50.1 through 50.4

50.10 through 50.13
50.22 through 50.24
50.30 through 50.33
50.34a, 2,3,4, and 4i, 5,6,8,9 and 10
50.34b 1 throubh 2ii, 3 through 5, 6i, 6iv and v, 7
50.35
50.37 through 40
50.45
50.50 through 50.53
50.54a through h
50.55
50.56
50.57a, 2 through 4, 6
50.57b
50.58
50.70
50.71
50.90
50.91
50.100
50.103
50.109

LEVEL C (Continued)

50.110
Appendix D and Part 51 as they are united
Appendix E
Part 20

Subpart F defines the NRC general safety design criteria. The dollar effect of Subpart F could be greater than the effect of the rest of 10 CFR 50. The pertinent titles in Subpart F can be assessed in the same three levels.

SUBPART F (GENERAL DESIGN CRITERIA)

LEVEL A

52.94	General Requirement, Sharing of Structures, Systems, and Components
52.103	Process Safety Features, Separation of Process Safety Features and Control Systems
52.110	Nuclear Criticality Safety, Ancillary Criteria for Nuclear Criticality Safety

LEVEL B

52.91	General Requirement, Quality Standards and Records
52.93	General Requirements, Protection against Fires and Explosions
52.97	General Requirements, Emergency Capability
52.99	Design Basis Natural Phenomena and Accidents, Confinement Barriers and Systems
52.100	Design Basis Natural Phenomena and Accidents, Ventilation systems
52.101	Process Safety Features, Protection
52.102	Process Safety Features, Instrumentation and Control Systems
52.104	Process Safety Features, Control Room
52.105	Process Safety Features, Process Systems
52.109	Nuclear Criticality Safety, Neutron Absorbers
52.111	Radiological Protection, Access Control
52.112	Radiological Protection, Radiation Control
52.113	Radiological Protection, Monitoring Systems

LEVEL C

52.91	General Requirements, Protection Against Environmental Conditions
52.95	General Requirements, Proximity of Sites
52.96	General Requirements, Testing and Maintenance of Systems and Components
52.98	Design Basis Natural Phenomena and Accidents, Design
52.106	Process Safety Features, Utility Services
52.107	Nuclear Criticality Safety, Safety Margins
52.108	Nuclear Criticality Safety, Methods of Control

SUBPART G (QUALITY ASSURANCE CRITERIA FOR ENRICHMENT FACILITIES)

LEVEL B

52.121 Quality Assurance Program

The liklihood of the NRC imposing or interpreting a 100 percent compliance requirement with 10 CFR 50 and Subpart F at a Level "A" appears small. The most severe case is a maximum credible case. In Exhibit E-10, the foregoing 10 CFR 50 analysis has been joined with the construction cost variables that could be affected by them. An assessment of 10 CFR 50 and general construction regulations that might affect the project is shown.

EXHIBIT E-10

ESTIMATE OF UNCERTAINTY OF EACH CONSTRUCTION COST VARIABLE

VARIABLE NO.	VARIABLE DESCRIPTION	MILLIONS OF DOLLARS
1	Separators and Compressors Systems	2000
	• Separator and compressor reliabilities are lower than projected. • Separator components deteriorate faster than expected. • Development is not completed on time. • More expensive substitute equipment is required.	
4	Freight-in	40
	• Plant is located farther away from vendor's plant. • Equipment weighs more than estimated amount. • Security requirements are imposed on transportation of separator systems.	
6	Land and Site Preparation	2
	• Assumed 3000-lb per sq ft soil is not found at site selected. • Exclusion-boundary fencing required to be chain link with security lighting. • Hidden underground gas lines required to be moved. • Excessive cutting of soil in hilly terrain. • Perimeter road around exclusion fence required. • Higher level of safeguarding required.	

EXHIBIT E-10 (Continued)

VARIABLE NO.	VARIABLE DESCRIPTION	MILLIONS OF DOLLARS
7	Administration and Auxiliary Buildings	
	• Larger and/or more buildings required.	1.5
	• Security separations required in building for safeguards.	
8	Rework, Overhaul, and Repair Area	
	• Safety-related decontamination chamber required.	2
	• Safety-related associated equipment required.	
	• Conversion from monorails to floor handling system required.	
	• Design to more stringent tornado and seismic-safe criteria required.	
9	Cascade Area	100
	• Piping and valves required to be ASME Section 3 Class I, II, III.	
	• Structure required to be missile proof.	
	• Separation of systems required.	
	• NRC Category I structure required.	
	• Testing of system without UF_6 for cold test required.	
10	UF_6 Feed and Withdrawal Area (TESA)	2.7
	• Accountability requires the feed.	
	• All TESA equipment required to be ASME Section 3 Class I, II, III.	
	• Under postulated accident conditions, the TESA operators not permitted to receive a one-time excess of TVL of approximately 40 times.	
	• Containment shell with gas-tight tank required.	

EXHIBIT E-10 (Continued)

VARIABLE NO.	VARIABLE DESCRIPTION	MILLIONS OF DOLLARS
11	Instrumentation • Separation of instrumentation systems required. (Not able to use common cable tray.) • Accountability requirement exceeds existing design.	50
12	Installation of Separator and Compressor Systems • Additional plumb tolerances required. • Additional leakage occurs in tie-in piping. • Additional separators or compressors required.	260
13	Architectural and Engineering • Additional queuing period during licensing required. • Engineering drawings and licensing document not accepted at minireview. • Postulated worse case accident condition proven or interpreted to be less severe than an NRC postulated worse case.	320
14	Project Management • The construction project ships because of licensing requirements.	150

Environmental issues underlie nearly all NRC-imposed licensing constraints. Radiological and chemical consequences of accidents, effluent release during normal operation, and disposal of radioactive wastes all represent hazards to the environment around the plant. Enrichment plants generally contain fewer elements with significant hazard potential than do nuclear power plants, conversion plants, and reprocessing plants. Licensing issues related to environmental hazards are those currently addressed in the environmental impact reports. Recent concern of siting regulators, however, has included socioeconomic issues. These concerns cover a range of topics such as impacts upon the local community as taxes, traffic, employment, sewage, and water requirements, or maintenance of the environmental elements such as rare and endangered species, parks, and coastlines. Monitoring programs are required to establish the site environs prior to construction and later during construction and operation of the plant to ensure a controlled environmental change. The Clean Air Act, National Environmental Policy Act, and the Water Quality Act define the environmental impact requirements. The requirement to evaluate alternative sites and processes ensures that decisions are made with a primary emphasis upon protecting the environment. The weighing of these alternatives is reflected in the Cost/Benefit chapter of the Environmental Impact Report where an attempt is made to quantify decision-making elements to ensure that alternatives are selected that best preserve the environment.

NRC has a history of fluctuating over licensing issues. Many changes in the past have resulted in severe capital and operating cost impacts. More significant, however, is the potential for lost revenue due to delay in startup or interruption of production occasioned by a licensing delay. Although this cost factor can not be predicted it can be minimized by providing suitable schedule allowances in the design approach with respect to licensing related issues and maintaining good communications with NRC during the design phase in order to recognize potential NRC objections early.

Many licensing issues are before the public today. One particularly important for the VSUEP Plant (assuming high enrichment levels are to be produced) is the issue of safeguards. Costs of systems to prevent clandestine or armed theft of special nuclear material or sabotage could be important uncertainties depending upon the mood of the public and how NRC reacts.

Licensing delays resulting from actions not specifically under the control of the plant owner or Operations Contractor can also cause serious cost impact. These delays include legislative or referendum-imposed moratoriums or problems in one element of the nuclear industry resulting in generic delays affecting other elements, e.g., the recent Vermont Yankee ruling.

LICENSING FUNCTION

The licensing engineer assigned to this study will be responsible for translating the complex and somewhat broadly defined NRC licensing requirements into an acceptable design approach with attendant design and cost constraints to guide conceptual design of the VSUEP Plant.

Ultimate control of licensing activities will remain with the owner or Operations Contractor, which must be the entity to deal with NRC in the licensing proceedings. The responsibility for this effort will reside with the director of quality assurance and licensing, reporting to the general manager.

The bulk of the effort required to prepare the licensing documents (EIR, PSAR, FSAR, etc.) will be handled by the licensing manager, who reports directly to the A&E Contractor management. Exhibits E-11 and E-12 identify submittals required by NRC and state agencies. The licensing manager will coordinate the various activities necessary to develop the documents and keep the licensing process moving on schedule. He will be making requests for and working with inputs from several sources, including:

(1) Facilities Program Management Group--Major interplay will be with the systems and process definition and program design-and-safety criteria functions in determining the license-related character of the process (e.g., possible hazard definition in the cascade area and TESA, material flow relationships required for accountability system analyses, for example). The licensing manager also will be interfacing directly with the owner or Operations Contractor director of quality assurance and licensing and the facilities program manager.

(2) Consultants--Environmental and similar licensing consultants as appropriate.

(3) On-Going Operations Group--This group provides detailed operating procedures and related material to establish a basis for the FSAR.

Major milestones in the licensing process are shown on the master program schedule, which is discussed later. Allotted elapsed time for NRC review and public hearings is based on discussions with NRC and other informed sources mentioned earlier.

PHYSICAL RISKS AND HAZARDS

General

The preliminary conceptual design has been reviewed for risks and hazards associated with natural phenomena, fire prevention and protection, release of hazardous materials, criticality accidents, and mechanical equipment failure.

Where nuclear materials are concerned, the VSUEP is similar in construction and operation to existing enrichment facilities. In all other respects, it is similar to a conventional industrial plant. Therefore, no risks and hazards are anticipated that cannot be reduced to acceptable levels through design and conformance with existing codes, standards, and regulations.

1. Fire Hazard

The VSUEP will be served by a 25,000-gallon backup to the fire protection water system for the automatic dry sprinkler systems and hose streams. Reliable service to these suppression systems will be provided.

EXHIBIT E-11

NRC REQUIRED DOCUMENTATION

LICENSING SUBMITTALS

Antitrust information
Application for facility license (including construction permit)
Preliminary safety analysis report (PSAR)
Environmental impact report (EIR)
Final safety analysis report (FSAR)
Security plan (with FSAR)
Application for operating license (with FSAR)
Application for special nuclear material license
Application for packaging license (with FSAR)
Application for operator licenses, if required, prior to startup
Special Nuclear Materials Accountability Manual

OPERATIONS DOCUMENTS TO SUPPORT SUBMITTALS

Health Physics Manual
Emergency Plan
Quality Assurance Manual
Criticality and Nuclear Materials Handling Manual
Design Criteria Documents
Packaging and Transportation Documents
Material Balance Procedures
Materials Safeguards Documents
Security Manual
Start-up Procedures Manual
Operations Procedure Manual

EXHIBIT E-12

TYPICAL SUBMITTALS TO STATE AGENCIES

Agency	Permit	Review: For Waste Control Order	Review: Documents From NRC	Review: Surveillance	Review: Public Hearings
State Department of Health		X	X	X	
State Water Quality Board	X		X		X
State Water Rights Commission	X		X		X
State Air Control Board	X		X	X	
General Land Office			X		
State Highway Department			X		
State Parks and Wildlife Department		X	X		
State Soil and Water Conservation Board			X		
State Railroad Commission		X	X		
Bureau of Economic Geology			X		
State Forest Service			X		
State Department of Agriculture			X		
State Industrial Commission			X		
Historical Survey Committee			X		
State Water Development Board		X	X		

An on-site plant fire brigade with modern equipment is assumed available at all times, and mutual-aid fire-fighting forces will be available from other nearby plants and the nearby city. Modern valve supervision and alarm equipment will be provided to signal inadvertent closing of valves.

The building will be of noncombustible construction. Essentially all floors will be of reinforced concrete on grade. With all equipment installed, and operating, and with maintenance in progress, the building and contents will have a low flame spread, fuel contribution, and smoke density ratings. The building will meet the required life-safety exit codes to enable occupants to evacuate in event of emergency and to provide access to emergency forces.

Few combustible and/or flammable materials will be present in the process area. The cable trays will contain instrument and/or power cables. The combustibility of these cables will vary; however, the cable coverings will be as fire retardant as possible. Plastic bags filled with vermiculite will be placed on the expanded metal covers. In the event of a cable tray fire, the plastic bags will burst and release a 2-1/2-in.-thick blanket of vermiculite through the cover to extinguish the fire.

The cooling tower will supply cooling water for process equipment, process gases, vacuum pumps, and air conditioning. Loss of the cooling water supply will cause shutdown of affected equipment until service can be restored. For backup in case of cooling tower loss, the design provides city water backup.

Because the cooling tower is of wood construction, it will be protected by an automatic deluge sprinkler system installed over the fill areas and under the fan decks. All piping inside the tower will be of copper, with brazed joints. A system of electronically supervised shutoff control valves will be installed. These will alarm at the Fire and Guard Building and other emergency centers.

2. Process Materials Hazards

An enrichment plant of necessity contains large quantities of uranium, in the form of UF_6, which, if released to the environs in an uncontrolled manner, could pose a health and safety hazard to the public. When UF_6 interacts with water (including moisture in the air), the resulting products are UO_2F_2 and HF (both toxic substances) produced as indicated in the following reaction:

$$UF_6 + 2H_2O \rightleftarrows UO_2F_2 + 4HF$$

The UO_2F_2 and the HF form fumes and gas respectively and, as such, are available for dispersion to the environs.

To provide an acceptably low toxicity hazard at the plant boundary, the conceptual design includes:

(a) Seismic and tornado-qualified low-leakage buildings

(b) A substantial exclusion zone around the plant to permit adequate reduction in concentration of the material which does leak from the plant

(c) Acid gas and particulate control systems in TESA to minimize the effect of UF_6 spills

Feed for the cascade will be obtained by placing 14-ton cylinders in hot-air ovens (heated by steam coils), where the UF_6 will be sublimed. UF_6 pressure in the cylinders will be maintained at an absolute pressure of one atmosphere.

In the case of a break in any section of this subatmospheric system, there will be an influx of moist air into the system and a small puff of fumes into the room as a result of back-diffusion and reverberation. No material is expected to leave the building. After an accidental release, operators will not be allowed in the area without protective clothing and breathing apparatus.

Desublimation (condensation) will be used for product and tails withdrawal in the product and tails finishing areas. When a product desublimer or a tails desublimer becomes full, it will be heated to about 180°F (UF_6 vapor pressure equals 38 psia) and drained through heated lines to a 10-ton holding cylinder. It is subsequently reheated and drained into either a 2-1/2 ton product or a 14-ton tails shipping cylinder. These cylinders will be maintained at room temperature.

Releases of liquid UF_6 could occur as a result of failure of the desublimer, piping, or rupture of the shipping cylinder during the liquid transfer operation. Failure or rupture of the desublimers, piping, or shipping cylinders, although credible, is considered to have a miniscule probability of occurrence. Other more probable accidents during periods of liquid transfer would include the rupturing of liquid-line manifold pigtails, leaks from cylinder valves, or sheared cylinder valves.

The actual transfer of liquid UF_6 from a desublimer to a shipping cylinder will be accomplished in less than 1 hour. Large shipping cylinders will not be heated, and the relatively small quantity of liquid UF_6 transferred to a cylinder will cool and solidify quickly, producing subatmospheric pressures in the cylinder.

Spares will be provided for both the product and tails shipping cylinders so that a filled cylinder need not be disconnected and removed from the building until the contents are solid. If a release occurred from a part of the transfer system where the pressure was above atmospheric, containment actions could be taken by personnel trained to cope with such an emergency. Building doors and openings would be closed, exhaust systems would be turned off and closed, heat would be removed, and the leak itself plugged, if possible. If not contained, this material would spill into the area and a portion could be exhausted to the environment through the building vent system. The vaporized UF_6 would react with moisture in the atmosphere to produce UO_2F_2, a particulate, and gaseous HF. The UO_2F_2 would settle on building surfaces and equipment and would be recovered. Although some HF would react with the building surfaces, most could be released to the environment. The reaction of 250 lbs UF_6 with moist air would produce 14.2 lbs of HF. The shutdown procedures are executed by automatic systems.

Removal of gaseous UF_6 from streams entering the vacuum pumps will be achieved through the use of two chemical traps operating in series. The first trap will contain sodium fluoride which provides for absorption of the uranium hexafluoride. This trap can be regenerated. The second trap in the series contains alumina and will be used to remove the last traces of uranium hexafluoride prior to discharge of the gas stream to the vacuum pump and then to the atmosphere. Since this trap cannot be regenerated, uranium recovery will be accomplished by leaching with nitric acid.

3. Lubricating and Vacuum Pump Oils Hazard

The cascade will have small amounts of lubricating oil and mechanical vacuum pump oil that could become contaminated with UF_6. Leakage or total loss would be cleaned up or would spill to the building floor drain system. The building floor drainage system will include floor drains and an in-line holding tank equipped with an oil-removal system. The effluent from the holding tank will flow to the settling pond which will be monitored for all pollutants. The amount of oil in any one mechanical vacuum pump will be limited to 20 liters by volume and geometry for criticality reasons. A floor pan will be provided around the mechanical vacuum pumps to contain any accidental oil release.

Reclaimable oil removed from equipment during maintenance, will be reused; the remainder will be disposed of by an approved method such as biodegradation or incineration.

A possible hazard could result from the accidental release of materials associated with the refrigeration process. Trichloroethylene will be used as a heat-exhange medium in the primary trap. This will be pumped at approximately -100°F through the coils of the trap, then back to the refrigeration unit where the heat will be extracted. Rupture of the pumping system could lead to a release of several hundred gallons of trichloroethylene in a short period of time. However, all material will spill to a floor drain which would be valved to the building holding tank as described above. Any bypass of the holding tank would discharge to the settling pond.

Liquid nitrogen will be used in the secondary trap. No hazard is expected to result from the vaporization and dispersion of liquid nitrogen.

4. Criticality Hazard

The VSUEP will process fissile materials that could, under certain very unlikely circumstances, produce an accidental critical reaction. The probability of an accidental reaction will be analyzed and evaluated. Examination of cascade equipment under normal and contingency operating conditions suggests an inherent criticality safety of the cascade. The highest risk part of the system is the UF_6 collector. Where the integrity of the equipment is not breached, criticality cannot occur in unmoderated uranium enriched up to 5 percent. Criticality is possible in moderated material (water being the most significant moderator) if the necessary quantity of material is accumulated in a favorable nuclear configuration. Though the VSUEP will process uranium in gaseous, liquid, and solid phases enriched to only 3.4 percent, the design must meet requirements for geometry, mass, and volume consistent criticality safety criteria. Operative and administrative controls may be used in addition to aid in prevention of criticality incidents as designs comply with:

1. ERDA MANUAL, Chapter 0530, "Nuclear Criticality Safety."

2. ORO 651, "Uranium Handling Procedures and Container Criteria," Rev. 3, August, 1973.

3. K-1019, "Criticality Data and Nuclear Safety Guide Applicable to the ORGDP." (Revision 5)

Based on results of a very conservative study performed by a process engineering firm for an earlier version of a gas-centrifuge uranium enrichment plant, no problem is expected in being able to demonstrate an acceptably low (practically zero) probability of a criticality accident for the plant as finally designed for the full range of imposed natural phenomena and operational modes. The separators and process piping, however, must be monitored for accumulation of UF_6. The applicability of the 10CFR70.24 regulations has not been examined.

Seismic Hazard

The seismic design of the building and facilities for the VSUEP will be according to the Uniform Building Code. Equipment mounting will be designed to resist movement or overturning in accordance with a sound engineering practice.

Tornado Hazard

The proposed VSUEP site is in Texas, an area of moderate tornado occurrence. Loss of the uranium inventory from the facility should pose no significant impact due to its small size and the dilution and dispersion that would be affected by rain and wind. For this project, tornado loads are not incorporated due to the very low probability of occurrence. Design wind loads are in accordance with Uniform Building Code and ERDA requirements.

ENVIRONMENTAL IMPACT

Directives

The following federal directives have been reviewed and applicable provisions complied with in the VSUEP conceptual design:

10CFR50

Executive Order 11752, "Prevention, Control, and Abatement of Air and Water Pollution at Federal Facilities" (Dec. 17, 1973)

ERDA Manual, Chapter 0510, "Prevention, Control, and Abatement of Air and Water Pollution"

ERDA Manual, Chapter 6301, "General Design Criteria"

ERDA Manual, Chapter 0531, "Safety of Nonreactor Nuclear Facilities"

Energy Conservation

In general, the energy conservation design guidelines as described in the ERDA Manual, Appendix 6301, "General Design Criteria" were used in this conceptual design of VSUEP.

Conservation of energy was considered in the design of the electrical system and choice of electrical equipment for the VSUEP. A partial list of energy conservation items considered in the electrical system includes:

1. Supplying only the required lighting foot-candle levels for the areas or facilities involved.
2. Providing switches in each office, room, or work space.
3. Using the most efficient type of lamp and/or fixture for each application. Incandescent lighting has been avoided.
4. Omitting use of lighting for visual effects.
5. Controlling outdoor-type lighting with photocells and providing local on-off switches. (The use of timers may be appropriate for some applications.)
6. Installing lighting fixtures as near the floor as possible in high bay areas. (If cranes are used in these areas, the fixtures may have to be at the ceiling level.)
7. Control circuits have been so designed that losses in control components are minimized.
8. Specifications for the purchase of electrical equipment are assumed to include, where appropriate, a capital cost penalty factor associated with power losses.

In addition, the following energy conservation measures will be incorporated in the design of environmental control systems:

1. Use of outside air for cooling when ambient weather conditions permit (except in humidity-controlled areas).
2. Shutdown of personnel comfort systems when areas are unoccupied.

3. Use of process cooling water where available for hot water heating coils and unit heaters.

4. Use of heat-recovery devices such as coil runaround and heat pipes where economically justified.

5. Use of ventilation and exhaust shutdown or reduction during unoccupied periods, when safety is not compromised.

SAFEGUARDS

The objective of the nation's safeguards program is to provide an acceptable level of protection against theft or diversion of special nuclear material, especially highly enriched material, and against sabotage which could result in serious health hazards to the public. In general, these potential problems must be addressed for both fixed installations handling the material and for transportation of material between facilities. For the VSUEP no difficulty is envisioned in being able to demonstrate adequate safeguards for the following reasons:

(a) No UF_6 of assay greater than 5 percent $^{235}UF_6$ will be on hand at any time. Hence, the plant would be an unlikely target for forceable weapons material theft.

(b) The plant provides a toll service on site and does not deal in transport of special nuclear material. Safeguards for transport will be provided by the transporter and because of the low assay of the material transported, transportation safeguards should not present a significant problem.

(c) An effective special nuclear material accountability system will be implemented in accordance with 10 CFR 50 to monitor day-to-day operations and prevent diversion of material in the unlikely event that anyone would be interested in stealing low-enrichment material.

(d) The possibility exists that a dedicated effort (amounting to a plant take-over) could, if not countered, result in production of highly enriched material. However, such an action could easily be countered before any significant quantity of material could be produced by simply cutting power to the plant. It is considered virtually impossible to surreptitiously produce highly enriched material during normal operations because of the extensive plumbing changes and/or operational changes which would have to be implemented. The special nuclear material accountability system, referred to above, will easily detect such an attempt almost immediately.

(e) Since there are no highly radiologically hazardous materials in the plant, sabotage resulting in significant danger to the public is not considered to be a problem.

QUALITY ASSURANCE (QA)

A quality assurance program is assumed established under the administrative direction of the director of quality assurance and licensing. The program is conceived designed to ensure conformance with the requirements of 10 CFR 50 (as presented in Regulatory Guide 3.35); all state, local, and other applicable codes; and the operational, safety, and reliability goals. The program includes all design, construction, and operating activities affecting these functions. This program is established at the earliest practical time consistent with the activity to be accomplished.

A quality manual is assumed to document the organizational structure, operating procedures, and quality requirements of the program. The quality program is staffed by personnel selected, trained, and assigned in accordance with the needs of the program. In addition, certain quality activities, such as instrument calibration, specialized inspections, and certain audit functions may be performed by subcontract, appropriately monitored and audited by the owner or Operations Contractor.

Each operating entity (supplier, vendor, or construction organizatioz) is assumed required to establish, maintain, and document a quality assurance program adequate to control its contribution to the quality effort.

MANNING

The Construction Project will use a project or site labor agreement with the unions for the proposed work. Typical contents for such an agreement are listed in Exhibit E-13. One construction company supplied the data in Exhibit E-14, which lists manpower on call for that particular company in several southeastern states.

PROJECT SCHEDULE AND CONTROLS

The critical path method (CPM) will be the primary construction project scheduling tool. Supplementary bar charts will be utilized at various levels for summary presentation.

Three schedule levels are assumed maintained for the program as follows:

(a) Master Project Schedule--This schedule provides an overall picture of the status of the project and facilitates determination by project management of the most cost-effective corrective action to be taken in the event of schedule problems. This schedule is updated throughout the program, utilizing both manual and computerized techniques.

(b) Summary Bar Charts (three-month look-ahead)--These charts, covering relatively narrow areas of activity, are directed toward more detailed schedule monitoring and control by the various levels of supervision involved.

EXHIBIT E-13

TYPICAL CONTENTS FOR PROJECT LABOR POLICY AGREEMENT

1. Introduction

Identification of parties to agreement and work covered by agreement

2. Purpose and Intent

Expeditious completion of work under conditions conducive to most efficient performance of work

3. Working Rules

To provide peaceful conduct of work

A. Selection of foremen and general foremen
B. Production limits and tools
C. Security of employer-provided tools
D. Starting and quitting times and work breaks
E. Practices not tolerated
F. Steward status
G. No stoppages for resolution of grievances or jurisictional disputes
H. Alternate labor if union unable to supply
I. Overtime
J. Shiftwork rates and crafts
K. Celebration of holidays
L. Work safety rules

4. Union Recognition

Barnaining agent jurisdiction

5. Subcontractors

Subcontractor compliance to project agreement

6. Jurisdictional Disputes

A. Rules and regulations to be used
B. Work assignment risponsibility
C. Resolution of dispute by business agents
D. Resolution of dispute by international representative or disputes board.

7. Grievance Procedure

A. Basis for identifying grievances
B. Grievance settlement procedure

EXHIBIT E-13 (Continued)

8. Travel Allowances, Subsistence and Travel Pay

   Per collective bargaining agreement

9. Utilization of Camp Facilities

   Employer sets rules for employees

10. No Strike - No Lockout

    Individual union agreement not to honor picket lines

11. Local Agreement Negotiations

    Continuing work while negotiating new agreements

12. Coverage

    Applicability of project agreement to work responsibilities and relation to local agreement

13. Protection of Customer

    Restriction of union activities to project and noninterference in other on-going customer activities

14. Definitions

    Definition of key terms in project agreement

15. Duration

    Time interval for which project agreement is in effect

16. Signatures

    A. Local general building and construction trades council contractor

    B. Union locals

EXHIBIT E-14

MANPOWER ON CALL FOR TYPICAL
SOUTHEASTERN CONSTRUCTION COMPANY

	Arkansas	Kansas	Mississippi	Oklahoma	Texas
Boilermakers	73	69	22	75	87
Brick layers	43	18	14		74
Carpenters	169	97	49	112	154
Cement finishers	72	45	30		43
Electricians	401	143	125	240	395
Insulators	182	92	53	78	173
Iron workers	197	163	154	96	185
Laborers	158	32	120		168
Millwrights	149	45	193	104	128
Operators "A"	27	14	20	12	18
Painters (brush)	28	23	45		19
Pipe fitters and welders	478	243	290	273	398
Sheet metal workers	102	29	23	78	147
Truck drivers	21	28	23		14
Total	2,100	1,041	1,200	1,068	2,003

(c) Short-Range Bar Charts--The period covered by this level of scheduling will be two to six weeks and will be directed toward field supervision at all levels. These short-range shedules will highlight the requirements for engineering releases, material and equipment deliveries, and manpower and construction equipment necessary to accomplish the work scheduled for the forthcoming period. Proper restraints then will be built into the plan so that all areas will be scheduled and properly interlocked.

PROGRESS MONITORING AND CONTROLS

Progress of engineering, procurement, and construction efforts will be monitored and controlled using standard techniques for the measurement of progress. These techniques deal not only with number of manhours expended, but also utilize various activity-oriented yardsticks of progress peculiar to the activity being monitored. The engineering project controls are assumed integrated with the master project plan so that release dates for drawings and specifications are coordinated with the construction effort.

Schedules will be updated for field use at least every two weeks. A forecast will be issued notifying all interested parties of specific activities to be accomplished during the following two weeks. This forecast includes, for example, such items as concrete to be poured, structural steel to be erected, equipment to be installed, etc. On a monthly basis, schedule originals and computer schedule listings are completely updated and an analysis of overall project status made for general distribution.

CONSTRUCTION SCHEDULE

The master construction project schedules are shown in Exhibit B-2.

SECTION F

CAPITAL COST ITEMS

INTRODUCTION

The capital cost estimate involved several steps. It is also organized to permit comparisons with cost estimates for other plants. To properly account for each item in the estimate and get it represented in the appropriate aggregates, an account number is useful. The logic behind the account numbers is summarized in a code of accounts. The code of accounts presented here includes more accounts than were actually used in the estimate. The more detailed the engineering estimate, the larger the number of account numbers needed.

