

ESSAYS ON URANIUM ENRICHMENT

by

RICHARD ALAN CHARPIE

B.S., Massachusetts Institute of Technology  
(1973)

S.M., Massachusetts Institute of Technology  
(1975)

SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE  
DEGREE OF

DOCTOR OF PHILOSOPHY

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FEBRUARY, 1979

© Massachusetts Institute of Technology 1979

Signature of Author.....*12/18/78*.....  
Department of Management, Date

Certified by.....  
Thesis Supervisor

Accepted by.....  
Chairman, Department Committee



FEB 23 1979

LIBRARIES

# ESSAYS ON URANIUM ENRICHMENT

by

RICHARD ALAN CHARPIE

Submitted to the Department of Management  
in February, 1979 in partial fulfillment of the requirements  
for the Degree of Doctor of Philosophy

## ABSTRACT

This thesis consists of three essays on uranium enrichment drawn from the author's work as a member of the M.I.T. Energy Laboratory's Nuclear Fuel Assurance Project.

The first essay provides the background information necessary to an understanding of the two subsequent essays. The essay begins with a brief description of enrichment technologies, and moves to a historical summary of the market, political, and institutional events which bear directly on the later essays. The major historical theme is a description of the promotion and subsidization of private industrial participation in the nuclear fuel cycle as the vehicle for making the transition from a military, politically controlled, industry to a commercial, privately controlled industry. Minor themes include the tension between the international political system and the international market system, and the gigantic uncertainties which currently prevail in international nuclear markets.

The second essay proposes an institutional model of U.S. enrichment policy, and substantiates two propositions which are suggested by this model. The model recognizes two sets of objectives which determine a nation's enrichment policy, and posits an organizational argument for presuming that commercial objectives, particularly enrichment privatization, will predominate over security objectives in the formulation of U.S. enrichment policy. This proposition is substantiated by examining U.S. enrichment policy with respect to enrichment production, pricing, contracting, and technology transfer.

In addition, the second essay proposes that the result of this behavior has been the destruction of U.S. credibility as a reliable supplier of enrichment services. The preeminence of the privatization policy over international multilateral policies, and the failure to reconcile the inconsistencies between these two policies, led to a foreign concern about nuclear fuel supply assurance and a resulting proliferation of foreign enrichment projects. This untoward result has defeated both the U.S.'s commercial and security objectives and created a circumstance of grave uncertainty in the international enrichment and uranium markets which continues to plague today's policy makers.

The third essay examines some aspects of one variant of the medium-term nuclear fuel bank proposed by the Carter Administration and the Nuclear Non-Proliferation Act of 1978. After describing the motivation for a fuel bank, and its linkage to the problem of nuclear fuel assurance and weapons proliferation, the essay offers a stockpile forecast which indicates that due to the prevailing excess enrichment capacity during the next decade, large geographically dispersed enriched uranium stockpiles will be created, even in the absence of a fuel bank. Therefore, the relevant policy choice is between this market-managed system of international stockpiling and the creation of an international administrative body to manage a centralized fuel bank. Having defined the broad policy alternatives the essay proposes a specific plan for such a fuel bank and proceeds to criticize it. This critique casts doubts on the benefits of such a fuel bank, due to the nature of the political compromises necessary for its creation, and points out some of the potentially adverse feedback effects that such a bank could have on the nuclear market.

Thesis Supervisor: Professor Henry Jacoby

## ACKNOWLEDGEMENTS

I wish to thank my thesis supervisor, Professor Henry Jacoby, for his assistance and encouragement throughout the duration of this thesis. His ability to successfully wear two hats, as co-principal investigator on the Nuclear Fuel Assurance Project and as thesis supervisor, has contributed substantially to the progress of my research by coaxing me in a direction which simultaneously satisfied academic and policy analysis goals. In addition, I wish to thank Dr. Thomas Neff, the Project's other co-principal investigator, for his assistance with the analysis. Lastly, thanks are due to the Department of Energy whose financial support of the Fuel Assurance Project made the research possible.

## TABLE OF CONTENTS

	<u>Page</u>
TITLE PAGE.....	1
ABSTRACT.....	2
ACKNOWLEDGEMENTS.....	4
TABLE OF CONTENTS.....	5
LIST OF TABLES AND FIGURES.....	12
<u>ESSAY #1:</u> ENVIRONMENTAL FACTORS RELEVANT TO THE EVOLUTION OF THE U.S. ENRICHMENT INDUSTRY.....	15
1.0 Enrichment Technology.....	16
1.1 The Gaseous Diffusion Technology.....	16
1.2 The Unit of Enrichment Capacity--The SWU.....	17
1.3 Other Enrichment Technologies.....	22
2.0 The Political Environment.....	24
2.1 The U.S. Transition from Military to Civilian Control of Atomic Energy (1948-1954).....	24
2.2 Atoms for Peace and the Promotion of Atomic Energy (1954-1964).....	27
2.3 Enrichment Privatization (1964-1978).....	30
2.4 International Attempts at Proliferation Controls (1970-1978).....	36
2.4.1 The Treaty on Non-Proliferation of Nuclear Weapons (NPT).....	36
2.4.2 The Zänger Committee and the London Suppliers' Conferences.....	38
2.4.3 The International Nuclear Fuel Cycle Evaluation (INFCE).....	41
2.4.4 The Nuclear Non-Proliferation Act of 1978.....	41

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
3.0 The International Market Environment.....	44
3.1 Uranium Oxide.....	44
3.1.1 Government Subsidization.....	44
3.1.2 Government Intervention: Three Embargoes.....	46
3.1.3 Spiralling Uranium Prices: Westinghouse's Commercial Impracticability and the Uranium Cartel.....	50
3.2 Competition in the Enrichment Market.....	52
3.3 Nuclear Reactors.....	55
3.3.1 Early Nuclear Power Programs (1955-1970).....	55
3.3.2 Reactor Slippage (1970-1978).....	57
4.0 Commercial Policies of AEC-ERDA-DOE.....	61
4.1 Reactor Subsidization and Promotion.....	61
4.2 Uranium Industry Subsidization and Protection.....	65
4.3 Operating History.....	67
4.3.1 Tails Assays.....	67
4.3.2 The Split Tails Program.....	68
4.3.3 The Advance Feed Program.....	70
4.3.4 The Preproduction Stockpile and Tails Recycle.....	71
4.4 Contracting History.....	72
4.4.1 Requirements Contracts.....	72
4.4.2 Long-Term Fixed Commitments Contracts, The Closing of the Order Books, and Conditional Contracts.....	73
4.4.3 ERDA'S Open Season and Case-by-Case Contract Relief.....	77

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
4.4.4 Adjustable Fixed Commitments Contracts.....	78
5.0 Summary.....	81
Essay # 1 Footnotes.....	87
Essay # 1 References.....	89
<u>ESSAY #2:</u> AN ORGANIZATIONAL MODEL OF U.S. ENRICHMENT POLICY.....	91
1.0 The Motivation for a Model.....	91
2.0 The Carnegie School of Organizational Theory.....	95
3.0 Application of Organizational Theory to U.S. Behavior.....	98
3.1 The Central Proposition.....	98
3.2 The Substantiation of the Proposition.....	100
3.3 The Implication of the Proposition: A Second Proposition.....	102
3.4 Subtleties Not Captured by the Propositions.....	104
3.5 Outline of the Essay.....	107
4.0 SWU Production.....	110
4.1 The Hatch-Levin Model.....	110
4.2 The Results of the Hatch-Levin Model.....	120
4.3 The Commercial Nature of the Hatch-Levin Model.....	122
4.4 Departure from Global Rationality.....	127
4.4.1 Operating Tails History.....	128
4.4.2 Stockpile Forecasting History.....	134
4.4.3 The Selection of Policies Based on Standard Operating Procedures.....	141
4.5 Summary.....	143

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
5.0 SWU Pricing and Contracting.....	145
5.1 A Narrative History of AEC Toll Enrichment Pricing.....	145
5.1.1 The 1966 Criteria: Cost Recovery REQ Pricing .....	145
5.1.2 Commercial REQ Pricing.....	150
5.1.3 A Return to Cost-Recovery REQ Pricing and a Change in Campaigns.....	152
5.1.4 The Initiation of LTFC Pricing and the Creation of an REQ-LTFC Price Differential.....	153
5.1.5 Further Price Increases and the Inclusion of Additional Costs.....	155
5.1.6 Fair Value Pricing.....	156
5.1.7 The Redefinition of the Cost-Recovery Campaign Period.....	162
5.2 Evaluation of the AEC Pricing Policies.....	163
5.2.1 Instability in Prices and Conventions.....	165
5.2.2 Underpricing of SWUs.....	172
5.2.2.1 Comparison with Accounting Cost.....	176
5.2.2.1.1 Lag Factors.....	176
5.2.2.1.2 The Use of Uninflated Costs.....	178
5.2.2.1.3 Levelized Pricing.....	178
5.2.2.1.4 Demand Overestimation....	179
5.2.2.1.5 Cost Underestimation....	180
5.2.2.1.6 Minor Factors.....	181
5.2.2.2 Comparison with Regulated Monopolist.....	182
5.2.2.3 Comparison with Fair Value Pricing.....	184
5.2.2.4 Comparison with Foreign Enrichers.....	187
5.2.2.5 Comparison with UEA.....	189
5.2.2.6 Underpricing Summary.....	193
5.2.3 Differential Pricing of SWUs.....	197
5.2.3.1 The REQ Surcharge.....	197



TABLE OF CONTENTS (CONT.)

	<u>Page</u>
5.2.3.2 The LTFC Advance Payment Credit.....	202
5.2.3.3 Summary of Differential Pricing.....	203
5.3 Pricing and Contracting Conclusion.....	205
6.0 SWU Technology Transfer.....	208
6.1 The 1971 Initiative.....	208
6.2 The 1974 Initiative.....	212
6.3 Technology Sharing Summary.....	213
7.0 The Decline in U.S. Supply Credibility.....	215
7.1 The Changing International Environment Confronted by the Enrichment Privatization Policy.....	216
7.2 The Momentum Grows for Privatization.....	218
7.3 The Failure of the 1971 Initiative.....	219
7.4 Intensified Pressure for Privatization and the Negative Impacts of LTFC Contracting.....	221
7.5 The Failure of the 1974 Initiative and the Weakness of Privatization.....	229
7.6 The Closing of the Order Books Further Tarnishes AEC Credibility.....	232
7.7 Subsequent Events Deepen Reigning Confusion.....	238
7.8 Conclusion.....	241
8.0 Summary.....	244
Appendix I Biases in the AEC Pricing of Split Tails Feed Sales (STFS).....	250
Essay #2 Footnotes.....	257
Essay #2 References.....	266

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
<u>ESSAY #3:</u> A CRITIQUE OF A MEDIUM-TERM NUCLEAR FUEL BANK PROPOSAL.....	269
1.0        Introduction.....	269
2.0        The Motivation for a Medium-Term Fuel Bank.....	271
2.1    A Definition of Medium-Term Assurance Fears.....	271
2.2    Two Polar Models of the Evolving Allocation System.....	274
2.3    Trends.....	278
2.4    The Role of a Medium-Term Fuel Bank.....	280
3.0        The Market Environment Without a Medium-Term Fuel Bank.....	281
3.1    Stockpile Forecasts.....	281
3.1.1    Demand Projections.....	282
3.1.2    Supply Projections.....	284
3.1.3    Aggregate Stockpile Forecast.....	297
3.1.4    Contracts Data.....	302
3.1.5    Disaggregated Stockpile Forecast.....	304
3.2    Summary.....	310
4.0        A Specific Medium-Term Fuel Bank Proposal.....	313
5.0        A Critique of the Fuel Bank Proposal.....	317
5.1    Depoliticization.....	317
5.2    Market Stimulation.....	324
6.0        Summary.....	327
Appendix I    Stockpile Accounting Conventions.....	334
Appendix II    The Impact of Uranium Supply on the Feasibility of International Stockpiling.....	343
Appendix III    The Direct Costs of an International Stockpile.....	346

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
Essay #3      Footnotes.....	348
Essay #3      References.....	351
Glossary of Acronyms.....	353

LIST OF TABLES

	<u>Page</u>
TABLE 1 COMPARISON OF USAEC NUCLEAR POWER FORECASTS 1961-1977.....	59
TABLE 2 FISCAL YEAR 1970-75 BUDGET SUBMISSIONS AND OBLIGATIONS FOR CIP/CUP.....	138
TABLE 3 FISCAL YEAR 1970-75 BUDGET SUBMISSIONS AND OBLIGATIONS FOR CASCADE POWER.....	139
TABLE 4 TOLL ENRICHMENT PRICING HISTORY.....	146
TABLE 5 PROJECTED AVERAGE COST OF SALES OF SEPARATIVE WORK FY 1966-1975.....	148
TABLE 6 ASSUMPTIONS USED AS BASIS FOR COMMERCIAL ENRICHMENT CHARGE OF \$28.70/SWU.....	151
TABLE 7 ASSUMPTIONS USED IN DETERMINING \$76/SWU FAIR VALUE PRICE.....	158
TABLE 8 COMPARISON OF \$53/SWU COST RECOVERY CHARGE AND \$76/SWU FAIR VALUE CHARGE.....	160
TABLE 9 COMPONENTS OF \$74.85/\$83.15 CHARGE.....	164
TABLE 10 COMPARISON OF ANNOUNCED REQ PRICE WITH ESCALATING PRICE CEILING.....	167
TABLE 11 COMPARISON OF EFFECTIVE REQ PRICE WITH ESCALATING PRICE CEILING.....	168
TABLE 12 COMPARISON OF PROPOSED FAIR VALUE PRICE WITH EFFECTIVE LTFC PRICE.....	185
TABLE 13 UEA AVERAGE SWU PRICE.....	191
TABLE 14 PRICE COMPARISON SUMMARY.....	194
TABLE 15 SHADOW PRICING OF TAILS MATERIAL.....	256
TABLE 16 OECD/IAEA FORECAST OF NON-COMMUNIST WORLD INSTALLED LWR NUCLEAR CAPACITY.....	283

LIST OF TABLES (CONT.)

	<u>Page</u>
TABLE 17 COMPARISON OF WORLD LWR CAPACITY ESTIMATES.....	285
TABLE 18 FORECASTS OF ENRICHMENT DEMAND DERIVED FROM OECD/IAEA GWE FORECASTS.....	286
TABLE 19 DOE ENRICHMENT CAPACITY.....	290
TABLE 20 FIRM FOREIGN ENRICHMENT CAPACITY.....	292
TABLE 21 POTENTIAL FOREIGN ENRICHMENT CAPACITY.....	296
TABLE 22 WORLD BASE CASE STOCKPILE FORECAST.....	299
TABLE 23 SENSITIVITY OF 1990 STOCKPILE TO INPUT ASSUMPTIONS.....	301
TABLE 24 DOE ENRICHMENT CONTRACT DELIVERIES.....	303
TABLE 25 EURODIF CONTRACT DELIVERIES.....	305
TABLE 26 URENCO CONTRACT DELIVERIES.....	306
TABLE 27 U.S.S.R. ENRICHMENT CONTRACT DELIVERIES.....	307
TABLE 28 DISAGGREGATED BASE CASE STOCKPILE FORECAST.....	308
TABLE 29 URANIUM SUPPLY AND DEMAND COMPARISONS.....	345

LIST OF FIGURES

	<u>Page</u>
FIGURE 1      SUMMARY TIME LINE.....	84
FIGURE 2      OPTIMUM TAILS ASSAY.....	117
FIGURE 3      THE REGION OF ACCEPTABLE CONTRACTS.....	273
FIGURE 4      BASE CASE STOCKPILES.....	309

Essay #1: ENVIRONMENTAL FACTORS RELEVANT TO THE EVOLUTION OF THE  
U.S. ENRICHMENT INDUSTRY.

This first essay shall provide the reader with the background information necessary to an understanding of the two subsequent essays. The essay begins with a brief description of enrichment technologies, and moves to a historical summary of market, political, and institutional events which bear directly on our later essays. This background material is neither sophisticated nor comprehensive. The information collected here is widely available in public sources. From these sources we have abstracted brief summaries of selective facts and events pertinent to uranium enrichment; the reader desiring more detailed information is referred to the citations.

## 1.0 ENRICHMENT TECHNOLOGY<sup>1</sup>

The enrichment stage is the crucial step in the front end of the light-water reactor (LWR) nuclear fuel cycle. A single efficiently sized enrichment plant represents a multibillion dollar capital investment whose output will supply the fuel demands of roughly 100 nuclear reactors.<sup>2</sup>

Enrichment is the process of raising the concentration of U-235 in uranium from naturally occurring levels (0.711%) to higher levels (3% for LWR fuel, 90% for nuclear weapons). Any enrichment process separates an incoming uranium feed stream into two outgoing streams: (1) an enriched product stream, consisting of uranium containing a greater percentage of U-235 than the feed stream, and (2) a tails stream, consisting of uranium containing a lesser percentage of U-235 than the feed stream.

### 1.1 The Gaseous Diffusion Process<sup>3</sup>

This separation may be achieved by any of a number of physical processes. Currently, the most widely used commercial enrichment process is the gaseous diffusion process, which is used in all U.S. and U.S.S.R. commercial enrichment facilities, and will soon be used in a newly constructed enrichment plant in France.



Gaseous diffusion operates on the physical result that isotopes of differing mass have differing mean speeds, and therefore will diffuse through a semipermeable barrier at differing rates. Specifically, U-235 diffuses through such a barrier more rapidly than U-238. As a result, if  $UF_6$  gas is pumped into a chamber divided by such a membrane, after awhile one half of the chamber will show a higher enrichment level than the other half of the chamber. If the more highly enriched gas is then used as the feed stream for a second chamber, the result is a progressively greater enrichment in the product stream. Because U-235 and U-238 are extremely similar in mass the degree of isotope separation accomplished by any single stage is small. Therefore it requires a series of many such diffusion chambers to achieve a 3% enriched product stream, and even more chambers to achieve a 90% enriched product stream. The electricity required to pump, compress, and cool the  $UF_6$  gas at each stage of the diffusion process renders this enrichment technology highly energy-intensive.

## 1.2 The Unit of Enrichment Capacity - The SWU

The capacity of a gaseous diffusion plant is measured in separative work units (SWUs). A SWU is a measure of the energy expended in separating a feed stream into a product stream and a tails stream. The greater the enrichment of the product stream, the greater the number of SWUs required to produce that stream; for

example, it requires more diffusion chambers, and thus more energy, to produce a 90% enriched product than a 3% enriched product.

The relationship between the feed stream, the product stream, and the tails stream is given by the following three formulae:

$$(1) F = T + P$$

$$(2) Fx_F = Tx_T + Px_P$$

$$(3) S = P(1-2x_P) \ln\left(\frac{x_P}{1-x_P}\right) - F(1-2x_F) \ln\left(\frac{x_F}{1-x_F}\right) \\ + T(1-2x_T) \ln\left(\frac{x_T}{1-x_T}\right)$$

where

- F = feed mass in kg
- T = tails mass in kg
- P = product mass in kg
- S = separative work units
- $x_F$  = feed assay (concentration U-235)
- $x_T$  = tails assay
- $x_P$  = product assay

Equation 1 states that total mass is conserved.

Equation 2 states that U-235 is conserved.

Equation 3 is a thermodynamic relationship which expresses the amount of work that must be done to separate the feed stream into the more highly enriched product stream and the depleted tails stream.

The three equations are usually written as:

$$(4) \quad F/P = \frac{x_P - x_T}{x_F - x_T}$$

$$(5) \quad T/P = \frac{x_P - x_F}{x_F - x_T}$$

$$(6) \quad S/P = (1 - 2x_P) \ln\left(\frac{x_P}{1 - x_P}\right) - \frac{F}{P} (1 - 2x_F) \ln\left(\frac{x_F}{1 - x_F}\right) \\ + \frac{T}{P} (1 - 2x_T) \ln\left(\frac{x_T}{1 - x_T}\right)$$

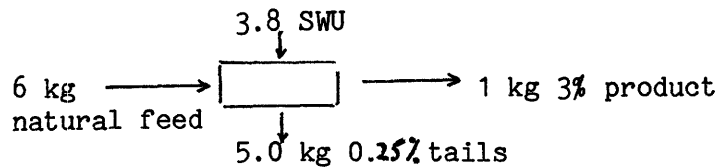
These equations reveal the strong relationship between uranium feed requirements, separative work requirements and tails assay. For example, suppose we wished to produce 1 kg of 3% enriched uranium. This could be done in a variety of ways:

1. We could operate the enrichment plant at a tails assay of 0.25%, i.e.,  $x_T = .0025$ , which means that we continue to deplete the feed stream by feeding it through diffusion chambers until the tails output has a U-235 assay of 0.25%. Given that

our product assay is 3% ( $X_p = .03$ ) we can use formulae 4-6 to calculate:

$$\begin{aligned} \text{feed assay } 0.711\% \left( \begin{array}{l} \text{F/P} \\ \text{S/P} \end{array} \right) \begin{array}{l} 3\% \text{ product assay} \\ 0.25\% \text{ tails assay} \end{array} &= 6.0 \\ 0.711\% \left( \begin{array}{l} \text{F/P} \\ \text{S/P} \end{array} \right) \begin{array}{l} 3\% \\ 0.25\% \end{array} &= 3.8 \end{aligned}$$

which tells us that 3.8 SWU must be applied to 6.0 kg of natural feed to produce 1.0 kg of 3% product; along the way, 5.0 kg of 0.25% tails will be produced. Diagrammatically,

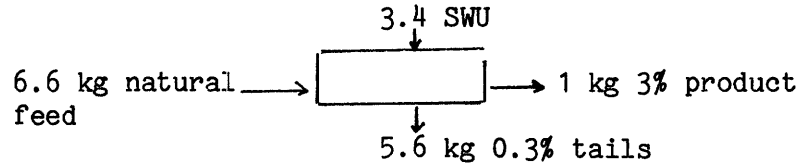


2. Similarly, we could choose to operate the enrichment plant at a higher tails assay of 0.3%. Because the feed stream need not be depleted as far, fewer SWUs must be applied to the task. Because the product contains the same number of atoms of U-235, however, just as the SWU requirement decreases, so the feed requirement increases. We calculate:

$$0.711\% \left( \frac{F/P}{0.3\%} \right)^{3\%} = 6.6$$

$$0.711\% \left( \frac{S/P}{0.3\%} \right)^{3\%} = 3.4$$

which yields the diagram:

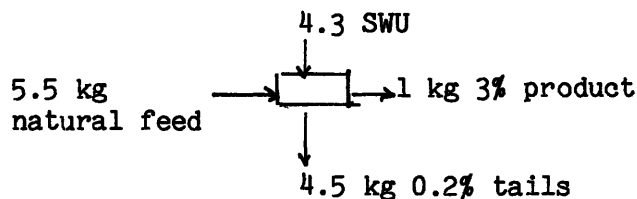


3. Conversely, we could reduce the tails assay to 0.20%, increasing the expenditure of separative work, but saving on feed requirements. We compute:

$$0.711\% \left( \frac{F/P}{0.2\%} \right)^{3\%} = 5.5$$

$$0.711\% \left( \frac{S/P}{0.2\%} \right)^{3\%} = 4.3$$

which yields the diagram:



In sum, the unit of enrichment capacity, the SWU, is not a measure of physical output, like tons/year, but a measure of the thermodynamic potential to create output. The physical output of an enrichment plant may only be calculated after values have been chosen for  $X_T$  and  $X_P$ .

### 1.3 Other Enrichment Technologies

A second emerging enrichment technology is the gas centrifuge process (GCP). The centrifuge process is currently in commercial use in the enrichment facilities of URENCO, a trinational enrichment consortium formed by Germany, Holland and the United Kingdom in 1970. The centrifuge process will also be the basis for the next increment of U.S. enrichment capacity, to be constructed at Portsmouth, Ohio.

The centrifuge process also takes advantage of the slight difference in the masses of the two uranium isotopes, U-235 and U-238, by filling a large cylindrical bowl with  $UF_6$  and spinning the bowl at very high speeds. Because the centrifugal force on the

heavier U-238 atoms is slightly greater than the force on the lighter U-235 atoms, the rotating  $UF_6$  gas is separated into an enriched product stream and a depleted tails stream.

The centrifuge process may eventually offer a cost advantage over the gaseous diffusion process because while its capital costs are comparable, it is significantly less energy consumptive. This feature, in conjunction with the fact that an efficiently sized centrifuge plant is roughly 1/3 as large as a diffusion plant, simplifies the siting of centrifuge facilities and permits a more flexible matching of SWU capacity to demand.

In addition to the centrifuge process, other enrichment technologies which are currently in the pilot plant, laboratory testing or early research stage include:

- (1) The Becker nozzle technology;
- (2) The South African stationary-wall centrifuge technology;
- (3) The laser enrichment technologies.

## 2.0 THE POLITICAL ENVIRONMENT

This section of the essay will provide a chronological sketch of the major domestic and international legislative events which have determined the political and institutional context within which the U.S. enrichment industry must operate.

### 2.1 The U.S. Transition from Military to Civilian Control of Atomic Energy (1948-1954)<sup>4</sup>

The discovery of natural radioactivity during the early years of the 20th century alerted scientists to the fact that energy was produced by the disintegration of heavy atoms. The fission process itself was discovered in 1939, and became the cornerstone of the first nuclear chain reaction in 1942. These experimental successes spawned the Manhattan Project, whose purpose was the development of an atomic bomb. Under the Project's control, nuclear reactors were built at Hanford, Washington, and later in South Carolina, for the production of weapons grade plutonium. In addition, uranium enrichment facilities were established at Oak Ridge, Tennessee, to produce highly enriched uranium. These efforts culminated in the explosion of two atomic bombs over Hiroshima and Nagasaki during August, 1945, and the subsequent surrender of the Japanese to end World War II.



In 1946, the U.S. put forth a comprehensive proposal for regulating nuclear power under the auspices of the United Nations. The Baruch Plan envisioned the establishment of an international authority responsible for managing all phases of the development and use of atomic energy. The authority was to establish a system of nuclear licensing, control, and inspection procedures in return for U.S. nuclear disarmament. The proposal failed due to the opposition of the Soviet Union, which wished to make U.S. disarmament a precondition of any negotiation of authority powers, rather than being contingent upon the successful conclusion of these negotiations.

Despite the failure of the Baruch Plan at the international level, the U.S. was left to confront the question of regulating the development of atomic energy at the national level. The result of these deliberations was the passage of the Atomic Energy Act of 1946 which transferred the control of nuclear power from the military services to a commission of five civilians. The Atomic Energy Commission (AEC) was subject to Congressional review by the Joint Committee on Atomic Energy (JCAE). The 1946 Act legislated a federal government monopoly of the nuclear fuel cycle. Private ownership of fissionable materials, or facilities for their production, or of patents relating to production technologies, was made illegal. All information concerning fissionable fuels, including their use as a source of electric power, was classified.

The AEC assumed the assets of the Manhattan Project on January 1, 1947, including the enrichment plants, research laboratories and production facilities located in the towns of Los Alamos, New Mexico, Oak Ridge, Tennessee and Hanford, Washington. They also inherited the nation's stock of atomic bombs, along with direct control of roughly 5,000 government employees as well as indirect control of 50,000 employees of private contractors. The AEC maintained absolute control over the entire nuclear fuel cycle, including responsibility for: (1) weapons production, (2) enrichment plant operation, (3) the promotion of a domestic yellowcake industry, (4) reactor licensing and leasing of fuel to reactor operations, (5) basic research in atomic and nuclear physics, and (6) determining and enforcing security classifications on information in its possession.

The AEC chose to pursue the contractor philosophy established under the Manhattan Project. Although the Atomic Energy Act of 1946 permitted the AEC itself to engage in research, construction and production, the Commission chose to employ private contractors for these purposes. Of the total AEC budget in any year, 95% was paid out to contractors, with only 5% being retained for AEC support personnel. Contractors have included universities, independent agencies, and industrial laboratories. In particular, enrichment plant contractors have included Union Carbide and Goodyear. Contracts were rarely let on the basis of competitive bidding; rather, contractors were selected on personal AEC judgments regarding

their efficiency, reliability and secrecy. Enrichment contractors are paid on a cost plus fixed fee basis. The relationship of the AEC to its contractors is a supervisory one. The AEC issues general policy guidelines, sets goals and reviews results; the contractor supplies scientific, engineering, administrative, management and direct labor skills.

During its early years the AEC functioned in an atmosphere of great secrecy, in an attempt to guard the state secrets relevant to the atomic bomb. Even information of only tangential importance to the weapons program was subject to strict security classifications. The Congressional watchdog committee assigned to AEC affairs, the Joint Committee on Atomic Energy (JCAE), did not know the size of the atomic stockpile, the current rate of output, or the unit cost of production. Therefore, the JCAE had no objective basis for evaluating performance or exercising control, and was often put in the position of merely rubber-stamping appropriations requests and giving formal approval to actions that had already been taken.

## 2.2 Atoms for Peace and the Promotion of Atomic Energy (1954-1964)<sup>5</sup>

On December 8, 1953, the first major step was taken towards lowering the barriers of secrecy that had been erected around the industrial applications of atomic energy. On this date President Eisenhower delivered his famous "Atoms for Peace" speech to the

United Nations. This speech proposed the creation of an International Atomic Energy Agency (IAEA) as a repository for fissionable materials contributed by the nuclear powers; the fissionable fuels were intended for use in the promotion of peaceful uses of nuclear power. Despite the rejection of the IAEA proposal by the U.S.S.R., the U.S. offer of international cooperation as a replacement for international competition in the commercialization of nuclear power was warmly received by most nations.

The implementation of President Eisenhower's proposals necessitated a series of legislative actions that were contained in the Atomic Energy Act of 1954. At the international level, the 1954 Act authorized the U.S. to negotiate Agreements for Cooperation with foreign nations regarding peaceful uses of nuclear energy. These Agreements were the foundation for exchanges of previously classified information concerning industrial uses of atomic energy, as well as some information on defense stocks essential to European allies.

Subject to the 1954 Act, the U.S. concluded a series of bilateral agreements for cooperation with foreign nations. These agreements specified that all nuclear materials would be used for peaceful purposes, that the U.S. had the continuing right to inspect all materials and facilities it supplied, and that U.S. consent was required to permit the retransfer of any material or facility to a

third nation. The conditions of these bilateral agreements set precedents for the multilateral negotiations that eventually led to the creation of the IAEA in 1957, although they may have limited the scope of powers available to the IAEA because they were already in place at the time of the IAEA's establishment. Despite President Eisenhower's original conception of the IAEA as a fuel bank for the promotion of peaceful nuclear power, it has never been used as a conduit for fissionable fuels or nuclear reactors. Instead, the Agency has functioned mainly as a locus of technical assistance to less-developed nations, and, since the passage of the Non-Proliferation Treaty in 1971, as an administrator of the international materials accounting safeguards system.

At the national level, the 1954 Act committed the government to the aggressive promotion of a private atomic energy industry as a replacement for government ownership of all stages of the nuclear fuel cycle. The AEC continued to retain title to all fissionable materials and continued to own the enrichment facilities, but private industry was permitted to possess (not own) fissionable fuels and to build, own and operate nuclear reactors under license from the AEC. During this era the AEC launched an extensive program of subsidization designed to encourage private industrial participation at various stages of the nuclear fuel cycle, with particular emphasis on the uranium mining and milling industry and reactor construction. (See Sections 4.1 and 4.2)

### 2.3 Enrichment Privatization (1964-1976)

In 1964 the AEC Act was amended to permit the private ownership of fissionable fuel. Subsequent to this amendment, a timetable was established for the termination of government nuclear fuel leases and the orderly transition to mandatory private ownership of fissionable fuels. This transition was concluded with the initiation of toll enrichment in 1971. As of January 1, 1971 utility customers must either purchase enriched uranium from the AEC, or supply their own natural feedstock and pay the AEC for the SWUs used to enrich this feed; these latter toll enrichment services were priced on the basis of the recovery of the government's costs. In addition, the AEC no longer guaranteed the repurchase of plutonium contained in utility spent fuel (see Section 4.1), although amendments permitted the establishment of private plants for spent fuel reprocessing. Finally, all existing government fuel leases had to be terminated by June 30, 1973, either by the purchase of the leased fuel, or its return to the government.

During this period, the government's stockpile of nuclear weapons had grown oversized, and its demand for fissionable materials had correspondingly declined. The bulk of the remaining military enrichment demand was for highly enriched uranium used to fuel naval submarine reactors. As the government demand declined, the civilian demand increased, largely as a result of the AEC's ten-year promotion

plan. Therefore, the primary function of the enrichment plants gradually evolved towards one of satisfying civilian needs for low enriched uranium to fuel LWRs, and away from one of satisfying military demands for highly enriched uranium for use in atomic weapons.

This evolution was accompanied by increasing political pressure for the privatization of the enrichment industry, that is the relinquishment of the government SWU monopoly, and a plan for the transition to a 100% privately owned fuel cycle. The role of the government was to be relegated to a posture of exercising regulatory oversight of health and safety standards through the vehicle of the licensing process. The process of privatization was foreshadowed by President Nixon's 1969 directive to the AEC which ordered them to prepare the three government enrichment plants for eventual sale to the private sector, by

"operating its uranium enrichment plants as a separate organizational entity within the AEC, in a manner which approaches more closely a commercial enterprise, ...(although) the President will not seek legislation at this time to authorize sale of the facilities to private industry...since the optimum time for this transfer will be sometime in the future."<sup>7</sup>

Although this sale was never carried out, the Nixon and Ford Administrations did succeed in engineering a broad reorganization of the federal atomic energy bureaucracy. On January 19, 1975, the Energy Research and Development Administration (ERDA), an independent agency responsible to the President and the Congress, was created,

along with the Nuclear Regulatory Commission. The responsibilities of the AEC were divided between these two agencies, by assigning ERDA responsibility for enrichment plant operations, SWU pricing, SWU contracting, the management of government stockpiles of natural and enriched uranium, and nuclear R&D (including the breeder program), while reserving to the NRC the health and safety regulatory issues surrounding the licensing process, including the question of permitting plutonium recycle in LWRs. This bifurcation was intended to separate the AEC's promotional, production, and research activities from its regulatory activities, on the grounds that it was logically inconsistent to ask the AEC to aggressively promote atomic development, on the one hand, and to conscientiously regulate its growth, in the public interest, on the other. Although ERDA was staffed, by and large, with old AEC personnel, ERDA assumed responsibility for many areas of non-nuclear R&D, including research into coal, solar, and geothermal technologies.

After President Nixon resigned his post, President Ford, and ERDA, carried the banner of enrichment privatization to the Congress in the form of the Nuclear Fuel Assurance Act (NFAA) of 1975. This legislation did not propose the sale of existing facilities, but rather supported the invitation to private corporations to build the next increment of enrichment capacity. The role of the Government was to assist in technology transfer and to provide a series of guarantees to private enrichers.



The NFAA was the culmination of a three year process of attracting private industrial interest in uranium enrichment. The process began in 1972, when the government invited private industry to make proposals for building, owning, and operating the next increment of domestic enrichment capacity. In response to this solicitation, a consortium of three corporations--Bechtel Corporation, Union Carbide Corporation, and Westinghouse Electric Corporation--formed the Uranium Enrichment Associates (UEA). Subsequently, Union Carbide and Westinghouse withdrew from UEA, however, Bechtel was later joined by Goodyear Tire and Rubber Company. In May 1973, the AEC awarded UEA the first Access Permit to previously classified uranium enrichment technology, and UEA entered a phase of project evaluation, which ended December 31, 1974, at a cost of \$6 MM.

This evaluation resulted in a UEA proposal to build, own, and operate, a 9 MMSWU gaseous diffusion enrichment plant in Dothan, Alabama, for operation in 1983. The projected cost of the facility was \$3.3 billion (1975 dollars), not including the cost of additional power supply to operate the plant, to be financed 15% by equity and 85% by debt; 40% of the financing was to be acquired from domestic sources and 60% from foreign sources. UEA proposed to offer 25-year toll enrichment contracts, priced to recover costs plus a 15% after tax rate of return on equity.

In addition, UEA concluded that some form of government cooperation and temporary guarantees were essential to UEA's ability to attract project financing. Therefore, on May 30, 1975, UEA submitted a proposal to ERDA asking for the negotiation of a contract to provide certain assurances to UEA. After review of the UEA proposal by ERDA, the State Department, and the Office of Management and Budget (OMB), President Ford submitted the NFAA to Congress on June 26, 1975. The NFAA would authorize ERDA to offer temporary assurances to private enrichment ventures, including:

1. buying enrichment services from private enrichers or providing enrichment services to private enrichers from the government stockpile to accommodate plant startup and loading problems;
2. guaranteeing the delivery of enrichment services to customers who hold SWU contracts with private enrichers;
3. assuming the assets and liabilities (including debt) of a private enricher if the project threatened to fail during the first year of commercial operation, at the call of the private enricher or the government, with compensation to domestic equity investors contingent on the reasons for failure and the performance of the equity investors.

The NFAA asked for contract authority of \$8 billion to provide these assurances, although if all went well, almost no government expenditures would be involved.

The NFAA became the center of a raging controversy in Congressional hearings, chiefly surrounding the nature of the guarantees suggested by the UEA proposal. The closing of the U.S. order books in mid-1974 (see section 4.4.2) was taken as undeniable evidence of the need for additional enrichment capacity, but many Congressional observers favored public rather than private ownership of uranium enrichment. Opposition to the NFAA was strengthened by a study of the UEA proposal, conducted by the Government Accounting Office (GAO), which characterized the NFAA as a "giveaway" to private industry. This viewpoint was adopted by enough members of Congress to stop passage of the NFAA during the 1975 and 1976 Congressional sessions.

With the accession of the Carter Administration in 1977, the emphasis on enrichment privatization was dropped. Instead, it was announced that the next increment of enrichment capacity would be 8.8 MMSWU of centrifuge capacity, to be built at Portsmouth, Ohio by the late 1980's, and to be government owned, but operated by private contractors. Presumably, this additional capacity will permit a re-opening of the order books as part of the Carter Administration's nuclear foreign policy of supply assurances aimed at restoring the

U.S.'s international image as a reliable supplier of enrichment services.

1977 also saw another reorganization of the federal energy bureaucracy. Slightly more than two years after the creation of ERDA, it was abolished and its responsibilities were assigned to the new Department of Energy (DOE). DOE was an attempt to consolidate bureaucratic responsibility for energy policy in a single agency, by combining ERDA with the Federal Energy Administration (FEA), in addition to consolidating energy-related portions of other agencies. DOE was chartered on October 1, 1977, and it assumed all of ERDA's prior responsibilities and personnel, including enrichment plant operations, contracting, pricing, and stockpile management. DOE was headed by James Schlesinger, who had been chairman of the AEC during the early 1970's. It was also during this period that the Joint Committee on Atomic Energy was abolished, and its watchdog role was transferred to the Senate Committee on Energy and Natural Resources, and the House Committee on Science and Technology.

## 2.4 International Attempts at Proliferation Controls (1970-1978)

### 2.4.1 The Treaty on Non-Proliferation of Nuclear Weapons (NPT)<sup>8</sup>

As the decade of the 1970's approached, the number of potential suppliers at each stage of the nuclear fuel cycle was increasing rapidly, and as weapons stockpiling programs tapered off, the goal of the nuclear industry switched from one of satisfying primarily military needs to one of satisfying commercial needs. With the forecasted rapid growth in commercial nuclear power and the rapid spread of nuclear technology, it became obvious that an international framework of safeguards was necessary to ensure that the commercialization of nuclear power was not accompanied by the widespread proliferation of nuclear weapons.