The cost estimates involved varying amounts of engineering detail. Some were obtained by scaling cost estimates for similar facilities. Where no reliable cost estimates were available to scale from or the nature of the facilities, novel, considerable engineering detail was required. The key calculations are presented after the base cost estimates.

CODE OF ACCOUNTS

PURPOSE

The code of accounts organizes the unit cost estimates into larger aggregate estimates. It also provides the audit trail showing the components of the larger aggregate costs.

DESCRIPTIONS OF ACCOUNTS

The account code consists of four parts:

(1) Engineering Discipline

(2) Variable No.

(3) Cost Classification No. within Variable No.

(4) Item No. within Cost Classification No.

The base cost estimates were prepared by engineering discipline. This fact determined the order of presentation of the material in this section. the Variable Number aggregates costs for use in Monte Carlo simulation of the enterprise cash flow using the AIRESEARCH PRIVATELY-OWNED URANIUM ENRICHMENT PLANT ECONOMIC RISK MODEL COMPUTER PROGRAM. The Cost Classification No. aggregates costs for subsystem summarization. Finally, Item No. cost estimates represent the total direct cost of getting the particular item installed in working order in the plant.

VARIABLE NO. 1: Separator and Compressor Systems and Spares Costs

Variable No. 1 identifies the cost aggregate which includes all costs to the Operation Contractor for separator and compressor systems, F.O.B. vendors' plants. (Recall that in the Construction Project Plan, the Operations Contractor procures all process equipment.)

VARIABLE NO. 4*: Separator and Compressor Systems Freight-In

Freight costs three percent of the value for Variabie No. 1 and represents all costs of moving separator and compressor systems and spares from the vendors' plants to the point of installation in the VSUEP.

VARIABLE NO. 6: Land, Site Development, and Outside Utilities Costs

Variable No. 6 identifies the cost aggregate which includes capital costs for:

a. Land purchase

b. Grading and demolition

c. Railroad work

d. Landscaping and irrigation

e. Roadways, parking lots, and walkways

f. Fencing

g. Storm drains and sewer lines

h. Settling ponds

i. City water and gas to outside building wall

j. All outside process gas piping to outside building wall

k. Fire hydrants

l. Cooling towers

m. Electrical utility service

n. Electrical service transformer and distribution switchgear

o. Area lighting

p. Intrusion alarm system (outside)

q. TV surveillance system (outside)

*There are no costs associated with Variables 2, 3, and 5.

VARIABLE NO. 7: Administration Building and Auxiliary Buildings Costs

This variable identifies the cost aggregate which includes capital costs for all of the architectural, structural, mechanical, electrical and industrial features (including office equipment) in all interior areas except the Cascade Area, RORA, and TESA.

VARIABLE NO. 8: Rework, Overhaul, and Repair Area (RORA) Costs

This cost aggregate includes all capital costs for process equipment rework, overhaul, and repair facilities. These facilities contain utility installations, work areas, and standard equipment necessary to rework, repair, or overhaul and check out or calibrate process equipment. It does not include the cost of metrology equipment which is part of instrumentation.

VARIABLE NO. 9: Cascade Area Costs

This cost aggregate includes all capital costs for installed process equipment except separator and compressors systems.

VARIABLE NO. 10: UF_6 Feed and Withdrawal Area (TESA) Costs

This cost aggregate includes all capital costs for installed facilities for all feed, product, and tails assay functions, for cascade feed and withdrawal functions, for all product and carrier gas blending functions, and for all shipping and receiving functions for uranium hexafluoride.

VARIABLE NO. 11: Instrumentation Costs

The cost aggregate includes all capital costs for installed instrumentation, data processing system for the process equipment and some of the process support equipoment. It includes the costs of metrology equipment.

VARIABLE NO. 12: Separator and Compressors Systems Installation Costs

The cost aggregate includes capital costs incurred in installation of the separator and compressor systems, but not including installation of utility services to this equipment.

VARIABLE NO. 13: Architectural and Engineering Costs

The cost aggregate includes all costs incurred in architectural and engineering design, calculations, drawings, checking and necessary field follow-up services necessary to provide a complete set of working drawings and specifications which are to be used to construct a complete and functional VSUEP. It includes A&E and construction project engineering and supebvisor costs incurred by the Operations Contractor before the start of the construction project.

VARIABLE NO. 14: Project Management Costs

This cost aggregate includes all costs incurred by the Operations Contractor in administration and management of the Construction Project. It does not include costs incurred by the Operations Contractor before the start of the Construction Project.

COST CLASSIFICATION NUMBERS

No.	Description of Costs in Account
1000	Land
1001	Land cost
1002	Land acquisition fees
1003	Survey costs
2000	Improvements to Land
2001	Site preparation and grading
2002	Landscaping
2003	Roads, walks, and paving
2004	Fences and guard buildings
2005	Storm sewers and ditches
3000	New Buildings - Structural Systems
3001	Foundation excavation and backfill
3002	Concrete foundations, piers, grade beams, walls, columns, and slabs on grade
3003	Major concrete slabs or floors above ground
3004	Concrete foundations for building* equipment
3005	Miscellaneous concrete work
3006	Structural steelwork in building superstructure
3007	Miscellaneous structural steel and iron work
3008	Roofing, flashing, and insulation
3009	Building siding and insulation
3010	Walls, partitions, ceilings, special flooring, millwork, carpentry, doors, sashes, etc.
3011	Painting and glazing
3012	Miscellaneous building hardware
3013	Interior fire protection system
3014	Interior fire alarm system
3015	Interior communication system
3016	Miscellaneous other costs

*Building equipment includes boilers, heating and ventilating equipment, air condition equipment.

No.	Description of Costs in Account
3100	New Buildings - Electrical System
3101	Interior electric lighting system
3102	Interior electric power system
3200	New Buildings - Plumbing and Drainage System
3202	Interior plumbing and drainage
3300	New Buildings - Instrumentation
3301	Building instruments and instrumentation lines
3400	New Buildings - Heating, Ventilating, and Air Conditioning
3401	Heating, ventilation, and air conditioning systems
3402	Roof mounted fire and smoke vents
5000	Other Structures
5001	Cooling tower
6000	Special Facilities - Piping and Equipment
6001	Concrete foundations for process equipment and piping
6003	Purge and evacuation system
6004	Interior recirculating cooling water system
6005	Compressed air system
6006	Feed, product, and tails piping systems
6009	Heat transfer systems
6010	Chilled water system
6012	Vacuum system
6013	Steam system
6014	Carrier-gas and process gas ducting
6015	Process area drains
6016	Process equipment
6017	Separators
6018	Compressors
6700	Special Facilities - Electrical Subsystems
6701	Process equipment power conditioning and distribution subsystems
6702	Instruments and instrument lines
6750	Special Facilities - Handling Equipment
6751	Cranes, monorails, and conveyors
6752	Intraplant transport equipment
6753	Special handling equipment

No.	Description of Costs in Account
6800	Special Facilities - Pipe and Equipment Cleaning and Testing
6801	Testing of equipment, piping and valves
6802	Cleanness control
6803	Cleaning of equipment, piping and valves
7000	Utilities - Switchhouse
7001	Electric utilities in switchhouse
7100	Utilities - Switchyard
7101	Foundation excavation and backfill
7102	Concrete
7103	Structural steel and miscellaneous iron work
7104	Painting and glazing
7105	Interior fire protection system
7106	Interior electric lighting system
7107	Interior plumbing and drainage
7108	High voltage switch structure
7109	Grounding, cable, bus duct, and conduit
7110	Instrument transformers
7111	Oil circuit breaker
7112	Power transformers
7113	Other protective equipment
7114	Underground electrical facilities
7200	Utilities - Service Outside Building 5-Foot Line
7201	Hot water heating system
7202	Exterior communication system
7203	Electric distribution system
7204	Utility tunnel
7205	Area lighting
7206	Alarm system
7207	Sanitary sewers
7208	Steam distribution and condensate system
7209	Water storage tank
7210	Sanitary water distribution system
7211	Fire water distribution system
7213	Pipe racks for utilities gas transmission lines
7300	Utilities - Process Systems Exterior to Buildings
7301	Liquid effluent system
7302	Recirculating water system
7303	Compressed air distribution system
7304	Other distribution systems

No.	Description of Costs in Account
7400	Utilities - Railroads
7401	Railroads
7500	Utilities - Instrumentation Outside Building 5-Foot Line
7501	Instrumentation and control
7502	Instrument tunnel
7600	Utilities - Transmission Lines
7601	High voltage transmission lines
8000	Standard Equipment
8001	Mobile equipment
8002	Medical equipment
8003	Laboratory equipment
8004	Motor vehicles
8005	Office furniture and equipment
8006	Railroad rolling stock
8007	Security and protection equipment
8008	Maintenance equipment
8009	Laundry equipment
8010	Cafeteria equipment
9000	Allowances
9001	Allowance for Construction Contractor miscellaneous material
9002	Allowance for Construction Contractor miscellaneous labor
9003	Allowance for Operations Contractor miscellaneous material
9004	Allowance for Operations Contractor miscellaneous labor
9005	Operations Contractor allowance for freight and state and local taxes
9006	Construction Contractor's area wage rate adjustment
9007	Construction Contractor indirects
9008	Operations Contractors incremental overhead
9010	Operations Contractor procurement costs
9011	Interest during construction
9012	Engineering fees
9013	Contingency
9100	Startup
9101	Start-up cost
9900	Working Capital

ARCHITECTURAL SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATES

DESCRIPTIVE SUMMARY

Site Design

1. Location

The parcel of land to be chosen as the site of the VSUEP will accommodate a structure within its boundary, with sideyard distances of about one-half mile. Road and railroad spurs will be constructed leading from existing approaches to the facility.

2. Site Improvements

The site improvements are designed to be expanded in an orderly manner with a minimum of plant disruption and demolition.

3. Work Phases

Improvements to the site will generally be restricted to the avenues of approach and to the close proximity of the building site.

4. Grading

Grading will be kept to a minimum with the site intended to remain in its natural state. Allowances will be made for proper drainage, transportation mode access, security, visibility, and aesthetics of the facility.

5. Parking Areas

Visitor and employee parking areas will be provided in two areas: the process and administrative area and feed and withdrawal area.

6. Security Fencing

Approved site fencing will be provided at the extreme outer boundary of the site. The primary security line will be protected by an approved fence and interior intrusion alarm system. Site lighting at recommended security and safety levels will be installed. Manned control stations will be located for protection of the site.

7. Outside Support Systems

Building orientation and outside support systems locations, such as mechanical cooling towers, secondary water supply tank, waste-water treatment, and electrical utility transformer yards were determined by the best stand-alone condition.

Building

1. Building Plan

The building plan is composed of three basic units of which there are four basic functional areas. It is designed around two basic levels.

2. Building Areas

The space in the buildings can be considered to consist of these four functional areas:

(1) Administrative Offices and Auxiliary Buildings

(2) Cascade Area

(3) Rework, Overhaul, and Repair Area (RORA)

(4) Feed and Withdrawal Area (TESA)

3. Minor Repair Work

Minor repair work will be performed in the Cascade Area while major component changes will be done in the Rework, Overhaul, and Repair areas (RORA).

4. Component Parts Storage

Adequate floor space will be allocated in the RORA for the storage of component parts.

5. Cascade Area

The upper-level floor will support isotope separator equipment. The lower level will contain most of the process compressors and other heat exchangers.

6. Feed and Withdrawal Area (TESA)

The Feed and Withdrawal Area is located for easy access by personnel. All feed, product, waste, and assay functions will occur in this area.

7. Administrative and Personnel Area

The administrative and personnel area will contain offices for the Plant Manager, Engineering, Security, and conference rooms. Support personnel areas will house ancillary functions including locker/showers, lunch/lounge, and medical departments.

8. Mechanical Equipment Area

The mechanical equipment area will house a central boiler plant, chiller room, and process mechanical equipment.

9. Inside Transportation and Conveyances

Inside transportation and conveyances will be provided by bridge cranes and monorail hoist systems.

Construction

1. Building and Site Improvements

The building and site improvements will comply with NRC Regulation 10CFR50 Subpart F, ordinances, laws, and guides of the applicable governing bodies of city, county, and state and other federal regulatory agencies. The building will conform to recommendations of environmental studies.

2. Structure Materials

The structure will be built of noncombustible materials. Basic shell will be constructed of precast concrete. For economical reasons and to hasten speed of construction, many of the building elements will be prestressed pre-cast. Some steel framing and metal decking will be protected with built-up composition roofing.

3. Interior Areas

The interior areas are subdivided into various cccupancies and areas by the use of metal-stud and drywall partitions, movable partitions, and wire mesh screens. Areas requiring reduced sound levels will be sound treated or insulated. Various finishes will be dependent upon the function of the area.

Site Security and Fire Protection

1. Design Features

Design features provided for security, including those discussed under site items, include site lighting, door alarm and control systems, intercom system, and television surveillance.

2. Fire Protection

Fire protection will be provided by smoke detection system, automatic signal to fire protection agencies, and building alarm. In addition, the building will be provided with a fire protection automatic sprinkler system, smoke hatches, fire hose reels, extinguishers, and wet standpipes. Fire hydrants will be spaced throughout the site. The plant will have a secondary water supply tank with diesel-driven fire pumps in the event of a loss of city water.

CONCEPTUAL DESIGN DRAWINGS

The architectural systems cost estimates are based on take-offs from the following drawings.

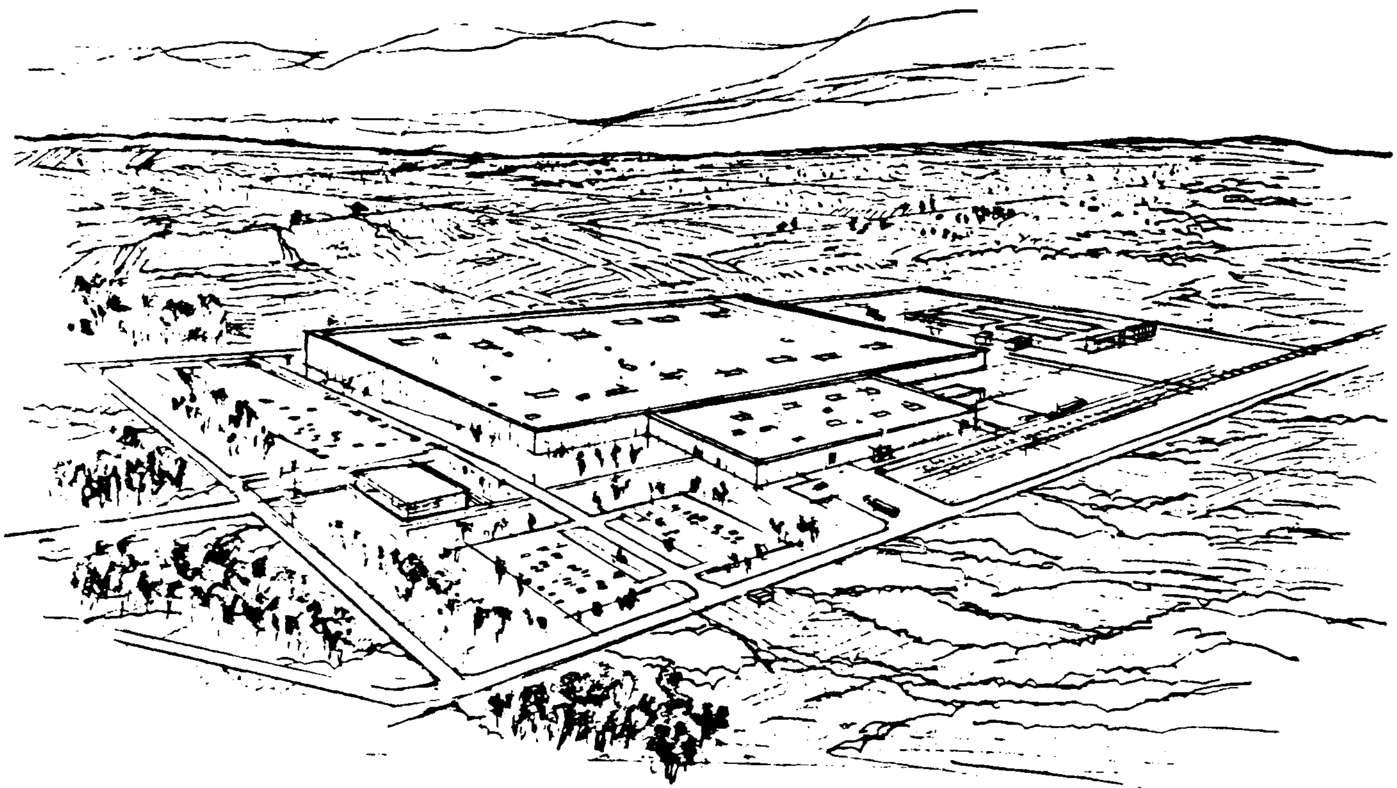
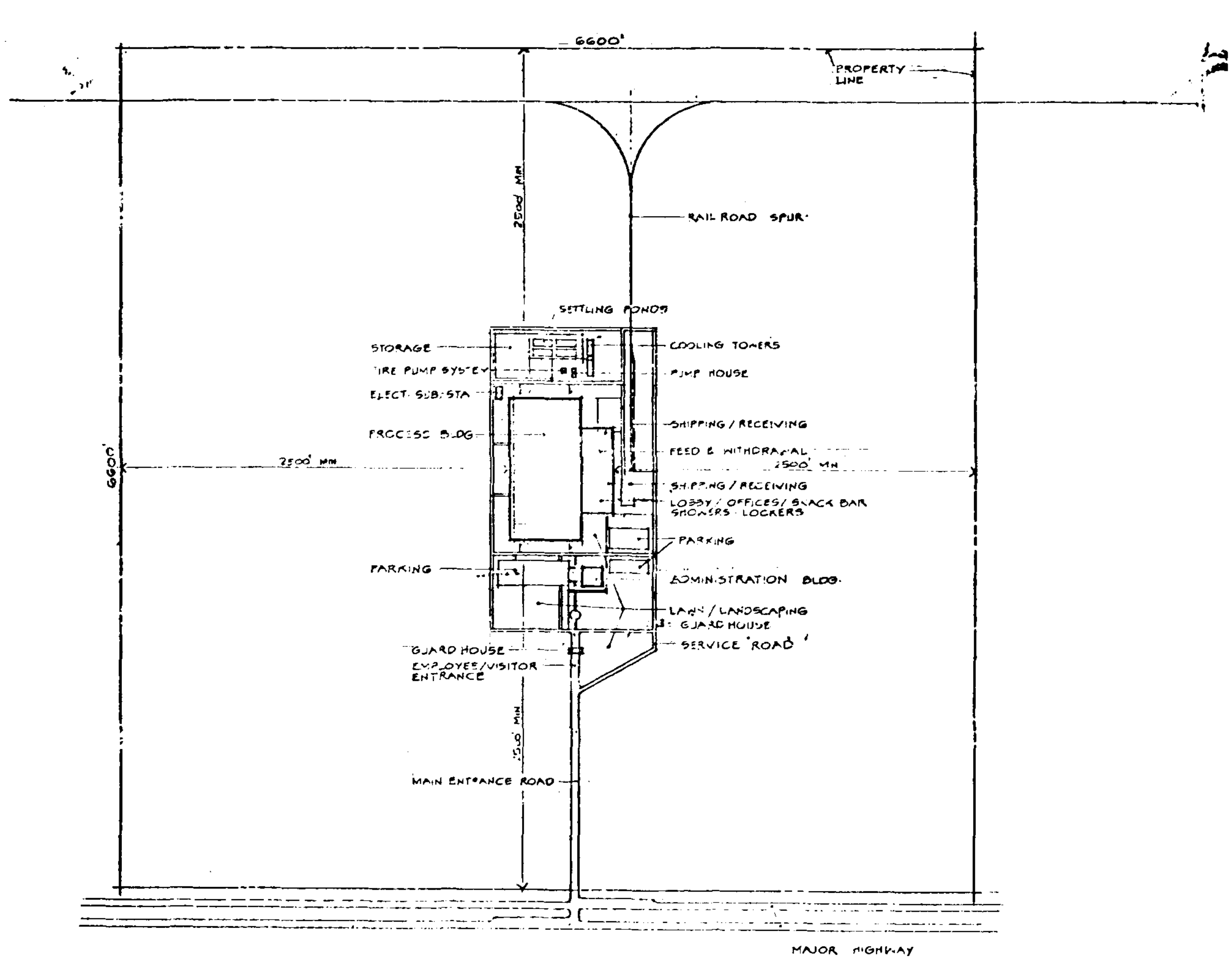


EXHIBIT F-I

E3F-12



SITE PLAN

N

0 500 1000 1500 2000 2500 3000 FEET

GRAPHIC SCALE

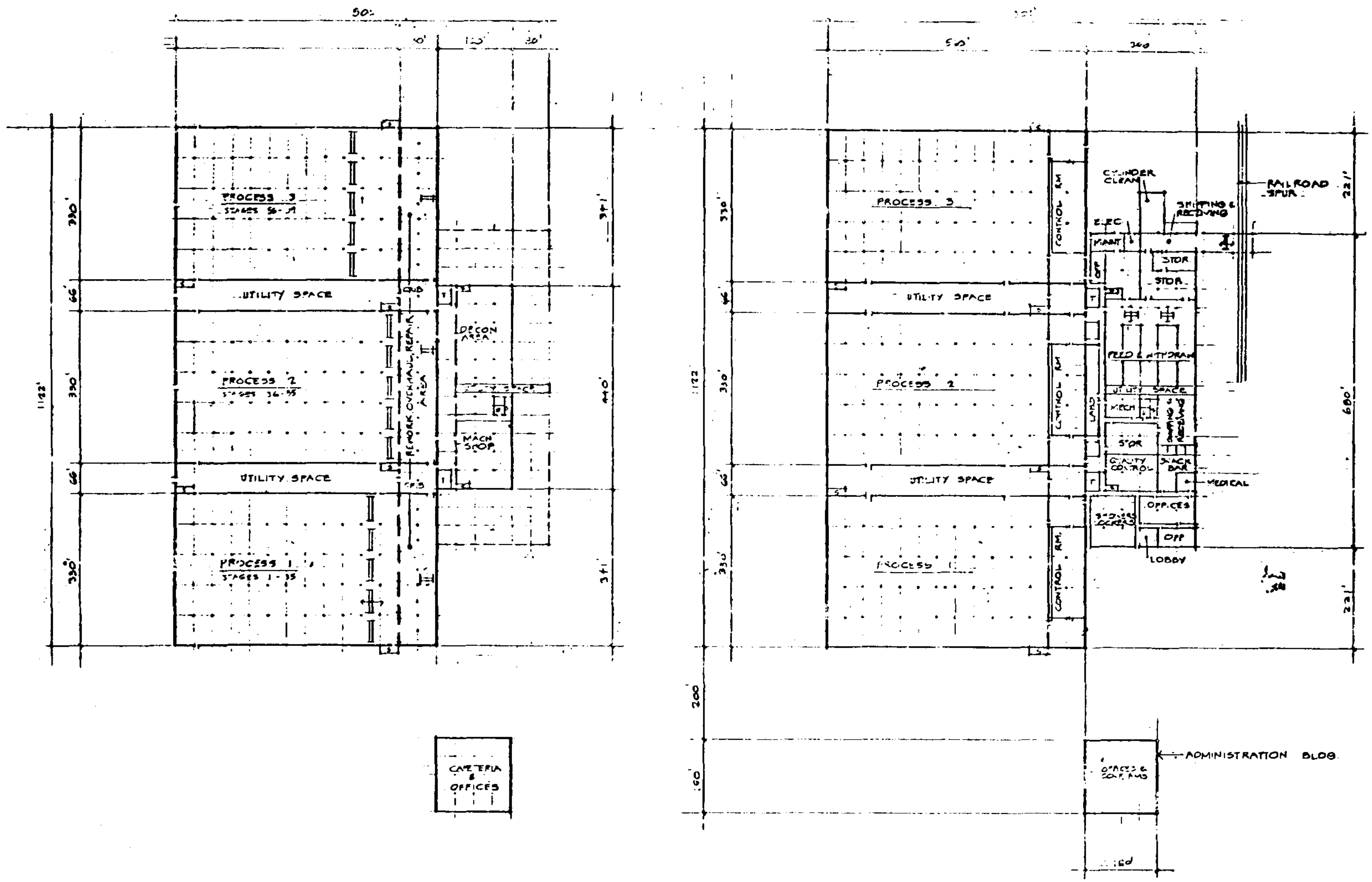
EXHIBIT F-2

F-13

SITE PLAN

SHARED SITE
TEXAS

PLANT ENGINEERING



LOWER LEVEL PLAN

UPPER LEVEL PLAN

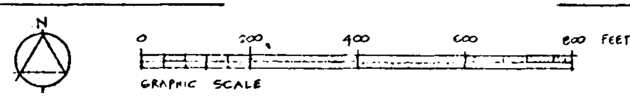


EXHIBIT F-3

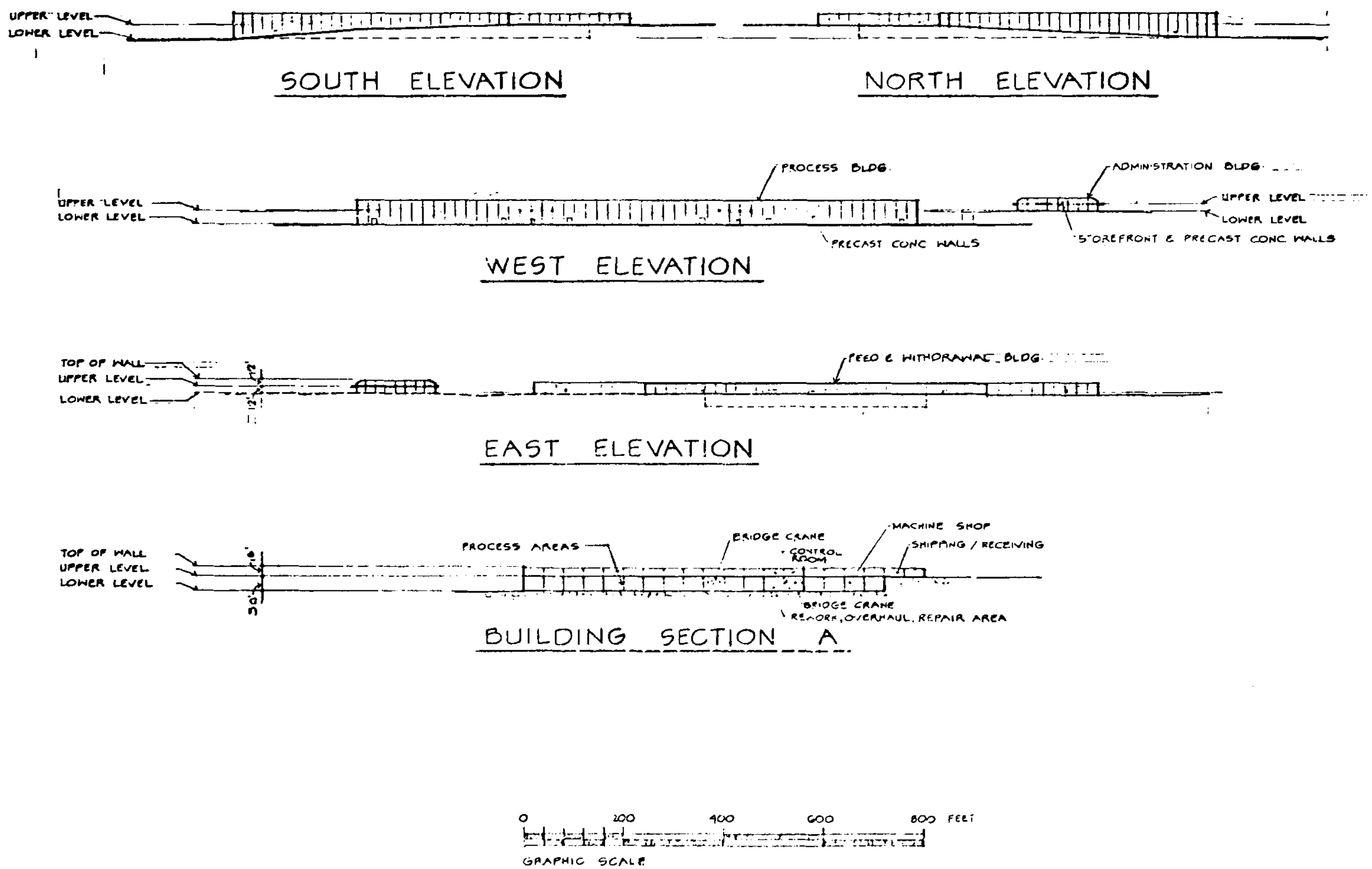

UPPER LEVEL
LOWER LEVEL
SOUTH ELEVATION
NORTH ELEVATION
PROCESS BLDG.
ADMINISTRATION BLDG.
UPPER LEVEL
LOWER LEVEL
PRECAST CONC WALLS
STOREFRONT & PRECAST CONC WALLS
WEST ELEVATION
TOP OF WALL
UPPER LEVEL
LOWER LEVEL
FEED & WITHDRAWAL BLDG.
EAST ELEVATION
TOP OF WALL
UPPER LEVEL
LOWER LEVEL
PROCESS AREAS
BRIDGE CRANE
CONTROL ROOM
MACHINE SHOP
SHIPPING / RECEIVING
BRIDGE CRANE
REWORK, OVERHAUL, REPAIR AREA
BUILDING SECTION A
0
200
400
600
800 FEET
GRAPHIC SCALE

EXHIBIT F-4

BASE COST ESTIMATE (ARCHITECTURAL)

The architectural-systems base cost estimates were scaled from a detailed engineering cost estimate for a much larger uranium enrichment plant. This scaling assumed that the architectural systems costs are directly proportional to floor area for each of the several plant areas. Exhibit F-5 shows how these architectural system costs are distributed among the VARIABLES.