This safeguards framework was established by the NPT, which entered into force in March, 1970. All non-nuclear-weapon states which sign the NPT are obligated not to acquire nuclear weapons or explosive devices, and to accept IAEA-administered safeguards standards and inspections on all peaceful nuclear activities under their control; in particular these standards require all NPT parties to comply with IAEA safeguards on nuclear exports to non-weapon states, whether or not the importer is an NPT member. In return for signing the NPT, non-weapon states receive a guarantee from nuclear suppliers that they shall "cooperate in contributing" to peaceful nuclear development, with special attention to lesser developed countries (LDCs).

During the eight years since its negotiation, the NPT has been signed or ratified by 40 of the 53 nations having at least one element of the nuclear fuel cycle (mine, mill, enrichment plant, reactor, reprocessing plant) in their territory; 9 of the remaining 13 nations have concluded non-NPT safeguards agreements with the IAEA. France is the only avowed, non-Communist, nuclear weapons state which has not ratified the NPT, nor has it negotiated any safeguards agreement with the IAEA, chiefly due to the French refusal to demand a veto over retransfers of French nuclear fuels or components to third parties. Other non-NPT signatories of special concern include Communist China, Argentina, Brazil, India, Israel, Pakistan, South Africa and Spain.

#### 2.4.2 The Zänger Committee and The London Suppliers' Conferences<sup>9</sup>

The ratification of the NPT by many of the nuclear supplier nations led to a series of informal supplier conferences, held to consider a mutually agreeable set of fuel and technology export controls. In particular a special committee, known as the "Zänger Committee", was convened to specify what material and equipment needed to be covered by IAEA safeguards. The Zänger Committee encountered immediate difficulties in defining a list of relevant materials and technologies. The U.S. advocated the adoption of a comprehensive "trigger list" of materials and equipment which would

automatically incur safeguards in any international transaction. Other nations, particularly Germany and Japan, opposed this comprehensive list on the grounds that it would inhibit their ability to penetrate the U.S.-dominated export market. Beyond these disagreements, negotiators questioned the value of such a list in view of the non-representation of France (not an NPT party) and the U.S.S.R. (banned for fear of industrial espionage) at the Committee meetings.

Little progress was made in defining the list until the Indian "peaceful nuclear explosion" of May, 1974, shocked the suppliers into action. A list was agreed to in August, 1974, but the failure of the French to deposit the requisite letter of intent cast doubts upon its effectiveness. This unsatisfactory result led the U.S. to convene a further series of secret meetings, during 1975, among nuclear supplier states (France, Great Britain, Germany, U.S.S.R., Canada, Japan and the U.S.). The aim of these so-called London Conferences was to remove safeguards from commercial competition and to ban, or at least strictly control, sales of enrichment or reprocessing technologies.

It is difficult to assess the results of the London Conferences, because the discussions were pursued in an atmosphere of strict secrecy, aimed at avoiding the image that an export cartel was being formed. Nonetheless, the broad policy directions of the participants

could be perceived, as summarized by Wonder

(19):

"Canada, for its part, continued to press for a 'model contract' which would standardize the safeguard terms. The United States stressed the regional fuel-cycle facility concept, though apparently did not present any concrete proposals in this regard. The British suggested some politically more acceptable equivalent of the NPT be found to accommodate non-parties who objected to the discriminatory overtones (e.g. imposing no real obligations on existing nuclear weapon states) of the treaty. The Germans and French emerged as the chief obstacles to a more comprehensive agreement. The French typically suspected ulterior commercial motives of the United States though it is said that the French position softened as time went on. The Germans, however, remained difficult. The German delegation maintained nuclear transactions were becoming conventional in character and that severe restriction on export activity would be counter-productive. The Germans and French perspectives on the discriminatory character of a cartel and the threat export restraint would pose to their industries grew almost indistinguishable."<sup>10</sup>

Needless to say, in the face of these conflicts, no comprehensive safeguards agreement was reached. The immediate achievement of the London meetings was an exchange of letters between supplier states, in January, 1976, in which the exporters agreed to notify each other and the IAEA before concluding a contract for reactors or fuel technology. Although this exchange of letters succeeded in formally incorporating France into a broad nuclear policy agreement, it was little more than a formalization of existing practice, in view of the absence of any veto powers in the agreement. Apparently this degree of consultation did little to stop the German agreement to sell enrichment and reprocessing technology to Brazil, or the French agreement to sell reprocessing technology to Pakistan.



### 2.4.3 The International Nuclear Fuel Cycle Evaluation (INFCE)<sup>11</sup>

The residual degree of non-participation in the NPT has left the proliferation concerns of many nations unanswered. These concerns have been exacerbated by the recent spread in enrichment and reprocessing technologies, and the continuing research on breeder reactor cycles. The inability of the NPT and the London Conferences to prevent the spread of these technologies led President Carter to sharply reverse the direction of U.S. nuclear policy by imposing a moratorium on the U.S. pursuit of plutonium technologies. Subsequent to the imposition of that moratorium, President Carter called for the convocation of a two-year International Nuclear Fuel Cycle Evaluation (INFCE) study, aimed at bringing together worldwide nuclear leaders to jointly assess the costs and benefits of alternative nuclear fuel cycles, with explicit recognition of the economics and proliferation resistance of each alternative. Presumably, INFCE hopes to produce an international consensus about the wisdom of pursuing plutonium-based fuel cycles. INFCE officially began during 1977, with about 40 nations being represented.

### 2.4.4 The Nuclear Non-Proliferation Act of 1978

Concurrent with the INFCE study, the U.S. Congress approved the Nuclear Non-Proliferation Act of 1978 (P.L. 95-242, 22 U.S.C 3201),

which is designed "to provide for more efficient and effective control over the proliferation of nuclear explosive capability," by negotiating the construction of international mechanisms for improving fuel supply assurance, and by unilaterally taking such actions as are required "to confirm the reliability of the United States in meeting its commitments to supply nuclear reactors and fuel to nations which adhere to effective non-proliferation policies." In addition to clearing the way for the re-opening of the contract order books and the further expansion of enrichment capacity, the Act empowers the President to initiate international negotiations with buyer and seller nations, aimed at:

- (1) the establishment of an International Nuclear Fuel Authority (INFA) as the instrument of international fuel assurance;
- (2) the creation of international spent fuel repositories and the establishment of an INFA-monitored spent fuel buy-back policy;
- (3) the creation of an interim stockpile, pending establishment of INFA, to which DOE would contribute roughly 10 MMSWU;

- (4) an assessment of the desirability of, and options for, foreign cross-investment in new United States enrichment facilities.

The Act envisions that the benefits of these fuel assurances will be made available only to those nations which:

- (1) accept IAEA safeguards on all their peaceful nuclear activities;
- (2) do not manufacture or otherwise acquire any nuclear explosive device;
- (3) do not establish any new enrichment or reprocessing facilities;
- (4) place all existing enrichment and reprocessing facilities under effective international auspices and inspection.

### 3.0 THE INTERNATIONAL MARKET ENVIRONMENT

#### 3.1 Uranium Oxide

##### 3.1.1 Government Subsidization<sup>12</sup>

The international uranium market developed and grew during the 1950's as a result of stimulation by the U.S. government in connection with its weapons program. At the close of the Second World War, U.S. uranium requirements were being met by foreign sources, particularly Canada and the Belgian Congo. Beginning in 1948, the AEC set out to encourage the building of a domestic uranium industry by making open market purchases at prices that would encourage domestic entry into the industry. The result of this and other forms of stimulation was a rapid growth in the domestic uranium industry. This expansion peaked during the 1950's and 1960's. By the late 1960's the AEC had reduced its support of the industry, which entered into a period of decline as anticipated commercial demand did not materialize to compensate for the declining military demand.

This history of government support of the uranium market was not unique to the United States. In response to the U.S. weapons demand, extensive exploration was undertaken in Canada, resulting in Canada's establishment as one of the world's leading producers. By 1958,

Canada had sold over 74,000 tons of  $U_3O_8$  to the AEC. This burgeoning commercial linkage was broken, however, when, in 1960, the AEC decided to limit new  $U_3O_8$  purchase contracts to domestic customers. The result was the rapid disintegration of the Canadian uranium industry, and the intervention of the Canadian government which by 1970 had accumulated natural uranium stockpiles at a cost of \$100 million.

In similar fashion the Australian Government encouraged uranium exploration by offering rewards for the discovery of uranium ore and conducting airborne radiometric surveys aimed at locating ore deposits. This period of stimulation lasted from 1947-1961 and resulted in the production of uranium in several deposits.

The South African government also responded to the weapons procurement needs of the U.S. and the U.K., by subsidizing the production of uranium as a by-product of the gold mining industry. The South African production history is much like the Canadian experience; production peaked in the late 1950's and dropped precipitously to roughly half of that peak value by 1965 due to the reduction in foreign weapons demands. Unlike the Canadian case, however, this roller coaster experience did not necessitate extensive intervention by the South African government, because uranium was not a primary mining product, but only a gold mining by-product.

In sum, as the decade of the 1970's approached and the long awaited civilian uranium demand began to materialize, uranium reserves and production capacity were primarily located in the U.S., Canada, South Africa and the Francophile countries (France, Gabon, Niger). These reserves and production facilities had grown in response to national subsidization programs aimed at satisfying U.S., U.K. and French weapons procurement demands. After a boom in production during the 1950's, the international industry suffered a decade of decline and overcapacity during the 1960's, with a resulting increase in national protection and support of the uranium industry through the mechanism of national stockpile accumulations. Despite these assistance programs, the uranium industry entered the 1970's in a seriously depressed condition.

### 3.1.2 Government Intervention: Three Embargoes<sup>13</sup>

This early era of government subsidization gave way to a period of direct government intervention in uranium markets. The late 1960's and early 1970's witnessed the imposition of three national embargoes aimed at exports or imports of natural uranium. The first of these was a U.S. embargo on the importation of foreign uranium imposed by the AEC in 1966. This embargo was maintained through a provision in the AEC enrichment contracts which prohibited the importation of foreign feed for enrichment in U.S. facilities, for subsequent use in domestic reactors. Because no U.S. utilities were

using natural uranium reactors and no U.S. utilities held enrichment contracts with foreign enrichers, this provision effectively insulated the domestic uranium industry against price competition from the anticipated wave of less costly uranium imports from Canada and South Africa. As it became clear, however, that the Canadians and Australians would not permit their producers to flood the market with low-priced supplies, the U.S. announced (in 1973) that the import embargo would be gradually lifted during the years 1977-1984.

The second of these embargoes was an embargo on Australian mining and exports of  $U_3O_8$  imposed by the newly elected Australian Labor Party in late 1972. This embargo brought a halt to the then-formative marketing efforts of potential Australian producers, removing a potential major source of inexpensive, high quality uranium resources from the world market. The stated motivation for the embargo was a growing concern in Australia about the proliferation of nuclear weapons, particularly a fear that Australian-supplied  $U_3O_8$  would be subjected to spent fuel reprocessing as a means of acquiring plutonium for weapons purposes.

The embargo remained in effect throughout the four-year tenure of the Labor Party, but it was subject to review when the Conservative Liberal Party returned to power in 1976. After an extended debate surrounding the proliferation and environmental impacts of uranium exports, the Australian Government agreed to

resume contracting for yellowcake exports, during 1977, subject to safeguards and pricing contract provisions established by Australian Government through the Australian AEC. The details of these more stringent safeguards provisions, and the pricing authority's determination of the world market price at which Australian  $U_3O_8$  may be sold, have not been finalized.

The third embargo, the Canadian uranium export embargo, was triggered by an exogenous proliferation event, the explosion of an atomic device in India in 1974. Although the detonation of this explosive device by the Indian Government was billed as a peaceful nuclear explosion, this event rudely awakened the world's nuclear powers to India's potential weapons capability. The international political response to the tangible evidence of weapons proliferation was one of shock and dismay, and many nations publicly decried India's actions.

Canada reacted particularly forcefully to the Indian explosion. Prevailing speculation was that the explosive device was constructed with plutonium reprocessed from spent fuel discharged from Canadian-supplied heavy water reactors, fueled by Canadian uranium. These suspicions caused Canada to embargo uranium exports to India and to undertake national contemplation of more stringent safeguards regulations applying to the retransfer, reprocessing, or other reuse of spent fuel generated with Canadian uranium.



As in Australia, an extensive period of Government review ensued leading to a September 5, 1974 proclamation by the Atomic Energy Control Board of Canada (AECB) that uranium export licenses would be subjected to two tests:

1. a reserve protection test--exports would only be permitted after uranium suppliers had demonstrated the commitment of at least a 30-year reserve of nuclear fuel for all existing, committed, and planned reactors in Canada for any ten-year forward period;
2. a price test--exports must be marketed at world market prices, as determined by the AECB.

Canada has always required that uranium producers submit their export contracts to the AECB for examination of safeguards provisions aimed at insuring that Canadian uranium would be used for purely peaceful purposes. Growing non-proliferation concerns, stimulated in large part by the Indian explosion, led to the imposition of a Canadian embargo on uranium exports, beginning January 1, 1977, pending the negotiation of a revised bilateral safeguards agreement between the Canadian government and the uranium buyer's host nation. The official Canadian policy legislated an embargo on exports to all

nations which had not ratified and signed the NPT. Although most nuclear nations have ratified the NPT, few have formally signed it.

The result of this embargo was a cessation of Canadian uranium exports to all nations except Finland (an NPT signatory), Spain (under old contracts), and the U.S. (with which Canada has a special "interim agreement"). Negotiations were immediately initiated with Japan and the European nations to establish interim agreements pending formal signature of the NPT, and the first new uranium export contracts were approved by the AECS in 1978.

In sum the 1970's was an era of severe dislocations in supply continuity in the international uranium market. The alternate disappearance and reappearance of major uranium producers like Canada and Australia created an atmosphere of uncertainty about the likely future course of the uranium market. Although both Canada and Australia have returned as  $U_3O_8$  suppliers, this re-entry has been accomplished at the cost of intensified safeguards demands and the creation of national marketing boards aimed at securing "world market prices" for uranium exports.

3.1.3. Spiralling Uranium Prices: Westinghouse's  
Commercial Impracticability and the Uranium  
Cartel<sup>14</sup>

The embargoes described in the preceding section coincided with an unprecedented rise in prices during the period November, 1972 through September, 1976. Spot uranium prices, as defined by the Nuclear Exchange Corporation's (NUEXCO's) Exchange Value for immediate delivery, rose by a factor of seven over this period with the most rapid rises occurring during 1974, when prices doubled, and 1975, when they doubled again. In the two decades prior to this increase, prices had been relatively stable, in current dollar terms.

This rapid price increase, caught Westinghouse Electric Corporation in a critical situation of uncovered short sales of  $U_3O_8$ , which resulted in the announcement during September, 1975, that due to "commercial impracticability" Westinghouse would be unable to deliver roughly 65 million pounds of  $U_3O_8$  that it had contracted to sell to various buyers. The predictable result of this announcement was the initiation of extended litigation by 27 utilities in 14 separate legal actions, attempting to compel uranium deliveries by Westinghouse.

During the conduct of its defense, Westinghouse unleashed a storm of legal and investigative activity by claiming that in large measure the rapid price rise leading to its contract default was the result of the creation of an international uranium cartel. This allegation is founded on evidence regarding price fixing agreements

made by foreign firms for uranium sales outside of the United States. In early 1972, at the suggestion of the Canadian and Australian governments, a number of foreign uranium firms met and founded the "Uranium Club", whose express purpose was to establish minimum price schedules and to allocate the non-U.S. market. The Canadian and Australian governments felt that such a cartel agreement was necessary to prevent predatory competition from arising due to the prevailing excess supply in the uranium export market. Despite evidence that such a cartel did exist, there is no firm evidence of cartel participation by U.S. firms, and at least two observers conclude that cartel activities cannot explain the uranium price increase.<sup>15</sup>

### 3.2 Competition in the Enrichment Market<sup>16</sup>

Throughout the 1960's, as international competition grew in the supply of natural uranium, UF<sub>6</sub> conversion facilities, fabrication services, and reactor systems, the U.S. maintained a near monopoly position in the supply of enrichment services. Prior to 1970, the only commercial enrichment competitor to the U.S. was the U.S.S.R., which concentrated its sales in Communist nations, and the only other nations possessing significant enrichment capacities were France and the U.K., both of whom operated small diffusion plants exclusively for weapons purposes.

In 1970 this circumstance was altered by the negotiation of the Treaty of Almelo which created a trinational enrichment venture, known as URENCO, which was backed by the West German, Dutch and British governments. URENCO was intended as a cooperative commercial venture to construct and operate a series of centrifuge enrichment plants by pooling classified R&D results derived in the heretofore independent national centrifuge enrichment research programs. URENCO proceeded to construct two centrifuge facilities, from which commercial deliveries began in 1976, and to sign toll enrichment contracts covering the eventual expansion of URENCO's capacity to 2.1 million SWUs (MMSWU).

The French also emerged as an enrichment competitor during the 1970's, with the formation of the EURODIF enrichment consortium. Chartered in 1972, the original members of France, Belgium, Spain, and Italy were joined by Iran in 1975. EURODIF is currently building a gaseous diffusion plant using French-supplied technology, from which the first commercial deliveries should be made in 1979, and has signed toll enrichment contracts covering an expansion of EURODIF capacity to 10.8 MMSWU.

During the 1970's the Soviet Union's commercial enrichment supplier, TECHNABSEXPORT, began to step up efforts to market toll enrichment services to non-Communist world buyers. Contracts were concluded with Austria, Belgium, Finland, France, West Germany,

Italy, Spain, Sweden, and the U.K., with delivery dates extending from 1976 to 1990. These contracts cover the Soviet expansion in the enrichment capacity available for commercial sales to non-Communist nations to 3 MMSWU.

In addition to these three toll enrichment competitors who have already signed SWU contracts, the year 1975 saw the announcement of three more potential toll enrichment competitors. The first of these potential entrants is COREDIF, a spin-off of the EURODIF consortium with the same participants but different ownership shares. COREDIF announced plans to build a 10.8 MMSWU gaseous diffusion plant by 1989. The second potential entrant is South Africa's Uranium Enrichment Corporation (UCOR), which announced its intention to build a commercial enrichment plant using its domestically developed stationary-wall centrifuge process. A pilot plant is currently in operation and unofficial South African sources estimate that a 5 MMSWU plant will go onstream in 1986. The third potential entrant is NUCLEBRAS, a joint venture of Brazil and West Germany, which has plans to build an 0.2 MMSWU demonstration plant in Brazil during the mid-1980's using the German-supplied Becker nozzle technology.

During 1976 the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC) announced plans to construct an 0.05 MMSWU gas centrifuge plant by 1980. If successful, this plant will be followed by a demonstration plant of roughly 0.5 MMSWU for

completion during the late 1980's, which shall be expanded to 4 MMSWU by 1995. Meanwhile, Japan has been actively seeking partnership in joint enrichment ventures, where Japanese financing can complement a partner's enrichment technology and uranium feed; these negotiations have been extensively pursued with Australia, which has developed its own version of the centrifuge technology, although no official agreement has yet been concluded.

A host of other nations have evidenced an interest in pursuing a commercial enrichment technology. Even without Japanese participation, Australia has expressed confidence in its ability to build a commercial facility using its domestic centrifuge technology. Although Canadian plans for a domestic joint enrichment venture with EURODIF are now in abeyance, this interest could revive if the market picks up. Portugal is conducting negotiations with Germany in an effort to create a nuclear pact modeled on the German-Brazilian agreement. Sweden has expressed interest in acquiring an established enrichment technology for use in a domestic enrichment plant. Other nations expressing interest in acquiring enrichment capability include India, Iran, and Zaire.

### 3.3 Nuclear Reactors

#### 3.3.1 Early Nuclear Power Programs (1955-1970) 17

The shape of early nuclear power programs was strongly conditioned by the military choices about the technologies suitable for weapons production. The commercial reactor programs were pursued earliest by the four nuclear weapons states--The U.S.S.R., France, U.K. and U.S.--based on variations of their military technologies. The U.S.S.R. put the world's first power reactor in place in 1954, using enriched uranium fuel produced in the enrichment facilities developed for its military program. The British and French reactors were of the MAGNOX variety, graphite-moderated and fueled by natural uranium, and were designed as efficient plutonium sources for weapons production, rather than economical producers of electricity. As a result, neither nation had any success exporting the MAGNOX reactor for commercial purposes, and both have abandoned its development in favor of reactors which use low-enriched uranium fuel.

The U.S. civilian reactor program got off to a slower start than that of foreign nations, particularly the United Kingdom. The U.S. chose to commercialize the LWR technology which used low enriched uranium reactor fuel. This strategy took advantage of the enrichment facilities built for weapons purposes, as well as the development of the pressurized-water reactor (PWR) to power the Navy's new Nautilus submarine, commissioned in 1955. The PWR technology was first exploited in the Shippingport, Pennsylvania plant in 1957, while the



boiling-water reactor (BWR) technology, developed in 1954, was utilized in the Dresden, Illinois plant in 1959.

The birth of the commercial nuclear era came in December, 1963, when Jersey Central Power and Light Company awarded a contract to General Electric to build a 560 megawatt (MWE) BWR at Oyster Creek. This event triggered a worldwide interest in U.S.-supplied LWR technology and catapulted the U.S. into the position of commercial leadership in nuclear reactor technology as the 1960's came to a close. More recently major commercial nuclear power industries were launched in West Germany, Sweden, Italy and Japan, all adopting variants of the LWR technology, and Canada, using a natural uranium fueled reactor. By the end of the 1960's the interest in commercial nuclear power had spread around the globe to include virtually every major industrialized nation as well as numerous less-developed countries.

### 3.3.2 Reactor Slippage (1970-1978)<sup>18</sup>

The preceding section described the development of different reactor technologies in the nuclear weapons states, followed by the large scale entry into the international reactor market by non-weapons states as the 1970's approached. This entry was in anticipation of the forecasted boom in reactor demand. This boom,

however, was slow in coming, and the 1970's were not an era of excess demand for reactors, but an era of chronic overcapacity.

This overcapacity was the result of scaling the reactor industry to meet the demands for nuclear reactors as reflected in official government estimates. Regional and national forecasts of installed nuclear capacity are published on a regular basis by DOE and its foreign atomic energy commission counterparts. Usually these forecasts are based on utility interview data, although recently some more sophisticated econometric modeling techniques have brought some rigor to long-run forecasting.

In the past, significant errors have resulted from accepting national forecasts at face value. In addition to the uncertainties associated with such a difficult forecasting task, many nations have a history of excessive optimism in forecasting nuclear power growth. The nation with the longest history of nuclear growth forecasts is the United States, and its forecasts present a good case study of the historical optimism of nuclear growth estimates. Using the 1970, 1975, and the 1985 installed nuclear capacities as a convenient point of reference, Table 1 shows a history of forecasted nuclear capacity as a function of the year in which the forecast was made. The striking feature of these time series is the precipitous decline in the forecasts beginning in 1970; in the four years from 1973-1977,

TABLE 1

COMPARISION OF USAEC NUCLEAR POWER

FORECASTS 1962-1977

AEC FORECAST Made in Year	Installed Power at EOY, GWe		
	1975	1980	1985
1962 (a)	16	40	-
1964 (b)	29	75	-
1966 (c)	40	95	-
1967 (d)	61	145	255
1969 (e)	62	149	277
1970 (f)	59	150	300
1972 (g)	54	132	280
1973 (h)	47	102	255
1975 (i)	40	82	205
1976 (j)	39	67	145
1977 (k)	39	60	127

- (a) Table 16 of Appendix IV of AEC Report to the President, "Civilian Nuclear Power", Dec. 1962.
- (b) WASH-1055, March 1965
- (c) AEC Press Releases S-20-66 (June 1, 1966) & S-23 (Sept. 8, 1966).
- (d) WASH-1084, December 1967
- (e) WASH-1139 statement of May 1969
- (f) WASH-1139, January 1971
- (g) WASH-1139 (72), December 1972
- (h) WASH-1139 (74), February 1974; mean of cases B&D
- (i) R.W.A. LeGassie, ERDA, Testimony to the U.S. Committee on Interior and Insular Affairs, Subcommittee on Energy and the Environment, April 23, 1975.
- (j) Grand Junction Conference, October 1976, ERDA "Mid" Case
- (k) Grand Junction Conference, October 1977, ERDA "Base" Case

SOURCE: (2), pg. 65, updated.

official forecasts of 1985 installed capacity were cut exactly in half. This pattern is repeated in the 1975 and 1980 data.

This upward forecasting bias is not confined to the United States. The prevalence of this phenomenon was revealed at a series of meetings of the International Energy Agency (IEA) in Paris during February, 1977. At these meetings, national representatives convened in confidential group sessions to produce joint forecasts of nuclear growth through 1990. These meetings were unusual because they operated through an iterative Delphi process which permitted national representatives to challenge the forecasts of other representatives in an effort to strip away the planner's dreams from the forecaster's realities. The result of these candid, closed-door proceedings was a set of sharply reduced growth estimates. Using the 1985 forecast as a point of reference, the upshot of the IEA meeting was a broad cut, on the order of 50% in many cases, in worldwide GWE growth estimates. Even this reduction has not written an end to the slippage story. Since the IEA meeting, the United States has further reduced its reactor forecast, while reports of foreign delays in the nuclear press reveal that foreign growth estimates will continue to decline.

#### 4.0 COMMERCIAL POLICIES OF AEC-ERDA-DOE

##### 4.1 Reactor Subsidization and Promotion<sup>19</sup>

As described in Section 2.2, the Atomic Energy Act of 1954 committed the government to the aggressive promotion of a private civilian atomic energy industry, where government licensing of fuel cycle facilities was substituted for direct government operation of these facilities as the primary form of regulation. The Act authorized private possession, but not ownership, of fissionable fuels, and encouraged private participation in all phases of the fuel cycle except enrichment, where the government ownership monopoly was maintained, although private contractors continued to operate the plants. The subsidies made available to private industry included: assistance in reactor construction intended to prove the commercial viability of atomic power, leases of nuclear fuel at subsidized rates, guarantees to buy back plutonium in spent fuels at subsidized prices, and the assumption by the government for liability to the public from nuclear accidents.

These subsidies were necessary to encourage private industry to undertake atomic energy. Although the AEC and Congress had assumed that private enterprise would welcome the access to previously restricted information as a vehicle for gaining admission to the nuclear power industry, this did not prove to be the case. Atomic

power was capital-intensive and risky; therefore, in view of the ample supply of low cost alternative fuels, private initiative in building nuclear reactors was not forthcoming. The disappointing response of private industry was evidenced by the few utilities who took advantage of the financial inducements offered by the AEC in 1955 and again in 1957 in the Commission's invitation of proposals for a number of reactor prototypes. In all, only 11 projects were undertaken in response to these subsidies.

This cautious response was not because the subsidies were anything less than generous. In 1953 Congress authorized the construction of the first large-scale civilian reactor at Shippingport, Pennsylvania. This 60 MWE facility provided electricity to the Duquesne Light Company at Pittsburgh. The total cost of the Shippingport plant was \$120 million, of which the government contributed \$100 million; Duquesne Light provided the site, \$15 million of generating equipment, and \$5 million toward the cost of the reactor. In short, roughly 85% of the plant was subsidized by taxpayer contributions.

The AEC Act of 1954 forbid this sort of direct subsidy, by prohibiting the AEC from contributing to the capital cost of privately owned reactors. Subsidies, however, remained available in other forms. The AEC provided its R&D findings to private industry at no charge. In some cases, nuclear fuel was provided at no

charge. It paid reactor operators for data they supplied regarding technical and economic experience. In 1957 Congress agreed to assume the bulk of the risk of a catastrophic nuclear accident by providing \$500 million of insurance to private utilities at a nominal charge. In addition, state regulatory commissions helped promote nuclear power by permitting accelerated amortization of nuclear plants, and the recovery of nuclear R&D costs in their rate structures.

The JCAE reacted vigorously to the foot-dragging of private industry by proposing that the development of civilian power could be accelerated if the government were to build and operate a series of demonstration plants. The Eisenhower Administration and the AEC resisted this suggestion as the result of a philosophical disposition in favor of private power rather than public power. Nevertheless, the JCAE persisted, and in 1960 the AEC announced a 10-year program aimed at making atomic power competitive in some parts of the country and overseas by 1970. This commercialization program concentrated on the successive construction and testing of experimental, prototype, and eventually full-scale demonstration reactors, with the emphasis on the most competitive reactor technologies. If construction proposals were not forthcoming from private industry, the AEC was to build the prototypes itself, but would stop short of building and operating full-scale demonstrations.

By 1970 there were 29 operating reactors in the U.S., representing 3% of the nation's electrical generating capacity. By 1975 nuclear power had grown to represent almost 8% of the nation's electrical generating capacity, and official forecasts showed nuclear power to be roughly 1/3 of domestic capacity by 1990. By these measures, the AEC has succeeded in promoting the creation of a major private atomic energy industry.

Even this promotional effort of the 1960's was not pursued without subsidy to private industry, chiefly in the form of the hidden subsidy in the nuclear fuel prices charged by the AEC. Prior to 1965, the AEC leased fuel to utilities at an annual rental charge of 4-5% of the average total cost, rather than the marginal cost of producing the fuel. Since utilities normally allow 6-12% for the cost of their fuel inventory, this rental charge involved a substantial subsidy. In addition, the AEC paid utilities for the plutonium that was produced as a by-product of power generation, even though much of this spent fuel leased by utilities was never reprocessed. Since early AEC cost data remain classified, it is impossible to assess the propriety of the plutonium price, or the effect of pricing at average rather than marginal cost, although both procedures may have contained significant elements of subsidy.

Throughout this era of aggressive promotion and subsidization, the JCAE played an increasingly important role. The JCAE regularly



opposed the slow-growth policy of the Eisenhower Administration and the AEC, who favored leaving the initiative in developing civilian atomic power to private industry. The JCAE favored a more direct role for the government and a more aggressive development of atomic energy, chiefly as an instrument of foreign policy. Although there was no impending energy crisis during this era, the JCAE tried to accelerate atomic development as a mark of national prestige, as a means of offering technical assistance to our allies, and through this assistance (and the development of the hydrogen bomb) as a contribution to national security. The JCAE-AEC struggle went on for years, with Congress continually giving the AEC appropriations in excess of the Commission's requests. The JCAE began to participate directly in the details of the AEC's decision-making process, and came to function "as a board of directors" for the atomic enterprise, with the AEC functioning in an administrative capacity.

#### 4.2 Uranium Industry Subsidization and Protection<sup>20</sup>

As with the reactor industry, the AEC vigorously promoted the development of a domestic uranium mining and milling industry during the 1950's and 1960's. The AEC established fixed floor prices for  $U_3O_8$  purchases, including bonus payments for initial uranium deliveries, for particularly high-grade ores, and for exploration and development procedures. The AEC encouraged the uranium milling industry by signing long-term cost plus profit contracts with

prospective millers which included substantial subsidies by allowing rapid depreciation of mill plant and equipment.

The result of this stimulation was a rapid growth in the domestic uranium industry. As indicated by the data in Table 4, this expansion peaked during the 1950's and early 1960's. By this period, however, the AEC had decided that it was no longer in the government's interest to encourage further expansion of the domestic uranium industry. Beginning in 1958, the AEC adopted a policy of signing no new  $U_3O_8$  contracts, and from 1962-1966, the AEC limited uranium purchases to 500 tons  $U_3O_8$  per property at a fixed price of \$8 per pound.

These "maintenance" contracts had a dual purpose. First, the reduced purchases were aimed at limiting the large uranium stockpile being accumulated by the AEC due to the enthusiastic response to the AEC stimulation policy plus the slackening of military uranium demand as weapons procurement targets were satisfied during the mid-1960's. Second, although civilian demand was not forthcoming to take up the slack left by the decline in military needs, the AEC recognized the need to preserve some semblance of a domestic uranium industry in anticipation of booming civilian needs. Therefore, the \$8 uranium price was intended to encourage the operation of existing firms by covering short-run variable costs, while discouraging the entry of new firms by covering long-run marginal costs.

As the 1966 termination date for the maintenance contracts approached, and the commercial demand had still not materialized, the AEC began to "stretch-out" its contractual commitments through 1970 to maintain a base load domestic uranium industry. During 1969-1970 the AEC priced contract deliveries on a cost-based formula aimed at covering only variable costs. During this period prices averaged \$6 per pound of  $U_3O_8$ .

The result of the AEC maintenance and stretch-out policy of the 1960's was a steady contraction of the domestic uranium industry. Many firms left the industry, exploratory and drilling activity declined sharply, and there was substantial merger activity. Therefore, as the decade of the 1970's approached the international uranium industry was in a seriously depressed condition, with the domestic industry being sustained only by the direct purchases of the AEC with the resulting accumulation of a massive AEC stockpile of 50,000 tons of  $U_3O_8$ .

#### 4.3 Operating History of DOE

##### 4.3.1. Tails Assays

During the Manhattan Project years the goal of enrichment plant operations was weapons production, not efficiency, and although precise operating tails assay data are classified, it is believed

that during the wartime years most enrichment was done at tails assays between 0.3% and 0.5%. With the advent of civilian control of the enrichment plants by the AEC in 1946, the operating tails assay was set at 0.2%, where it remained throughout the 1950's and 1960's. During these two decades all of the wartime tails material was recycled through the enrichment plants to reclaim its U-235 content in excess of 0.2%. Beginning July 1, 1971, the operating tails assay rose to 0.3%, and on July 1, 1975, it was lowered to 0.25% where it is forecasted to remain through 1990.

#### 4.3.2. The Split Tails Program

Despite the depressed financial condition of the domestic uranium industry, described in Section 4.2, the AEC announced its intentions to dispose of its natural uranium stockpile. The scheme for disposing of this stock, with a minimum of disruptive effect on the production industry, was the split tails policy, announced in March, 1972. This scheme was conceived while James Schlesinger, now administrative head of DOE, was Chairman of the AEC. The split tails policy took advantage of the recent rise in the AEC operating tails assay to 0.3%, effective July 1, 1971. This increase in operating tails from 0.2% to 0.3% had increased uranium demand roughly 20%.

The AEC took advantage of this demand increase by maintaining the transactions tails assay at its historical value of 0.2%, which had

originally been established in 1968. This transactions tails assay was the tails assay applicable to transactions between the AEC and its toll enrichment customers. AEC toll enrichment contracts contained Appendices which specified a customer's natural uranium deliveries to the AEC, and enriched fuel returns from the AEC, as a function of the tails assay established by the AEC. The AEC enrichment contracts permit the AEC to unilaterally choose the tails assay, and to vary that tails assay on 540 days notice in the Federal Register. Therefore, the AEC chose to maintain the transactions tails assay of 0.2%, such that SWU customers continued to supply uranium to the AEC as if the diffusion plants were running at the 0.2% tails assay. In fact, of course, the enrichment plants were operating at a tails assay of 0.3% (later 0.25%) and the AEC was supplying the necessary additional natural feed to the diffusion plants from the AEC stockpile.

The achievement of the split tails policy was to leave expectations founded on the historical 0.2% tails assay unchanged, while slowly disposing of the domestic uranium stockpile without unduly depressing the uranium price. Naturally the split tails policy did reduce  $U_3O_8$  demand, but most uranium industry participants agreed that the split tails policy was far preferable to simply "dumping" large portions of the government stockpile on the open market. Because the government  $U_3O_8$  stockpile averaged roughly 4 years worth of recent domestic production, massive open market

transactions would undoubtedly have significantly lowered the  $U_3O_8$  market price.

In addition the split tails policy was a hedge against a repetition of the boom-bust cycle exhibited by the uranium market during the 1960's. By analogy the AEC feared that raising the transaction tails assay to the operating tails assay would cause a boom in uranium demand, and excessive entry into the mining industry, that would eventually become excess capacity when sufficient SWU capacity was constructed to permit operating at the planned long-run equilibrium tails assay at 0.20%. Additionally, the AEC wished to avoid conferring windfall profits on mining companies. Because these companies tend to be capital-intensive, rather than labor-intensive, a sudden leap in uranium demand could bestow large short-term profits on existing sellers.

#### 4.3.3. The Advance Feed Program

The effort of the split tails policy to dispose of the AEC stockpile with minimum market disruption is consistent with the history of AEC involvements in the creation and protection of a domestic uranium industry. Protection of the uranium market was also a motivating factor in ERDA's creation of the advance feed program during 1975. Advance feed deliveries resulted from the drastic reactor timetable slippages discussed previously. Because of these

postponements of demand, toll enrichment customers successfully pleaded with ERDA to permit renegotiation of ERDA enrichment contract delivery schedules without paying termination charges (See Section 4.4).

These adjustments in enriched product delivery schedules were not, however, directly translated into adjustments in natural uranium feed deliveries. Rather ERDA created the advance feed program whereby a customer slipping enriched product deliveries further into the future would still have to deliver natural feed to ERDA subject to a schedule similar to the original enrichment contract delivery schedule. The purpose of this program was to prevent short-term disruptions in ERDA's enrichment plant operations due to the sudden unavailability of feed, and to protect the uranium industry from a sharp decline in demand as the result of ERDA's actions in declaring an open season. Given the large ERDA stockpile of domestic uranium as an easement to scheduling problems, one may conclude that protection, rather than scheduling, was the main motivation for the advance feed policy.

#### 4.3.4. The Preproduction Stockpile and Tails Recycle

While the currently ongoing split tails program is drawing down DOE's natural uranium stockpile, DOE is creating in its place a substantial preproduction stockpile of enriched uranium. This

preproduction stockpile is being built up during the 1970's, when DOE enrichment capacity exceeds contract demands, for draw-down during the 1980's, when contract demand will exceed forecasted capacity. The feed for this preproduction stockpile is being supplied from the DOE U<sub>3</sub>O<sub>8</sub> stockpile, the advance feed program, and the tails recycle program.

The current DOE tails recycle program is an outgrowth of the DOE experience in the recycling of wartime tails during the 1960's. The current DOE tails stockpiles consist of a substantial quantity of 0.3% tails resulting from the operation of the diffusion complex at an 0.3% tails assay from 1971-1975. The recycling program proposes to feed this tails material into the enrichment plants during the years 1977-1979 to recover its U-235 content in excess of 0.25%.

#### 4.4 Contracting History of DOE

##### 4.4.1 Requirements Contracts

DOE enrichment contracting has undergone many major changes since the original offering of SWU services, and is currently in a state of flux. Initially, the AEC offered nuclear fuel to utilities only on a leased basis, pursuant to the provisions of the 1946 AEC Act. All uranium and enriched fuel was legally owned by the U.S. Government. In 1964, Congress amended the AEC Act to permit private utilities to



own nuclear fuel, and subsequent to these amendments the AEC first offered toll enrichment services in 1971, whereby they contracted to enrich uranium supplied by the utilities. These contracts were known as requirements (REQ) contracts because utility buyers contracted for the requirements of a specific reactor; in turn, the AEC agreed to supply these requirements for the life of the reactor. While utilities maintained updated forecasts of fuel demands on file with the AEC, the precise size of fuel deliveries could be specified on 180 days notice by the utilities.

The prices for requirements contracts were established on a cost-recovery basis by the AEC, and were constrained by an escalating price ceiling. Contract prices were published in the Federal Register, effective 180 days after publication.

#### 4.4.2 Long Term Fixed Commitments Contracts, The Closing of the Order Books, and Conditional Contracts<sup>21</sup>

In 1973, the AEC discontinued the negotiation of REQ contracts, and replaced them with long term fixed-commitment (LTFC) contracts. The four crucial distinctions of this new contract form from the requirements contracts were: (1) The SWU contract was not reactor specific; (2) the fixed commitment contract was much longer term (30 years) and much less flexible: rather than firming up fuel deliveries on 180 days notice, utilities were locked into firm

schedules on a rolling 10-year period and buyers were subject to substantial penalties for failing to take deliveries on schedule; (3) the contract price, while based on cost recovery, was not limited by any ceiling price clause--prices are changed on 60 days notice by publication in the Federal Register; (4) SWU customers were required to make advance payments of \$3.3 million/GWE in three installments during the first two years following contract execution--these prepayments are credited against SWU charges for the first fuel deliveries, and are forfeited if the customer terminates the contract before the first fuel delivery. Further, when AEC announced the institution of the LTFC contracts, they specified that prior to July, 1974, no contracts would be signed for reactors with planned first-core loadings after July, 1982.