EXHIBIT F-5

ARCHITECTURAL SYSTEMS BASE COST ESTIMATES
thousands of dollars

Variable	Description	Amount
6	Land and Site	11,664
7	Administration Building and Auxiliary Buildings	1,041
8	RORA	641
9	Cascade Area	1,885
10	TESA	749
11	Instrumentation	0
12	Separator and Compressor Systems	0
13	Architectural and Engineering	0
14	Project Management	0
	Total	15,980

STRUCTURAL SYSTEMS DESIGN AND COST ESTIMATE

DESCRIPTIVE SUMMARY

The following table (EXhibit F-6) summarizes the criteria, by area, used in designing the structural systems of the VSUEP.

EXHIBIT F-6

STRUCTURAL PROJECT SUMMARY

DESIGN CRITERIA BY AREA			
VARIABLES	7 AND 8	9	10
Area Description	Offices, Laboratories, Employee Services, Tool Crib, Shipping and Receiving, RORA	Central Process	TESA
Design Criteria	Uniform Building Code	Tornado and Seismic Qualified	Tornado and Seismic Qualified and Tornado Generated Missile
Soil Pressure	3000 PSF	4000 PSF	4000 PSF
Wind Velocity	80 MPH	200 MPH	200 MPH
Wind Pressure	15 PSF	100 PSF	100 PSF
External Atmospheric Pressure Drop	0	-1 PSI (-144 PSF)	-1 PSI (-144 PSF)
Seismic	Uniform Building Code - Zone 4 (1/2 SSE)	SSE - Safe Shutdown Earthquake	SSE - Safe Shutdown Earthquake
Construction Type	Roof: Metal deck on steel framing. Walls: 6" precast concrete.	Roof: 12" thick concrete slab on post-tensioned concrete girder. Walls: 12" precast concrete.	Roof: 12" thick concrete slab on post-tensioned concrete girder. Walls: 12" precast concrete.

BASE COST ESTIMATE (STRUCTURAL)

Exhibit F-7 presents the structural systems base cost estimates.

EXHIBIT F-7

AiResearch Manufacturing Company Torrance, California	Cost Estimate Sheet Heading STRUCTURAL	Site/Building Prep for Occ Occupancy	Classification Date 5-10-78
Job Title and Description VELOCITY SLIP E -PLANT		Prepared by S. VEGH	Page 1 of 4

Account Number	Description 7-ADMINISTRATION & AUXILIARY AREA	Quantity	Unit Cost $	$ Sub-Totals	$ Total
			Amount Forwarded		
3002	CONTIN. FOOTINGS FOR 6" PRECAST CONC. WALLS	250 CU.YDS	200	50,000	
	FOOTINGS FOR STRUCT. STEEL COLUMNS	150 CU.YDS	200	30,000	
	6" SLAB ON GRADE	1,100 CU.YDS	100	110,000	
3003	UPPER LEVEL - 4" FLOOR DECK	700 CU.YDS	200	140,000	
3005	6" PRECAST CONC. WALLS	35,000 □'	6	210,000	
3006	STRUCTURAL STEEL GIRDERS, JOISTS, COLUMNS ETC.	850 TON	1,200	1,020,000	
3007	UPPER FLOOR & ROOF DECK, 1½" - 18 GA STEEL	109,000 □'	1.50	163,500	
					1723500
			Forwarded		

E3F-17

EXHIBIT F-7 (Continued)

GARRETT	AiResearch Manufacturing Company Torrance, California	Cost Estimate Sheet Heading STRUCTURAL	Site/Building ____ Prep for Occ ____ Occupancy ____	Classification Date 5-10-78
Job Title and Description	VELOCITY SLIP E - PLANT	Prepared by	S. VEGH	Page 2 of 4

Account Number	Description 8 - RORA	Quantity	Unit Cost $	$ Sub-Totals	$ Total
		Amount Forwarded			
3002	CONTIN. FOOTINGS FOR 12" PRECAST CONC. WALLS	300 CU.YD	200	60,000	
	FOOTINGS FOR STRUCT. STEEL COLUMNS	110 CU.YD	200	22,000	
	6" SLAB ON GRADE	3,000 CU.YD	100	300,000	
	14" RETAINING WALLS	2,200 CU.YD	200	440,000	
3006	STRUCTURAL STEEL COLUMNS	350 TON	1,200	420,000	
	BRIDGE CRANE SUPPORT BEAMS	60 TON	1,200	72,000	
	STRUCT. STEEL SUPPORTING GRATING	40 TON	1,200	48,000	
	GRATING	20,000 □'	6	120,000	
					[illegible]
			Amounts Forwarded		[illegible]

E3F-18

EXHIBIT F-7 (Continued)

AiResearch Manufacturing Company Torrance, California	Cost Estimate Sheet Heading STRUCTURAL	Site/Building ____ Prep for Occ ____ Occupancy ____	Classification Date 5-10-78

Job Title and Description VELOCITY SLIP E-PLANT   Prepared by S. VEGH   Page 3 of 4

Account Number	Description 9 - PROCESS AREA	Quantity	Unit Cost $	$ Sub-Totals	$ Total
			Amount Forwarded		
3002	CONTIN. FOOTINGS FOR 12" PRECAST CONC. WALLS	1500 CU.YDS	200	300,000	
	FOOTINGS FOR STRUCT. STEEL COLUMNS	3500 CU.YDS	200	700,000	
	12" SLAB ON GRADE	20,000 CU.YDS	100	2,000,000	
3003	UPPER LEVEL - 12" FLOOR DECK	23,400 CU.YDS	200	4,680,000	
	12" CONC. ROOF DECK ON POST TENSIONED CONC. GIRDERS	630,000 □'	14	8,820,000	
3005	12" PRECAST CONC. WALLS	255,000 □'	12	3,060,000	
3006	STRUCT. STEEL GIRDERS, JOISTS, COLUMNS ETC.	9000 TONS	1,200	10,800,000	
3007	BRIDGE CRANE SUPPORT BEAMS	550 TONS	1,200	660,000	
	STRUCT. STEEL SUPPORTING GRATINGS	400 TONS	1,200	480,000	
	STEEL GRATING	200,000 □'	6	1,200,000	
	UPPER FLOOR DECK 1½" - 18 GA STEEL	600,000 □'	1.50	900,000	
					33,6[illegible]
			Amounts Forwarded		33,6[illegible]

E3F-19

EXHIBIT F-7 (Continued)

GARRETT AiResearch Manufacturing Company Torrance, California	Cost Estimate Sheet Heading STRUCTURAL	Site/Building ____ Prep for Occ ____ Occupancy ____	Classification Date 5-10-78
Job Title and Description VELOCITY SLIP E – PLANT		Prepared by S. VEGH	Page 4 of 4

Account Number	Description 10 – FEED & WITHDRAWAL AREA (TESA)	Quantity	Unit Cost $	$ Sub-Totals	$ Total
			Amount Forwarded		
3002	CONTIN. FOOTINGS FOR 12" PRECAST CONC. WALLS	300 CU. YDS	200	60,000	
	FOOTINGS FOR STRUCT. STEEL COLUMNS	500 CU. YDS	200	100,000	
	12" SLAB ON GRADE	2,400 CU. YDS	100	240,000	
3003	UPPER LEVEL – 12" FLOOR DECK	2,600 CU. YDS	200	520,000	
	12" CONC. ROOF DECK ON POST TENSIONED CONC. GIRDERS	135,000 □'	14	1,890,000	
3005	12" PRECAST CONC. WALLS	20,000 □'	12	240,000	
3006	STRUCT. STEEL GIRDERS, JOISTS, COLUMNS ETC.	1,400 TON	1,200	1,680,000	
3007	BRIDGE CRANE SUPPORT BEAMS	100 TON	1,200	120,000	
	UPPER FLOOR DECK, 1½" – 18 GA STEEL	71,000 □'	1.50	106,500	
			Amounts Forwarded		4,956,500

PROCESS SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATE

DESCRIPTIVE SUMMARY

Uranium enrichment requires two process areas - the Cascade Area where enrichment actually takes place and the feed and withdrawal area (TESA) where the feed UF_6 is vaporized and sent to the process-gas mixing device and where enriched UF_6 is collected and packaged.

Cascade Area

The Cascade Area contains the equipment and piping necessary to transform natural UF_6 into enriched UF_6. It is the production area of the plant. Appendix I describes the cascade, its equipment, and its operations.

The Cascade Area is air conditioned and maintained at 76°F and 50 percent maximum relative humidity. It is served by vacuum, tower cooling water, sanitary sewer, R114-cooling, and contaminated-waste-collection systems, and distribution systems for 100-psig compressed air, nitrogen, helium, and process gas. It contains the process gas mixer, the velocity-slip isotope separation devices, the helium separation devices, and helium accumulators.

There is a control room in the Cascade Area which is served by separate air handlers with high-level filtration. The air handlers are served with chilled water for cooling and hot water for heating. Nuclear contaminant filtration equipment has not been included in the design of this area although it may prove to be necessary after the analysis for the Environmental Impact Report has been completed.

Before either the heads or tails UF_6 stream gets to the TESA area it is run through a helium separation device which recovers the helium carrier gas. These separation units are located at the respective end stages of the cascade. The helium separation units are essentially recuperative heat exchangers. They include duplicates of the end stage compressor modules, plus an additional centrifugal stage to provide enough pressure to force the recovered carrier gas back into the helium accumulator.

The process gas mixer disperses the UF_6 cascade feed stream in the helium carrier gas at a pressure of 25 Torr. For lack of data on the stage cuts for the helium portion of the process gas, these cuts are assumed to be identical with the corresponding UF_6 stage cuts. This assumption eliminates any need for equipment to separate helium and UF_6 for any more than the cascade end stages - a particularly cost-reducing assumption indeed.

The helium accumulators are parallel-piped vacuum vessels. The accumulator volume is determined by optimization of the combined costs of these vessels, of the helium separator devices and the compressors required to force helium through the helium separation devices and into these vessels.

UF_6 Feed and Withdrawal Area

The UF_6 Feed and Withdrawal Area (TESA) consists of the following functional areas described briefly in this section.

(a) UF_6 shipping and receiving dock

(b) Cylinder storage and cleaning areas

(c) Feed station

(d) Sampling and weighing stations

(e) Desublimation and primary transfer station

(f) Offices and laboratories

The TESA is served by compressed air at a -40°F dewpoint, liquid nitrogen refrigeration system, -100°F refrigeration system; 180°F heating fluid system, cooling-tower water (in the machinery room), and a vacuum system.

The -100°F refrigeration system consists of a complete cascade-type refrigeration unit, insulated cold bath to contain trichloroethylene, submerged coils to cool the trichloroethylene, and controls. The cascade-type refrigeration unit consists of a single-stage, high-temperature compressor with oil separator, slug eliminator, water-cooled condenser and liquid receiver, and a two-stage low-temperature compressor with oil separator, cascade condenser, liquid receiver, and suction heat exchanger. All required sight glasses, dryers, solenoid valves, expansion valves, motor starters, and switches are provided.

The cold bath (trichloroethylene receiver) is a double-walled, aluminum or stainless steel vessel. Low temperature insulation (cellular glass or equivalent) is installed between the walls. The lid of the vessel is easily removable to provide access to the interior of the vessel. The vessel is equipped with a drain valve, liquid-level sight glass, and an electrically driven stirrer. The systems are sized to maintain a trichloroethylene temperature of -100°F. Trichloroethylene is also used in the 180°F heating fluid system.

Vacuum is required in both the Cascade Area and TESA. The process compressors, of course, maintain the process gas at a pressure below 25 torr. They are supplemented by the TESA vacuum system in pump-down of the cascade during startup and in exchanging velocity-slip isotope separation units.

The TESA vacuum pumps have large capacity at approximately 25 torr. Units are installed with cross-connections for redundancy. These pumps are water cooled. Vacuum pumps used for UF_6 feed and withdrawal draw a much deeper vacuum, but at a much lower mass flow rate.

In all cases vacuum pumps are protected by molecular sieves and cold traps. All discharges to atmosphere are through appropriate scrubbers. The scrubber liquids are discharged to the hoolding pond. The vacuum pump sealing fluids are handled as nonaqueous contaminated waste.

UF_6 distribution lines are of welded aluminum 3003. Lines are valved for control and orificed, if necessary, to maintain specified pressures.

The TESA contains the sampling autoclaves, feed autoclaves, desublimation-fusion chambers, and UF blending facilities. The UF_6 is fed from cylinders in the feed autoclaves to a mixer for blending with the helium carrier gas and from there to the cascade area for enrichment. After enrichment, it is fed back to the TESA product and tails desublimation-fusion chambers, respectively, where it is first condensed as a solid and then melted for transport as a liquid. From the product desublimation-fusion chambers, the melted product is transferred to holding chambers where it freezes. These chambers are later heated to remelt the UF_6 for transfer to the customer's 2.5-ton UF_6 bottles. In the tails desublimation-fusion chambers, the UF_6 is first condensed then later heated and transferred to tails storage bottles. When full, these storage bottles are removed to a permanent storage yard. This permanent storage yard is not part of the Velocity-Slip Isotope Separation Plant. The TESA contains an adjacent structure which houses the bottle and chamber washing area. This facility has an exhaust system which discharges its air through a scrubber. The contaminated scrubber water is discharged to settling ponds.

The fire protection is provided through a dry-pipe system or a CO_2 system.

The TESA is air conditioned and humidity controlled. The air handlers for this area are provided with nuclear contaminant filtration systems.

1. <u>UF_6 Shipping and Receiving Dock</u>

The TESA is designed to processing the full range of standard UF_6 cylinders presumed to arrive or be shipped by truck or rail. Appropriate means for cylinder handling are provided. The shipping and receiving area is maintained at 76°F and 50 percent maximum relative humidity. There are no nonelectrical utility services in this area.

2. <u>Cylinder Storage and Cleaning Area</u>

Feed UF_6 is expected to arrive in relatively large batches and will be stored on the premises pending receiving inspection and subsequent processing. Interim storage is also provided for customer product awaiting shipment. Tails material will be stored outside as soon as it has been collected and inspected. Facilities are provided to clean plant-owned cylinders as required. (Although the plant operator does not assume responsibility for cleanness of customer product cylinders, these cylinders will also be cleaned upon request, on a best efforts basis.)

3. Feed Station

The feed station includes several autoclaves, one actively vaporizing UF_6, and the other heating new feed cylinders so they can be connected to the cascade feed system as their turns come.

Plumbing of the autoclaves will permit immediate utilization of any as a feed autoclave in the event of a serious feed autoclave malfunction.

The autoclaves are electric forced-air or steam heated devices sized to handle the AEC UF_6 bottle. They have an end door opening, tracks, and a sliding cradle to fit the AEC bottles. A device that senses UF_6 temperatures and a pressure relief valve are provided. The temperature sensing device will shut down the heating system and the pressure relief valve will discharge UF_6 through liquid-nitrogen cooled trap. Manufacturers of these autoclaves are Hodge Boiler of Boston, Mass., and Bemco Environmental Chambers of Los Angeles, Calif.

The process gas preparation system will be fed from the 14-ton AEC bottles heated to 180°F in the autoclaves. The feed piping will be insulated, electric or steam traced, and thermostatically controlled, to maintain a pressure of 38 psig and prevent freezeup of lines.

4. Sampling and Weighing Stations

One autoclave is provided for use in melting and homogenizing the contents of a cylinder containing solid UF_6 preparatory to drawing a sample for analysis. Customer-supplied 14-ton AEC bottles of UF_6 are positioned in one autoclave and heated to 180°F. When the UF_6 has fused, a sample is withdrawn and sent to the laboratory for assay. Samples will also be taken at other process stations as required for on-line process control. Suitable high-precision scales are also located in this area.

5. Desublimation and Primary Transfer Stations

It is at these stations that the product and tails streams from the helium separators at the end stages of the process cascade are collected by desublimation, i.e., condensation as frost. The product is collected in desublimation-fusion chambers and then transferred to plant-owned 10-ton product cylinders. Tails material is similarly collected and then transferred to 14-ton standard tails cylinders.

Each station includes three desublimation-fusion chambers, each of which operates sequentially in three modes:

(a) Draining

(b) Filling (desublimation of a UF_6 gas stream)

(c) Melting and gravity transfer to 10-ton unblended product cylinders or 14-ton standard tails cylinders

Suitable vacuum systems, cold traps, and redundant cylinder heating and cooling equipment are provided for these stations.

The desublimation-fusion chambers are pressure vessels fabricated in accordance with ASME Section 3 specifications and N stamped for nuclear service. The chambers have inner fins, liquid annulus, insulation, and piping connections. Units will be complete with redundant pressure relief valves set for 40 psia and redundant temperature sensing devices set for 180°F. Temperature sensing devices will shut down heating media. The pressure relief device will discharge through a liquid-nitrogen cooled trap.

There are three banks of three desublimation-fusion chambers: one for product, one for tails, and one spare. In each bank, one unit is in each operating mode. The primary cooling is achieved through heat exchange with trichloroethylene cooled to -100°F. This trichloroethylene is cooled by the cascade refrigeration system. The secondary cooling is achieved by heat exchange with liquid nitrogen at -320°F. Fusion is achieved by heat exchange with 180°F trichloroethylene. Heat-traced liquid drain lines will transfer tails UF from the chambers to 14-ton UF_6 cylinders which are stored on site.

The product lines from the chambers are heat traced and discharged into 10-ton holding cylinders. The holding cylinders are filled, stored, and then relocated in the blending area, reheated in an autoclave, and discharged into customer-owned 2.5-ton AEC bottles. The chambers are provided with burping and vacuum pumps which discharge through a scrubber.

6. Filling Station

Two autoclaves are used for filling 2.5-ton customer cylinders. One autoclave holds a cylinder hot while it is being filled. The other is heating another cylinder preparatory to filling it.

7. Offices and Laboratories

In addition to the office space provided for station supervisorial and administrative personnel, the following laboratory facilities and equipment are provided:

(a) Mass spectrometers for assay determinations.

(b) Specialized chemical and radiological equipment for monitoring the chemical (other than UF_6) and the isotopic (other than ^{235}U and ^{238}U) content of the feed, product, and tails for conformance with applicable standards.

(c) Personnel health-monitoring analytical equipment peculiar to operations involving handling of radioactive and toxic substances.

CONCEPTUAL DESIGN DRAWINGS (PROCESS)

Exhibit F-8 presents the process schematic diagram for the VSUEP. Exhibit F-9 presents some detail information about the TESA's desublimation-fusion chambers and autoclave.

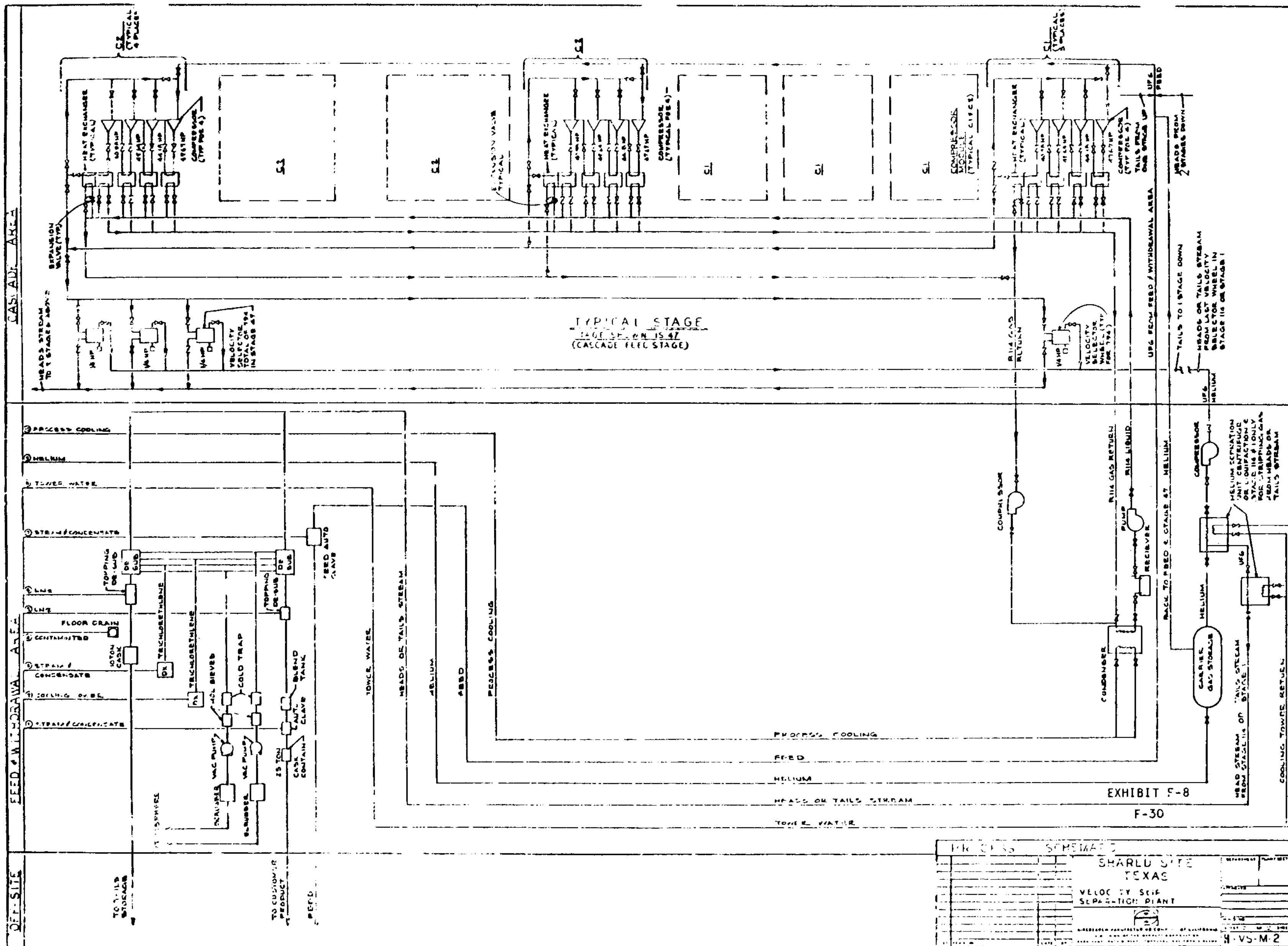


EXHIBIT F-8

F-30

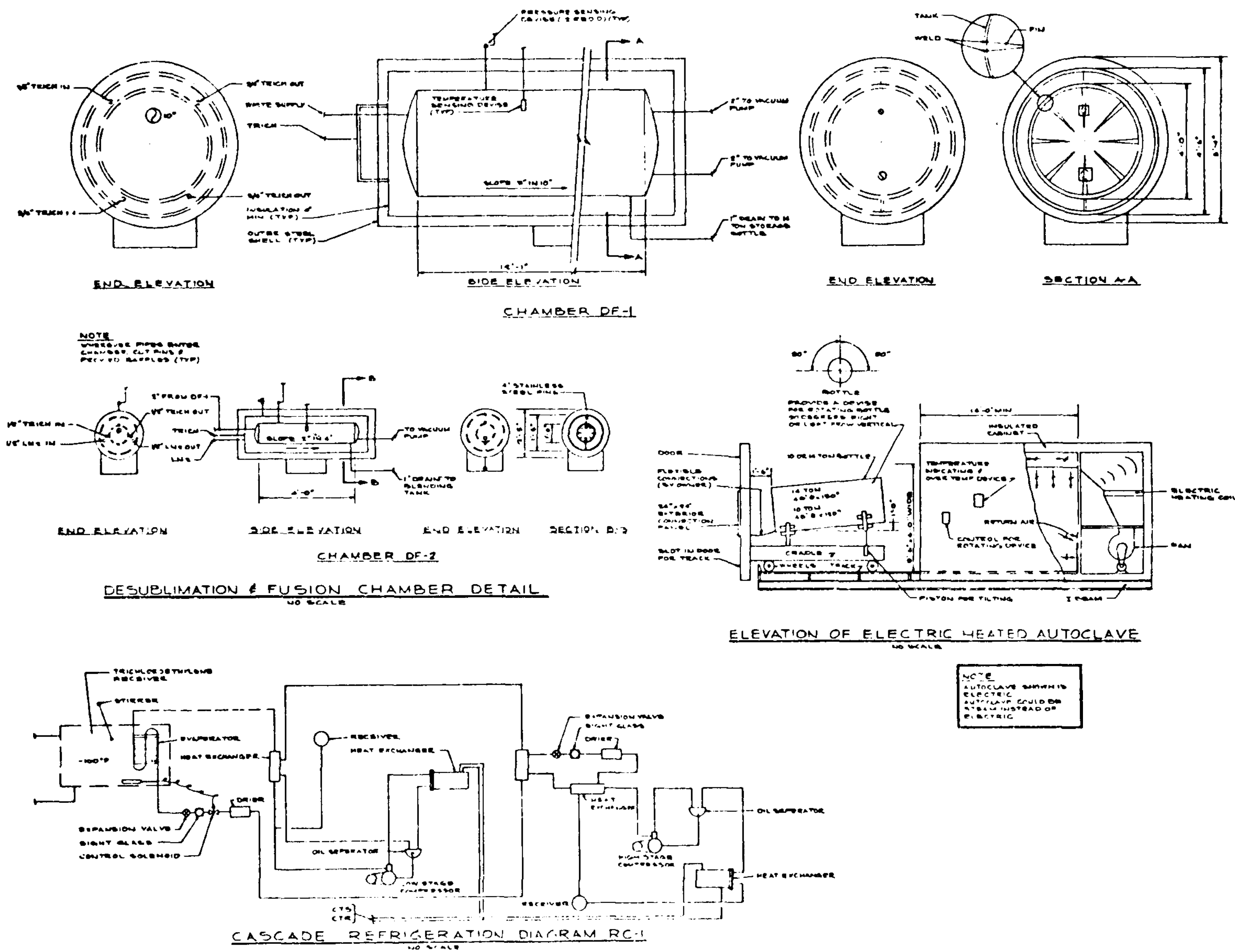


Exhibit F-9. Desublimation-Fusion Chambers and Autoclaves

BASE COST ESTIMATE (PROCESS)

Exhibit F-10 presents the cascade area process system base cost estimate. The base cost estimate for the TESA process systems is included in the mechanical systems cost estimate.

E3F-29

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ___ MECH ___ SITE/BLDG ___ CIVIL ___ ELEC ___ O/S UTIL ___ ARCH ___ OWNER ___ OCCUP. ___	CLASSIFICATION PRELIMINARY DATE
JOB TITLE AND DESCRIPTION:	PREPARED BY	PAGE ___ OF ___

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	Unit Material dollars	Unit Labor dollars	UNIT COST	SUB-TOTALS	TOTAL
6	from Mechanical Base Cost Estimate					AMOUNT FORWARDED		446,487
7	from Mechanical Base Cost Estimate							1,235,615
8	from Mechanical Base Cost Estimate							70,001
9	from Mechanical Base Cost Estimates [illegible]							[illegible]
	Velocity Selectors	42423	ea	5000	500	5500	233,326,500	
	V.S. Spares (1%)	424	ea	5000	500	5500	2,332,000	
	C1 Compressor Modules	269	ea	2,438,000	250 000	2688000	723,072,000	
	C1 Spares (1%)	3	ea	2,438,000	250 000	2688000	8,064,000	
	C2 Compressor Modules	227	ea	1,544,000	150 000	1694000	384,538,000	
	C2 Spares (1%)	3	ea	1,544,000	150 000	1694000	5,082,000	
	C3 Compressor Modules	55	ea	963,000	100 000	1063000	58,465,000	
	C3 Spares (2%)	2	ea	963,000	100 000	1063000	2,126,000	
	Helium Compressors	3	ea					
	Helium Accumulators	3	ea					
	Helium Separation Devices	3	ea				100,000	
	Process Gas Mixer	2	ea					
	Helium	LT. A	SCF					
							1417,105,500	1,417,105,500
10	from Mechanical Base Cost Estimate							3417,744
						AMOUNTS FORWARDED		1,623,815,100

EXHIBIT E-10

KEY CALCULATIONS (PROCESS EQUIPMENT)

The key calculations on which the process equipment base cost estimates are based are described in Exhibits F-11 through F-18.

EXHIBIT F-11

CALCULATION OF SPACE REQUIRED FOR COMPRESSORS

<u>Nomenclature</u>

C1	First-stage Module C1 impeller tip diameter, ft	10.208
C2	Second-stage Module C1 impeller tip diameter, ft	6.125
C3	Third-stage Module C-1 impeller tip diameter, ft	3.067
C4	Fourth-stage Module C1 impeller tip diameter, ft	2.042
C5	First-stage Module C2 impeller tip diameter, ft	6.125
C6	Second-stage Module C2 impeller tip diameter, ft	3.067
C7	Third-stage Module C2 impeller tip diameter, ft	2.042
C8	Fourth-stage Module C2 impeller tip diameter, ft	1.025
C9	First-stage Module C3 impeller tip diameter, ft	3.067
C10	Second-stage Module C3 impeller tip diameter, ft	2.042
C11	Third-stage Module C3 impeller tip diameter, ft	1.025
C12	Fourth-stage Module C3 impeller tip diameter, ft	0.558

Module C1 footprint: 29.2' x 16.9'

C13	Length of the compressor module, ft	29.222

C13 = 1.7 x C1 + 1.3 x C2 + 2.5 or
1.7 x C1 + 1.7 x C3 + 1.3 x C4 + 4, whichever is greater

C14	Width of the compressor module, ft	16.900

C14 = 1.3 x C1 or 1.7 x C2 + 1.3 x C3 + 2.5, whichever is greater

C15	Height of the compressor module, ft	17.354

C15 = 1.7 x C1

Module C2 footprint: 18.2' x 9.9'

C16	Length of the compressor module, ft	18.216

C16 = 1.7 x C5 + 1.3 x C6 + 2 or
1.7 x C5 + 1.7 x C7 + 1.3 x C8 + 3, whichever is greater

C17	Width of the compressor module, ft	9.869

C17 = 1.3 x C5 or 1.7 x C6 + 1.3 x C7 + 2, whichever is greater

C18	Height of the compressor module, ft	10.413

C18 = 1.7 x C5

EXHIBIT F-11 (Continued)

Module C3 footprint: 10.7 x 6.8

C19	Length of compressor module, ft	10.682

C19 = 1.7 x C9 + 1.3 x C10 + 2 or
1.7 x C9 + 1.7 x C11 + 1.3 x C12 + 3, whichever is greater

C20	Width of compressor module, ft	6.804

C20 = 1.3 x C9 or 1.7 x C10 + 1.3 x C11 + 2, whichever is greater

C21	Height of compressor module, ft	5.214

C21 = 1.7 x C9

	Module C1	Module C2	Module C3	Total
Unit length, ft	30	19	11	
Unit width, ft	17	10	7	
Unit height, ft	18	11	6	
Unit floor area, sq ft	510	190	77	
Unit weight lbs	847,399	170,787	24,587	
Unit power, hp	47,201	8,520	429	56,150
Number required	269	226	51	2,184
Total floor area, sq ft	137,190	42,940	3,927	184,057
Total power, kilowatts	35,197	6,353	320	41,870
Total weight, lbs	22,795,033	38,597,862	1,253,937	2.678×10^8

EXHIBIT F-12

CALCULATION OF UNIT WEIGHTS OF COMPRESSOR MODULES

Assume minimum parallelopiped occupied by compressor and drive motor is 35 percent steel.

Volume of C1 paralJelopiped

$1.7 \times C1 + 1.7 \times C1 \times 1.3\ C1 = 3.76\ C1^3$

Total volume of Module C3 compressors parallelopipeds

$3.76 \times (C1^3 + C2^3 + C3^3 + C4^3) = 5004.01$ cu ft

Total volume of Module C2 compressors parallelcpipeds 1008.52 cu ft

Total volume of Module C3 compressors parallelopipeds 145.19 cu ft

Weight of Module C1 compressors = 847,399 lbs

$5004.01 \times 1728 \times 0.28 \times 0.35$

Weight of Module C2 compressors = 170,787 lbs

$1008.52 \times 1728 \times 0.28 \times 0.35$

Weight of Module C3 compressors = 24,587 lbs

$145.19 \times 1728 \times 0.28 \times 0.35$

EXHIBIT F-13

CALCULATION OF SPACE REQUIRED FOR VELOCITY SELECTORS

D1	impeller diameter, ft	0.983
D2	length of velocity selector, ft	0.983
D2	= D1	
D3	width of velocity selector, ft	1.672
D3	= 1.7 x D1	
D4	= height of velocity selector, ft	1.672
D4	= 1.7 x D1	

Unit length, ft	1.000
Unit width, ft	1.8
Unit height, ft	1.8
Unit floor area, ft	1.8
Unit weight, lbs	46,537
Unit power, kilowatts	0.25
Number required	42,423
Total floor area, sq ft	76,362
Total power, kilowatts	10,400
Total weight, lbs	19,742,277

Calculation of Unit Weight of Velocity Selectors

D2 x D3 x D4 x 1728 x 0.28 x 0.35 = 465.37 lbs

EXHIBIT F-14

ESTIMATION OF SINGLE STAGE COMPRESSOR COSTS

The compressor cost estimates are scaled from those of a three-stage compressor now under construction at AiResearch for subatmospheric UF_6 compression service. This compressor has 14.5-inch diameter wheels. The scaling relationships are shown in Exhibit F-15.

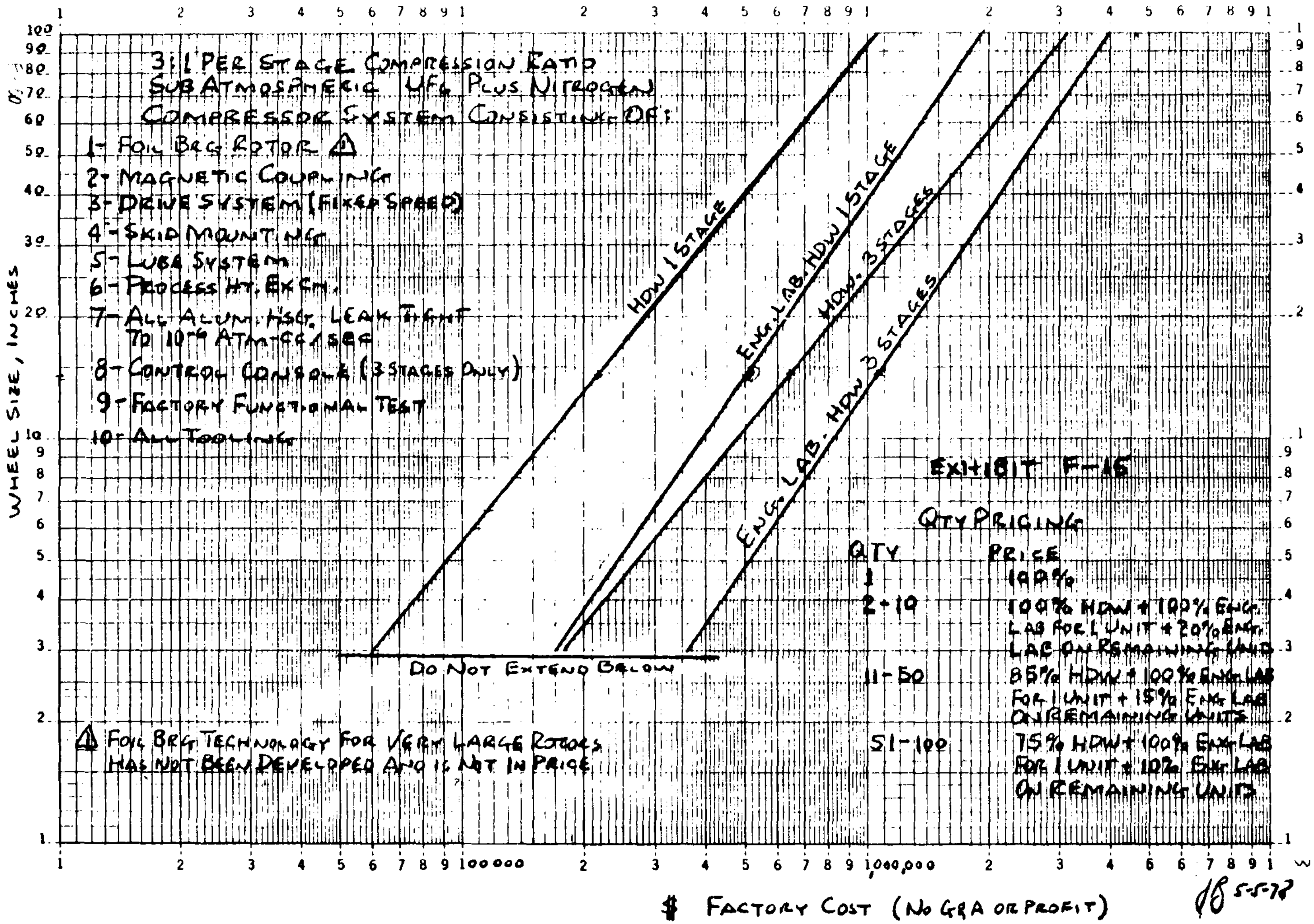

3:1 PER STAGE COMPRESSION RATIO
SUB ATMOSPHERIC UF6 PLUS NITROGEN
COMPRESSOR SYSTEM CONSISTING OF:
1- FOIL BRG ROTOR
2- MAGNETIC COUPLING
3- DRIVE SYSTEM (FIXED SPEED)
4- SKID MOUNTING
5- LUBE SYSTEM
6- PROCESS HT. EXCH.
7- ALL ALUM. HSG. LEAK TIGHT TO 10-4 ATM-CC/SEC
8- CONTROL CONSOLE (3 STAGES ONLY)
9- FACTORY FUNCTIONAL TEST
10- ALL TOOLING
HDW 1 STAGE
ENG. LAB. HDW 1 STAGE
HDW. 3 STAGES
ENG. LAB. HDW 3 STAGES
DO NOT EXTEND BELOW
FOIL BRG TECHNOLOGY FOR VERY LARGE ROTORS HAS NOT BEEN DEVELOPED AND IS NOT IN PRICE
EXHIBIT F-16
QTY PRICING
QTY
PRICE
1
100%
2-10
100% HDW + 100% ENG. LAB FOR 1 UNIT + 20% ENG. LAB ON REMAINING UNITS
11-50
85% HDW + 100% ENG LAB FOR 1 UNIT + 15% ENG LAB ON REMAINING UNITS
51-100
75% HDW + 100% ENG LAB FOR 1 UNIT + 10% ENG LAB ON REMAINING UNITS
WHEEL SIZE, INCHES
$ FACTORY COST (NO G&A OR PROFIT)
100000
1,000,000
5-5-78

EXHIBIT F-15

EXHIBIT F-16

ESTIMATION OF SINGLE-STAGE COMPRESSOR COSTS

From the following chart, exhibit

Compressor Module	Compressor Number	Wheel Size, inches	Factory Cost, dollars: Hardware Cost X	Factory Cost, dollars: Engineering Cost Y
C1	1	122.5	1,280,000	1,000,000
	2	73.5	820,000	730,000
	3	36.8	458,000	502,000
	4	24.5	335,000	390,000
C2	1	73.5	820,000	730,000
	2	36.8	458,000	502,000
	3	24.5	335,000	390,000
	4	12.3	190,000	260,000
C3	1	36.8	458,000	502,000
	2	24.5	335,000	390,000
	3	12.3	190,000	260,000
	4	6.7	116,000	179,000

Wheel Diameter, inches	Number of Compressors Required: Module C1	Module C2	Module C3	Total
122.5	269	0	0	269
73.5	269	226	0	495
36.8	269	226	51	546
24.5	269	226	51	546
12.3	0	226	51	277
6.7	0	0	51	51

Lot Size Compressors	Factors: C	Factors: D
1	1.00	1.00
2-10	1.00	0.20
11-50	0.85	0.15
51-100	0.75	0.10

EXHIBIT F-16 (Continued)

HP-65 CODE FOR CALCULATING BASE COST
OF COMPRESSORS OF ONE SIZE

```
RCL 1     Hardware cost
  ↑
RCL 3     Factor C
  X
RCL 5     Total number required
  X
RCL 2     Engineering cost
  +
RCL 2     Engineering cost
  ↑
RCL 4     Factor D
  X
RCL 6     Total number required minus one
  X
  +
R/S       Total cost of compressors
RCL 5
  ÷
RTN       Unit cost of compressors
```

Compressor Cost: 122.5-inch diameter wheel

Hardware Cost, thousands of dollars	1280
Engineering Cost, thousands of dollars	1000

	Factors		Cost, thousands of dollars	
Number of Compressors	C	D	Total	Unit
1	1.00	0	2,280	2,280
2	1.00	0.20	3,760	1,880
5	1.00	0.20	8,200	1,640
10	1.00	0.20	15,600	1,560
11	0.85	0.15	14,468	1,315
25	0.85	0.15	31,800	1,272
50	0.85	0.15	62,750	1,255
51	0.75	0.10	54,960	1,078
75	0.75	0.10	80,400	1,072
100	0.75	0.10	106,900	1,069
200	0.75	0.10	212,900	1,065
269	0.75	0.10	286,040	1,063

EXHIBIT F-16 (Continued)

Compressor Cost: 73.5-inch diameter wheel

Hardware Cost, thousands of dollars 820
Engineering Cost, thousands of dollars 730

Number of Compressors	Factors C	Factors D	Cost, thousands of dollars Total	Cost, thousands of dollars Unit
1	1	0	1,550	1,550
2	1	0.2	2,516	1,258
5	1	0.2	5,414	1,083
10	1	0.2	10,244	1,024
11	0.85	0.15	9,492	863
25	0.85	0.15	20,783	831
30	0.85	0.15	40,945	819
51	0.75	0.10	35,745	701
75	0.75	0.10	52,257	697
100	0.75	0.10	69,457	695
200	0.75	0.10	138,257	691
300	0.75	0.10	207,057	690
400	0.75	0.10	275,857	690
495	0.75	0.10	341,217	689

Compressor Cost: 36.8-inch diameter wheel

Hardware Cost, thousands of dollars 458
Engineering Cost, thousands of dollars 502

Number of Compressors	Factors C	Factors D	Cost, thousands of dollars Total	Cost, thousands of dollars Unit
1	1	0	960	960
2	1	0.2	1,518	759
5	1	0.2	3,194	639
10	1	0.2	5,986	599
11	0.85	0.15	5,537	503
25	0.85	0.15	12,042	482
50	0.85	0.15	23,657	473
51	0.75	0.10	20,531	403
75	0.75	0.10	29,979	400
100	0.75	0.10	39,822	398
200	0.75	0.10	79,192	396
300	0.75	0.10	118,562	395
400	0.75	0.10	157,932	395
500	0.75	0.10	197,302	395
546	0.75	0.10	215,412	395

EXHIBIT F-16 (Continued)

Compressor Cost: 24.5-inch diameter wheel

Hardware Cost, thousands of dollars	335
Engineering Cost, thousands of dollars	390

Number of Compressors	Factors C	Factors D	Cost, thousands of dollars Total	Cost, thousands of dollars Unit
1	1	0	725	725
2	1	0.2	1,138	569
5	1	0.2	2,377	475
10	1	0.2	4,442	444
11	0.85	0.15	4,107	373
25	0.85	0.15	8,913	357
50	0.85	0.15	17,494	350
51	0.75	0.1	15,154	297
75	0.75	0.1	22,120	294
100	0.75	0.1	29,376	294
200	0.75	0.1	58,401	292
300	0.75	0.1	87,426	291
400	0.75	0.1	116,451	291
500	0.75	0.1	145,476	291
546	0.75	0.1	158,828	291

Compressor Cost: 12.3-inch diameter wheel

Hardware Cost, thousands of dollars	190
Engineering Cost, thousands of dollars	260

Number of Compressors	Factors C	Factors D	Cost, thousands of dollars Total	Cost, thousands of dollars Unit
1	1	0	450	450
2	1	0.2	692	346
5	1	0.2	1,418	284
10	1	0.2	2,628	263
11	0.85	0.15	2,427	221
25	0.85	0.15	5,234	209
50	0.85	0.15	10,246	205
51	0.75	0.1	8,828	173
75	0.75	0.1	12,872	172
100	0.75	0.1	17,084	171
200	0.75	0.1	33,934	170
277	0.75	0.1	46,910	169

EXHIBIT F-16 (Continued)

Compressor Cost: 6.7-inch diameter wheel

Hardware Cost, thousands of dollars	116
Engineering Cost, thousands of dollars	179

Number of Compressors	Factors		Cost, thousands of dollars	
	C	D	Total	Unit
1	1	0	295	295
2	1	0.2	447	223
5	1	0.2	902	180
10	1	0.2	1,661	166
11	0.85	0.15	1,532	139
25	0.85	0.15	3,288	132
50	0.85	0.15	6,425	128
51	0.75	0.1	5,511	108

Compressor Module Cost: thousands of dollars

Module	Cost, thousands of dollars
C1	2,438
C2	1,544
C3	963

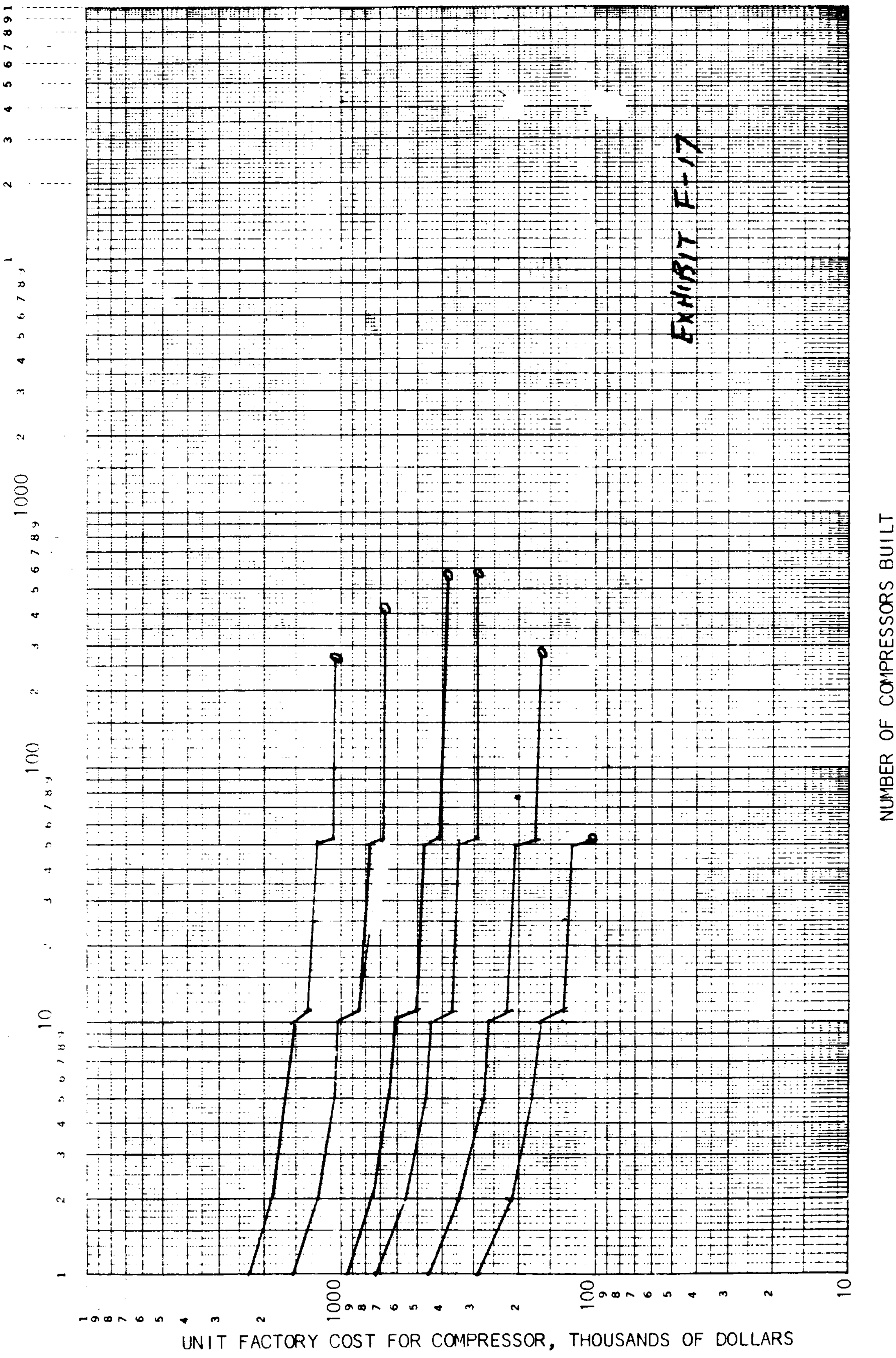


EXHIBIT F-17
NUMBER OF COMPRESSORS BUILT
UNIT FACTORY COST FOR COMPRESSOR, THOUSANDS OF DOLLARS

EXHIBIT F-17

EXHIBIT F-18

ESTIMATION OF VELOCITY SELECTOR COST

BENCHMARK 1

Cost of a turbine of similar size with adjustments for materials and tolerances: $5000

BENCHMARK 2

An independent estimate of the unit cost of a velocity separator in the first lot of 5 amounted to:

Hardware	$137,100
Other	237,130
	$374,230

This unit cost is consistent with those for compressors of similar wheel diameter.

A very optimistic estimate of the cost-improvement factor (learning curve) for the velocity selector would be 70%. With this rate of improvement, the unit cost of 42,423 velocity selector (separators) would be $3,550. Because the total cost of these devices would be $151 million, it can be argued that surely with this amount of money, substantial technology advance can be brought to bear on construction.

MECHANICAL SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATE

DESCRIPTIVE SUMMARY

Site Utilities Area

The plant site is served by storm sewer and sanitary sewer facilities. Because of the distance to the site boundary, the storm sewer and city water services are looped to maintain better pressure and flow distributions. The fire protection system is backed up with a storage tank and redundant diesel fire pumps for emergency fire fighting. Certain areas in and around the plant are landscaped and provided with automatic sprinkler systems.

Storm Sewer

If the plant is built in an arid desert area the storm sewer system may be eliminated and the surface water drained to a remote area that is still on site. The system as shown is planned for an area that has storm drainage. The system is sized for three inches per hour maximum rainfall. The building roof load is dumped to leaders which in turn are drained to storm sewer mains at each side of the compound.

Sanitary Sewer

The sanitary sewer system will consist of multiple discharges from the building.

Contaminated Waste Collection System

The contaminated waste collection system will serve floor drains in the decontamination, cascade, and UF_6 Feed and Withdrawal areas (TESA). All waste water and steam condensate used for decontamination and washdown will be collected and discharged into fenced-in, large-surface-area evaporation pools (settling ponds). After the contaminates have settled out, and when its contaminant load has reached a safe level, the water is pumped through a filter to the sanitary sewer. The contaminated solid material is then collected and buried. The burial site is not on the Velocity-Slip Uranium Enrichment Plant site.

Fire Protection

The fire sprinkler system is a multiriser sprinkler system configured and sized for ordinary hazard. The main is looped to provide for the minimum flow at each riser as required by NFPA No. 13. In addition, standpipes with hose reels and perimeter fire hydrants are provided. The UF_6 feed and withdrawal area has a dry-pipe or CO_2 system.

In addition, the fire protection system is backed up by an emergency secondary water system. The secondary system consists of an above-ground tank and a diesel-powered pump.

Fuel Oil Systems

There are two fuel-oil systems: one for diesel fuel for the standby generators and fire pump and one for oil for the boilers. The diesel-fuel distribution system consists of underground tanks and piping systems. The diesel-fuel storage provides for 20 hours of operation at full load.

The boiler-oil storage will provide for 30 days of boiler operation. The boiler-oil system will consist of underground tanks and piping, plus above-ground pumps. If LPG is available at the site, it may be used for either the boiler or diesel generators instead of fuel oil.

Cooling Towers

The cooling towers are two-cell double-flow units or dry-fan blow-through units capable of cooling from 105°F to 90°F at a 78 FWB outdoor ambient. Each cell is provided with a fan or fans and valving bypass arrangement for water temperature control during low outdoor ambient temperatures. Water is pumped through a header to the structure chiller and process cooling-liquid heat exchanger by a bank of pumps. The towers are adequately sized to provide any other incidental cooling as may be needed, namely, intercoolers and aftercoolers on the air compressors and vacuum pumps. The towers will be provided with blowdown for solids control.

Administrative Office and Personnel Area

The desired temperature in the administrative office and personnel office is maintained by thermostatically-controlled air handlers served by liquid chillers and steam boilers. The temperature is maintained all year at 76°F at 50 percent relative humidity maximum. The area is provided with food preparation facilities, lavatory facilities, and general office areas. The food preparation area is served by electrical power for food preparation and an exhaust system for food odors. These areas as well as all areas of the plant are adequately protected by sprinkler systems.

Decontamination Area

The decontamination area contains the facilities required for assembly, disassembly, and decontamination of the process equipment. The total area is served by air handlers which maintain a temperature of 76°F at 50 percent maximum relative humidity. The area is provided with vacuum systems, liquid and gaseous nitrogen, and compressed air. In addition, there is a decontamination facility which contains a special exhaust system. This system discharges its air through filters and a scrubber and thence to atmosphere. All waste liquid from this area flows to the settling ponds for settling out of contaminants.

Mechanical Equipment Area

The mechanical equipment area contains the boilers and all associated equipment, chillers, process gas compressors, air compressors, dryers, domestic water heaters, closed-loop heat exchangers, water softening equipment, and all associated pumps.

Ventilation is accomplished by thermostatically controlled two-stage wall-mounted, propeller-type exhaust fans which draw air through louvered openings. Fans are rated to allow a 30°F temperature gradient.

Boilers

The plant is served by multiple medium pressure 300-hp boilers. Boilers are fuel-oil fired and complete with deaerator, receiver, and blow-down tank, plus all safety controls. Steam supplies are manifolded to a common header. Boiler water makeup is to be treated.

Steam is distributed through insulated lines at 100 psig going throughout the plant ot domestic hot water generators to heat exchangers, autoclaves, and cylinder cleaning stations. Steam is also used to humidify the control rooms if humidity control proves to be necessary. Condensate will be a pumped-return with pumps located at strategic locations.

Special Exhaust System

A special exhaust system for the disassembly, decontamination, and cylinder cleaning area will be provided for removal of UF_6 gas and UO_2F_2 particulate matter. The duct system will be coated, air tight, and the air from the system will discharge through the roof through a scrubber. Liquid overflow and discharge from the scrubber will flow into the contaminated waste collection system.

Air Conditioning

Air conditioning of the structure is achieved by a central, ducted chilled water system. The system consists of centrifugal chillers with individual air handlers stationed around the structure. The air handlers are single-zone straight-through units and contain fans, chilled water coils, hot water coils, and filters. The air handlers serving the UF_6 feed and withdrawal area (TESA) are provided with nuclear containment-type filter systems consisting of a primary system and secondary system. Both systems have redundant filters and fans. All areas are maintained at 76°F and 50 percent maximum relative humidity. There is fresh-air makeup of about 15 percent in office areas and 10 percent in other areas. TESA is complete with air locks and is maintained at a minus 0.065 static pressure water gauge (spwg) pressure.

Air handlers serving the control room will have high-level filtration for the control devices. All air handlers will be thermostatically controlled. Control may be either pneumatic or electric.

The TESA air conditioning system is a multiple system that provides for either recirculation or 100 percent outside air. When on recirculation the area is maintained at 76°F at 50 percent relative humidity. When on 100 percent outside air there is a minimal or no cooling or heating provided.

Domestic Hot and Cold Water

The domestic hot water is generated by a converter in the Boiler Room Prime energy will be steam. Individual electric power sources may be used at remote locations.

Compressed Air

Compressed air can be used for operation of process control valves, dampers, hoists, and general house air. The system will consist of a wye or horizontal, 125-psi, two-stage unit with intercooler and aftercooler. A receiver will be provided to give about 30 minutes operation in case of some minor failure. In addition, a cross connection to gaseous nitrogen line is provided for a total failure backup. Because moisture is an inherent problem in operation, the system will be provided with a refrigerator dryer to bring new point temperatures down to 25°F at atmospheric pressures. Where possible, supply headers will be looped to obtain minimum pressure drop.

In addition, a dessicant, or heatless purge dryer will be provided in the TESA for -40°F dew point air.

Nitrogen

Liquid nitrogen is used in several areas. Liquid nitrogen lines will be approximately 1-in. diameter, vacuum insulated, Invar lines with cryogenic valves. Take-off will be provided at strategic locations in the building for Dewar bottle filling.

Gaseous nitrogen is distributred throughout the plant to provide purge capability at the cascade as well as back-up pressurization of the compressed-air system. Only the distribution piping and valves are supplied as part of the structure. The exterior bulk storage tanks and evaporators are generally supplied as a total package by the nitrogen supplier.

Helium

Helium is used as a low-molecular-weight carrier or transport gas for UF_6 isotopes in the cascade. Because of the requirements for containing UF_6, little loss of helium is expected. A storage vessel for higher pressure helium is required so that makeup helium is available when needed.

Sound Attenuation

The rotating equipment, separators and compressors will be designed to minimize noise, of course. Even so, the large number of rotating devices in the plant may create a high noise level. The conceptual design assumes that a 120 decibel noise level is attentuated to conform with OSHA requirements.

CONCEPTUAL DESIGN DRAWINGS (MECHANICAL)

The mechanical systems cost estimates are based on take-offs from the following drawing.