The initiation of the LTFC contracts created a surge in enrichment contracting which forced the closing of the AEC contract order books in July, 1974, only 9 months after LTFC contracts were first offered. This surge far exceeded the demand that the AEC had anticipated. This unexpected demand reflected a problem inherent in the LTFC contracting system,

"Utilities, understandably anxious to protect themselves against even the remote risk of enrichment shortages, were generally inclined to put in for the largest quantities of separative work they thought they might possibly need, and some asked for deliveries at dates that looked much too early to the Commission. Also, with some notable exceptions, their estimated enrichment needs made no allowance for plutonium recycling.

However, AEC was in no position to say to any utility that its estimates of its own needs were unrealistic and would not be accepted as the basis for contracting."22

In other words, because the AEC was the only established supplier of SWU services there was a strong incentive for utilities to push forward their reactor timetables to qualify for the July, 1982 cutoff date. In addition, because the costs associated with stockpiling excess enriched fuel<sup>were</sup> far outweighed<sup>by</sup> the costs of having to idle generating facilities for lack of fuel, utilities forecasted reactor load factors well in excess of anticipated results as a form of self-insurance during the firm 10-year commitment period. The net result of this overordering was an artificial exaggeration of actual enrichment needs and the premature exhaustion of the AEC's supply capability.

During the first 9 months of LTFC contracting, enough contract requests were received to exhaust AEC forecasting SWU capacity through 1985, leaving AEC in the unpleasant position of having to deny contracts to willing buyers. At the time of contract suspension, the AEC had executed contracts representing the needs of 273 GWE of nuclear capacity, and had received requests for LTFC enrichment contacts from an additional 91 GWE of reactors. At that time the AEC's projected available SWU capacity was large enough to sustain approximately 290 GWE, at 0.3% operating tails with no plutonium recycle. The AEC exercised its legislative authority to

enter into a small number of contracts above nominal capability by contracting for a total of 320 GWE of generating capacity.

This still left 44 GWE of generating capacity without the requested SWU contracts. To satisfy those customers, AEC agreed to enter into a limited number of conditional enrichment contracts. These contracts were identical to the standard LTFC contracts in every sense but one; their execution was conditional upon an NRC finding in favor of plutonium recycle. The logic of this condition was that if plutonium recycle was approved, ERDA would have the additional capacity to satisfy these conditional contracts. No advance payments were required from conditional customers until the contracts were made firm.

Not all of the proffered conditional contracts were signed; a total of 27 conditional contracts were executed by ERDA, bringing the enrichment contract commitments to 341 GWE of electrical capacity. No generic decision has been rendered by the NRC regarding plutonium recycle, and in the meantime, 18 conditional customers exercised their option to terminate their conditional contracts, either because they had been assigned a firm contract by another ERDA customer, or had seen their own reactor plans delayed or cancelled.

In an effort to restore faith in U.S. enrichment supply reliability, President Nixon stated, on August 6, 1974, that the U.S.

would "in any event" fulfill the fuel commitments of the conditional contracts from domestic sources.<sup>23</sup> This announcement, coming one month after the closing of the order books, effectively made the conditional contracts firm. This public promise was finalized during September, 1977 when the U.S. offered to firm up the contracts of the remaining 9 conditional customers.

#### 4.4.3 ERDA's Open Season and Case by Case Contract Relief<sup>24</sup>

Subsequent to the closing of the order books, the continuing slippage in reactor installations led utilities holding LTFC contracts to petition ERDA for an "open season" during which customers would adjust their contracted delivery schedules to reflect recent delays without incurring onerous penalty costs. Eager to free up overcommitted SWU capacity, ERDA granted this request for an open season during the thirty days following June 19, 1975. One hundred ninety-three (193) of the 247 utilities holding LTFC contracts took advantage of this opportunity to alter their contracts; the effective result was a cumulative demand reduction of 27 MMSWU during the period 1976-1988, corresponding to a reduction in the nuclear capacity under ERDA enrichment contracts from 341 GWE to 329 GWE, and an average slippage in reactor demands of two years.<sup>25</sup>

Despite the readjustments of the first open season, further erosion of utility timetables once again brought pressure to bear on

DOE for a second open season. DOE's response, in April 1977, was a statement that they would consider case-by-case contract relief for enrichment customers who have mismatches between contract commitments and actual needs. The dimensions of this relief have not been specified except to state that there would be no second open season free ride for customers, rather, penalties shall be imposed for termination or postponement. A DOE survey during early 1977 revealed the magnitude of the requested contract adjustments: sixteen reactors were judged to be likely candidates for total termination, and the average requested delay was 1-2 years. If granted, the requested adjustments would reduce DOE deliveries over the decade 1978-1988 by 30 MMSWU.

#### 4.4.4 Adjustable Fixed Commitments Contracts

It is likely that the contract adjustments will take the form of an option for LTFC customers to convert to Adjustable Fixed-Commitments (AFC) contracts. On February 7, 1978, DOE released a draft of the proposed AFC contract for use by DOE upon the resumption of long-term enrichment services contracting. The AFC contract is a compromise between the REQ and LTFC contracts; its specific aim is to offer the customer greater flexibility than the LTFC contract. It retains many features of the LTFC contracts including advance payments, no ceiling on SWU prices, a 10-30 year contract life, the customer's option to acquire tails material, a

designated (but not required) reactor use, termination penalties, the maintenance of the embargo on foreign feed, and the ability to dispose of excess enriched uranium by assignment, sale in private markets, or accumulation of a stockpile. The distinguishing flexibility features are:

- (1) A reduction in the firm commitment period from a rolling 10-year period to a 5-year rolling period, of which the first three years shall be firm commitments, the fourth year's commitments shall be subject to a variation of  $\pm 10\%$ , and the fifth year's commitments may vary by  $\pm 20\%$ .
- (2) The ability of the the customer to delay the initial delivery period up to a maximum of 5 years, for a reduced penalty charge.
- (3) The variable tails assay option which permits the utility customer to specify, within limits, the transaction tails assay(s) for each uranium delivery to the enrichment plant. This allows the customer to fine tune his enriched fuel output, by varying his natural fuel input, to meet his specific needs.

DOE has yet to determine: (1) the termination charges associated with the conversion from an LTFC to an AFC contract, (2) whether

advance feed provisions will accompany contract conversion, and (3) the non-proliferation terms under which the AFC contract will be extended to foreign users. The finalization of these decisions will permit a reopening of the contract order books.



## 5.0 SUMMARY

The chronology of major events described in Essay #1 is recapitulated in the timeline of Figure 1. We shall be making reference to these events in subsequent essays and the reader may find it useful to return to Figure 1 to refresh his memory regarding an event's historical context. The essence of this chronology is the unique attempt to make the long-run transition from a military, politically controlled, industry to a commercial, privately controlled industry, and the major theme of this first essay has been a description of the promotion and subsidization of private industrial participation in the nuclear fuel cycle, as the major vehicle for making this transition. We have recounted the role of the AEC, and its foreign counterparts, in subsidizing the national and international acceptance of civilian nuclear power, and in promoting the creation of private domestic reactor and uranium industries. In addition, we have documented the effort to extend this privatization policy to the enrichment sector. Along the way, we have also encountered two minor themes which have characterized the evolution of this transition:

1. The tension between the international political system and the international market system

As noted, the military-commercial transition was to be accomplished by encouraging the participation of private industry at various stages of the nuclear fuel cycle. Because, however, enrichment and reprocessing technologies represent potential sources of nuclear weapons, nations were unwilling to relinquish total control of nuclear technologies to private entities. The result has been a series of international political attempts (Atoms for Peace, NPT, London Conferences, INFCE) to define the ground rules within which private nuclear industries must function. These international efforts have revealed broad disagreements between nations as to the degree of regulation that should be applied to nuclear trade. While some countries see the imposition of strict rules on technology transfers as a necessary part of a non-proliferation policy, others perceive these restrictions as discriminatory attempts to preserve the market power of established nuclear weapons states through technological barriers to entry.

2. The gigantic uncertainties prevailing in the international nuclear markets

Clearly the military-commercial transition is not yet completed; therefore, nuclear markets display a complex mixed public-private structure, with which the infant nuclear industries must deal. The result has been a painful period of self-education for market participants. A series of events have rocked the commercial uranium

and enrichment markets, including: the closing of the U.S. order books, the rapid uranium price increases, the Canadian and Australian export embargoes, and the Westinghouse claim of commercial impracticability. These destabilizing events, among others, have created an atmosphere of tremendous uncertainty about the future of the commercial nuclear markets. The unpredictable role of international politics in determining fuel supplies, and the continuing slippage in reactor installations, which has increased the uncertainties in demand, have left both suppliers and consumers worried about the stability of fuel supply. Whether these uncertainties will be resolved, such that a series of smoothly functioning markets can exist, remains to be seen.

FIGURE 1

SUMMARY TIME LINE

- 1946 Atomic Energy Act passed in U.S., signalling era of secrecy.
- 1953 Eisenhower proposes Atoms for Peace.
- 1954 Atomic Energy Act amended to signal era of internationalism and promotion.
- 1957 IAEA created.
- 1964 Congress amends AEC Act to permit private ownership of fissionable fuels.
- 1966 AEC institutes foreign feed embargo.
- 1970 URENCO created by Treaty of Almelo.  
First ratification of NPT
- 1971 Initiation of toll enrichment.  
AEC raises tails assay from 0.2% to 0.3%



Westinghouse announces default on  $U_3O_8$   
contract deliveries due to "commercial impractic-  
ability."

COREDIF announces creation of enrichment  
consortium.

South Africa announces plans for commercial  
centrifuge enrichment plant.

$U_3O_8$  market prices double again.

1976 Japan announces plans for commercial centrifuge  
enrichment plant.

First commercial deliveries from URENCO  
facilities.

1977 ERDA announces case by case contract relief will  
be offered to enrichment customers experiencing  
reactor delays.

DOE is created by the combination of ERDA and FEA.  
First meeting of INFCE

1978 DOE proposes draft of adjustable fixed commitments  
enrichment contract for use in re-opening  
enrichment contract order books.

U.S. passes Nuclear Non-Proliferation Act

ESSAY #1

FOOTNOTES

- 1 For a layman's introduction to the technologies of the nuclear fuel cycle, the reader is referred to (2), pp. 105-123, and (11), pp. 389-407.
- 2 (2), pg. 117.
- 3 For more detail regarding enrichment technologies, see (3).
- 4 (17), pp. 175-177; (16), pp. 539-540, 542-547.
- 5 (17), pp. 177-184; (16), pg. 541.
- 6 (18), pp. 7-8, 27-34, 61-63; (16), pp. 553-554; (10), pp. 33-44.
- 7 (15), pg. 7.
- 8 (17), pp. 190-191.
- 9 (19), pp. 23-28.
- 10 Ibid., pp. 25-26.
- 11 For more detail see "INFCE Working Groups Being Firmed Up," Nuclear Fuel. Vol. 2, No. 20 October 3, 1977, pp. 3-5
- 12 (9), pp. 126-131; (14).
- 13 (12); (14).
- 14 (12); (9), pp. 143-150.
- 15 (9), pp. 168-170; (5).
- 16 Material excerpted from news reports compiled in (4).
- 17 (17), pp. 184-186.
- 18 (8), pp. 24-25.

- 19 (16), pp. 550-553.
- 20 (9), pp. 126-131.
- 21 For more detail regarding LTFC contracts, see (13);  
for more on the closing of the order books and  
conditional contracting, see (6), pp. 511-521.
- 22 (6), pp. 572-573.
- 23 (6), pg. 528.
- 24 (7) and "Utilities May Want Out of 16 SWU Pacts,"  
Nuclear Fuel Vol. 2, No. 12, June 13, 1977, pp. 1-1a
- 25 (7)



ESSAY #1

REFERENCES

1. Allardice, Corbin, and Trapnell, Edward. The Atomic Energy Commission. Praeger Publishers, New York, NY. 1974.
2. Atlantic Council, Nuclear Fuels Policy. Westview Press, Boulder, Colorado. 1976.
3. Benedict, Manson. "Enrichment: A Critical Status Report" Proceedings of the International Conference on World Nuclear Energy edited by Ruth Farmakes, Washington D.C., November 14-19, 1976.
4. Blumkin, S. "Survey of Foreign Enrichment Capacity, Contracting and Technology: January 1976 - December 1976. Union Carbide Enrichment Planning Department, Operations Analysis and Planning Division. ERDA Report K/OA-2547, part 4, April 18, 1977.
5. Fallin, Jack F., Jr. and Furbush, Malcolm H. "Interim Report Re: Uranium Marketing" Commission Resolution L-184. Public Utilities Commission of the State of California.
6. Future Structure of the Uranium Enrichment Industry Hearings before the Joint Committee on Atomic Energy Phase III, June 25, 26 and 27; July 16, 17, 18, 30, 31; August 6; November 26; and December 3, 1974. Two volumes.
7. Huffman, Clark F. "Results of Expanded Contract Offer" reprinted in Uranium Enrichment Conference: Oak Ridge, Tennessee, November 11, 1975. ERDA. Conf-751134.
8. Jacoby, Henry D. "Uranium Dependence and the Proliferation Problem" Technology Review, June, 1977. Vol. 79, No. 7. pp 18-29.
9. Joskow, Paul L. "Commercial Impossibility, The Uranium Market, and the Westinghouse Case" Journal of Legal Studies. Vol. VI(i) January 1977.

10. Moore, Thomas Gale. Uranium Enrichment and Public Policy. American Enterprise Institute. Washington D.C. 1978.
11. Nuclear Energy Policy Study Group. Nuclear Power Issues and Choices. Ballinger Publishing Company, Cambridge, MA 1977
12. "Nuexco Report Analyzes Price Increases"  
Nuclear News. December 1976.
13. Proposed Changes in AEC Contract Arrangements for Uranium Enriching Services. Hearings before the Joint Committee on Atomic Energy. March 7, 8, 26; and April 18, 1973.
14. Streeter, Alvin. Country Reports on Spain, Canada Australia, South Africa and the Francophile Producers. Internal documents of the MIT Energy Laboratory Nuclear Fuel Assurance Project.
15. Uranium Enrichment Pricing Criteria. Hearings before the Joint Committee on Atomic Energy. June 16 and 17, 1970.
16. Wilcox, Clair Public Policies Toward Business, Fourth Edition. Richard D. Irwin, Inc., Homewood, Illinois. 1971.
17. Willrich, Mason, and Taylor, Theodore B. Nuclear Theft: Risks and Safeguards Ballinger Publishing Company, Cambridge, MA 1974.
18. Wonder, Edward F. Nuclear Fuel and American Foreign Policy: Multilateralization for Uranium Enrichment Westview Press, Boulder, CO 1977.
19. Wonder, Edward F. Multilateralism and Unilateralism in the Nuclear Fuel Cycle. Program in Science and International Affairs, Harvard University. April 26, 1976.

ESSAY #2: AN ORGANIZATIONAL MODEL OF U.S. ENRICHMENT POLICY

1.0 THE MOTIVATION FOR A MODEL

From an industrial economics viewpoint, the performance of AEC-ERDA-DOE in the enrichment market offers a unique perspective. This executive agency, which we shall abbreviate simply as the AEC for convenience, has long held a near-monopoly position in the international commercial enrichment market. From this monopoly position the AEC has been responsible for both the promotion and regulation of the domestic civilian atomic energy industry, while simultaneously acting as a primary instrument of U.S. nuclear foreign policy.

The multiple roles filled by the AEC have created situations of conflicting motivations within the agency where, for example, domestic and foreign policy objectives have called for differing solutions to a perceived problem. A historical review of U.S. enrichment policy reveals two categories of objectives which determine the course of a nation's enrichment policy: security objectives and commercial objectives. Security objectives include both contributing to the national defense, and the preservation of national security by limiting the proliferation of nuclear weapons. In the context of enrichment policy, security objectives translate

into limiting the spread of enrichment technologies, as enrichment plants offer one route to the acquisition of nuclear weapons.

Commercial objectives include the promotion of a domestic civilian nuclear power industry both as an innovative force in nuclear technology and as a source of export revenues aimed at improving the balance of payments. In the context of enrichment policy, U.S. commercial objectives include the following dimensions:

- (1) a desire to encourage the installation of privately owned nuclear reactors as a source of electrical power;
- (2) a desire to protect and stimulate domestic nuclear fuel cycle industries, such as uranium mining and milling, and reactor vessel manufacturing;
- (3) a desire to encourage the export of nuclear fuels and nuclear fuel cycle components as a source of international trade revenues;
- (4) a desire to eventually transfer operation and ownership of domestic enrichment facilities to private corporations.

The reader must keep the multidimensional nature of commercial objectives in mind when reading these essays. If not explicitly

stated, the context of any generic references to "commercial objectives" should permit the reader to infer which dimensions of commercial objectives are being discussed.

These two sets of objectives are, at times, both conflicting and interdependent. For example, a conflict may arise when the nation considers the transfer of its enrichment technology. While commercial objectives associated with stimulating international export trade may be satisfied by such a transfer, the resulting dispersion of enrichment technology may run contrary to security objectives. An example of the interdependence of objectives arises in the establishment of toll enrichment contract terms. If prices and other contract terms are set solely on the basis of commercial objectives associated with enrichment privatization, the result may be to increase the incentive for foreign entry into the enrichment market. This entry, in turn, may have an undesirable impact on U.S. national security.

This essay concerns itself with the interplay of these two sets of objectives in the formulation of U.S. enrichment policy. Given that conflicts arise between these objectives, how are these conflicts resolved? Stated another way, how does the U.S. Government weigh these objectives? To posit an answer to these questions is to implicitly offer a model of U.S. behavior which must then be examined

against the experience of the last 30 years. The following essay proceeds to propose and scrutinize such a model.

## 2.0 THE CARNEGIE SCHOOL OF ORGANIZATIONAL THEORY

We shall find the roots of our propositions in a bureaucratic process model of the AEC. This model rejects the notion of comprehensive rationality, according to which organizations pursue value-maximizing behavior. A comprehensively rational organization would presumably consider the set of all possible alternative courses of action, weigh the global costs and benefits of each alternative, and pursue the optimal alternative as defined with respect to an explicit objective function. Such a model is used in the traditional microeconomic theory of the firm, which posits that firms search the universe of alternatives and choose to pursue that series of actions which yields maximum profits.

To replace these maximizing assumptions, we appeal to Herbert Simon's concept of "bounded rationality", as applied to firm behavior by Cyert and March (3), according to which organizations pursue satisficing behavior, which does not seek only the optimal alternative, but is glad to accept any alternative which satisfies broad constraints. Rather than examining the universe of possible alternative actions, the process of organizational search is simple-minded. Search is motivated to find a solution to an immediate problem, and it begins in the neighborhood of the current solution and proceeds sequentially until a satisfactory alternative is generated. This firefighting behavior, where organizations react

to the stimulus of a short-run problem rather than seeking the development of a long-run strategy, is consistent with an organization's inability to simultaneously confront the global implications of any alternative action without encountering an information overload. Organizations further seek to avoid the necessity of dealing with uncertainty by imposing standard operating procedures on the environment which predetermine the direction of organizational response.

The application of these concepts to the prediction of organizational decision-making conveys a profound respect for the difficulties of engineering any major change in organizational behavior. In the pursuit of an organizational objective the organization develops immense inertia, therefore, the course of organizational actions can only be altered by the repeated application of consistently directed external forces. Organizations are inherently blunt instruments whose efforts cannot be redirected simply by directives from the top, or changes in the external environment, which demand a sharp reordering of the organization's priorities. Rather, such a change requires the replacement of existing standard operating procedures with new routines, and the passage of sufficient time to allow the organization to learn these new repertoires.