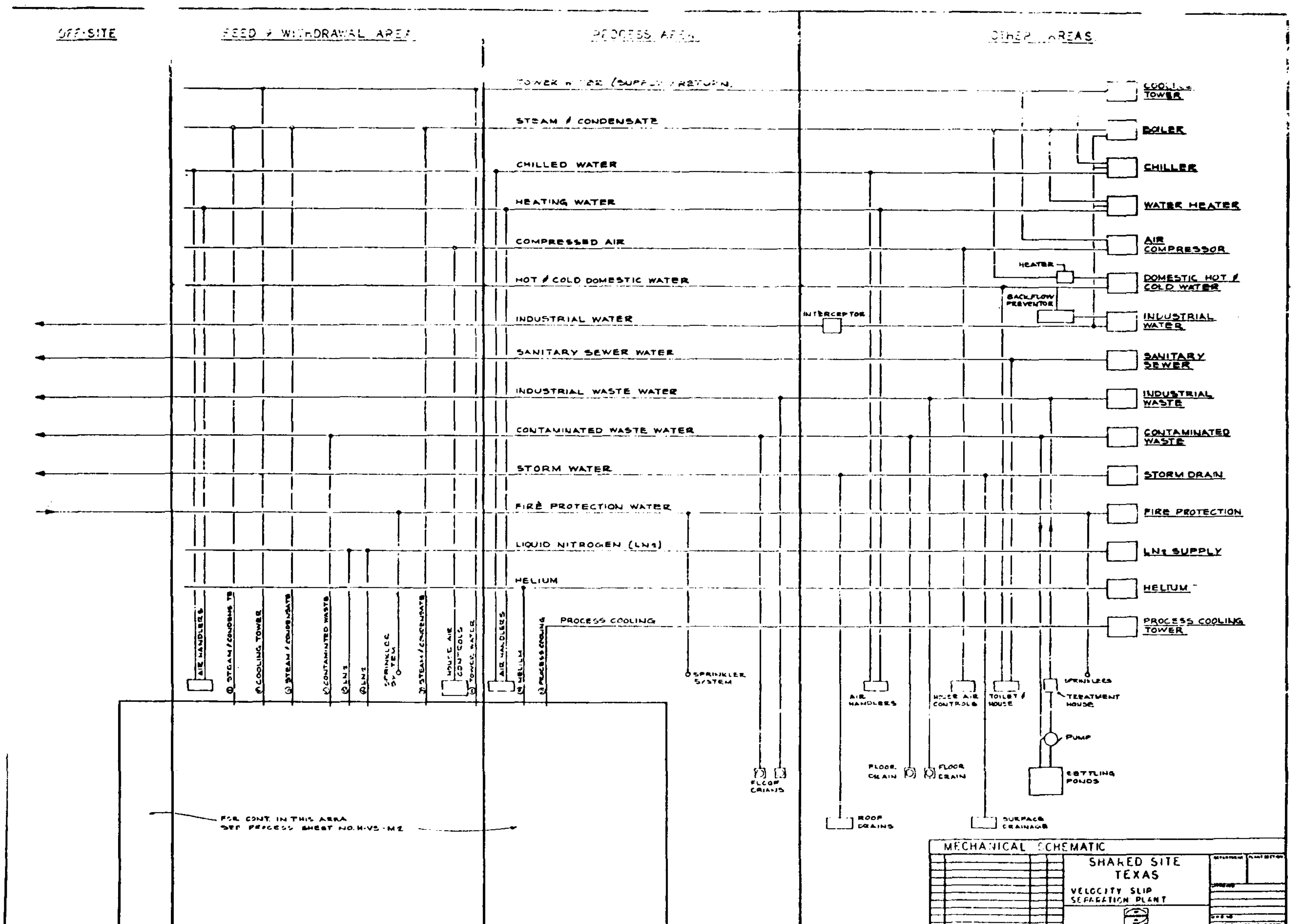

OFF-SITE
FEED & WITHDRAWAL AREA
PROCESS AREA
OTHER AREAS
TOWER WATER (SUPPLY & RETURN)
STEAM & CONDENSATE
CHILLED WATER
HEATING WATER
COMPRESSED AIR
HOT & COLD DOMESTIC WATER
INDUSTRIAL WATER
SANITARY SEWER WATER
INDUSTRIAL WASTE WATER
CONTAMINATED WASTE WATER
STORM WATER
FIRE PROTECTION WATER
LIQUID NITROGEN (LN2)
HELIUM
PROCESS COOLING
COOLING TOWER
BOILER
CHILLER
WATER HEATER
AIR COMPRESSOR
HEATER
DOMESTIC HOT & COLD WATER
BACKFLOW PREVENTOR
INTERCEPTOR
INDUSTRIAL WATER
SANITARY SEWER
INDUSTRIAL WASTE
CONTAMINATED WASTE
STORM DRAIN
FIRE PROTECTION
LN2 SUPPLY
HELIUM
PROCESS COOLING TOWER
AIR HANDLERS
STEAM/CONDENSATE
COOLING TOWER
CONTAMINATED WASTE
LN2
SPRINKLER SYSTEM
HOUSE AIR CONTROLS
TOWER WATER
PROCESS COOLING
AIR HANDLERS
HOUSE AIR CONTROLS
TOILET & HOUSE
SPRINKLERS
TREATMENT HOUSE
PUMP
SETTLING PONDS
FLOOR DRAINS
FLOOR DRAIN
ROOF DRAINS
SURFACE DRAINAGE
FOR CONT. IN THIS AREA SEE PROCESS SHEET NO. H-VS-M2
MECHANICAL SCHEMATIC
SHARED SITE TEXAS
VELOCITY SLIP SEPARATION PLANT
H-VS-M-1

EXHIBIT F-19

BASE COST ESTIMATE (MECHANICAL)

Exhibit F-20 presents the mechanical systems base cost estimate.

. .ESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTI...E SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: LAND & SITE
PREPARED BY C. Rollow
PAGE 1 OF 3

6 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
2002-1	8" IPS Coated Pipe	375	L/F	68.50	25,690	120	30	3600			29,290
-2	Sweep Heads	30	Ea	3.30	9,900	660	↓	19,800			29,700
-3	Spaced Heads	250	Ea	25	6,250	200		6,000			12,250
2005-1	Manhole 4'ϕ x 10'	12	Ea	1.2K	14,400	120	30	3600			18,000
-2	Catch Basin	10	Ea	4.32K	4320	90	30	2700			7,020
-3	Trenching Allowance	6311	Yd³	10					63,110		63,100
3005-1	Conc. Thrust Blks	1	Lot	L/S	10,000	215	30	6450			16,450
6801-1	Test Piping	1	Lot	L/S					50,000		50,000
6802-1	Cleanliness Control	1	Lot	L/S					5300		5300
6803-1	Clean Piping	1	Lot	L/S					168,000		168,000
									AMOUNTS FORWARDED		399,110

EXHIBIT F-20

E3F-51

AiResearch MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY

DATE 5-6-78

JOB TITLE AND DESCRIPTION: LAND & SITE

PREPARED BY C. Rollow

CODE 6	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~[illegible]~~										
7201-1	Ric-Wtl. Miscl sizes	1	Lot	L/S	39,300	612	30	18,360			57,600
7202-1	2" thru 4" Soil Pipe	1	Lot	L/S	31,875	637	30	19,110			50,985
-2	CI Soil Pipe Fittings	1	Lot	L/S	10,643	227	↓	6,810			17,453
-3	Cleanout to Grade	15	Ea	50-	750	38	↓	1,140			1,890
7208-1	Ric-Wtl Miscl Sizes	1	Lot	L/S	28,748	543	30	16,290			45,038
7210-1	4" C.I. Pipe	6450	LF	6-	38,700	1003	30	30,100			68,800
-2	2" thru 3" C.I. Pipe	1	Lot	L/S	5,600	213		6,390			11,990
-3	Miscl C.I. Fittings	1	Lot	L/S	8,750	280		8,400			17,150
-4	Water Meter	1	Ea	.61K	610	21		630			1,240
-5	Detector Check	1	↓	.87K	870	24		720			1590
-6	BF Preventer	1	↓	1.3K	1300	35		1,050			2350
-7	2" thru 4" S.O.V.	1	Lot	L/S	6800	206		6,180			12,980
-8	Valve Boxes	1	↓	↓	1,346	36		1,080			2426
-9	Valve Covers	1	↓	↓	788	27		810			1598
-10	Pre Cast Conc. Vault	1	↓	↓	800	60		1800			2600
									AMOUNTS FORWARDED		295,690

EXHIBIT F-20 (Continued)

AiRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: LAND & SITE

PREPARED BY

6 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	MATERIAL UNIT COST	MATERIAL SUB. TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
7211-1	100K Storage Tank	1	Ea	L/S					27,200		27,200
	8"-12" C I Pipe	1	Lot	L/S	82,200	400	30	12,000			94,200
	C I Pipe Fittings	1	Lot	L/S	11,381	270	↓	8100			19,481
	P I Valve	6	Ea	1.3K	7800	85	↓	2550			10,350
	Fire Pump	1	↓	25K					25,000		25,000
	Fire Hydrant	14	↓	.64K	8960	60	30	1800			10,760
7301-1	2"-4" C I Soil Pipe	1	Lot	L/S	6750	250	30	7500			14,250
	C I Fittings	1	↓	↓	1207	35		1050			2257
	SOV w/ Cover	1	↓	↓	1585	40		1200			2785
	Effluent Pump	2	Ea	.5K	1000	60		1800			2,800
	Filter	2	Ea	1.6K	3200	80		2400			5,600
	Shut Off Valves	1	Lot	.9K	900	48		1440			2,340
	Lagoon 100'x150'x3'	1	Ea	L/S					$102,800		102,800
	Lagoon Equip	1	Lot	L/S					53,100		53,100
7304-1	12K Gal Fuel Tanks	2	Ea	L/S					48000		48,000
									AMOUNTS FORWARDED		420,923

EXHIBIT F-20 (Continued)

AiResearch Manufacturing Company
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION: PRELIMINARY

DATE

JOB TITLE AND DESCRIPTION:

PREPARED BY

PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		

TOTAL COST OF #6 LAND & SITE: $1,115,723.00

AMT ALLOCATED TO PROCESS:

.40 X 1,115,723 = $446,289.00

AMT ALLOCATED TO MECHANICAL:

1,115,723 - 446,289 = $669,434.00

AMOUNTS FORWARDED

EXHIBIT F-20 (Continued)

E3F-53

E3F-54

AiRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION PRELIMINARY

DATE 5-6-78

JOB TITLE AND DESCRIPTION: ADMINISTRATION & UTILITY BUILDINGS

PREPARED BY C Rollow

CODE 7	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
3002-1	Conc Pad & Foundation	785	yd³	150-					~~117,750~~ 150		117,750
3013-1	Wet FP System	1	Lot	L/S					15,600		15,600
-2	Fire Dept. Conn.	2	Ea	.5K					~~1,000~~ 500		1,000
-3	Wet Standpipe	2	Ea	1.5K					~~3,000~~ 1,500		3,000
3014-1	Alarm System	2	Ea	1.5K					~~3,000~~ 1,500		3000
3202-1	½" thru 4" IPS Pipe	1	Lot	L/S	21,840	437	30	13,110			34,950
-2	½ thru 4 Fittings	1	↓	↓	8,597	172	↓	5,160			13,757
-3	Miscl Pipe Hangers	1			2,840	326		9,780			12,620
-4	Roof Drains	54	Ea	28-	1,512	40		1200			2,712
-5	Plbg. Fixtures	1	Lot	L/S	18,010	526		15,780			33,790
-6	Booster HW Htr.	4	Ea	1.4K	5600	144		4320			9,920
-7	Circulating Pump	6	Ea	.4K	2,400	64		1920			4,320
-8	Cleanouts	18	Ea	50-	900	14		420			1,320
-9	½" thru 2" B/F Preventer	1	Lot	L/S	673	18	↓	540			1,213
									AMOUNTS FORWARDED		254,952

EXHIBIT F-20 (Continued)

E3F-55

AiRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: ADMINISTRATION & UTILITY BUILDINGS
PREPARED BY C. ROLLOW
PAGE 2 OF 4

7 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~[illegible]~~										
3601-1	Sheet Metal Duct										
-2	Diffusers & Grilles	1	Lot	4/s	4387	103	30	3090			7,477
-3	Dampers	1	Lot		2054	46		1380			3,424
-4	Air Handler	2	Ea	3.5K	7000	80		2,400			9,400
-5	Air Handler	2	Ea	7.2K	14,400	120		3600			18,000
-6	Filter Bank	1	Ea	10.9K	10,900	366		10,980			21,880
-7	Heat Exchanger	4	Ea	4.8K	19,200	160		4800			24,000
-8	Temp. Regulators	1	Lot	4/s	10,000	80		2400			12,400
-9	A/C Chiller	4	Ea	144K	576,000	160		4800			580,800
-10	Plant Air Compr	1		50K	50000	160		4800			54,800
-11	Aftercooler	1		1.8K	18,000	40		1200			3,000
-12	Filter-Dryer	1		5K	5000	40		1200			6200
-13	H.W. Generator	1		7.2K	7200	60		1800			9000
-14	H.W. Converter	1		2.8K	2800	24		720			3,520
-15	Expansion Tank	2		1.1K	1100	15		450			1,550
-16	A/C Chilled Wtr Pump	3		.9K	2700	40		1200			3900
-17	H.W. Circ. Pump	3		.9K	2700	40		1200			3900
-18	300 HP Boiler	1	↓	61K	61,000	320	↓	9600			71,300
-19	Firebox	1	Lot	4/s					11,800		11,800
-20	Boiler Feed Control	1		2.5K	2500	35	30	1,050			3550
-21	Rotary Oil Burner	1	↓	1.7K	1700	35	30	1,050			2,750
									AMOUNTS FORWARDED		852,651

EXHIBIT F-20 (Continued)

ESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78
PAGE 3 OF 4

JOB TITLE AND DESCRIPTION: ADMINISTRATION & UTILITY BUILDINGS
PREPARED BY C. Rollow

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
3401-22	Day tank & Pumps	1	Lot	21K	2100	110	30	3300			5,400
-23	Boiler Feed Pumps	1		.85K	850	35		1050			1,900
-24	Safety Shutdown	1		1.5K	1500	40		1,200			2700
-25	Wtr Treatment Equip	1		1.8K	1800	28		840			2640
-26	De-aerator	1		2.3K	2300	80		2400			4,700
-27	½" thru 6" IPS Pipe	1		L/S	24,338	430		12,900			37,138
-28	8" thru 12" IPS Pipe	1			42,763	720		21,600			64,363
-29	Temp Control	1			7200	80		2,400			9,600
-30	Condenser	1							1500		1500
-31	Condenser Control	1							602		602
-32	Balance & Adjust	1				230	30	6900			6900
5001-1	Cooling Tower	1	Ea	L/S					1,400,000		1,400,000
-2	Cooling Tower Pumps	10	Ea	29K	290,000	2416	30	72,480			362,480
6001-1	Conc. Foundation's	1	Lot	L/S	56000				56000		56,000
6009-1	Heat Exchanger	1	Lot						28000		28,000
-2	Heat Exchanger Control	1	Lot						1480		1480
									AMOUNTS FORWARDED		1,985,403

EXHIBIT F-20 (Continued)

E3F-57

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ✓
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION: PRELIMINARY
DATE 5-6-78
PAGE 1 OF 4

JOB TITLE AND DESCRIPTION: ADMINISTRATION & UTILITY BUILDINGS
PREPARED BY

CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
6010.1	Process Chiller	1	Ea	80K	80,000	105	30	3,150			83,150
6013.1	Pipe Valves & Fittings	1	Lot	L/S	23,570	471	30	14,130			37,700
6014.1	Process Ducting	1	Lot	L/S					126,151		126,151
7304.1	Surface Condenser	1	Ea	480K	480,000	1342	30	40,260			520,260
-2	R114 Compr	1	Ea	56K	56,000	335		10,050			66,050
-3	R114 Pump	4	Ea	14K	56,000	380		11,400			67,400
-4	Pipe, Valves & Fittings	1	Lot	L/S					125,000		125,000
									AMOUNTS FORWARDED		1,025,711

EXHIBIT F-29 (Continued)

AiRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION
PRELIMINARY
DATE
PAGE ____ OF ____

JOB TITLE AND DESCRIPTION:
PREPARED BY

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT					UNIT COST	SUB-TOTALS	TOTAL
								AMOUNT FORWARDED		
	TOTAL COST OF #7 ADM BLDG & ETC: $4,118,717.00									
	AMT ALLOCATED TO PROCESS:									
	.30 X 4,118,717 = $1,235,615.00									
	AMT ALLOCATED TO MECHANICAL:									
	4,118,717 - 1,235,615 = 2,883,102.00									
								AMOUNTS FORWARDED		

EXHIBIT F-20 (Continued)

GARRETT RESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ______ MECH ✓ SITE/BLDG ______
CIVIL ______ ELEC ______ O/S UTIL ______
ARCH ______ OWNER ______ OCCUP. ✓

CLASSIFICATION
PRELIMINARY
DATE

JOB TITLE AND DESCRIPTION: REWORK, OVERHAUL & REPAIR (RORA)

PREPARED BY C Rollow

8 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
3013-1	Wet FP System	1	Lot	L/s					13,500		13,500
-2	Fire Dept Conn.	1	↓	↓					500		500
-3	Wet Standpipe	1	↓	↓					2,000		2,000
3014-1	Alarm System	1	Lot	L/s					1500		1,500
3202-1	½" thru 4" IPS Pipe	1	Lot	L/s	2,045	43	30	1290			3,335
-2	Miscl Fittings & Hangers	1	↓	↓	648	18		540			1,188
-3	Plbg Fixtures	1	↓	↓	4835	78		2340			7,175
-4	Cleanouts	1	↓	↓	378	13		390			768
-5	½ thru 2" BF Preventers	1	↓	↓	425	12		360			785
3401-1	Sheet Metal Duct	1	Lbs	2.45							6,053
-2	Diffusers & Grilles	1	Lot	L/s							11,042
-3	Dampers	1	↓	↓							12,687
-4	Air Handler	1	↓	↓							8,280
-5	Temp Control	1	↓	↓							650
-6	Pipe & Fittings	1	↓	↓							2,400
									AMOUNTS FORWARDED		71,863

EXHIBIT F-20 (Continued)

AiRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE

JOB TITLE AND DESCRIPTION: REWORK, OVERHAUL & REPAIR AREA (RORA)

PREPARED BY C. Rollow

PAGE 2 OF 2

8 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
6801-1	Test Equip & Lines	1	Lot	L/s					15,000		15,000
6802-1	Cleanliness Control	1	Lot	L/s					5,100		5,100
6803-1	Clean Equip & Lines	1	Lot	L/s					48,038		48,038
									AMOUNTS FORWARDED		68,138

EXHIBIT F-20 (Continued)

E3F-61

...ESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTI...E SHEET STRUCT. ____ MECH ____ SITE/BLDG ____ CIVIL ELEC ____ O/S UTIL ____ ARCH ____ OWNER ____ OCCUP. ____	CLASSIF...ATION PRELIMINARY DATE
JOB TITLE AND DESCRIPTION:	PREPARED BY	PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~[illegible]~~										
	TOTAL COST OF $ REWORK & ETC. (RORA): $140,031.00										
	AMT ALLOCATED TO PROCESS:										
	.50 X 140,031 = $70,016.00										
	AMT ALLOCATED TO MECHANICAL:										
	140,031 − 70,016 = $70,015.00										
									AMOUNTS FORWARDED		

EXHIBIT E-20 (Continued)

(R)ESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTI(MA)TE SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: ~~PROCESS~~ AREA
PREPARED BY C. ROLLOW
PAGE 1 OF 4

9 CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
3013-1	Wet FP System	13680	Hds	75					1,026,000		1,026,000
-2	Fire Dept Conn.	3	Ea	L/S					1,500		1,500
-3	Wet Standpipe	3	Ea	L/S					71,220		71,220
3014-1	Alarm System	3	Ea	1.5K					4,500		4,500
3202-1	1/2" thru 4" IPS Pipe	1	Lot	L/S	24,238	430	30	12,900			37,138
-2	1/2" thru 4" Fittings	1			3,609	95		2850			6,459
-3	Miscl Pipe Hangers	1			1,800	36		1080			2880
-4	Roof Drains	1			5040	571		17,130			22,170
-5	Plbg Fixtures	1			14,800	280		8,400			23,200
-6	Cleanouts	1			3,520	131		3,930			7,450
-7	B/F Preventers	1			687	21		630			1,317
3401-1	Sheet Metal Duct	41040	Lbs	2.95					121,068		121,068
-2	Diffusers & Grilles	1	Lot	L/S					123,120		123,120
-3	Dampers	1	Lot	L/S					54,720		54,720
-4	Air Handler	18	Ea	7.2K	129,600	1080	30	32,400			162,000
									AMOUNTS FORWARDED		1,664,742

EXHIBIT F-20 (Continued)

GARRETT AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ___ MECH ___ SITE/BLDG ___ CIVIL ___ ELEC ___ O/S UTIL ___ ARCH ___ OWNER ___ OCCUP. ___
CASCADE	CLASSIFICATION PRELIMINARY DATE 5-6-78
JOB TITLE AND DESCRIPTION: ~~PROCESS~~ PROCESS AREA	PREPARED BY C. ROLLOW PAGE 2 OF 4

9 CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
3401-5	Temp. Control Valve	1	Lot	L/S	7200	80	30	2400			9600
-6	1/2" thru 4" IPS Pipe	1	↓	↓	24238	430		12,900			37,138
-7	1/2" thru 4" Fittings	1	↓	↓	13910	221		6630			20,540
-8	Miscl Pipe Hangers	1	↓	↓	7300	115		3450			10,750
-9	Balance & Adjust	1	↓	↓		230		6900			6,900
6014-1	2" thru 10" Process Duct	1	Lot	L/S					329,800		329,800
-2	Collector-Dispenser Fabrication	1	↓	↓					3,517,100		3,517,100
-3	Dispenser to Wheel lines (1½" equivalent)	1	↓	↓					9,328,500		9,328,500
-4	Heads 1st Collection Header	8483	Ea	.4K					3,393,200		3,393,200
-5	Tails - 1st Collection Header	8483	↓	.65K.					5,514,000		5,514,000
-6	Heads Header-2nd	1696	↓	2K					3,392,000		3,392,000
-7	Tails Header-2nd	1696	↓	325K					5,512,000		5,512,000
	Heads & Tails 12"-18"	463,869	L/F	53"					25,000,000		25,000,000
-8	Main Collector (2' to 11' Φ) 11' AVG DIA	.37	Ea	L/S					2,127,500		2,127,500
-9	↑ 9	33	↓	↓					1,138,500		1,138,500
-10	6	13	↓	↓					149,500		149,500
-11	5	13	↓	↓					89,700		89,700
-12	4	6	↓	↓					24,200		24,200
-13	↓ 3	6	↓	↓					13,100		13,100
									AMOUNTS FORWARDED		59,614,028

EXHIBIT F-20 (Continued)

…ESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTI…E SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION: PRELIMINARY

DATE 5-6-78

JOB TITLE AND DESCRIPTION: ~~PROCESS~~ AREA

PREPARED BY

9 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~…~~										
6014-											
-15	11'φ Avg Mixer (37stgs)	1866,531	Lbs	7.00					13,065,700		13,065,700
-16	9' (33stgs)	906,924	↓	↓					6,348,500		6,348,500
-17	6' (13 stgs)	130,656							914,600		914,600
-18	5' (18stgs)	78,065							546,500		546,500
-19	4' (6stgs)	21,986							153,900		153,900
-20	3' (6stgs)	12,363							86,500		86,500
-21	2' ↓ (6stgs)	3664	↓	↓					25,600		25,600
-22	52"φ Avg Dispersion Duct	12,781	L/F	514					6,569,400		6,569,400
-23	24"	5120	↓	140					716,800		716,800
-24	12" ↓	700	↓	35.00					25,000		25,000
-25	1½" EP Activation Vacuum Valve	42,415	Ea	.675K					28,630,000		28,630,000
-26	2"			1.170K					59,700		59,700
-27	3"			1.475K					62,562,000		62,562,000
-28	4"			1.75K					74,622,000		74,622,000
-29	10"			2.7K					780,000		780,000
-30	12" ↓			3.3K					168,000		168,000
-31	24" (SPECIAL FAB)			11K					2,486,000		2,486,000
-32	52" (SPECIAL FAB)			27K					7,263,000		7,263,000
									AMOUNTS FORWARDED		205,023,200

EXHIBIT F-20 (Continued)

GARRETT AIRESEARCH MANUFACTURING COMPANY
Torrance, California

CASCADE

COST ESTIMATE SHEET

STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION
PRELIMINARY

DATE 5-6-78

JOB TITLE AND DESCRIPTION: ~~PROCESS~~ S AREA

PREPARED BY

9 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~[illegible]~~										
6801-1	Test Equip & Lines	1	Lot	L/S					125,000		125,000
6802-1	Cleanliness Control	1	Lot	L/S					78,000		78,000
6803-1	Cleaning of Equip & Lines	1	Lot	L/S					453,000		453,000
									AMOUNTS FORWARDED		656,000

EXHIBIT F-20 (Continued)

E3F-66

...RESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTI...E SHEET

STRUCT. ______ MECH ______ SITE/BLDG ______
CIVIL ______ ELEC ______ O/S UTIL ______
ARCH ______ OWNER ______ OCCUP. ______

CLASSIFICATION PRELIMINARY

DATE

JOB TITLE AND DESCRIPTION:

PREPARED BY

PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		

~~SITE~~

TOTAL COST OF #9 PROCESS: $267,013,330.00 266,957,970

AMOUNT ALLOCATED TO PROCESS:

98 × ~~267,013,330~~ 266,957,970 = ~~$261,673,060.00~~ 261,618,811

AMOUNT ALLOCATED TO MECHANICAL:

~~267,013,330~~ 266,957,970 − 261,673,060 = ~~$5,340,270.00~~ 5,339,159

AMOUNTS FORWARDED

EXHIBIT F-20 (Continued)

...RESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION
PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: TOLL ENRICHMENT AREA (TESA)
PREPARED BY C FOLLOW
PAGE 1 OF 3

10 CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~[struck out]~~										
3013-1	Dry FP System (CO_2)	1	Lot	L/S					188,000		188,000
3014-1	Alarm System	1	Ea	L/S					5,000		5,000
3202-1	½" thru 4" IPS Pipe	1	Lot	L/S	18,397	360	30	10,800			29,197
-2	½" thru 4" Fittings	1	↓	↓	5,435	109	↓	3,270			8,705
-3	Miscl Pipe Hangers	1			1,897	38		1,140			3,037
-4	Plbg Fixtures	1			9,047	181		5430			14,477
-5	Cleanouts	1	↓	↓	873	18	↓	540			1,413
3401-1	Sheet Metal Duct	18,131	Lbs	2.95					53,486		53,486
-2	Filter Bank - HP	2	Ea	32K	64,000	366	30	10,980			74,980
-3	Filter Bank - Roughage	2	Ea	18K	36,000	366	↓	10,980			46,980
-4	Temp. Regulators	1	Lot	8.6K	8,600	80		2,400			11,000
-5	Air Filter - Dryer	1	Ea	4.5K	4,500	35	↓	1,050			5,550
									AMOUNTS FORWARDED		441,825

E3F-67

EXHIBIT F-20 (Continued)

E3F-68

RESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ______ MECH ✓ SITE/BLDG ______
CIVIL ______ ELEC ______ O/S UTIL ______
ARCH ______ OWNER ______ OCCUP. ✓

CLASSIFICATION: PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: TOLL ENRICHMENT AREA (TESA)
PREPARED BY C ROLLOW
PAGE 2 OF 3

ID CODE	DESCRIPTION	QUANTITIES: AMOUNT	QUANTITIES: UNIT	MATERIAL: UNIT COST	MATERIAL: SUB TOTAL	LABOR: MAN HOURS	LABOR: UNIT COST	LABOR: SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~SITE~~										
6003-1	Purge & Evacuation 2" thru 10" IPS	21,500	Lb	7.50					161,300		161,300
-2	Vacuum Lines - Avg.	50	Ea	1.67K					95,190		95,190
-3	Manifold 14"/7"	17592	Lb	7.00					123,000		123,000
-4	Vacuum Pumps	2	Ea	30K					60,000		60,000
-5	Demisting HEPA & Dump	1	L/S	Lot					60,500		
-6	LN_2 Storage	1	Ea	15K	15000	233	30	7000			22,000
6006-1	1" thru 4" Duct (Feed & Tails)	1	Lot	L/S					40,000		40,000
-2	1" thru 4" Vac. Valves	12	Ea	17.5K	21,000	420	30	12,600			33,600
-3	Spec. Constr	1	Lot	L/S					14,000		14,000
6008-1	Desublimer - 1	3	Ea	30K	90,000	750	30	22,500			112,500
-2	Desublimer - 2	3	↓	30K	90,000	750	↓	22,500			112,500
-3	Autoclave	.3	↓	75K	225,000	1875	↓	56,250			281,250
6009-1	1" LN_2 Dewar Line	500	L/F	50	25,000	667	30	20,010			45,010
-2	Miscl. Solenoid Valves	1	Lot	L/S	52,332	362	↓	10,860			63,192
-3	Miscl Balance Valves	1	Lot	L/S	3,398	99	↓	2,970			6,368
									AMOUNTS FORWARDED		1,169,910

EXHIBIT F-20 (Continued)

...RESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ✓ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ✓

CLASSIFICATION PRELIMINARY
DATE 5-6-78

JOB TITLE AND DESCRIPTION: TOLL ENRICHMENT AREA (TESA)
PREPARED BY C. ROLLOW
PAGE 3 OF 3

IO CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	MATERIAL UNIT COST	MATERIAL SUB TOTAL	LABOR MAN HOURS	LABOR UNIT COST	LABOR SUB TOTAL	UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
	~~Note~~										
6001-4	1/2" R114 Line	612	L/F	5-					3060		3,060
-5	7/8"	4680	↓	7-					32,760		32,760
-6	1 3/8"	4068		10-					40,680		40,680
-7	1 5/8"	6725		12-					80,700		80,700
-8	2 1/8"	6725		14-					94,150		94,150
-9	3/8" Cu Aftercooler	459		4-					1,836		1,836
-10	1/2"	2712		5-					13,560		13,560
-11	7/8"	4842	↓	7-					33,894		33,894
-12	7/8" thru 3 7/8 Manifold	1	Lot	L/S					446,700		446,700
-13	10" B.I. Liquid	2000	L/F	75-					150,000		150,000
-14	16" BI Suction	2600	↓	135-					351,000		351,000
-15	18" BI Liquid	150		160-					24,000		24,000
-16	3/8 thru 6" Suction	3,100	↓	43-					133,300		133,300
-17	3/8 thru 7/8" Exp Valve	1	Lot	L/S					60,360		60,360
-18	3/8 thru 7/8 Servo Valves		↓	↓					119,000		119,000
-19	Manifold Valves								20,000		20,000
-20	Heat Exchanger	2	Ea	6K	12 000	200	30	6000	18,000		18,000
-21	Receiver	2		1.5K	3 000	60	30	1800	4,800		4800
6801-1	Test Equip & Lines	1	Lot	L/S					250,000		250,000
									AMOUNTS FORWARDED		1,877,800

E3F-69

EXHIBIT F-20 (Continued)

RESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ____ MECH ____ SITE/BLDG ____ CIVIL ____ ELEC ____ O/S UTIL ____ ARCH ____ OWNER ____ OCCUP. ____	CLASSIFICATION PRELIMINARY	DATE
JOB TITLE AND DESCRIPTION:	PREPARED BY		PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		

TOTAL COST OF TOLL ENRICHMENT (TESA) UF_6 FEED & WITHDRAWAL: $3,489,535.00

AMT ALLOCATED TO PROCESS:

.98 × 3,489,535.00 = $3,419,744.00

AMT ALLOCATED TO MECHANICAL:

3,489,535 − 3,419,744 = $69,791.00

AMOUNTS FORWARDED

EXHIBIT F-20 (Continued)

KEY CALCULATIONS (MECHANICAL)

1. Air Conditioning:

$$600' \times 1200' \times 2 = 1,440,000 \text{ sq ft}$$
$$100' \times 200 \times 2 = 40,000 \text{ sq ft}$$
$$1,480,000 \text{ sq ft}$$

Assume 1 cu ft per sq ft. 400 cu ft = 1 ton. Adjust for 20°F ΔT instead of 27.6°F

$$\frac{(1,480,000)(1)(27.6)}{(400)(20)} = 5106.$$ Say 5000 tons; use four 1500-ton compressors at 0.83 demand factor.

$$CFM = \frac{(5000)(12,000)}{(1.06)(20)} = 2,830,189$$

2. Determine Fan Horsepower: Assume 2" SP and fan efficiency at 50%.

$$BHP = \frac{2,830,189 \times \frac{62.4}{12} \times 2}{33,000 \times 0.50} = 1783.8$$

Use 20 roof-mounted air handlers; 90 HP

3. Cooling Tower Load:

12,000	tons, process
700	tons, R114 cooling
5,000	tons, air conditioning
17,700	tons. Use 20,000 tons

GPM at 15° ΔT: $\frac{(2000)(12,000)}{(8.33)(60)(15)} = 32,000$ GPM

4000' 12" Φ	50'
NPSH	15
Cooling Tower Ht.	65
Miscellaneous	25
	167' TDH

4. Cooling Tower Pumps: $BHP = \frac{32,000 \times 167}{3960 \times 0.75} = 1799.32$

Use ten 200 HP pumps at 0.9 demand factor.