Therefore, organizational behavior usually changes at a glacial rate. Over long periods of time, organizations may learn from experience which causes changes in goals, operating procedures, and search routines, but these changes are incremental and adaptive, rather than quantum leaps. In sum, the best predictor of what an organization shall do tomorrow is what it did today, which is only infinitesimally different from what it did yesterday. Predictions of behavior are based on explanations of the organizational routines, and the trends in these routines, unveiled by prior organizational history.

### 3.0 APPLICATION OF ORGANIZATIONAL THEORY TO U.S. BEHAVIOR

#### 3.1 The Central Proposition

We shall seek to apply the preceding organizational theory to an explanation of U.S. enrichment policies. The AEC's commercial mandate, as expressed in the Atomic Energy Act of 1954, has been to promote the creation of a domestic civilian atomic energy industry, to be owned and operated by private corporations rather than public agencies. Therefore, we shall postulate that the AEC has been the guardian of the domestic commercial objective.

What does this assumption imply? If our organizational theory is indeed borne out in practice, this assumption would imply that the AEC would fashion enrichment policy primarily to satisfy domestic commercial objectives, with inadequate concurrent consideration of international security objectives. In circumstances characterized by broad uncertainties in potential outcomes due to the interdependency between commercial and political objectives, the AEC would seek to avoid a global analysis of these interactions by adhering to well-established standard operating procedures for promoting domestic privatization while leaving the international security aspects to work themselves out. In short, conflicts between commercial and security objectives would be resolved by giving primary weight to commercial considerations. Furthermore, the AEC would be slow to respond to changes in the external environment which necessitated a

reordering of organizational objectives. Instead, the "commercialization-first" mentality would continue to persist, despite accumulating evidence of its non-workability, and only marginal changes would be made in enrichment policy, aimed at relieving short-run pressures rather than changing long-run strategies.

Our insights into organizational theory lead us to expect that the AEC's organizational inertia in pursuit of domestic commercial objectives was the dominant force in shaping U.S. enrichment policy. As indicated in essay #1, during the description of the running battle between the AEC and JCAE, the preferences of the AEC are not translated directly into U.S. policy prescriptions, but are subject to external review. In the case of the AEC, forces acting to alter AEC policies come from a variety of sources which may be conveniently summarized as the Administration (President, OMB, State Department, and other agents of the Executive Branch), and the Congress (JCAE). However, in attempting to influence AEC behavior from the outside, these external forces have an inherent disadvantage: the tenure of political office is typically so brief, in comparison to the life of a bureaucratic organization, and the focus of political officers is so tied to critical, short-run issues, that effecting changes in the strategic long-run behavior of a bureaucracy is uncommon.

Therefore, this essay shall seek to describe the United States' enrichment policy as the vector resultant of the AEC's powerful organizational inertia in pursuit of commercial objectives and the imposition of tangential external forces from a series of Presidential Administrations and the Congress aimed at incorporating the security objective into the AEC's decision-making calculus. In sum, the organizational theory leads to the following proposition:

U.S. enrichment policies may be understood not as the result of a continuous global rebalancing of domestic commercial and international security considerations, but as the result of the AEC's primary emphasis on domestic commercial objectives, often to the neglect of the security implications of the resulting enrichment policies.

### 3.2 The Substantiation of the Proposition

The history of the AEC, as discussed in essay #1, lends some evidence to our proposition. The subsidization of domestic civilian atomic power during the 1950's and 1960's was obviously consistent with the dimension of the AEC's commercial mandate which encourages the broad acceptance of nuclear power. The AEC vigorously promoted atomic energy through the encouragement of a private domestic uranium industry as well as a private domestic reactor industry, while steadfastly resisting pressure from the JCAE for direct government

participation in these industries. Essay #1's description of uranium price floor guarantees, the dispersal of technical data, the subsidization of enriched fuel prices, and the support for enrichment privatization, reveals the continuing growth of bureaucratic momentum behind the various dimensions of the domestic commercialization objective.

In examining our proposition our primary emphasis shall be on the influence of the dimension of commercial objectives relevant to the enrichment privatization policy. The enrichment sector was the last remaining stage of the fuel cycle under government control and the relinquishment of this technology to private control was seen as the next logical step in the twenty-year process of privatizing the nuclear fuel cycle. As described in essay #1, the legislative approval of toll enrichment in 1964 removed a key legal barrier to enrichment privatization and cleared the way for the initiatives of the Nixon-Ford Administrations, culminating in the UEA proposal and the NFAA of 1975.

We shall trace the effect of enrichment privatization in three areas of enrichment policy: SWU production, SWU contracting and pricing, and SWU technology transfer. In each area we shall look to see whether the actions of the AEC conform to our hypothesis.

### 3.3 The Implication of the Proposition: A Second Proposition

Even if our proposition proves to have some validity, it had little adverse impact on U.S. nuclear policy prior to the late 1960's because no large-scale conflict had arisen between commercial and security objectives. Rather, the United States Government had successfully pursued a consistently integrated nuclear strategy. Domestically, this strategy consisted of the subsidization, and subsequent protection, of private industries at each stage of the LWR fuel cycle with the exception of uranium enrichment. Internationally, U.S. strategy chose to position the U.S. as the monopoly supplier of enrichment services, where in return for this monopoly the U.S. guaranteed the entire non-Communist World a reliable, adequate supply of enrichment services at a reasonable price.

This international strategy simultaneously satisfied commercial and security objectives. The best means of controlling the spread of enrichment technology was to make foreign nations technologically dependent on the U.S. This technological dependency in turn encouraged the growth of U.S. reactor exports and the realization of significant revenues from sales of enrichment services, both of which satisfied U.S. commercial objectives. As Wonder (23) summarizes it, "The diplomacy of Atoms for Peace created a framework within which American corporate interests could be pursued."<sup>1</sup>

This framework within which security and commercial objectives conveniently complemented each other, began to disintegrate during the late 1960's. It is the source of that disintegration which is the focus of this essay. We shall argue that the failure of the U.S. Government to respond to rapidly changing environmental conditions by implementing a revised strategy was in large measure responsible for this disintegration. We shall trace this strategic oversight to the property of bureaucratic inertia in support of the policy of enrichment privatization, and the resulting blindness to the fact that the pursuit of commercial objectives in the form of enrichment privatization was inconsistent with the pursuit of security objectives in the form of supply assurances. The failure to implement a revised strategy led to a U.S. enrichment policy that was both confusing and inconsistent. This inconsistency, in turn, damaged U.S. credibility as a reliable supplier of enrichment services, which has had undesirable effects in both commercial and security spheres.

In sum we are led to a second derivative proposition:

The failure of U.S. enrichment policy to achieve a balance between commercial and security objectives contributed to the decline in U.S. credibility as a reliable enrichment supplier, which had negative impacts in both commercial and security domains.

### 3.4 Subtleties not Captured by the Propositions

Even though we would argue that the validity of our propositions results because an organizational theory which recognizes bounded rationality is more realistic than an organizational theory founded on global rationality, our simplistic identification of the AEC with the domestic commercialization objective fails to capture at least two additional aspects of reality.

First, because the AEC is a collection of individuals and subunits with disparate demands, different perceptual biases, and limited boundaries of concern, there will never be a consensus regarding the operational goals of the organization. Our inference that the AEC strongly supported enrichment privatization as an extension of its domestic commercial mandate, may be more carefully stated by inferring that enrichment privatization received strong support at the AEC Commissioner level. This inference is founded on public statements by AEC Commissioners and their successors at ERDA and DOE.

Undoubtedly this Commissioner-level support was an effective force behind privatization, but it does not imply that similar support existed uniformly throughout the AEC. Certainly the Production Division of the AEC, which was responsible for the existing plants and their technology, was not altogether enthusiastic



about the prospect of privatization, as this would constitute a form of bureaucratic hari-kari. In addition to the natural impulse to preserve its influence and existence, the Production Division had grown increasingly protectionist of their own technology, and opposed a giveaway to private industry. Therefore we must recognize that the AEC Commissioners encountered opposition to enrichment privatization from forces internal to the AEC, as well as some of the external forces mentioned earlier.

Second, whenever judging the actions of the AEC it is prudent to recall that the AEC personnel are only an administrative veneer which sits atop a massive foundation of employees responsible first to private contractors. In the case of enrichment operations these private contractors are the corporate giants Union Carbide and Goodyear. As such, the AEC does little work in-house, but instead uses the resources of its contractors, particularly Union Carbide at Oak Ridge, to see to the daily operation of the enrichment plants as well as to conduct long-range planning studies. Given the strong influence of Union Carbide on the AEC's long-run strategic plans, it is not surprising that many AEC decisions look like they were generated by a private, commercial firm.

The impact of the private enrichment contractors on the question of enrichment privatization is less clear. Both Union Carbide and Goodyear are paid on a cost-plus fixed fee basis, and although they

insist that their enrichment operations are done more for public service than corporate profit, it is difficult to assess the value of these contracts without further research. It is perhaps significant that no corporation has seen fit to compete with Union Carbide for its AEC contract, and representatives of Carbide suggest that they would gladly relinquish the contract if such competition should arise.

If indeed the AEC enrichment operations contracts are far from lucrative, there is little reason to expect Union Carbide and Goodyear to oppose enrichment privatization. Presumably they would be in a particularly good position to enter the market as private enrichers, if they so desired. Although Union Carbide was an original member of UEA, they backed out of the consortium after evaluating the proposal. Goodyear also evidenced some interest in private enrichment, but only as a supplier of centrifuges for use in a private enricher's plant, not as a private enricher itself.

In sum, our identification of the AEC as the custodian of the domestic commercial objective is certainly a simplification. This assumption is both weakened and reinforced when we choose to model the AEC based not only on the public pronouncements of its Commissioners, but when we also allow for the internal structure of the AEC and the relationship to its contractors. The reader must

carry these qualifications in mind when reading the balance of this essay.

### 3.5 Outline of the Essay

The format of the essay will be as follows. The influence of the privatization initiative, and associated commercial objectives relative to reactor exports and the domestic uranium industry, will be traced by examining U.S. policy in three areas of enrichment operations: SWU production, SWU contracting and pricing, and SWU technology transfer. In each instance we shall seek to explain U.S. policy choices primarily in terms of commercial objectives, as modified by prevailing security objectives.

In the area of SWU production we shall show that the roots of the AEC production strategy lie in a computer model which is founded solely on the commercial objective of providing nuclear fuel at minimum cost, with no concurrent consideration of security objectives. We shall demonstrate how an apparently minor modification of this program in an attempt to incorporate security objectives, could result in significant changes in the operating plan. In addition, we shall describe how the major policy results of this commercial model have been institutionalized as AEC standard operating procedures, which has led to the continuation of these policies after the disappearance of their analytic reason for being.

In the area of SWU pricing and contracting we shall narrate the history of changes in the methods for calculating toll enrichment prices. We shall indicate how these changes were consistent with an AEC attempt to increase prices, as an encouragement to private enrichers, within the broad legal limits of AEC pricing discretion. In addition, we shall demonstrate that the AEC has historically underpriced SWU's relative to the prices that would have been yielded by an alternative institutional structure. Prior to the 1970's, this underpricing was consistent with the dimension of the commercial objectives which subsidized the generic growth of nuclear power, and during more recent years the AEC's partially successful struggle against this underpricing bias is consistent with the enrichment privatization dimension of commercial objectives. Lastly, we shall find that AEC SWUs are differentially priced, and we shall demonstrate that the motivation for this differential pricing is as much an incentive for customers to convert to long-term contracts, similar to those suggested by potential private enrichers, as it is an unbiased attempt to recover actual differences in costs.

In the area of SWU technology transfer we shall examine the two U.S. enrichment multilateralization initiatives of 1971 and 1974. We shall find that in both instances, the implementation of these foreign policy proposals was guided by the demands of the balance of trade and enrichment privatization dimensions of commercial objectives, rather than security objectives.

Finally, we shall trace the undesirable feedback effects of these production, pricing, contracting, and technology transfer policy choices in an effort to demonstrate how they unintentionally contributed to the decline in U.S. credibility as a reliable SWU supplier, as suggested by our second proposition.

#### 4.0 SWU PRODUCTION

This section of the essay examines the AEC's rationale in choosing the operating characteristics of the enrichment plants, i.e. the tails assays and feed loading patterns which determine the physical output of the diffusion complex. We shall focus on three aspects of AEC production strategy--(1) the choice of the operating tails assay, (2) the tails recycle program, and (3) the preproduction stockpile program (including the split tails feed sales and advance feed policies)--and ask what they reveal about the AEC's objectives, in light of our first hypothesis. We shall trace the origin of these decisions to a Union Carbide computer model, and we shall see how the justification for these policies has evolved over time. In this manner we shall show that these operating decisions are founded on purely commercial considerations, often to the neglect of security objectives, and that the AEC has continued to pursue these policies despite shifts in the external environment which have caused the original economic justifications for these decisions to disappear.

#### 4.1 The Hatch-Levin Model

The roots of the current enrichment operating strategy are to be found in a computer model created by Union Carbide Corporation under contract to the AEC during the mid-1960's. This model was described by its authors, Hatch and Levin, in a journal article published in

1969; the succeeding paragraphs give a flavor of the Hatch and Levin (6) analysis.

The genesis of the position faced by the AEC in the mid-sixties has been stated quite colorfully by Congressman Craig Hosmer,

"In the late 1940's and early 1950's the United States sized and built its massive three unit enrichment complex on the basis of requirements for atomic bombs. Even before the complex went on-line, the H-bomb was invented and the entire investment became obsolete. We took a \$2.5 billion bath."<sup>2</sup>

Nonetheless, the plants were operated at high production rates until about 1964, when the military SWU demand declined and commercial demand was not forthcoming to replace it.<sup>3</sup> Accordingly, power levels were cut back sharply and have only begun to be restored during the 1970's to satisfy anticipated commercial requirements.<sup>4</sup> The problem of making the best economic use of this excess enrichment capacity is the fundamental issue confronted by the Hatch-Levin model.

The authors begin by stating the AEC's motivation for developing this computer model;

"The basic objective of the long range planning studies is the development of a detailed, logical operating plan for producing the enriched-uranium requirements at minimum cost,"<sup>5</sup>

which is obviously desirable since "the ultimate purpose of all this is to provide nuclear electric power at minimum cost." Because the total costs of the enriched uranium product are the sum of the enrichment costs of the AEC and feed costs of its customers, the authors translate the broad goal of cost minimization into the specific objective of minimizing the present value of the combined controllable costs of the AEC and its customers for the production of the enriched uranium requirements. In this context "controllable" describes those incremental costs which have not yet been incurred, as distinguished from previously "sunk" costs, including the construction costs of the existing plants and the acquisition cost of the already existing AEC enriched uranium stockpile. The authors point out that this cost minimization objective in no way restricts AEC pricing policies; no matter how the enriched material is priced economic efficiency is served by producing the desired output at minimum cost.

Hatch and Levin characterize their model as an "optimizing economic model of the enriched-uranium industry," and they adopt the following general criteria for economic optimization, as stated by Baumol:

1. Optimal Activity Level: The scale of an activity should, if possible, be expanded so long as its marginal net yield (taking into account both benefits and costs) is a positive value; and



the activity should, therefore, be carried to a point where this marginal net yield is zero.

2. Relative Activity Level: For optimal results, activities should, wherever possible, be carried to levels where they yield the same marginal returns per unit of effort (cost).

As applied to the AEC diffusion complex, the first of these criteria requires that existing plants be operated such that "the incremental cost of enriched product in any year is equal to the discounted cost of product from eventual new diffusion plants."<sup>6</sup> This requirement is illustrated in the following example.

Suppose that the long run marginal cost (LRMC) of fuel from a new diffusion plant in 1985 is \$300/kg U, and further suppose that the applicable discount rate is 5%. Then we can calculate that enriched fuel should be produced during the year 1978 until the marginal cost of producing the last unit equals the present value of \$300/kg U, which is:

$$\frac{\$300}{(1.05)^8} = \$203.05$$

At this point the marginal net yield of the last unit is zero; assuming rising marginal cost, prior to this unit the marginal yield was positive and after this unit the net yield will be negative.

Note that if demand is not sufficient to require the construction of new enrichment plants during the period under study, then the appropriate value for comparison is not the LRMC of product from additional plants, but the highest value of incremental cost occurring during the period of study, discounted from the year of occurrence. This determines that the optimization study must cover a sufficient period to insure identification of the year of highest incremental cost.

The second optimization criterion requires that the AEC choose the operating tails assay such that "the marginal cost of product due to feed equals the marginal cost of product due to separative work."<sup>7</sup> Such a choice is illustrated in the following example.

Suppose that we wish to solve the simpler one-period problem of meeting a product demand  $P$  with an existing separative work capacity  $S$ . How should we choose the tails assay? In this instance the incremental cost of feed is the market price for natural  $U_3O_8$  as  $UF_6$ , which we shall call  $p_1$ . The incremental cost of separative work is the cost of the electricity needed to power the diffusion cascades, which we shall call  $p_2$ .