5. Plant Air Requirements:

100/120 psig line pressure 1/2" air drop. 1/4" ARO quick disc. Assume 20 cu ft per drop. 300 work benches with drops. 300 additional. Use:

$$Q = q\,N^{1/2} = 20\,(600)^{1/2} = 490, \text{ Say } 500$$

where q = 20 SCFM
Q = demand SCFM
N = Number of drops

$$CR/stg = \sqrt{\frac{120 + 14.7}{14.7}} = 3.02$$

Use one Worthington wye head 2 stg, 150 HP, skid-mounted compressor.
(150 HP x $333/HP) = $44,950, say $50,000

6. Boiler HP Required:

$$\frac{1M^2 \text{ BTUH} \times 10}{34,375} = 290, \quad \text{Use } 300$$

7. 100 percent makeup required:

$$\frac{(300)(3215)}{(60)(8.33)} = 19.5 \text{ GPM}, \quad \text{Say } 20 \text{ GPM}$$

8. Rotary Burner Required:

$$\frac{(300)(34,375)}{(144,000)(.80)\,60} = 1.49 \text{ GPM}, \quad \text{Say } 1.5$$

9. Lagoon:

100' x 150' x 3' = 45,000 cu ft

Effluent flowrate: $\frac{1000 \times 75}{1440} = 52$ GPM avg.

4 hr max: 1.7 x 52 = 88.4 GPM, Say 90

4 hr min: 0.4 x 52 = 20.8 GPM, Say 21

Detention Time = $\frac{45,000 \times 24}{75,000} = 14.4$ hrs

10. Use 3 pumps: 52 GPM at 35' TDH, 1 HP

ELECTRICAL SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATES

DESCRIPTIVE SUMMARY

The Velocity-Slip Uranium Enrichment Plant total connected electrical load is approximately 119 MW with an approximate demand load of 107 MW.

These loads represent three major systems:

a. Building and site power

b. Process power

c. Building and site lighting

The plant will be served by two 60 MVA service transformers with oil and fan cooling for added capacity. The plant distribution system will be underground 13.8 KV, 3 phase, 60 Hz.

The major components of the demand load are:

a.	Isotope separators	25.5 MW
b.	Cooling towers	2.5 MW
c.	Chillers	5.0 MW
d.	Process compressors	74.1 MW
e.	Miscellaneous building power	7.0 MW
f.	Lighting system	4.8 MW

Parts of the Cascade Area, Feed and Withdrawal Areaa, and building lighting will be backed up electrically by a 500 KVA diesel generator set with an automatic transfer switch in the event of a power failure.

The building and site lighting system will be designed with energy conservation in mind. The process area lighting will be high bay, metal halide type. Fluorescent fixtures will illuminate the administration building and low bay areas.

Secondary power distribution voltages will be: 4160 volts, 3 phase; 480 volts, 3 phase; and 120/208 volts, 3 phase.

All electrical installations and equipment will comply with local and national codes and ordinances, and O.S.H.A. and N.E.M.A. standards.

CONCEPTUAL DESIGN DRAWINGS (ELECTRICAL)

The electrical systems cost estimates are based on take-offs from the following drawings.

E3F-74

F-78

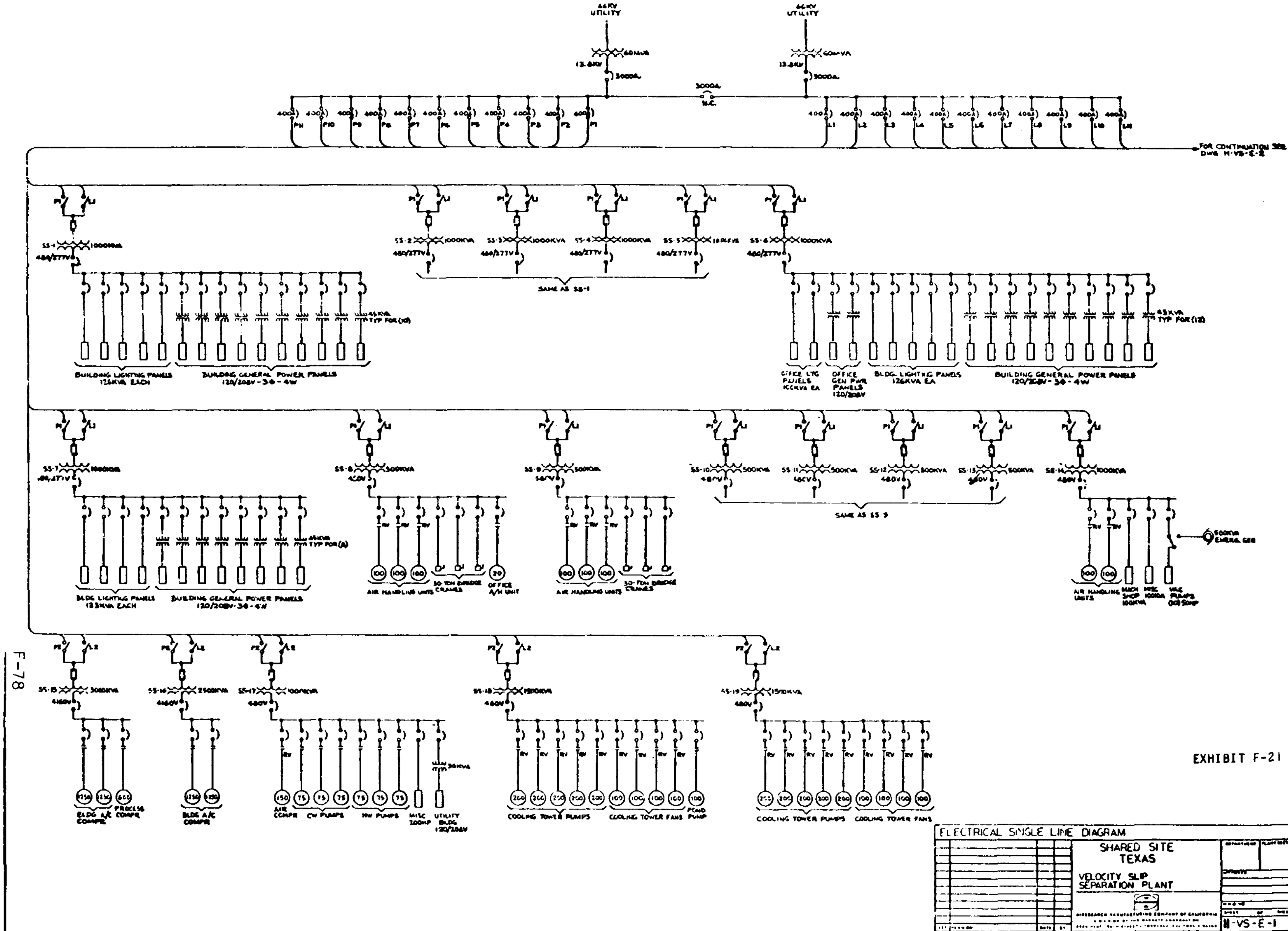


EXHIBIT F-21

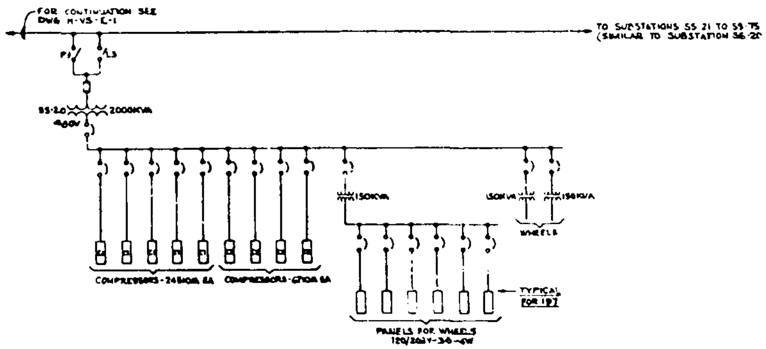


EXHIBIT F-22

EXHIBIT F-22

LINE DIAGRAM

SHARED SITE
TEXAS

VELOCITY SLIP
SEPARATION PLANT

PLANT ENGINEERING

H-VS-E-2

E3F-75

BASE COST ESTIMATES (ELECTRICAL)

Exhibit F-23 presents the electrical systems base cost estimates for a 300,000 SWU per year VSUEP located in Texas.

E3F-77

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC X O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY

DATE 5/10/78

JOB TITLE AND DESCRIPTION: PREPARED BY

PAGE 1 OF ____

6 LAND AND SITE

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	UNIT COST	SUB-TOTALS	TOTAL
				AMOUNT FORWARDED		
7112	SERVICE TRANSFORMERS	2	EA			762,000
7114-1	13.8KV SERVICE FEEDERS	LOT				22,000
-2	13.8KV METALCLAD SWITCHGEAR	LOT				640,000
[illegible]	[illegible] POWERED PHONE SYSTEM	LOT				20,000
7203	13.8KV U.G. FEEDERS	5500	FT			413,000
7205	AREA LIGHTING	LOT				170,000
7206-1	AREA ALARM SYSTEM	LOT				85,000
-2	CLOSED CKT TV SYSTEM	LOT				8,000
7211	FIRE WATER PUMP SYSTEM	LOT				15,000
7301	WATER TREATMENT	LOT				60,000
				AMOUNTS FORWARDED		2,195,000

EXHIBIT F-23

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ✓ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY
DATE 5/10/78
PAGE 2 OF ____

JOB TITLE AND DESCRIPTION: 7 ADMINISTRATION BLDG. & AUX. BLDGS
PREPARED BY

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
3013	FIRE PROTECTION SYSTEM	LOT									15,000
3014	FIRE ALARM SYSTEM	LOT									45,000
3015	PA SYSTEM	LOT									15,000
3101-1	1000KVA UNIT SUBSTA.	1	EA								45,000
-2	UNIT SUBSTA. PRI. FDR.	300	FT								23,000
-3	LIGHTING PANELS & FDRS	2	EA								25,000
-4	LIGHTING FIXTURES & CKTS.	LOT									231,000
-5	EMERG. LTG. SYSTEM	LOT									25,000
-6	BLDG. SECURITY LIGHTING	LOT									12,000
3102-1	120/208V PNL., TRANSF. & FDR.	3	EA								19,000
-2	120V BRANCH CKTS	LOT									30,000
-3	OFFICE A/H UNIT	1	EA								3,000
-4	MISC. A/C & VENT	LOT									5,000
-5	CAFETERIA EQUIP.	LOT									30,000
									AMOUNTS FORWARDED		523,000

EXHIBIT F-23 (Continued)

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ___ MECH ___ SITE/BLDG ___ CIVIL ELEC X O/S UTIL ___ ARCH ___ OWNER ___ OCCUP. ___	CLASSIFICATION PRELIMINARY DATE 5/10/78

JOB TITLE AND DESCRIPTION: PREPARED BY PAGE ___ OF ___

8 CODE	REWORK, OVERHAUL, REPAIR AREA DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		
3013	FIRE PROTECTION SYSTEM	LOT									41,000
3014	FIRE ALARM SYSTEM	LOT									121,000
3015	P.A. SYSTEM	LOT									41,000
3101-1	LIGHTING PANELS & FDRS	4	EA								20,000
-2	LIGHTING FIXTURES & CKTS	LOT									481,000
-3	EMERG. LTG SYSTEM	LOT									50,000
3102-1	1000KVA UNIT SUBSTA	1	EA								45,000
-2	UNIT SUB PRI FDR.	250	FT								19,000
-3	120/208V PNL., TRANSF., FDR	7	EA								35,000
-4	120V BRANCH CKTS.	LOT									13,000
-5	WORK BENCH WIRING	LOT									10,000
-6	A/H UNITS	2	EA								13,000
-7	MACH. SHOP POWER	LOT									16,000
5001	COOLING TOWER	LOT									19,000
6751	BRIDGE CRANES	3	EA								5,000
									AMOUNTS FORWARDED		929,000

EXHIBIT F-23 (Continued)

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ____ MECH ____ SITE/BLDG ____ CIVIL ____ ELEC X O/S UTIL ____ ARCH ____ OWNER ____ OCCUP. ____	CLASSIFICATION PRELIMINARY DATE 5/10/78
JOB TITLE AND DESCRIPTION:	PREPARED BY	PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	QUANTITIES UNIT	UNIT COST	SUB-TOTALS	TOTAL
9	PROCESS AREA					
				AMOUNT FORWARDED		
3013	FIRE PROTECTION SYSTEM	LOT				292,000
3014	FIRE ALARM SYSTEM	LOT				876,000
3015	P.A SYSTEM	LOT				292,000
3101-1	1000 KVA UNIT SUBSTA.	4	EA			180,000
-2	1500 KVA UNIT SUBSTA	1	EA			55,000
-3	UNIT SUB PRI. FDRS.	1200	FT			90,000
-4	LIGHTING PANELS & FDRS.	29	EA			145,000
-5	LIGHTING FIXTURES & CKTS	LOT				3,501,000
-6	EMERGENCY LTG. SYSTEM	LOT				350,000
-7	SECURITY LIGHTING	LOT				87,000
3102-1	500 KVA UNIT SUBSTA	6	EA			210,000
-2	1000 KVA UNIT SUBSTA	1	EA			45,000
-3	1500 KVA UNIT SUBSTA	2	EA			110,000
-4	2500 KVA UNIT SUBSTA	1	EA			65,000
-5	3000 KVA UNIT SUBSTA	1	EA			75,000
-6	UNIT SUB. PRI. FDRS	1600	FT			120,000
-8	120/208V PNL, TRANSF & FDR.	.54	EA			270,000
-9	120V BRANCH CKTS	LOT				94,000
-10	A/H UNITS	16	EA			104,000
-11	500 KVA DIESEL GEN.	LOT				82,000
-12	VAC. PUMPS	LOT				50,000
				AMOUNTS FORWARDED		7,093,000

EXHIBIT F-23 (Continued)

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC X O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY
DATE 5/10/78
PAGE ____ OF ____

JOB TITLE AND DESCRIPTION: | PREPARED BY

9 PROCESS AREA

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
									AMOUNT FORWARDED		7,093,000
-13	BLDG A/C CHILLERS	4	EA								120,000
-14	AIR COMPRESSOR	1	EA								10,000
-15	CW & HW PUMPS	6	EA								15,000
-16	MISC. PUMPS	LOT									16,000
6701-1	1500KVA UNIT SUBSTA.	2	EA								110,000
-2	2000KVA UNIT SUBSTA.	54	EA								3,510,000
-3	UNIT SUB. PRI. FDRS.	6300	FT.								473,000
-4	PROCESS CHILLER	1	EA								28,000
-5	C1 COMPRESSORS	269	EA								996,000
-6	C2 COMPRESSORS	226	EA								272,000
-7	C3 COMPRESSORS	51	EA								178,000
-8	TRANSF., FDRS., PNLS. FOR WHEELS	197	EA								3,448,000
-9	WHEELS	42,423	EA								6,576,000
6702-1	INSTRUMENTATION TRAY & CABLES	LOT									475,000
-2	CONTROL ROOM EQUIP.	LOT									1,700,000
-3	INSTRU. WIRING	LOT									1,230,000
6751	BRIDGE CRANE	16	EA								24,000
7301	POND PUMP	1	EA								5,000
									AMOUNTS FORWARDED		26,279,000

EXHIBIT F-23 (Continued)

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ELEC X O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION: PRELIMINARY

DATE 5/10/78

JOB TITLE AND DESCRIPTION:

PREPARED BY

PAGE ____ OF ____

CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	UNIT COST	SUB-TOTALS	TOTAL
10	FEED AND WITHDRAWL					
				AMOUNT FORWARDED		
3013	FIRE PROTECTION SYSTEM	LOT				43,000
3014	FIRE ALARM SYSTEM	LOT				127,000
3015	P.A. SYSTEM	LOT				43,000
3101-1	1000KVA UNIT SUBSTA	1	EA			45,000
-2	UNIT SUB PRI. FDR.	250	FT			19,000
-3	LIGHTING PANELS & FDRS.	5	EA			25,000
-4	LIGHTING FIXTURS & CKTS	LOT				505,000
-5	EMERG. LTG SYSTEM	LOT				52,000
-6	SECURITY LIGHTING	LOT				25,000
3102-1	120/208V PNL., TRANSF & FDR	7	EA			35,000
-2	120V BRANCH CKTS	LOT				14,000
-3	A/H UNITS	2	EA			13,000
-4	480 POWER	LOT				16,000
5001	COOLING TOWER	LOT				19,000
6751	BRIDGE CRANES	2	EA			3,000
				AMOUNTS FORWARDED		984,000

EXHIBIT F-23 (Continued)

KEY CALCULATIONS (ELECTRICAL)

The physical data used in preparing the base cost estimates was read off the site plans.

P&W VACUUM PUMPS (10)-50HP = 518 KVA

EMERG. GEN 500KVA DIESEL FOR VAC PUMPS - (TIME DELAY CONTROLS TO PREVENT SIMULTANEOUS START OF VAC. PUMPS AFTER OUTAGE)

UTIL. BLDG. BLDG. A/C ~~5000 TONS~~ 6000 TONS OF REFRIG. 5000 KVA 4160V

COOLING TOWERS

FANS - 12,000 TONS 1500 TONS/100HP (8)-100HP UNITS 800 KVA

PUMPS - 2000 HP (10)-200HP UNITS 2000 KVA

UTIL. BLDG. PROCESS REFRIG.

800 TONS - (1)-600HP UNIT 600 KVA 4160V

MISC. PUMPS

UTIL. BLDG.
- (3)-75HP CW PUMPS 230 KVA
- (3)-75HP HW PUMPS 230 KVA
- (1)-50HP SETTLING POND PUMP 52 KVA
- (10)-20HP MISC. 215 KVA

727 KVA

A/H UNITS (20) @ 100HP EA 2000 KVA

BRIDGE CRANES

(18) 30 TON 900 KVA

12.7 MVA

UTIL. BLDG. AIR COMPRESSOR (1)-150HP 150 KVA

128.3 MVA
CONNECTED

1/2 HP - 75HP - 480V RV
100 - 250HP - 480V - RV OFF SUBSTA.
OVER 250HP - 4160V
2000 & OVER - 12KV.

42,423 1/4HP MOTORS @36/PANEL = 1179 PANELS 24KVA/PANEL 66.5A.

28.3MVA

SEPARATION UNITS

28.3MVA

COMPRESSORS 269 @ 245KVA = 65.9 MVA

226 @ 67KVA = 15.2 MVA

51 @ 24KVA = 1.2 MVA

82.3 MVA

COMPRESSORS

C1 (4)-60HP = 245KVA 269 TOTAL = 65.9 MVA

C2 (4)-15HP = 67 KVA 226 TOTAL = 15.2 MVA

C3 (4)-5HP = 24KVA 51 TOTAL = 1.2 MVA

82,300 KVA - COMPR
28,300 KVA - SEP. UNITS
110,600 KVA

56 UNIT SUBS
2000KVA

31-4
29-5

240
14-3
46-4

240

43-3
17-4

(43)-3
(17)-4

(14)-3 C2
(46)-4 C2

(51)-C3
(9)-0 C3

(31)-4-C1
(29)-5-C1
33-5 C1

17-4
15-5

TYPICAL FOR 240

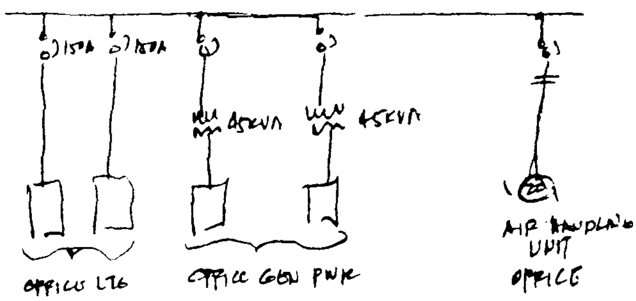
MAIN BLDG. - 2 FLOORS - 1200' X 600'   1,440,000 SQ. FT.

LIGHTING & GEN. POWER LOAD 4 WATTS/SQ. FT   **5,760 KVA**

(6) - 1000KVA UNIT SUBS.
240,000 SQ FT/UNIT SUB
720KW LTG · 240 KW GEN PWR

OFFICE - 100' X 200'   2 FLOORS   40,000 SQ. FT

LIGHTING & GEN. POWER 7 WATTS/SQ.FT. = **280 KVA**



51,200 SQ FT OFFICE @ 7W/ft² = 358 KW.

1,503,740 ft² @ 5 w/ft² = 7,519 KW

7,877 KW

1,559,940 ft² (total) x 2 w/ft² = 3.1 MW (pwr.)

COMPRESSORS = 82.3 MVA

WHEELS = 28.3 MVA

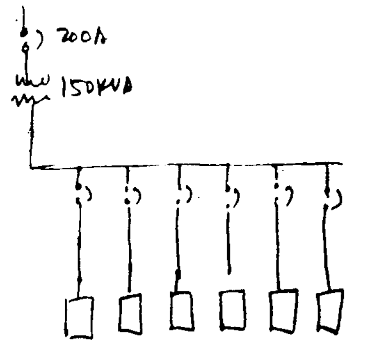
BLDG PWR = 12.7 MVA

123.3 MVA @ 90% PF = 111.0 MW

BLDG LTG. & PWR = 7.9 MW (8.8 MVA)

STAGES 1-35

667PA CO
13,644 WHEELS 9.1MVA @ 36/PANEL = 379 PANELS USE 378 PANEL



(9) - 4 TRANSF

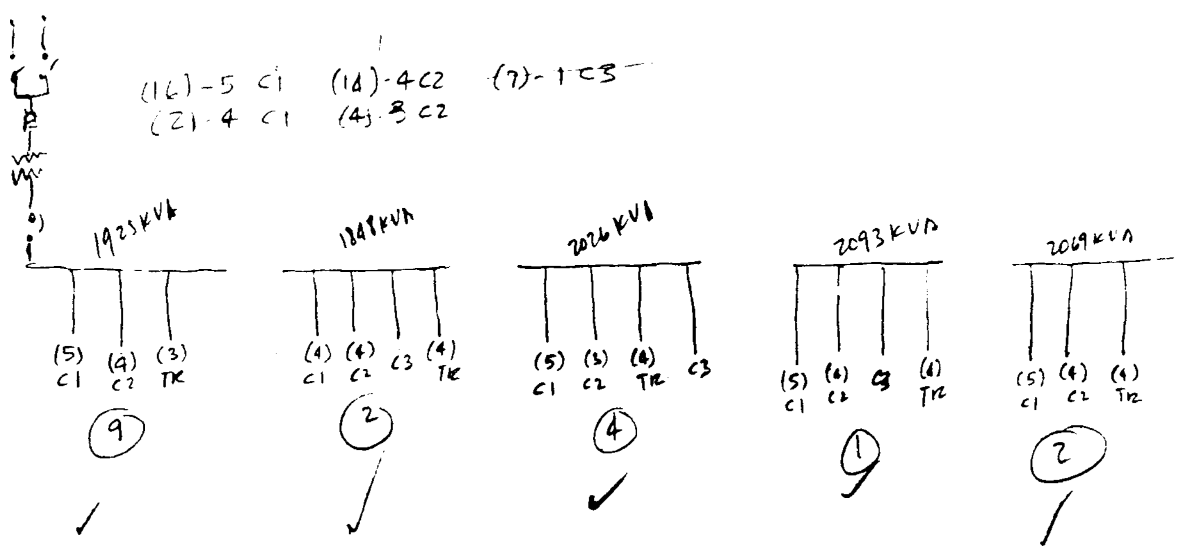
TYPICAL FOR 63

9,072
21,560
4,556
168
35,356 KVA

(88)	C1 - 245KVA	21560 KVA
(68)	C2 - 67KVA	4556 KVA
(7)	C3 - 24KVA	168 KVA

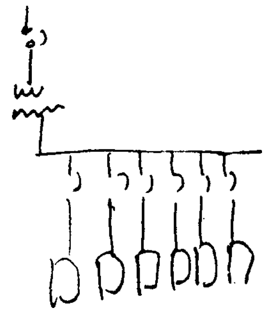
18 UNIT SUBS

(16)-5 C1 (14)-4 C2 (7)-1 C3
(2)-4 C1 (4)-3 C2



STAGES 36-55

14,428 WHEELS 9.6MVA @36/PANEL 401 PANELS OR 402 PANELS



TYP FOR 67

(97) - C1 - 245KVA 23,765KVA

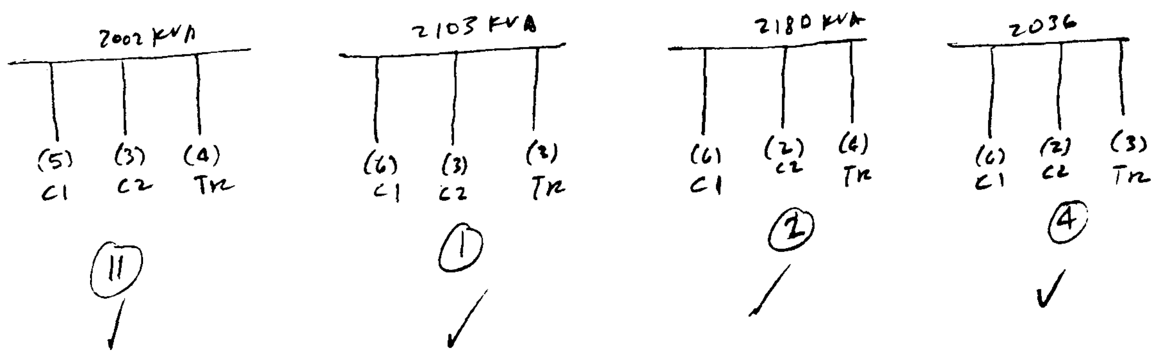
(48) - C2 - 67KVA 3,216KVA

9648
23,765
3216
36,629

18 UNIT SUBS

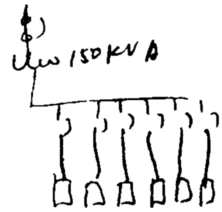
(7) - 6 C1 ~~(6) - 2 C2~~ ~~(5) - 3 TR~~

(11) - 5 C1 (12) - 3 C2 (13) - 4 TR



37
18
15

14,351 WHEELS 9.6 MVA @36/PANEL - 399 PANELS USE 402 PANELS



TYP FOR 67 (61)

(78) (84) C1 - 245KVA 20580KVA

(102) (110) - C2 - 67KVA 7370KVA

(40) (44) - C3 24KVA 1056 KVA

9648
20580
7370
1056

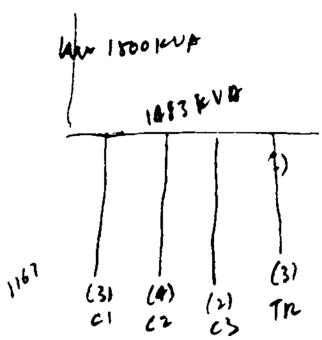
38654

20 UNIT SUBS

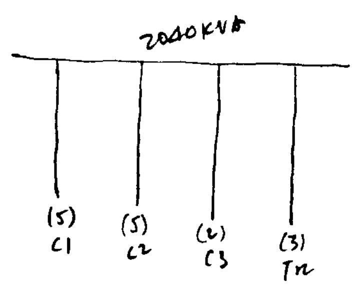
(2) - 1800KVA

(12) - 4 C1 (6) - 5 C2 (14) - 2 C3 (11) - 3 TR

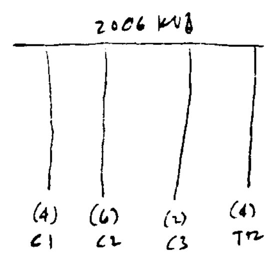
(8) - 5 C1 (12) - 6 C2 (4) - 3C3 (7) - 4 TR



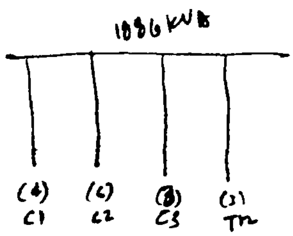
(2)



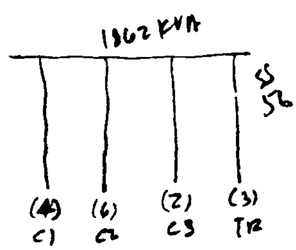
(6)



(7) SS-57



(4)



(1)

INSTRUMENTATION AND CONTROL SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATES

DESCRIPTIVE SUMMARY

The instrumentation and control system for the plant provides for:

- Data acquisition, storage, and manipulation for both technical and commercial aspects of plant operation
- Process control
- Protection of process hardware and plant equipment
- Safety monitoring for operating personnel
- Special nuclear materials accounting and safeguards

Data acquisition, storage, and manipulation systems and personnel safety systems for this plant are similar to those for a gas centrifuge enrichment plant of equivalent capacity. The costs for these items are consistent with gas-centrifuge enrichment plant estimates.

The instrumentation and control system envisioned for this plant consists of a main computer system with backup, data bus switching system, and various remote data units. All of these items, with the exception of the remote data units are scaled from similar units for a gas-centrifuge uranium enrichment plant. The remote data units can be simple sensing and signal processing units or a more complex system with built-in control logic, depending on the hardware or system items being monitored or controlled. The philosophy followed in the conceptualization of this system was to provide as many of the control functions as possible at the lowest system level so as to not burden the main computer system. The main computer system will provide system performance monitoring and control system override as required for process variation or sublevel control malfunction.

Process monitors and controls are provided for the following systems:

- Cascade
- Compressors
- Product stream helium separation device
- Tails stream helium separation device

The TESA is also tied into the system computer for monitoring and control of the feed, tails, and product streams. Functions of the various equipment elements, such as the autoclaves and desublimation chambers are monitored.

Monitor and control functions for the main process gas include gas pressure and temperature at various locations, gas compositions, and various functions of the process components.

BASE COST ESTIMATE (INSTRUMENTATION)

Often process control and equipment protective instrumentation cost is estimated* to be 13 percent of the vendors' invoice total for the equipment instrumented. The cost of installing instrumentation is estimated to be 50 percent of its acquisition cost. The process equipment for the VSUEP is extraordinarily expensive, relative to the remainder of the plant but the required instrumentation is not. So the cost of process equipment instrumentation for the VSUEP is assumed to be 9.8 percent of the installed cost of the process equipment or $168,907,000. The cost of the required data acquisition systems is included in this ~10 percent. The cost of the safety monitoring and safeguards systems is negligible relative to the other instrumentation costs.

INDUSTRIAL SYSTEMS CONCEPTUAL DESIGN AND COST ESTIMATES

DESCRIPTIVE SUMMARY

Industrial systems include equipment for shipping and receiving goods, materials handling, shop tools, and furniture for 163 desk workers.

Exhibit F-24 shows a functional flow diagram for the VSUEP.

*Peters, M. S. and K. D. Timmerhaus (1968). Plant Design and Economics for Chemical Engineers, New York: McGraw Hill Book Company.

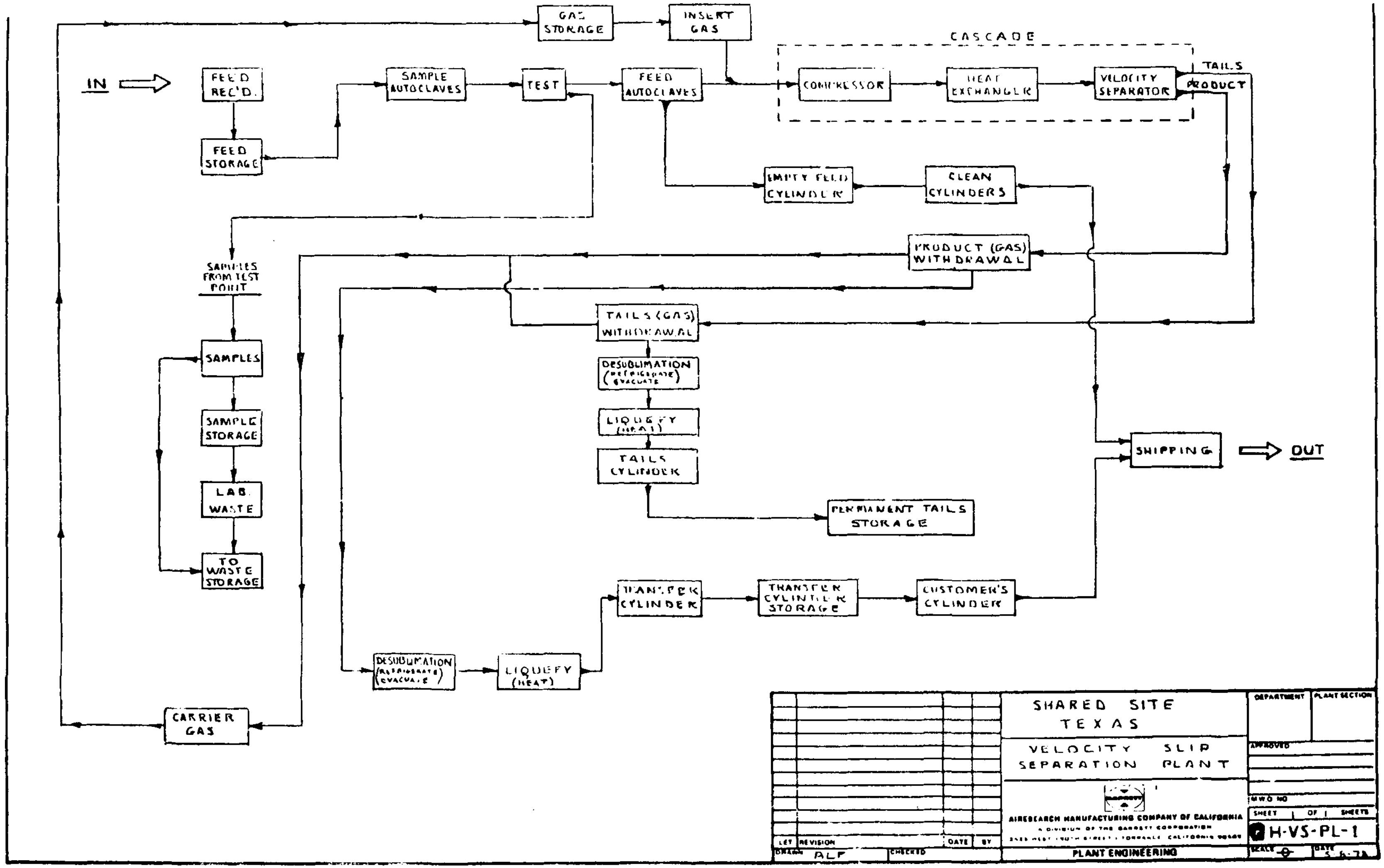

GAS STORAGE
INSERT GAS
CASCADE
IN
FEED REC'D.
FEED STORAGE
SAMPLE AUTOCLAVES
TEST
FEED AUTOCLAVES
COMPRESSOR
HEAT EXCHANGER
VELOCITY SEPARATOR
TAILS
PRODUCT
EMPTY FEED CYLINDER
CLEAN CYLINDERS
SAMPLES FROM TEST POINT
PRODUCT (GAS) WITHDRAWAL
TAILS (GAS) WITHDRAWAL
SAMPLES
DESUBLIMATION (REFRIGERATE) (EVACUATE)
LIQUEFY (HEAT)
SAMPLE STORAGE
TAILS CYLINDER
SHIPPING
OUT
LAB. WASTE
PERMANENT TAILS STORAGE
TO WASTE STORAGE
TRANSFER CYLINDER
TRANSFER CYLINDER STORAGE
CUSTOMER'S CYLINDER
DESUBLIMATION (REFRIGERATE) (EVACUATE)
LIQUEFY (HEAT)
CARRIER GAS
SHARED SITE
TEXAS
VELOCITY SLIP
SEPARATION PLANT
AIRESEARCH MANUFACTURING COMPANY OF CALIFORNIA
A DIVISION OF THE GARRETT CORPORATION
PLANT ENGINEERING
DEPARTMENT
PLANT SECTION
APPROVED
MWO NO
SHEET 1 OF 1 SHEETS
H-VS-PL-1
LET
REVISION
DATE
BY
DRAWN ALF
CHECKED
SCALE
DATE

EXHIBIT F-24

BASE COST ESTIMATES (INDUSTRIAL)

Exhibit F-25 presents the base cost estimates

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. X

CLASSIFICATION PRELIMINARY

DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT

PREPARED BY A.L. PEPIN

PAGE 1 OF 9

6 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
8001	MOBILE EQUIPMENT								AMOUNT FORWARDED		
8004	5 TON TRUCK	5							15000	75000	
-1	½ TON PICKUP TRUCKS	2							6000	12000	
8001	3YD FRONT END LOADER	1							55000	55000	
-1	TRASH CONTAINERS	10							300	3000	
6753	(LUMBER) STRADDLE CARRIER	2							300 000	600 000	
-1	15T FK. LIFT TRUCK	1							60 000	60 000	
									AMOUNTS FORWARDED		805 000

EXHIBIT F-25

E3F-96

E3F-97

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ___ MECH ___ SITE/BLDG ___ CIVIL ___ ELEC ___ O/S UTIL ___ ARCH ___ OWNER ___ OCCUP. X	CLASSIFICATION PRELIMINARY DATE 5-8-78
JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT	PREPARED BY A.L. PEPIN	PAGE 2 OF 9

7 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
8002	MEDICAL EQUIPMENT								AMOUNT FORWARDED		
-1	NURSES DESK	1							330	330	
-2	DESK CHAIR	1							140	140	
-3	TYPEWRITER	1							900	900	
-4	(WAITING) SIDE CHAIRS	6							70	420	
-5	INSTRUMENT CABINETS	2							125	250	
-6	MEDICINE CABINETS	3							125	375	
-7	WHIRLPOOL BATH	1							1000	1000	
-8	SPECIAL SINK CONTROLS	2							100	200	
-9	EXAMINATION CHAIR	2							1000	2000	
-10	EXAMINATION TABLE	1							4000	4000	
-11	WHEEL CHAIR	1							200	200	
-12	STRETCHERS	4							75	300	
-13	4 DRAWER FILES	4							135	540	
-14	COUCHES	4							200	800	
-15	REFRIGERATOR	1							500	500	
-16	STERALIZER	1							1000	1000	
-17	ROLL-A-ROUND TABLES	2							150	300	
-18	DIATHERMOY MACHINE	1							1500	1500	
-19	MEDICAL SCALES	1							150	150	
-20	HEAT LAMPS	2							200	400	
-21	HOT PLATE	1							100	100	
-22	MAGNIFIER GLASS UNIT	2							100	200	
									AMOUNTS FORWARDED		15,605.

EXHIBIT F-25 (Continued)

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. ____ MECH ____ SITE/BLDG ____ CIVIL ____ ELEC ____ O/S UTIL ____ ARCH ____ OWNER ____ OCCUP. X	CLASSIFICATION PRELIMINARY DATE 5-8-70
JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT	PREPARED BY A.L. PEPIN	PAGE 3 OF 9

7 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
	(CONT.)								AMOUNT FORWARDED		
8002	MEDICAL EQUIPMENT										
-23	MEDICAL INSTRUMENTS	GROUP							500	500	
-24	MEDICAL SUPPLIES	GROUP							2000	2000	
-25	MEDICAL MISC.	GROUP							1000	1000	
6752	SHOP ELECT. TRUCK	2							800	1600	
-1	3WHL BICYCLE	2							300	600	
									AMOUNTS FORWARDED		5700.

EXHIBIT F-25 (Continued)

E3F-99

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ______ MECH ______ SITE/BLDG ______
CIVIL FLEC ______ O/S UTIL ______
ARCH ______ OWNER ______ OCCUP. X

CLASSIFICATION PRELIMINARY

DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT

PREPARED BY A. L. PEPIN

PAGE 4 OF 9

7 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	UNIT COST	SUB-TOTALS	TOTAL
8000	STANDARD EQUIPMENT			AMOUNT FORWARDED		
8005	OFFICE DESK	300		330	99000	
-1	OFFICE DESK CHAIRS	300		140	42000	
-2	OFFICE SIDE CHAIRS	200		70	14000	
-3	OFFICE TABLES	200		190	38000	
-4	DRAFTING TABLES	20		425	8500	
-5	4 DRAWER FILES	200		135	27000	
-6	2 DRAWER FILES	200		100	20000	
-7	2 DR. 18" X 36" CABINETS	150		110	16500	
-8	36" BOOK CASES	150		40	6000	
-9	WASTE PAPER BASKETS	300		10	3000	
-10	55 GAL TRASH DRUMS	100		10	1000	
-11	DRAWING FILE CABINETS	2		900	1800	
-12	VERICAL FILES	20		150	3000	
-13	TYPEWRITERS	75		900	67500	
-14	CALCULATORS	50		150	7500	
-15	STATIONERY	MISC.		VARIOUS	2000	
-16	PENCIL SHARPENERS	100		10	1000	
-17	CLOCKS	10		80	800	
-18	CARD FILES	50		20	1000	
-19	DRAFTING LIGHTS	20		60	1200	
-20	DRAFT'G. BD. ST. EDGES	20		40	800	
-21	COPIER MACHINE	2		35000	70000	
				AMOUNTS FORWARDED		431,600.

EXHIBIT F-25 (Continued)

E3F-100

AIRESEARCH MANUFACTURING COMPANY Torrance, California	COST ESTIMATE SHEET STRUCT. MECH SITE/BLDG CIVIL ELEC O/S UTIL ARCH OWNER OCCUP. X	CLASSIFICATION PRELIMINARY DATE 5-8-78
JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT	PREPARED BY A.C. PEPIN	PAGE 5 OF 9

7 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT	UNIT COST	SUB-TOTALS	TOTAL
8000	STANDARD EQUIPT.			AMOUNT FORWARDED		
-22	BLUE PRINT MACHINE	2		20,000	40 000	
-23	DATA PROCESS'G. EQUIPT.	GROUP		250,000	500 000	
6752	SHOP GAS TRUCKS	2		800	1600	
-1	SHOP ELECT TRUCKS	4		800	3200	
-2	3 WHL BOX BICYCLES	8		300	2400	
8010	CAFETERIA EQUIPMENT					
-1	KITCHEN EQUIPT.	GROUP		300 000	300 000	
-2	TABLES	350		40	14000	
-3	CHAIRS	100		100	10500	
-4	SNACK BAR EQUIPMENT	GROUP		70 000	70 000	
				AMOUNTS FORWARDED		941,700

EXHIBIT F-25 (Continued)

TOTAL 1,394,610

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY
DATE 5-4-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEP. PLANT
PREPARED BY A.L. PEPIN
PAGE 6 OF 9

8 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
8000	MAINT. EQUIPMENT								AMOUNT FORWARDED		
-1	SCISSOR LIFT-A-LOFT	2							2000	4000	
-2	PEDISTAL GRINDERS	4							150	600	
-3	LADDERS	50							50	2500	
-4	TOOL CRIB SUPPLIES	GROUP							GROUP	20 000	
-5	BRAKE	1							5000	5000	
-6	SHEAR	1							6000	5000	
6751	JIB CRANES	3							1200	3600	
1-1	BRIDGE CRANE	1							20000	20 000	
6752	FORK LIFT TRUCK	1							10 000	10 000	
8008 -7	WORK BENCHES	300							75	22500	
-8	SHOP STOOLS	300							50	15000	
-9	BENCH VISES	300							100	30 000	
-10	ARBOR PRESS	4							1000	4000	
-11	SHAPER	2							8000	16000	
-12	GRINDER	2							8000	16000	
-13	LATHE	2							15 000	30 000	
-14	WELDER	6							1200	7200	
-15	METAL SAW	4							1200	4800	
-16	DO-ALL SAW	4							1500	6000	
-17	STOCK RACKS	300 FT							400	12000	
-18	PARISHABLE TOOLS	GROUP							GROUP	20 000	
-19	HAND TOOLS	GROUP							GROUP	20 000	
									AMOUNTS FORWARDED		274 200

EXHIBIT F-25 (Continued)

E3F-102

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. X

CLASSIFICATION
PRELIMINARY

DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT

PREPARED BY A. L. PERIN

8 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT							UNIT COST	SUB-TOTALS	TOTAL
8008	MAINT. EQUIPMENT									AMOUNT FORWARDED		
6752-1	SHOP GAS TRUCKS	8								800	6400	
-2	SHOP ELECT TRUCKS	8								800	6400	
-3	3 WHL BOX BICYCLES	15								300	4500	
-4	GARAGE REPAIR EQUIPT	GROUP								50 000	50 000	
•												
										AMOUNTS FORWARDED		67300

EXHIBIT F-25 (Continued)

TOTAL 341,500

E3F-103

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION: PRELIMINARY

DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT

PREPARED BY A. L. PERINE

PAGE 8 OF 9

9 CODE	DESCRIPTION	QUANTITIES AMOUNT		UNIT	UNIT COST	SUB-TOTALS	TOTAL
8005	OFFICE [illegible]				AMOUNT FORWARDED		
-1	SUPV. STANDUP DESK	7	10		[illegible]	1500	
-2	FOREMAN'S DESK	1	2		330	660	
-3	FOREMAN'S CHAIR	1	2		140	280	
-4	FOREMAN'S SIDE CHAIRS	6	10		70	700	
-5	FOREMANS TABLE	1	2		190	380	
-6	PROCESS SEC'Y DESK		1		330	330	
-7	TYPEWRITER		1		900	900	
-8	SECY CHAIR		1		100	100	
-9	BOOKCASE	1	2		40	80	
-10	4 DR FILE	2	4		135	540	
-11	2 DR 18X36 CABINETS	1	2		110	220	
-12	WASTE PAPER BASKETS	2	3		10	30	
6751	30T BRIDGE CRANES		4		90 000	360 000	
-1	15T FK LIFT TRUCK		4		60 000	240 000	
-2	10T FK LIFT TRUCK		4		50 000	200 000	
6753	15T WEIGH SCALE (± 1#)		10		60 000	600 000	
						14	05,720
						~~14~~	~~06,640~~
					AMOUNTS FORWARDED		~~805,720~~

EXHIBIT F-25 (Continued)

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET
STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY
DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT
PREPARED BY A. L PEPIN
PAGE 8 OF 9

9 CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
8005	OFFICE FURN. & EQUIPT								AMOUNT FORWARDED		
-1	SUPV. STANDUP DESK	10							150	1500	
-2	FOREMAN'S DESK	2							330	660	
-3	FOREMAN'S CHAIR	2							140	280	
-4	FOREMAN'S SIDE CHAIRS	10							70	700	
-5	FOREMANS TABLE	2							190	380	
-6	PROCESS SEC'Y DESK	1							330	330	
-7	TYPEWRITER	1							900	900	
-8	SECY CHAIR	1							100	100	
-9	BOOKCASE	2							40	80	
-10	4 DR FILE	4							135	540	
-11	2 DR 18X36 CABINETS	2							110	220	
-12	WASTE PAPER BASKETS	3							10	30	
6751	30T BRIDGE CRANES	4							90 000	360 000	
-1	15T FK LIFT TRUCK	4							60 000	240 000	
-2	10T FK LIFT TRUCK	4							50 000	200 000	
6753	15T WEIGH SCALE (± 1#)	10							60 000	600 000	
									AMOUNTS FORWARDED		1405 720

EXHIBIT F-25 (Continued)

E3F-105

AIRESEARCH MANUFACTURING COMPANY
Torrance, California

COST ESTIMATE SHEET

STRUCT. ____ MECH ____ SITE/BLDG ____
CIVIL ____ ELEC ____ O/S UTIL ____
ARCH ____ OWNER ____ OCCUP. ____

CLASSIFICATION PRELIMINARY

DATE 5-8-78

JOB TITLE AND DESCRIPTION: VELOCITY SLIP SEPARATOR PLANT

PREPARED BY A.L. PEPIN

ID CODE	DESCRIPTION	QUANTITIES AMOUNT	UNIT						UNIT COST	SUB-TOTALS	TOTAL
	FEED & WITHDRAWAL								AMOUNT FORWARDED		
6751	30T BRIDGE CRANES	2							90 000	180 000	
-1	15T FORK LIFT TRUCKS	2							60 000	120 000	
-2	10 T FORK LIFT TRUCKS	2							50 000	100 000	
-3	15T WEIGH SCALES	5							60 000	300 000	
•											
6702	Q.C. & LAB. EQUIPT.	GROUP							300 000	300 000	
-1	TEST EQUIPT.	GROUP							200 000	200 000	
3013	FIRE EXTINGISHERS	50							300	1500	
									AMOUNTS FORWARDED		1201500

EXHIBIT F-25 (Continued)

A&E COST ESTIMATES

DESCRIPTIVE SUMMARY

Exhibit F-26 identifies the resources used in development of the construction schedules. Variable 13 contains the entire costs of the architectural and engineering effort represented by resources 17, 23, 29, 35, 37, 40, 41, 43, and 45.

COST ESTIMATE

The A&E cost estimate is $508 million. Typically, these A&E costs represent 14 percent of construction project cost (exclusive of land) for gas-centrifuge uranium enrichment plants. This value is perhaps twice that experienced in the chemical process industry.

PROJECT MANAGEMENT COST ESTIMATES

DESCRIPTIVE SUMMARY

Variable 14 contains the entire costs of the project management effort represented by resources 01, 08, 09, 10, and 11 identified Exhibit F-26.

COST ESTIMATE

The project management cost estimate is $290 million. Typically, this cost represents 17 percent of the combined construction project and A and E costs for DOE projects.

ALLOWANCES, INDIRECT COSTS, FEES, INTEREST DURING CONSTRUCTION, AND CONTINGENCY COSTS

DESCRIPTIVE SUMMARY

Exhibit F-27 shows the logic for calculating allowances, markups, indirect costs, fees, interest during construction, contingency, and start-up costs.

Allowances are costs incurred by construction subcontractors over and above their costs for direct labor and materials. The subcontractors will charge a fee on their burdened labor cost and a markup on their burdened material costs. The prime contractor, construction, and operations, will have indirect and overhead costs.

Contingency is a cost estimating account to cover unidentified miscellaneous costs, oversights, and uncertainty. It is difficult to subdivide contingency with any confidence. The entire amount is speculative. AiResearch experience has shown 21 percent to be a prudent amount to allow for contingency.

EXHIBIT F-26

CONSTRUCTION PROJECT RESOURCES DICTIONARY

VARIABLE	RESOURCE ACCOUNT NO.	DESCRIPTION OF RESOURCE	PARTICIPANT
14	01 PROJECT MANAGEMENT		OWNER
	07 FACILITIES PROGRAM MANAGEMENT		OPERATOR
14	08	ADMINISTRATION	
13	09	A&E	
13	10	CONSTRUCTION	
14	11	QUALITY ASSURANCE	
13	16 A&E		A&E
13	17	CONCEPTUAL DESIGN LABOR	
13	23	INTERIM CRITERIA LABOR	
13	29	TITLE I - PRELIMINARY DRAWINGS LABOR	
13	35	TITLE II - WORKING DRAWINGS LABOR	
13	36 LICENSING		A&E
13	37	SPECIAL NUCLEAR MATERIAL ACCOUNTABILITY	
13	40	ENVIRONMENTAL IMPACT REPORT	
13	41	SAFEGUARDS	
13	43	PRELIMINARY SAFETY ANALYSIS REPORT	
	44 CONSTRUCTION MANAGEMENT		A&E
	45	TITLE III - SUPERVISION	
6,7,8,9,	50	NONMANUAL FIELD LABOR	
10,11,12	51	INDIRECT COSTS	
	55 CONSTRUCTION		CONSTRUCTOR
	56	CRAFTSMAN, CIVIL	
	57	CRAFTSMAN, INSTRUMENTATION	
	58	CRAFTSMAN, ARCHITECTURAL	
6,7,8,9,	59	CRAFTSMAN, STRUCTURAL	
10,11,12	62	CRAFTSMAN, MECHANICAL	
	65	CRAFTSMAN, ELECTRICAL	
	66	CONSTRUCTION MATERIAL	
	68	CRAFTSMAN, MILLWRIGHT	
1	69 SEPARATOR AND COMPRESSOR MANUFACTURING		VENDOR
1	70	COMPONENT MANUFACTURER	
1	71	RAW MATERIAL AND OUTSIDE PURCHASES	
1	72	SUBASSEMBLY MANUFACTURER	
1	73	TOOLING, FREIGHT-IN, SHIPPING	
1	74	FINAL ASSEMBLY MANUFACTURER	
	75 STARTUP		
	76	START-UP CREWS	OPERATOR

EXHIBIT F-27

FIXED-CAPITAL COST EXTENSION

	Land	Other Architectural Systems	Structural Systems	Separator & Compressor Systems	Other Process Equipment	Other Mechanical Systems	Electrical Systems	Industrial Systems	Instrumentation	Totals*
Base Cost Estimate	R	S	T	U	V	W	X	Y	Z	
Freight in				+3% of base						
Subtotal	R	S	T	1.03U	V	W	X	Y	Z	
Allowances for Indirect, Procurement, Insurance, FICA, State and Local Taxes, Small Tools, Scrappage and Overage, Premium Labor Rates Costs	0%	+28%	+28%	+50%	+28%	+28%	+28%	+28%	+28%	
Subtotal	R	1.28S	1.28T	1.55U	1.28V	1.28W	1.28X	1.28Y	1.28Z	
Subcontractors' Markups and Fees	0%	0%	+10%	+10%	+10%	+10%	+10%	+10%	+10%	
Subtotal	R	1.28S	1.41T	1.70U	1.41V	1.41W	14.1X	1.41Y	1.41Z	
Construction Contractor's Indirect Costs		+15%	+15%			+15%	+15%	+15%		
Operations Contractor's Overhead	0%			+15%	+15%				+15%	
Subtotal	R	1.47S	1.62T	1.95U	1.62V	1.62W	1.62X	1.62Y	1.62Z	
Construction Project Cost (less land)						1.47S + 1.95U + 1.62 (T + V + W + X + Y + Z) =				P
Engineering (A&E) Fees Cost										+14%
Subtotal										1.14P
Project Management Costs										+7%
Subtotal										1.22P
Contingency for Oversight and Unidentified Miscellaneous										+21%
Subtotal										1.48P
Interest during Construction										23% of (1.48P+R)
Subtotal										1.82P + 1.23R
Start-up Costs										3 months of operating costs
Total										1.82P + 1.23R + 3 months of operating costs

*Land is not included in totals until calculation of interest during construction

Capital is required to finance the construction project. Interest on this capital is part of the fixed capital of the enterprise. It can be appreciable for construction projects extending over many years and if significant costs are incurred early in the construction period. A value of 23 percent has been used in gas-centrifuge project cost estimates.