Therefore defining F = units of natural feed supplied by  
toll enrichment customers

S = separative work units supplied by  
the AEC

We can write the cost function as

$$C(P) = p_1 F + p_2 S.$$

Using the ideal cascade equations reproduced on page 18 of essay #1,  
we can rewrite F and S as functions of the product mass (P), product  
assay ( $X_p$ ), feed assay ( $X_f$ ) and tails assay ( $X_t$ ):

$$C(P) = p_1 \left\{ P * \frac{(X_p - X_t)}{(X_f - X_t)} \right\} \\ + p_2 \left\{ P * (1 - 2X_p) \ln \left[ \frac{(X_p)}{(1-X_p)} \right] \right. \\ - P * \frac{(X_p - X_t)}{(X_f - X_t)} (1 - 2X_f) \ln \left[ \frac{(X_f)}{(1-X_f)} \right] \\ \left. - P * \frac{(X_p - X_f)}{(X_f - X_t)} (1 - 2X_t) \ln \left[ \frac{(X_t)}{(1-X_t)} \right] \right\}$$

Because P,  $X_p$ ,  $X_f$ ,  $p_1$ , and  $p_2$  are fixed, this cost

function can be minimized by operating at that tails assay where  $\frac{dC}{dP} = 0$ . Performing this differentiation yields the

transcendental equation:

$$\frac{p_1}{p_2} = (2x_F - 1) \ln \frac{x_T(1-x_F)}{x_F(1-x_T)} + (2x_T - 1) \frac{(x_F - x_T)}{x_T(1-x_T)}$$

which can be solved iteratively for  $X_t^*$ . Harkening back to the original formula for the cost function,

$$C(P) = p_1 F + p_2 S$$

we can see that this  $X_t^*$  is that tails assay where the

marginal cost of product due to feed  $\left(\frac{dC}{dF}\right)_S$  equals the

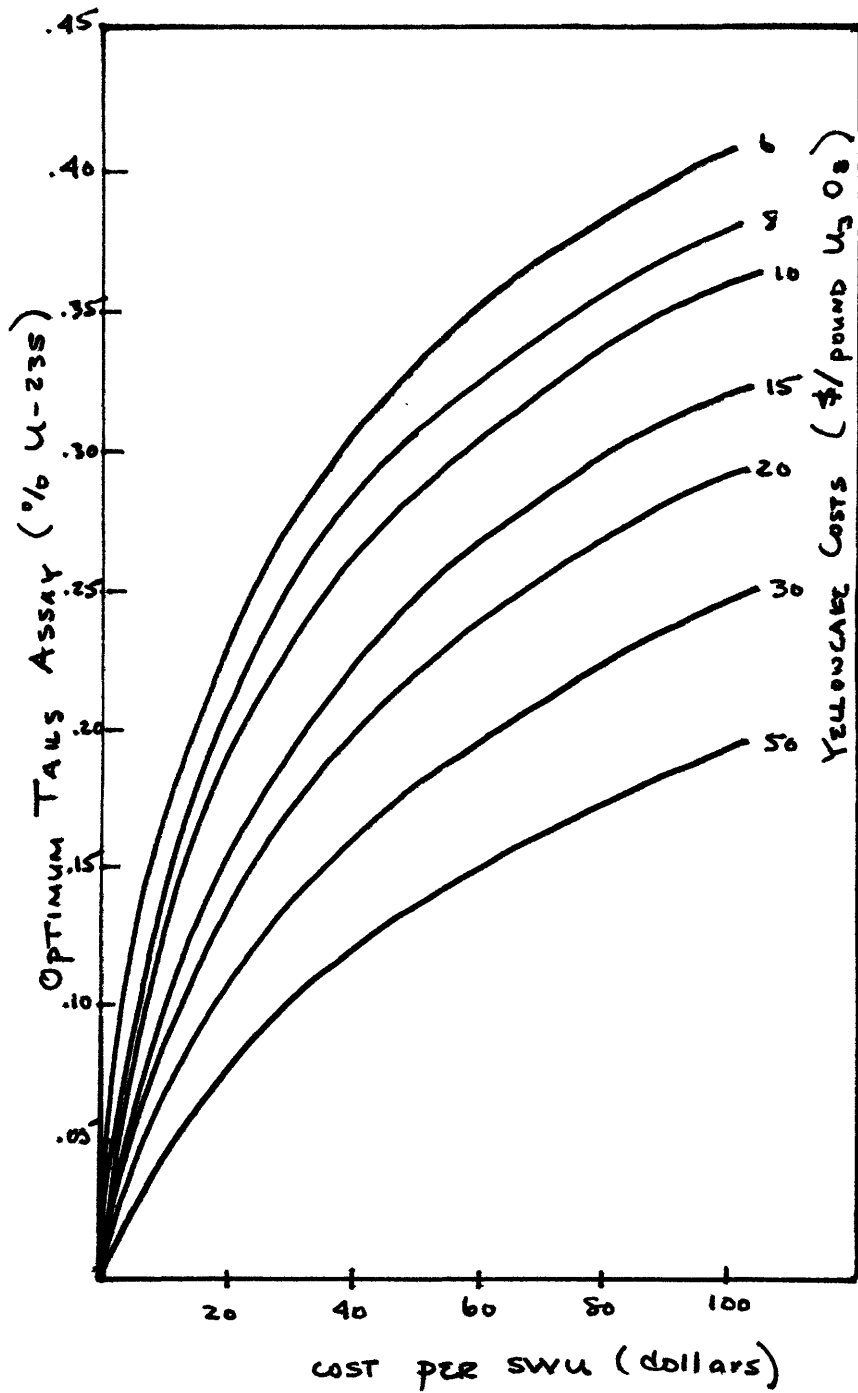
marginal cost of product due to separative work

$\left(\frac{dC}{dS}\right)_F$ . Thus when  $p_1 = \$30/\text{lb } U_3O_8$  and  $p_2 = \$100/\text{SWU}$ , the

optimum one-period operating tails assay is  $X_t = 0.25\%$ . Figure 2 plots the optimal tails assay as a function of SWU price and uranium price for a number of cases.

In applying these two optimization criteria to the design of an operating strategy, the basic consideration is that until at least the early 1980's, AEC SWU capacity exceeds demand, meaning that some of this excess capacity may be used to preproduce a stockpile of

FIGURE 2  
OPTIMUM TAILS ASSAY



SOURCE: [9], pg. 13.

enriched uranium for use in meeting demands during the subsequent era when annual demands outstrip capacity. Carried out wisely, such a preproduction program offers an economic advantage by delaying the need for expensive increments to enrichment capacity, albeit it at the expense of the carrying costs incurred on the AEC inventory of preproduced fuel.

Therefore, Hatch and Levin use these optimization criteria to dictate the tradeoffs of: (1) preproduction of fuel in existing facilities whose incremental costs are solely due to additional power, vs. later production of fuel in new facilities whose incremental costs include a capital cost component as well as an electricity cost component, and (2) preproduction at less costly lower-power levels vs. later production at higher-power levels at which power is used less efficiently by the diffusion complex. They summarize the application of these criteria as follows:

"The discounted incremental cost of product due to both feed and separative work should be everywhere equal in all years up to the year of highest incremental cost in the existing plants, subject to the constraint that production requirements are met in all years"<sup>8</sup>.

In order to apply these criteria, the Hatch-Levin model requires exogenous forecasts of enriched uranium demand, gaseous diffusion costs, feed costs, the discount rate, and the rate of technological change. These forecasts were obtained as follows:

(1) SWU demand--AEC reactor forecasts were used to compute enrichment demands;

(2) Gaseous Diffusion Plants costs--capital costs were estimated based on actual AEC construction costs, inflated to the present using the Engineering News-Record (ENR) Construction and Building Cost Indexes. Forecasts assumed that construction costs would continue to escalate at the same rate as they had in the past. Operating costs, which consist mostly of electric power costs, were assumed to remain stable because, "power costs have remained essentially constant over a considerable period of time."

(3) Feed costs--AEC estimates of future prevailing market prices, rather than AEC acquisition costs, were used to forecast feed costs.

(4) Discount rate--rates used ranged from 5% - 15%.

(5) Rate of technological change--estimates were made based on the experienced rate of technical development and the theoretical limits of the gaseous diffusion technology.

Using these exogenous forecasts the model proceeds through a nested hierarchy of iterations that yields a general solution which satisfies the optimization criteria, exhausts AEC-owned stockpiles in the last year of the production plan, and requires the construction of additional separative capacity in the year after the end of the production plan. Because the input forecasts were subject to a degree of uncertainty, sensitivity tests were made to analyze the effects of variations in input assumptions on the operating plan.

#### 4.2 The Results of the Hatch-Levin Model

When this model was used by the AEC during the 1960's to choose the diffusion operating plan for the next campaign, it produced three results which are pertinent to our discussion: (1) it selected an operating tails assay equal to roughly 0.30%, (2) it recommended the preproduction of a large SWU stockpile, and (3) it mandated a program of tails recycling. In a broad sense the model's "reasoning" in each of these three results is as follows:

(1) The operating tails assay is generally simply a function of the relative price of natural feed and enrichment services, and during the mid-sixties uranium price forecasts were for \$6/lb.  $U_3O_8$  and SWU price forecasts were for \$30/SWU. This price ratio called for an operating tails assay of approximately 0.30%; ex post



the  $U_3O_8$  price was underestimated relative to the SWU price, so today an optimum tails assay of approximately 0.20% is indicated.

(2) The large electrical demand charges, relative to stockpile carrying costs, determined that SWU capacity should be used at full capacity at all times. Because in the early years of a campaign, SWU capacity exceeded SWU demand, and conversely SWU demand exceeded SWU capacity in the later years of the production plan, full capacity operation resulted in the creation of a significant stockpile in the early years of the production plan which was drawn down to satisfy demands in later years.

(3) The time profile of buildup of the preproduction stockpile was not particularly important, as long as it did eventually get built to satisfy future demands. If anything, there was an economic incentive for building the stockpile slowly by recycling enrichment tails from previous operations. Tails recycle consumes lots of excess SWUs, moderates the rate of the stockpile's increase, and recovers valuable fuel from what was otherwise waste. The economic advantage of tails recycle arises from the fact that enrichment tails are stored as  $UF_6$ . Therefore, tails are ready to be vaporized directly in the enrichment cascade, unlike natural uranium which must be converted to  $UF_6$  before it is a fit enrichment feedstock. Thus, subject to demand constraints, tails feedstock has an absolute cost advantage over natural feedstock equal to the cost of conversion,

roughly \$4.15/kg UF<sub>6</sub> (1977 \$). Based on these sorts of considerations the Hatch-Levin model recommended an extensive program of tails recycling over the campaign period.

#### 4.3 The Commercial Nature of the Hatch-Levin Model

The Hatch-Levin model is a comprehensive and sophisticated piece of operations analysis. Unlike many "economic" computer models, it rests on a firm foundation of economic principles and resists falling prey to the use of average costs instead of marginal costs, and acquisition costs instead of market prices; it is correctly specified, as far as it goes. At the time of the model's creation it required the state of the art computer technology available at The Oak Ridge National Laboratory.

Not surprisingly, however, the model's outputs did not yield an optimal production strategy, due simply to inaccuracies in the input forecasts. With the benefit of hindsight it is easy to see that demand was overestimated, while uranium prices, diffusion plant costs (particularly electric power costs), and the discount rates were underestimated. Ex post, these forecasting errors combined to select a higher than optimal tails assay and to accumulate a larger than optimal preproduction stockpile, although these results cannot be taken as evidence that the model was poorly formulated or improperly used.

What is interesting for our purposes is not the input forecasting errors, but the nature of the model and what it reveals about the influence of commercial objectives on AEC operations. The Hatch-Levin model, designed as the AEC's response to the 1964 Amendments to the Atomic Energy Act calling for toll enrichment, is purely a commercial model, i.e., one built with the sole objective of cost minimization in mind. This efficient, business-like approach has certain security objective implications which the model fails to consider.

The AEC preproduction stockpile has an impact on the perceived degree of supply assurance. Specifically, a large stockpile represents both insurance to SWU buyers that enriched fuel will be available in the event of unforeseeable production shortfalls, and a competitive threat to potential entrants into the enrichment market. Therefore, the larger the stockpile, the greater the potential for assuring a supply of enriched fuel and the greater the barriers to entry into the enrichment market. As a result, it has been argued, particularly by elements at the State Department, that a large preproduction stockpile decreases the incentives for foreign nations to pursue enrichment, reprocessing, and breeder technologies, and thus reduces the drift towards the proliferation of nuclear weapons. In the terminology of welfare economics, this argument maintains that the AEC preproduction stockpile provides an external benefit which would not be internalized in a competitive market price. Because the

Hatch-Levin model contemplates the tradeoffs between preproduction, idle capacity, and the use of varying feedstocks solely in terms of market prices, it fails to capture this external effect.

The most important instance of this omission arises in the creation of the tails recycle program. As noted earlier, tails recycle is favored on economic grounds because it saves on  $UF_6$  conversion costs, as tails material is already in the form of  $UF_6$ . If, however, we tentatively accept the argument that the preproduction stockpile provides an external assurance benefit, not reflected in market prices, we could attempt to capture this benefit by adding a "security premium" to each kilogram of enriched fuel added to the preproduction stockpile. It is clear that tails recycle slows the buildup of the preproduction stockpile, and therefore provides a smaller potential external benefit than would be derived if natural feed was used for preproduction purposes. Therefore, the inclusion of a security premium will tip the scales more in favor of using natural feed, rather than tails feed, for preproduction purposes than would be the case if solely market prices were used.

Viewed in this manner, the timing of the tails recycle program is determined by the tradeoff between the postponement of the  $UF_6$  conversion costs associated with natural feed and the reduction in the size of the preproduction stockpile associated with tails recycle. To understand how this tradeoff works, consider the

following example. Suppose that the DOE production plan calls for recycling 0.3% tails down to the operating tails assay of 0.25% during the next N years. What is the security premium which we must be willing to pay in order to render us indifferent to the selection of tails feed vs. natural feed for the purpose of building the preproduction stockpile?

We calculate that the preproduction of 1 kilogram of 3% enriched uranium can proceed by either of two routes:

1 kg U 3% fuel = 6.0 kg U natural  $U_3O_8$   
+ 6 kg U conversion services  
+ 3.8 SWU

OR

1 kg U 3% fuel = 55 kg U 0.3%  $UF_6$  tails  
+ 7.6 SWU

Therefore we may compare the costs and benefits of the following two production plans--

- A. (the current plan) recycle 55 kg U of tails in year 1 and feed 12 kg U of natural uranium in year N+1;
- B. (the alternate plan) feed 12 kg U of natural uranium in year 1 and feed 55 kg U of tails in year N+1.

In case B, the size of the preproduction stockpile will exceed the size of the case A preproduction stockpile by 1 kg U of 3% fuel throughout the years 1, 2, ...N, even though both plans require the same amount of SWUs. Therefore defining the security premium per kg U of preproduced fuel as P, and the discount rate as r, the net present value of the additional external benefits of pursuing plan B rather than plan A are (assuming benefits accrue at year-end)

$$\text{Additional benefits} = \sum_{t=1}^N \frac{P}{(1+r)^t}$$

The net present value of the additional costs of plan B is simply the difference in conversion costs as the result of using the 12 kg U of natural feed in year 1 rather than in year N + 1 (assuming costs occur at beginning of year):

$$\text{Additional costs} = \$4.15 * 12 \left[ 1 - \frac{1}{(1+r)^N} \right]$$

Therefore we would be indifferent between the selection of tails feed vs. natural feed for preproduction purposes at the point where the additional costs of pursuing plan B equalled the additional benefits of pursuing plan B, i.e., for that P\* such that

$$\sum_{t=1}^N \frac{P^*}{(1+r)^t} = \$49.80 \left[ 1 - \frac{1}{(1+r)^N} \right]$$

Choosing as representative numbers N = 3 (the length of the current DOE tails recycling program) and r = 10%, we solve this relationship to find P\* = \$5. For assigned values of P < \$5, the current operating plan A, which chooses to recycle tails at the margin, is preferred,

while for  $P > \$5$ , natural feed, rather than tails feed, should be used at the margin (plan B).

In sum, if we value stockpile increments at \$1000/kg U (corresponding roughly to a uranium market price of \$40/lb.  $U_3O_8$ , a conversion market price of \$4.15/kg U, and a SWU market price of \$100/SWU)<sup>9</sup>, then the inclusion of a small security premium of \$5/kg U (equal to 0.5% of the value of a stockpiled fuel unit) will offset the economic advantages of tails recycle.

#### 4.4 Departures from Global Rationality

If the Hatch-Levin model had remained the root of the AEC production planning through the present, we would have little to add to the preceding criticism. While the model is clearly commercial in nature, its decisions are based on an honest attempt at cost minimization rather than political attempts at the protection or promotion of domestic commercial interests. Although our point regarding the neglected security implications of tails recycle is still valid, there is little to indicate that this program, by itself, has had serious negative international ramifications. As such, the continued use of the model for production planning would lend only slight support to our behavioral hypothesis. Fortunately, for our purposes, this has not been the case.

#### 4.4.1 Operating Tails History

One can trace the history of AEC production planning through years of AEC testimony before the JCAE. During the original 1966 testimony surrounding the establishment of toll enrichment, the AEC indicated that "we would expect that the plant would operate at a tails assay equivalent to that set up in the table of enriching service,"<sup>10</sup> namely 0.2%. This 0.2% operating assay was confirmed in the original announcement of a \$26/SWU toll enrichment charge in September, 1967.<sup>11</sup> By February, 1971, the rise in the SWU price had resulted in a revised operating plan subject to which the 0.2% operating tails assay would slowly rise to 0.25% during the years 1975-1980.<sup>12</sup> Presumably this plan was the result of simulations of the Hatch-Levin model.

This operating plan was subsequently revised to implement the split tails feed sales (STFS) policy. As recently as October, 1971, AEC officials explicitly refer to simulations of the Hatch-Levin model as the key determinant of the operating plan. As of this date the simulations called for a steady state operating tails assay of 0.25% and the need for additional enrichment capacity in 1982. This operating plan was modified for split tails by establishing an operating tails assay of 0.3% and a transactions tails assay of 0.20% during the years 1972-1974. After 1974 STFS were to have been completed, the operating and transactions tails assays were to have



been equalized at 0.25%, and the 0.3% tails generated during STFS operations were to be recycled during later years of the campaign.<sup>13</sup>

By August, 1973, the AEC was "projecting an operating tails assay of around 0.3 percent U-235 for its plants for a substantial period into the future"<sup>14</sup> although the then-current costs of feed and separative work would have indicated a tails assay of 0.26%.<sup>15</sup> The source of this operating plan is not clear from the record, but it appears to be a definite deviation from the dictates of the Hatch-Levin analysis. Raising the operating tails assay was a way to increase preproduction and continue to postpone the need for new privately owned enrichment capacity until 1982, consistent with earlier AEC projections.

The inference that the tails assay had become more the captive of the domestic privatization policy than the outcome of a cost minimizing strategic calculation is supported by later events. During the testimony preceding the initiation of the LTFC contracts, the AEC indicated that "it is estimated that the capacity of the existing diffusion plants, as improved and uprated, will not be completely contracted for until about the end of calendar year 1974."<sup>16</sup> Specifically, the AEC estimated that it could support 382 GWE of enrichment contracts at a tails assay of roughly 0.30%, assuming the adoption of plutonium recycle beginning in 1980 as

indicated in the appendices to the AEC enrichment contracts.<sup>17</sup> The AEC recognized, however, that the timing of the increase from 110 GWE to 382 GWE of enrichment contracts could not be predicted precisely, so they rewrote the enrichment criteria to permit AEC to enter into enrichment contracts in excess of the "available capability" of the diffusion plants, which had been historically defined as the capacity of the base plant plus the two current capacity expansion programs, the Cascade Improvement Program (CIP) and the Cascade Upgrading Program (CUP) (See Essay #3 section 3.1.2), operated at the "economic" tails assay, then defined as 0.3%. The open-endedness of this posture was emphasized in correspondence between AEC Commissioner Dixie Lee Ray and the JCAE where she provided her interpretation under the revised criteria that, "No limitation is placed on the mode of operation of the plants."<sup>18</sup>

The removal of this "available capability" restriction permitted the AEC to enter into contracts which would necessitate operation at an uneconomically high tails assay if these contracts were eventually satisfied from AEC diffusion facilities. In fact, AEC anticipated that any contracts above economically available AEC capacity would be terminated in favor of a domestic private enricher. Therefore, the AEC saw this additional flexibility as necessary to avoid a contracting gap between the time at which AEC capacity was exhausted and the time when a private enricher began writing contracts, thereby

smoothing the transition to private enrichment. As summarized by the GAO,

"AEC...believed that by the end of 1974 industry could be in a position to assume responsibility for providing any additional enrichment capability needed and all contracts beyond AEC's capability would then be consummated between the private enricher and the customer."<sup>19</sup>

The logic of these events lends credence to the argument that the tails assay of 0.3% was selected not on economic grounds, but was the assay necessary to keep the AEC order books open through the end of 1974, when a private enricher was anticipated.

As described in essay #1, the removal of this restriction did not succeed in keeping the order books open. The unanticipated rush in enrichment contracting forced the closing of the books as of June 19, 1974, at which time the AEC had executed or received requests for 364 GWE of enrichment contracts. Given the unexpectedly high contract load factors, and the limited interest in plutonium recycle, included by utilities in the LTFC contract appendices,<sup>20</sup> the contracting rush guaranteed that the AEC enrichment plants would be operated at a tails assay of 0.3% or greater, pending contract termination in favor of a private enricher, if contract demands were to be met.

In sum, the mismanagement of the LTFC contracting process had turned the problem of choosing an operating plan on its head. Rather

than selecting an operating assay on economic grounds and then signing contracts to meet the projected supply, the unanticipated contracting rush had forced ERDA to select an operating assay which would produce enough enriched uranium to satisfy projected demands.

The necessity of stylizing the operating plan to the overstated contract demands became the public basis for ERDA's production policy. As summarized at the Oak Ridge Enrichment Conferences of 1975 by the ERDA Chief of Operational Planning, "The 0.30% tails assay is essentially fixed by our contracting policy,"<sup>21</sup> rather than determined by a Hatch-Levin economic calculation. In his opening remarks at these conferences, the Director of the ERDA Production Division observed that, "The considerations leading to a determination of the preproduction stockpile level now must be different from those originally used in the mid-1960's." Nevertheless he argued that, "Preproduction is generally accepted as the proper thing to do. This preproduction stockpile must now provide inventory for a transition to private operation of new enrichment plants." <sup>22</sup> Therefore, he publicly modified the AEC objective function to read, "The objective of the (AEC) operating plan is to maximize the preproduction stockpile within identified assumptions and constraints." (emphasis added).<sup>22</sup> He continued, however, to certify the health of the AEC policy of non-interference in the domestic uranium market by adding, "One of the constraints imposed is that ERDA will not purchase additional feed."