COST ESTIMATE

Exhibit F-27 shows the calculations of the fixed-capital cost. The cost estimate itself is shown in Exhibit A-5.

START-UP COST ESTIMATE

DESCRIPTIVE SUMMARY

There is a period of time from when the first piece of process equipment is started until the plant is on-stream at steady-state. The costs incurred in getting the process equipment operating at steady-state are part of the enterprise fixed-capital costs. The VSUEP will come on-stream quickly but probably not smoothly. Several months of costs associated with startup will be incurred before the full-capacity SWU production rate is achieved.

COST ESTIMATE

The cost of startup is estimated to be equivalent to the cost of three months of steady-state operation of the plant. Exhibits F-27 and A-5 show the calculations of the start-up costs.

WORKING CAPITAL REQUIREMENT ESTIMATE

The working capital requirement is estimated to be equal to the value of three weeks production of separative work or about $1.4 million.

SECTION G

OPERATIONS PLAN

TIMING OF OPERATIONS

Implementation of the VSUEP Operations Plan starts when construction is completed and the plant becomes operational. The Construction Project Management turns over to the Operations Management a VSUEP which is on-stream at steady state.

The plant is designed for a 20-year life. The market for enriched uranium in 2009 is likely to be very different from that projected for 1989 so the technology of the Conceptual-Design VSUEP may well become obsolete. Also the plant may not be competitive by then because of more efficient enrichment methods.

NORMAL VSUEP OPERATIONS

The VSUEP will operate 24 hours per day, seven days a week, every day of the year. Standby equipment provided in the conceptual design is sufficient to allow switchout of process system components in need of repair, overhaul, or rework. The Design and Cost Estimates presume that the appropriate research and development work has been done to ensure process equipment reliability consistent with the standby and rework facilities provided. The cost of this development has not been included in the Estimates.

The normal operation of the plant will separate 0.0215 kg per sec of natural uranium UF_6 into 0.0011 kg per sec of UF_6 containing 3.31 mole percent $^{235}UF_6$, 0.0022 kg per sec of UF_6 containing 3.24 mole percent $^{235}UF_6$, and 0.0182 kg per sec of UF_6 containing 0.25 percent by weight $^{235}UF_6$.

OFF-DESIGN OPERATIONS

The cascade is designed to accept UF_6 feed 0.711 percent by weight $^{235}UF_6$. This feed is called natural feed. Because the cascade is designed for a particular set of assays so that it has no internal mixing losses, the plant separative capacity can be increased or decreased by accepting different assays for the feed, products, or tails streams.

The cascade produces two product streams. These streams can be blended in various proportions as shown in Exhibit G-1 to match a market demand for enriched uranium similar to that shown in Exhibit G-2. If all the two product streams are blended with enough natural feed to produce a single UF_6 product stream containing 3.2 percent by weight $^{235}UF_6$ the plant separative work loss would amount to 847 SWUs per year. If all these two streams could be sold separately, the effective plant separative capacity would be increased.

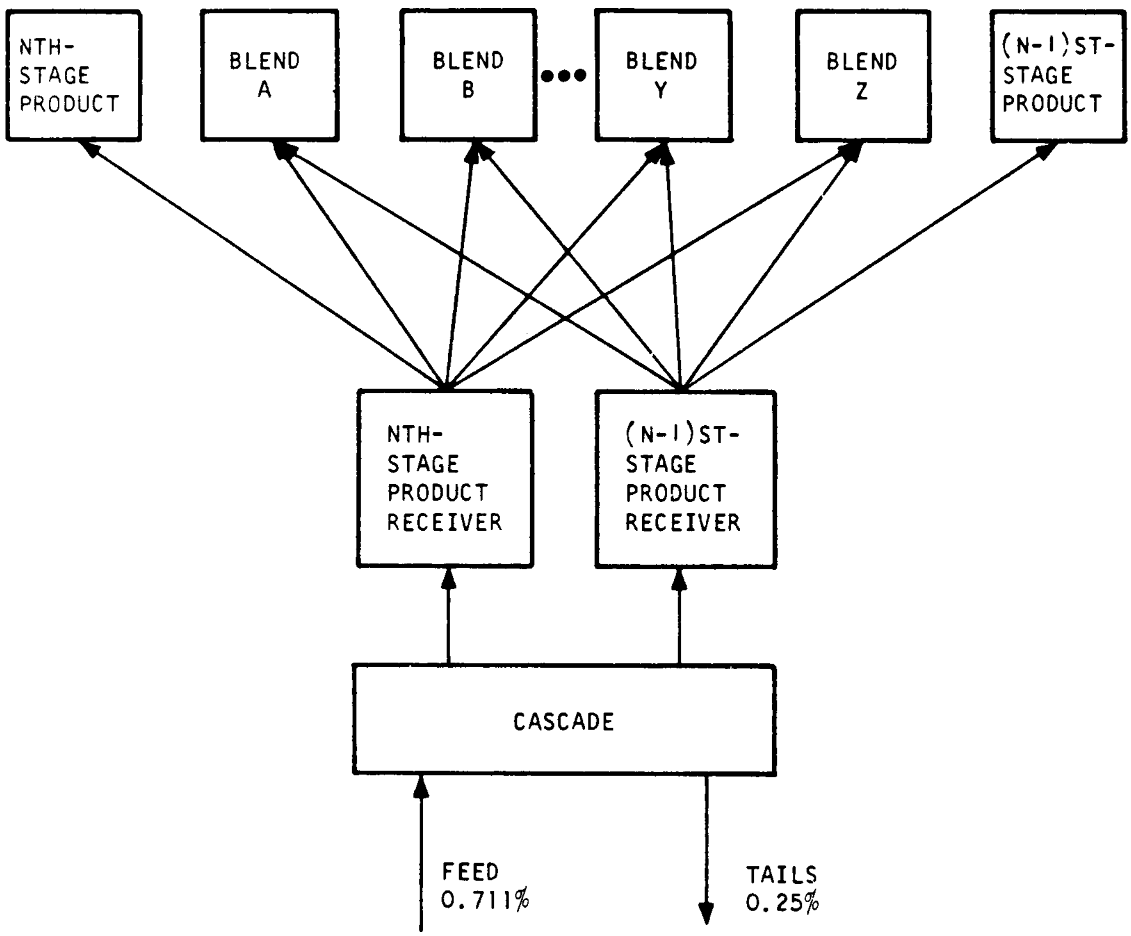


Exhibit G-1. Product Blending Relationships

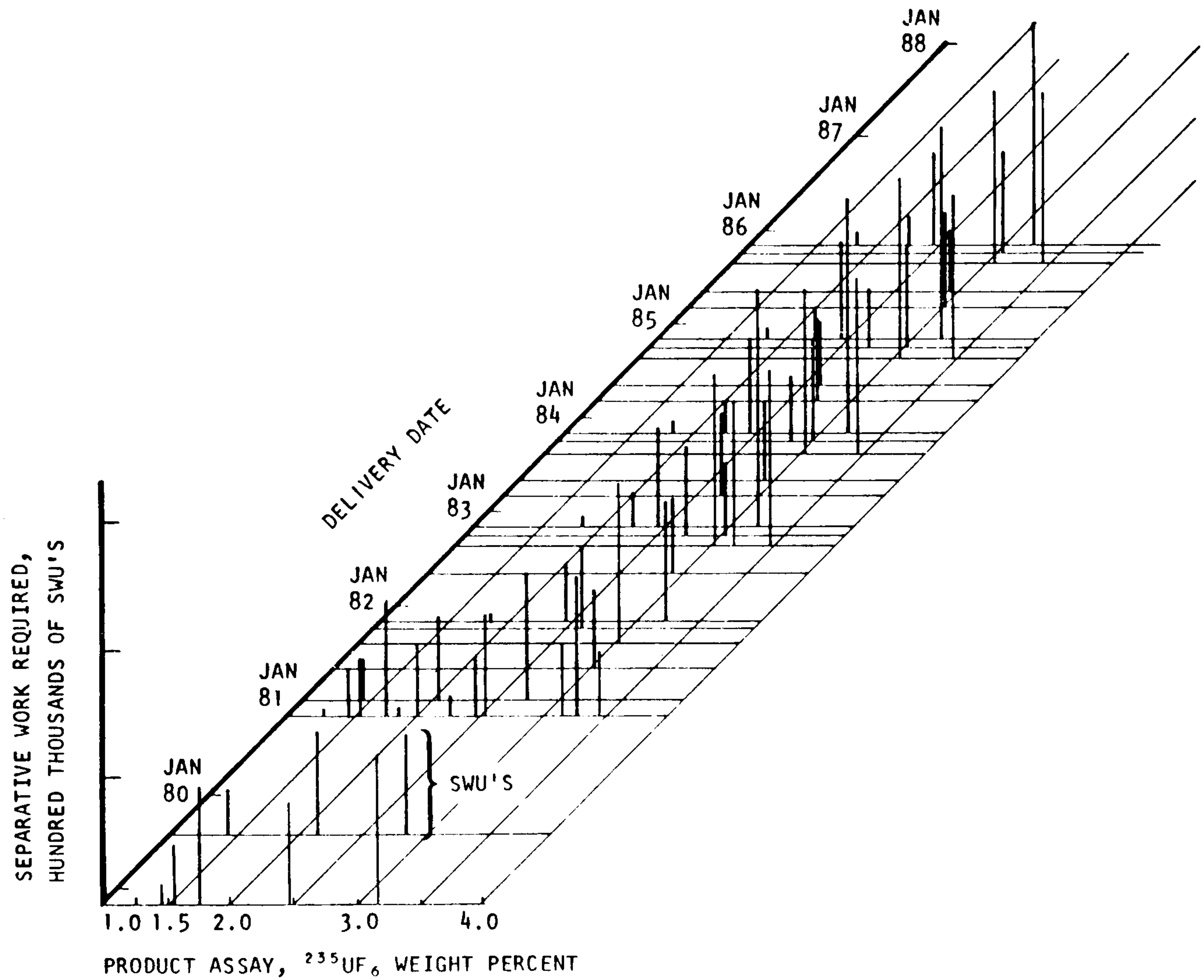


Exhibit G-2. A Projection of Assays and Separative Work Required to Fuel U.S. Reactors in the 1980's

The decision on whether to incur the mixing losses in the feed, the product, or inside the cascade will change from time to time and will depend on the joint effects of prices of natural UF_6, imputed value of tails, marginal cost of separative work, and prices of enriched uranium hexafluoride in the marketplace.

Any particular customer needs UF_6 of a particular assay but the plant manufacturers separative work. Separative work and UF_6 can be combined in a variety of ways to produce UF_6 of the customer's required assay. The VSUEP's separative work product is stored in the form of UF_6 having assays differing from that of natural uranium. The plant UF_6 inventory will consist of at least materials coming from the two product streams, the natural feed inventory, and plant tails not yet shipped to the Government stockpile. The plant can also buy enriched UF_6 in the marketplace.

This inventory will represent a substantial portion of the working capital even though the customers own the UF_6 in the enriched product they buy. In order to have adequate product blending scheduling flexibility, the plant must own a certain amount of UF_6 to hold its inventory of separative work. This separative work inventory must be optimally distributed among UF_6 lots of different assays so that the plant can continually strive to jointly optimize:

- The residual value of plant-owned UF_6.
- The cost-of-goods-sold in current UF_6 sales.
- The investment in UF_6 and separative work inventories.
- Scheduling flexibility.

FINANCIAL PLANS

ACCOUNTS RECEIVABLE

Although physical delivery of the end product may be irregular (generally once a year), the customer will verify the quantity and quality of the material and pay on a monthly basis. Based on terms of net 30 days, accounts receivable will equal one month's sales.

INVENTORY

The value of inventories of separative work, UF_6, and compressed gases is equal to three weeks' production of separative work.

ACCOUNTS PAYABLE, LABOR

Two weeks' labor is unpaid at any given time.

ACCOUNTS PAYABLE, MATERIAL AND SUPPLIES

One month's purchase of material and supplies is unpaid at any given time.

FEED AND PRODUCT CONTAINERS

The VSUEP will need UF_6 containers in addition to those supplied by the customers. These containers are, for purposes of this Cost Estimate, leased. The lease payments are included among overhead costs.

RESERVE FOR DECOMMISSIONING

Current regulations require that an enterprise processing radioactive nuclear materials create a fund adequate to fully pay for decommissioning the facility at the end of its life. An allowance for this reserve is part of overhead costs.

INCOME TAXES

A total tax rate on income is 52 percent. This includes 48 percent for federal income taxes and 4 percent for state income taxes. Computation of taxable income together with operating loss carryovers and use of investment tax credit is on a book basis. The project is likely unable to utilize all initial operating losses for profit protection within the loss carryover period specified by current tax regulations.

INVESTMENT TAX CREDIT

A credit against income tax is allowed for investments in qualified property. Because of the special-use nature of the building, the total capital investment in building, equipment, and machines will be eligible for the maximum credit of 7 percent. The credit is applied after all operating loss carryovers have been exhausted and must be used within seven years from the time the assets are placed in service. Due to the capital intensive nature of the project, even with government financial assistance, it appears not possible to utilize all of the investment tax credit within the time period specified by current tax regulations. The loss of this credit results in an increase in required price for a SWU.

CASH

The major portion of funds required will be borrowed on an as-required credit arrangement. Accordingly, the nominal cash balance is 20 percent of accounts payable.

REVENUE

Revenues include the monthly payments by the utility customers as SWU's are produced.

DEPRECIATION

The required depreciation allowances are estimated by use of a capital recovery factor of 0.16275.

INTEREST

Interest on the prior year's borrowings is calculated at an annual rate of 10 percent on the outstanding debt at the end of the prior year. Interest on current year borrowings is calculated at an annual rate of 5 percent on the current year borrowings on the assumption that the average outstanding amount borrowed is only 50 percent of the total borrowed. Interest on debt retired during any year is calculated in the same manner.

To maintain the 85:15 debt/equity (invested capital) ratio, 85 percent of the net cash required is borrowed.

DEBT

It is anticipated that 85 percent of the funds will be borrowed. Accordingly, a debt/equity (invested capital) ratio of 85:15 is being used. Borrowings are determined on a year-by-year basis. At such time as there is an overall positive cash flow, net borrowings cease.

All funds produced from operations will be used to reduce debt except for a modest dividend. When the debt/equity ratio becomes 50:50, the balance of the debt at that time is assumed to be retired over the remaining life of the project.

INVESTED CAPITAL

As noted under the debt section above, it is anticipated that the equity investors will contribute 15 percent of the net cash required to finance the project. Contributions are made on a year-by-year basis.

DIVIDEND

As a project approaches maturity and demonstrates the ability to generate a net profit, a dividend on equity capital is paid.

FINANCIAL MODEL

AiResearch has developed a computer program to analyze the major interactions anticipated during the construction and operation of the plant. The program involves the user with a measurement of the risk, with respect to SWU pricing policy, by utilizing a range of values associated with each specific variable. Construction and operating costs utilized in the financial model are derived from information in Exhibits D-3 and D-4 in Section D of this document. The detailed cost estimates are compiled into 14 major variables for construction cost and 5 major variables for operations. Two other elements, schedule and production, were prepared from a critical path method analysis and cascade performance analysis, respectively. Each variable has been assigned minimum (most optimistic), nominal (most probable), and maximum (most pessimistic) values, from which a probability distribution for each variable is derived. The maximum and minimum values are speculative. No attempt has been made to reconcile them with the information in Exhibit B-1 of this document. This computer program has not been applied to the VSUEP project because the unit cost of separate work from it is so far larger than any prices the market is likely to accept.

SECTION H

OPERATIONS ITEMS

CODE OF ACCOUNTS

PURPOSE

The code of accounts identifies the unit cost estimates with larger aggregate estimates.

DESCRIPTION OF ACCOUNTS

The operations costs code consists of Variable No. alone. As for the capital items, the Variable No. aggregates costs for use in Monte Carlo simulation of the enterprise cash flow using the AIRESEARCH PRIVATELY-OWNED URANIUM ENRICHMENT PLANT ECONOMIC RISK MODEL COMPUTER PROGRAM. Exhibit H-1 shows the components of operations costs. Exhibits D-4 and H-2 through H-6 give the numerical values of these variables.

VARIABLE NO. 16: LABOR

Variable No. 16 identifies the costs of labor, including fringe, associated with VSUEP operations. Exhibit H-2 identifies the labor categories reflected in the cost estimates.

VARIABLE NO. 17: PROCESS EQUIPMENT UPKEEP MATERIALS

Variable No. 17 identifies all costs associated with stocking spares and other process-equipment replacement parts, routine maintenance and overhaul materials, and of lost production capacity during process-equipment failure-induced downtime. It does not include maintenance, repair, and overhaul labor. This labor is included in costs identified by Variable No. 16. Exhibit H-3 shows the details of the cost estimate which applies to separators and compressor systems only.

VARIABLE NO. 18: STANDARD EQUIPMENT AND BUILDING UPKEEP

Standard equipment and building and grounds upkeep is provided by subcontractors. The costs estimates for these services represent the costs of the subcontracts for the items identified. The subcontractor's bill will cover his costs of labor and materials as well as his mark-ups, overhead, and profits. Exhibits H-4 and H-5 identify the components of the cost estimates for Variable No. 18.

VARIABLE NO. 19: UTILITIES

Electric power is the primary "raw material" for the manufacture of separative work. The velocity-slip process also consumes some helium and uses much cooling water.

VARIABLE 20: OVERHEAD AND MISCELLANEOUS

The items included in the cost aggregate identified by Variable No. 20 are listed in Exhibit H-6.

VARIABLE 21: PRODUCTION

Variable H-21 represents not a cost estimate but the effective separative capacity of the VSUEP.

BASE COST ESTIMATES FOR ANNUAL DIRECT COST OF OPERATIONS

Annual direct costs of operations consist of the costs of labor, maintenance, utilities, and overhead. Because the customer supplies the UF_6 processed, there is no cost of raw materials. The cost of the enterprise-owned inventory is included in working capital. Exhibit H-1 presents the base cost estimates for the annual direct cost of operation.

EXHIBIT H-1

ANNUAL COSTS OF OPERATIONS

	Costs, Millions of Dollars
Labor	6.764
Separator and Compressor Maintenance	278.955
Other Process Equipment Maintenance	20.000
Other Maintenance	22.907
Power	37.492
Other Utilities	0.726
Overhead	107.540
Total	474.39

EXHIBIT H-2

ANNUAL COSTS OF LABOR

Function	No. of People	Unit Annual Direct Cost, Dollars	Total Annual Direct Cost, Dollars
President	1	60,000	60,000
Executive Vice-President	1	55,000	55,000
Assistants	2	40,000	80,000
Secretaries	4	18,000	72,000
Subtotal	8		267,000
Finance			
Vice-President	1	45,000	45,000
Controller	1	40,000	40,000
Purchasing Manager	1	30,000	30,000
Treasurer	1	30,000	30,000
Risk Manager	1	30,000	30,000
Information System Manager	1	40,000	40,000
Professionals	6	25,000	150,000
Programmers	2	20,000	40,000
Clerks	3	15,000	45,000
Secretaries	6	12,000	72,000
Subtotal	23		522,000
Marketing			
Vice-President	1	60,000	60,000
Sales Manager	1	50,000	50,000
Physical Distributions Manager	1	40,000	40,000
Professionals	2	25,000	50,000
Clerks	4	12,000	48,000
Secretaries	2	12,000	24,000
Subtotal	11		272,000
Administration			
Corporate Secretary	1	35,000	35,000
NRC Liaison Manager	1	30,000	30,000
Public Relations Manager	1	30,000	30,000
Personnel Manager	1	35,000	35,000
Security Manager	1	30,000	30,000
Auditor	1	30,000	30,000
Nurses	3	14,000	42,000
Professionals	10	25,000	250,000
Clerks	3	12,000	36,000
Secretaries	3	12,000	36,000
Subtotal	25		554,000

EXHIBIT H-2 (Continued)

Function	No. of People	Unit Annual Direct Cost, Dollars	Total Annual Direct Cost, Dollars
Counsel			
Corporate Counsel	1	50,000	50,000
Clerks	1	20,000	20,000
Secretaries	1	15,000	15,000
Subtotal	3		85,000
Quality Assurance and Technical Services			
Manager	1	40,000	40,000
Professionals	3	30,000	90,000
Inspectors	6	17,000	102,000
Technicians	8	17,000	136,000
Clerks	2	12,000	24,000
Secretaries	2	12,000	24,000
Subtotal	22		416,000
Manufacturing			
Vice-President	1	50,000	50,000
Materiel Manager	1	40,000	40,000
Inspectors	10	17,000	170,000
Schedulers	2	15,000	30,000
Clerks	5	12,000	60,000
Secretaries	2	12,000	24,000
Subtotal	21		374,000
Operations Manager	1	40,000	40,000
Supervisors	3	24,000	72,000
Cascade Operators	6	15,000	90,000
Control Room operators	6	15,000	90,000
TESA Operators	6	15,000	90,000
Drivers	4	14,000	56,000
Safeguard and Plant Protection Personnel	20	12,000	240,000
Clerks	3	12,000	36,000
Secretaries	1	12,000	12,000
Subtotal	50		726,000

EXHIBIT H-2 (Continued)

Function	No. of People	Unit Annual Direct Cost, Dollars	Total Annual Direct Cost, Dollars
Manufacturing (Continued)			
Process Engineering Manager	1	45,000	45,000
Engineers	1	27,000	27,000
Technicians	1	17,000	17,000
Programmers	1	24,000	24,000
Secretaries	1	12,000	12,000
Subtotal	5		125,000
Plant Engineering Manager	1	40,000	40,000
Supervisors	3	24,000	72,000
Draftsmen	2	22,000	44,000
Clerks	2	12,000	24,000
Secretaries	2	12,000	24,000
Engineers	3	24,000	72,000
Instrumentation Technicians	5	18,000	90,000
Separator-System Technicians	8	18,000	144,000
Electronics Technicians	5	18,000	90,000
Computer and Data System Technicians	5	18,000	90,000
Subtotal	36		690,000
Turbine Mechanics	5	22,000	110,000
Utility men	4	12,000	48,000
Mechanics	15	18,000	270,000
Refrigeration Mechanics	3	18,000	54,000
Grounds Maintainers	3	12,000	36,000
Steam Engineers	1	18,000	18,000
Plumbers	3	18,000	54,000
Sewage Plant Operators	1	18,000	18,000
General Laborers	5	12,000	60,000
Mechanical Foreman	3	24,000	72,000
Carpenters	2	18,000	36,000
Painters	2	18,000	36,000
Millwrights	6	18,000	108,000
Sheet Metal Workers	4	18,000	72,000
Electricians	10	20,000	200,000
Technicians	4	20,000	80,000
Machinists	4	18,000	72,000
Welders	2	18,000	36,000
Subtotal	77		1,380,000
Total	281		5,411,000
Fringes at 25%			1,352,750
Grand Total			6,763,750

EXHIBIT H-3

ANNUAL DIRECT COSTS OF SEPARATORS
AND COMPRESSOR SYSTEMS FAILURES AND
REPLACEMENT PARTS AND MATERIALS

	Time Interval Between Overhauls, Months	Period out of Service per Overhaul, Days	Between-Overhaul Failure Frequency per Year	Replacement Parts and Materials Costs per Overhaul, Dollars	Failure Induced Costs, Dollars	Annual Cost of Overhaul, Dollars	Annual Cost of Failures, Dollars
Separators	48	2	5,300	1,500	5,500	15,908,625	29,150,000
122.5" Compressors	48	2	34	150,000	1,500,000	10,087,500	51,000,000
73.5" Compressors	48	2	62	103,500	1,033,000	12,808,125	64,046,000
36.8" Compressors	48	2	68	59,250	592,500	8,087,625	40,290,000
24.5" Compressors	48	2	68	43,650	436,500	5,958,225	29,682,000
12.3" Compressors	48	2	35	25,350	253,500	1,755,488	8,872,500
6.7" Compressors	48	2	7	16,200	157,500	206,550	1,102,500
						54,812,138	224,143,000

ANNUAL COSTS OF REPLACEMENT PARTS AND MATERIALS FOR REMAINDER OF PROCESS EQUIPMENT

According to Jelen* annual costs for replacement parts and materials for a complex chemical process plant with severe corrosion conditions will amount to 4 percent of the investment. The investment in process equipment, exclusive of separators and compressor systems amounts to $440.6 million. Thus the cost of replacement parts and materials for the remainder of the process equipment amounts to $17.6 million per year.

The total additional costs incurred from failures in equipment other than separators and compressor systems are estimated to amount to $20 million per year.

*Jelen, F. C. (1970). Cost and Optimization Engineering, New York: McGraw-Hill Book Company, p. 348.

EXHIBIT H-4

STANDARD EQUIPMENT AND FACILITIES MAINTENANCE (SUBLET)

	Cost, Dollars per Year
Janitorial services	3,400,000
Grounds upkeep	238,000
Paving upkeep	561,000
Painting	1,564,000
Roof maintenance	586,000
Replacements (lights, tiles, toilet supplies, machine parts, etc.)	4,828,000
Outside utilities installations	1,530,000
Inside utilities installations	1,428,000
Carpentry	850,000
Air conditioning maintenance	1,462,000
Furniture maintenance	425,000
Typing and printing equipment maintenance	289,000
Rolling stock maintenance	340,000
Standard equipment replacements	4,624,000
Computer maintenance	782,000
Total	22,907,000

EXHIBIT H-5

ANNUAL UTILITY COST,
thousands of dollars

Utility Name	Units	Number of Units per Year	Cost per Unit, Dollars	Annual Cost, Dollars
Power	kwhr	937,300,000	0.04	37,492,000
Water	gallons	527,013,120	0.04	281,825
Fuel Oil	gallons	903,287	0.45	406,479
Nitrogen	gallons	12,000	0.24/100 SCF	2,793
Helium	lbs	2,000	4.50/100 SCF	10,000
Gas Equipment Rental	ea	2	12,000	24,000

EXHIBIT H-6

OVERHEAD

	Cost, Dollars per Year
Property taxes	66,000,000
License fees	50,000
Legal and consulting fees	50,000
Travel expense	20,000
Supplies and services	250,000
Insurance	40,000,000
Research and development	0
Advertising	0
Communications services	100,000
Storage containers	200,000
Q clearances	70,000
Miscellaneous	100,000
Government coordination	50,000
Decontamination reserve allowance	150,000
Financial fees and interest	100,000
TOTAL	107,540,000

SECTION I

GLOSSARY

ACR	acre
AEC	U.S. Atomic Energy Commission
A&E	architectural and engineering
CFR	Code of Federal Regulations
CPFF	cost plus fixed fee, a contract term
CPM	Critical Path Method of Scheduling
CY	cubic yard
DF	desublimer for UF_6
DOE	U.S. Department of Energy
EA	each
EEL	energy rating
EIR	Environmental Impact Report
ERDA	U.S. Energy Reserach and Development Administration
FOB	free of board, a contract term
FSAR	Final Safety Analysis Report
FWB	Fahrenheit wet bulb
GCUEP	gas-centrifuge uranium enrichment plant
GN	gaseous nitrogen
GNC	Garrett Nuclear Corporation
He	helium
HF	hydrogen fluoride
HP, hp	horsepower
HVAC	heating, ventilation, and air conditioning
HX	heat exchanger
H&N	name of construction contractor
JMUEP	jet-membrane uranium enrichment plant
KVA	kilowatt-amperes
kw	kilowatts
LF	linear foot
LN_2	liquid nitrogen
MGT	management
MSF	thousands of square feet
MW	megawatts
NFPA	National Fire Protection Association
NPSH	net positive suction head
NM	modified Mercalli scale
NRC	U.S. Nuclear Regulatory Commission
N_2	nitrogen
PGM	program
PSAR	Preliminary Safety Analysis Report
PSF	pounds per square foot
PSI	pounds per square inch
psig	pounds per square inch guage
QA	quality assurance
RH	relative humidity
RORA	Repair, Overhaul, and Rework Area
SAR	Safety Analysis Report
SCAQMD	South Coast Air Quality Management District

SCFM	standard cubic feet per minute
SEPARATORS	velocity-slip isotope separation devices
SF	square feet
SNMA	Special Nuclear National Accountability
SSE	safe-shutdown earthquake
swpg	static pressure water guage
SY	square yards
SWU	separative work unit equivalent to the amount of separative work required to prepare 0.33 kilograms of uranium enriched to 2.8 percent ^{235}U from 2 kilograms of natural uranium. SWU is also equivalent to the older term kgU of separative work.
TDH	total dynamic load
TESA	UF_6 Feed and Withdrawal Area
^{235}U	the isotope of uranium having atomic weight of 235
UF_6	uranium hexafluoride
UO_2F_2	uranyl fluoride
VELOCITY SELECTORS	velocity-slip isotope separation devices
VSUEP	Velocity-Slip Uranium Enrichment Plant
Y	ratio of specific heats for the gas

SECTION J

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