This feed constraint served to guarantee the continuation of the tails recycle program. Slippages in REQ contract deliveries meant that the AEC natural uranium stockpile was being depleted more rapidly than had been anticipated. In the absence of dwindling natural stocks the only source of enrichment feedstocks for preproduction purposes was 0.3% tails. At Oak Ridge, ERDA indicated that 0.3% tails would be recycled "in order to maximize the operating tails assay and thus the production of enriched uranium." <sup>24</sup> This recycling would be made possible by the reduction in the operating tails assay "to perhaps as low as 0.25%...(due to the) reduced demands and the associated reduced feed availability during the 1976-1979 time period."<sup>25</sup> Despite this temporary reduction in operating tails. ERDA spokesman made it clear that the long-run operating tails assay would be at least 0.30%.

During mid-1975, ERDA administered the open season on enrichment contracts, which reduced ERDA's total contractual commitment to 329 GWE while delaying deliveries under most contracts. Nonetheless, contract demands, rather than cost minimization, continued to shape diffusion plant operating plans. In November, 1975 ERDA presented four alternate operating plans which displayed the possible range of tails assays required to satisfy contract demands under various assumptions regarding plutonium recycle and split tails feed sales. Long-run equilibrium tails assays ranged from 0.29% to 0.37%, and all plans included tails recycle programs. In the face of these broad

uncertainties, ERDA did not attempt to define one operating plan. Rather, ERDA representatives indicated that the formulation of such a plan would be an ongoing process pending the resolution of these uncertainties, and reminded customers that, "the final tails assays will be determined by the requirements in the appendices of your toll enrichment contracts." 26

By October, 1977 enough of these uncertainties had been resolved to permit DOE to state,

"we plan to continue to operate our enrichment plants at a tails assay of 0.25% and eventually customers will have to supply uranium feed on that same basis. The current 0.20% transaction tails assay will be continued, however, at least until October 1, 1980."27

This decrease in the tails assay, made possible by the anticipated Portsmouth centrifuge plant (despite the Presidential ban on plutonium recycling), was intended to reflect the rapid rise in uranium market prices during 1974-1975 which rendered an 0.3% operating tails assay obsolete from a cost minimization viewpoint.

#### 4.4.2 Stockpile Forecasting History

Because the size of the preproduction stockpile is necessarily determined by the AEC choice of operating tails assays and power levels, the history of AEC stockpile forecasting has fluctuated

widely with each change in operating plans. As conceived originally by the Hatch-Levin analysis, the preproduction stockpile was to be exhausted by 1982, the year when additional enrichment capacity was needed. This notion that the preproduction stockpile was being built only to be drawn down in later years is reflected in the July, 1973 testimony of AEC Commissioner Clarence Larson who indicated that the AEC operating plan would yield a preproduction stockpile which peaked at 34 MMSWU in 1978 and was drawn down to zero by 1983. 28

Following the initiation of LTFC contracts, and the subsequent closing of the order books, AEC policy shifted abruptly to contemplate the construction of a steady-state preproduction stockpile, intended to cover a variety of contingencies including unforeseen events that would affect the output of existing plants, and the need to provide a backstop against possible slippages in production from prospective new private enrichers. During the heyday of the Nixon-Ford privatization initiatives, as much as 42 MMSWU of preproduced uranium was seen as desirable to provide back-up for commercial enrichers, as embodied in the NFAA of 1975.<sup>29</sup> This portion of the preproduction stockpile would be used to guarantee that enriched fuel would be available under all circumstances to those customers who signed contracts with private enrichers. On top of this commercial backstop function, ERDA contended that there was a basic commercial reason for maintaining a 90-day working inventory of preproduced uranium necessary to insure smooth delivery to enrichment

customers; this minimum reserve stockpile amounted to roughly 8 MMSWU.

Therefore the enrichment privatization policy encouraged the increase in the long-run operating tails assay from 0.25% to 0.30% as a means of maximizing preproduction, while indirectly necessitating this increase to satisfy the artificially inflated demands created by the LTFC contracting fiasco.

While ERDA was busy planning how to maximize the preproduction stockpile, events occurred which caused the stockpile forecasts to grow alarmingly. During 1973, AEC plans forecasted that the preproduction stockpile would be exhausted by 1983;<sup>30</sup> in 1974 the AEC forecasted that the stockpile would reach a level of roughly 32 MMSWU by 1986;<sup>31</sup> in 1975 the AEC again revised its estimate of the 1986 preproduction stockpile up to 45 MMSWU.<sup>32</sup> This growth in the stockpile was the result of slippage in REQ contract demands, the LTFC open season, and the extension of the STFS policy.

This growth in stockpile forecasts attracted attention from the Office of Management and Budget. Budget-conscious program monitors saw the growing stockpile forecasts as evidence that DOE was overbuilding enrichment capacity and was wasting tax dollars by incurring carrying costs on an excessive preproduction stockpile.



Just as budgetary pressure was brought to bear during the early 1970's to encourage disposal of the  $U_3O_8$  stockpile, so OMB encouraged reductions in the preproduction stockpile by delaying CIP/CUP and cutting back power levels. As shown in Tables 2 and 3 both the AEC and OMB consistently reduced AEC Production Division appropriations requests for CIP/CUP investment funding and cascade power funding during the early 1970's. Many times these reductions were partially offset by Congressional appropriations in excess of OMB requests, due chiefly to the efforts of the JCAE which had historically supported an aggressive preproduction policy.

OMB was not alone in its suspicions about the size of the preproduction stockpile. Potential private enrichers pointed to a large preproduction stockpile as evidence of both demand slippages and prevailing excess enrichment capacity which made enrichment privatization unacceptably risky without extensive government guarantees. Further lack of a clear DOE policy detailing the acquisition and dispersal of the preproduction stockpile has aggravated existing uncertainties in the uranium and enrichment markets. Quoting a representative of the French Atomic Energy Agency,

"...it is now more important for the uranium mining industry to know what the long-term stockpiling policy of utilities or governments will be than to know if it is the low or the high estimate of installed reactor capacity which will actually be achieved in a given year."<sup>33</sup>

TABLE 2

FISCAL YEAR 1970-75 BUDGET SUBMISSIONS AND OBLIGATIONS FOR CIP/CUP (103 DOLLARS)

<u>Fiscal Year</u>	<u>Division Request</u>	<u>Changes by AEC</u>	<u>Additional Changes by OMB</u>	<u>Request to Congress</u>	<u>Approved by Congress</u>	<u>Actual</u>
CIP:						
1970	25,800	0	(25,800)	0	0	0
1971	60,940	0	(55,940)	5,000	21,100	4,989
1972	68,000	0	(68,000)	0	25,000	40,484
1973	20,000	0	0	20,000	25,000	25,627
1974 (est.)	146,100	(10,400)	(20,000)	115,700	115,700	115,700
1975 (est.)	133,000	(32,000)	0	101,000	118,000	-----
CUP:						
1972	6,000	( 6,000)	0	0	0	0
1974 (est.)	6,000	0	0	6,000	6,000	6,000
1975 (est.)	71,400	(30,000)	0	41,400	44,400	-----

SOURCE: (10) pg. 799

TABLE 3  
FISCAL YEAR 1970-75 BUDGET SUBMISSIONS AND OBLIGATIONS FOR CASCADE POWER (\$10<sup>6</sup>)

<u>Fiscal Year</u>	<u>AEC Division Request</u>	<u>Changes by AEC</u>	<u>Additional Changes by OMB</u>	<u>Request to Congress</u>	<u>Approved by Congress</u>	<u>Actual</u>
1970	74.4	( 0.8)	0	73.6	73.6	74.2
1971	97	( 3.0)	( 5.0)	89	89	93
1972	126	( 2.0)	1.0	125	125	128
1973	182	( 3.0)	(28.0)	151	166	168
1974	222.8	0	0	222.8	230.9	201.5
1975	321.5	(13.0)	0	308.5	308.5	

Therefore, DOE now has a variety of reasons to try to reduce the apparent size of the preproduction stockpile. A reduced stockpile will reduce the budgetary pressure to cut back on appropriations used to expand the diffusion complex through CIP/CUP, while increasing the apparent necessity for future enrichment capacity, preferably privately owned and operated. As a result DOE has been receptive to TVA requests to cutback power deliveries to the diffusion complex, <sup>34</sup> to delays in the Portsmouth GCP startup schedule, <sup>35</sup> to calls for a contribution to an international fuel bank, <sup>36</sup> and to negotiations with the Japanese for the sale of a portion of the preproduction stockpile.

Similarly the continuation of the tails recycle program may be viewed as an excellent way to reduce the size of preproduction stockpile while continuing to operate the diffusion complex at full capacity. In addition the tails recycle program has become a necessary complement to the STFS policy. Given DOE's commercial objective of fostering a stable uranium demand, the department maintains a policy of no direct purchases in the feed market. Therefore, as the natural uranium stockpile is depleted by STFS and enriched fuel preproduction, tails material becomes the only alternative source of preproduction feed for the cascades.

#### 4.4.3 The Selection of Policies Based on Standard Operating Procedures

In sum, this review of the AEC operating history has demonstrated that, like many comprehensive, rational, decision-making algorithms, the Hatch-Levin model has been increasingly ignored since its use during the late 1960's, and has been replaced by a piecemeal bureaucratic approach to production planning. Despite the changing prices and market conditions, the Hatch-Levin model has not been continuously resimulated during the intervening years. Instead it has lapsed into disuse, and yet its broad results, namely the creation of a preproduction stockpile and the tails recycle program live on after it. That these results have been institutionalized is a natural implication of the assumption of bounded rationality. Individuals tend to accept the broad policy prescriptions of the early Hatch-Levin simulations without recalling their precise origins or the assumptions that lay behind them.

Today many of the original justifications for the preproduction stockpile and tails recycle program have vanished. The broad slippages in demand have postponed the need for aggressive capacity expansion and subsequent maximum use of this expanded capacity for preproduction purposes, yet only recently has DOE shown indications of responding to this changing environment by cutting back on preproduction plans. Similarly, the current DOE natural uranium

stockpile has already been fully converted to UF<sub>6</sub>, <sup>37</sup> thereby eliminating the economic rationale that tails recycle saves on conversion costs, and yet a substantial tails recycle program is currently ongoing.

This review of operating policies reveals that these policies are less the result of a grand economic plan than the accumulation of a sequence of feedback-react responses by the AEC to a variety of pressures. Operating assays, stockpile sizes and feed loading patterns, were chosen to satisfy the disparate demands of enrichment privatization, uranium industry protection and a reduced federal budget, rather than the original economic objective of cost minimization. Because the size of AEC stockpiles of natural and enriched uranium are presumably measurable quantities, <sup>38</sup> these stockpiles have been used by external agents as indicators of AEC performance. Much as a utility's rate of return is a critical variable which is monitored by a regulatory commission, so the magnitude of the AEC stocks has become the focus of external attention in assessing AEC performance. Therefore the AEC has been placed in a satisficing posture of trying to keep the preproduction and U<sub>3</sub>O<sub>8</sub> stockpiles within acceptable limits while trying to promote uranium industry protection (through STFS, advance feed deliveries, tails recycle and a policy of no feed purchases) and

enrichment privatization (by providing a back-stop preproduction stockpile).

#### 4.5 Summary

We conclude that our investigation into the AEC's SWU production planning process yields evidence favorable to our central proposition. Our research into the Hatch-Levin model has demonstrated that the roots of the AEC's toll enrichment production strategy lie solely in the commercial objective of cost minimization. Furthermore, we have shown that the single-minded pursuit of cost minimization, where market prices are used as proxies for operating costs, may not yield a production plan which incorporates security objectives; our sample tails recycle calculation has demonstrated how the inclusion of a vanishingly small stockpile security premium in the AEC's calculations could significantly alter the AEC's operating plan. Finally we have documented how the broad policy prescriptions of the Hatch-Levin model, such as tails recycle and a large preproduction stockpiling program, have become institutionalized as part of the AEC's standard operating procedures. As a result these programs continue to exist despite the disappearance, or weakening, of their economic justifications. This in turn leads to a situation where AEC enrichment policies are chosen more in response to short-term

external pressures than the guidelines set down by strategic long-run planning.



## 5.0 SWU PRICING AND CONTRACTING

This section of the essay focuses on the AEC's enrichment pricing policies and their interaction with the changeover from requirements (REQ) to long-term fixed commitments (LTFC) enrichment contracts. The management of this changeover process has been described in detail in essay #1. We shall begin by providing a narrative history of the AEC's toll enrichment pricing policies which shall explain in some detail the evolution of the current procedure for pricing SWUs sold under REQ and LTFC contracts, as well as the proposed fair value pricing scheme. Then we shall return to evaluate these policies, and describe their interaction with the changeover to LTFC contracts, in light of our behavioral hypothesis. This research shall lend further evidence to the assertion that the AEC has been motivated primarily by commercial objectives in its pricing and contracting policies.

### 5.1 A Narrative History of AEC Toll Enrichment Pricing

#### 5.1.1. The 1966 Criteria: Cost-Recovery REQ Pricing

The history of toll enrichment prices is documented in Table 4. The original REQ toll enrichment prices were established on the basis of the 1966 Uranium Enrichment Services Criteria promulgated by the AEC pursuant to the 1964 Amendments to the Atomic Energy Act, which required that the charges for enrichment services shall be

TABLE 4

## TOLL ENRICHMENT PRICING HISTORY

Effective

<u>Date</u>	<u>REQ. Price (\$/SWU)</u>	<u>LTFC Price (\$/SWU)</u>
07-01-62	\$30.00/SWU	-
01-01-68	26.00	-
02-02-71	28.70	-
11-14-71	32.00	-
08-14-73	38.50	36.00
01-01-74	38.90	36.40
07-01-74	39.30	36.80
12-18-74	47.27	42.10
01-01-75	47.80	42.95
07-01-75	48.80	43.85
08-20-75	-	53.35
12-18-75	59.80	-
01-01-76	60.95	-
04-27-76	-	59.05
08-25-76	65.83	-
10-01-76	-	61.30
01-27-77	69.75	-
07-01-77	67.58	-
11-29-77	-	74.85
03-29-78	76.82	-
07-01-78	83.15	-

Source: (23), pg. 6.

"nondiscriminatory" and shall "provide reasonable compensation to the Government". The Criteria proceeded to add that, "AEC's charge for enriching services will be established on a basis that will assure the recovery of appropriate Government costs projected over a reasonable period of time."<sup>39</sup> The Criteria specified that the AEC should seek to establish an average charge over this time period which should be kept "as stable as possible." The criteria explicitly recognized the possibility of preproduction stockpiling and indicated that "interest on the separative work costs of any such preproduced inventories" would be included in the SWU price.

The AEC implemented these criteria by posting a \$26/SWU toll enrichment price as of September 21, 1967.<sup>40</sup> This price equaled the projected average cost of sales of separative work for fiscal years 1966-1975, as calculated in Table 5. The important points to note about the Table 5 calculation are:

1. The 5% discount rate was based on the average rates on U.S. Treasury interest-bearing debt;
2. As specified by the criteria, depreciation was determined on the historical cost of investment in plant which is actually used, and excludes costs properly allocable to plant in standby and excess capacity resulting from military procurement policies;

TABLE 5

PROJECTED AVERAGE COST OF SALES OF  
SEPARATIVE WORK FY 1966-1975 (\$/SWU)

1.	Direct and indirect costs of operating the gaseous diffusion plants (primarily power)	\$13.90
2.	Depreciation	3.65
3.	Interest at 5% on plant and working capital	2.93
4.	Other costs	0.87
5.	Interest at 5% on preproduction	<u>1.15</u>
6.	Total of (1)-(5)	22.50
7.	15% contingency	<u>3.50</u>
8.	Total average cost	<u><u>\$26.00</u></u>

Source: (28), pg. 108.

3. SWU demand was calculated on an operating plan which assumed an 0.2% operating assay over the 10-year period;
4. The 15% contingency, which amounted to using a risk-adjusted discount rate of 7.5% rather than the risk-free Government borrowing rate of 5%, was intended to allow for unpredictable uncertainties such as cost inflation;
5. "The AEC noted that for this purpose a 7.5 percent rate of return could be considered as a possible composite cost of money from debt and equity sources associated with a privately financed enrichment enterprise, including an assessment of the business risks associated with such an enterprise. The possibility of future uranium enrichment operations being conducted in the private sector of the economy is currently under study." 41

In order to guarantee enrichment customers an upper bound on enrichment prices, the criteria specified that toll enrichment prices would be constrained by an escalating price ceiling. In calculating the ceiling, 1/3 of the 1965 ceiling price of \$30/SWU was fixed to provide for recovery of investment in the diffusion plants, while the remaining 2/3 was escalated to cover variable costs; the labor portion (\$5) was escalated in line with the six-month moving average hourly wage of production workers in the Chemical and Allied Products

Subdivision of Manufacturing Industries, while the energy portion (\$15) escalated according to the six-month moving average cost per kilowatt-hour of electric energy used in all AEC diffusion facilities.

#### 5.1.2 Commercial REQ Pricing

Unfortunately, the desired price stability did not come to pass, and the AEC reacted to rising costs and the Nixon privatization initiatives by raising the toll enrichment price to \$28.70/SWU during 1971. This price increase represented an entirely new "commercial basis" for enrichment pricing, and the AEC revised the criteria accordingly. The AEC indicated that the revised criteria were consistent with President Nixon's 1969 announcement that the AEC "is to operate its uranium enrichment facilities in a manner which approaches more closely a commercial enterprise"; the criteria implemented this decision by establishing a price which would "best meet the criteria of comparability to a commercial operator", because the price would equal "the estimated cost of separative work from a new enriching plant utilizing advanced technology and designed and operated for the primary purpose of meeting civilian nuclear power requirements." <sup>42</sup> The assumptions used to calculate this "commercial" price are listed in Table 6.

The important facts to be noted about the \$28.70/SWU price and the revised commercial criteria are:

TABLE 6

ASSUMPTIONS USED AS BASIS FOR  
COMMERCIAL ENRICHMENT CHARGE OF \$28.70/SWU

Plant: A new gaseous diffusion plant,  
constructed at a separate site and  
incorporating technology anticipated to  
be available in 1975.

Capacity: 8.75 MMSWU

Investment: \$880 million (1970 dollars)

Power Usage: 2400 MWE

Power Cost: 4.5 mills/KWH

Operation & Maintenance (excluding power), R&D and

Process Support: \$16 million/yr.

Financial:

Debt/Equity Ratio: 50/50

After-tax Return on Equity: 12%

Interest Rate on Debt: 7%

Amortization Period: 25 years

Source: (28) pp. 3-4.

1. Rather than basing prices on the recovery of backwards-looking historical costs, the commercial criteria contemplate the forward-looking construction of a hypothetical new plant;
2. The commercial pricing criteria retained the escalating \$30/SWU price ceiling;
3. The commercial criteria adopted private, rather than Government, discount rates, which include a return to equity;
4. The commercial criteria indicated that the AEC would periodically review the SWU price to keep it in line with updated forecasts of investment costs and discount rates, rather than attempting to maintain a constant price over a ten-year campaign period.

5.1.3 A Return to Cost-Recovery REQ Pricing and a Change in Campaigns

These commercial criteria were only in effect for a few months. Their establishment drew sharp criticism both from dissenting AEC Commissioner James Ramey and the members of the JCAE who argued that the only justification for the commercial criteria was "to create a higher profit image and thereby facilitate transfer of the gaseous



diffusion plants to private ownership", <sup>43</sup> and that it was likely to fail in this attempt because "(given current circumstances) nobody in his right mind would touch these diffusion plants by way of purchase with a 10-foot pole." <sup>44</sup>

Congressional disapproval of the commercial criteria resulted in the passage of an Omnibus Bill which provided that the SWU price should be established "on the basis of assuring recovery of appropriate Government costs for work done in existing Government plants." <sup>45</sup> Consistent with this legislative mandate the AEC revised the criteria to return to the original cost-recovery criteria established in 1966, except that the AEC chose to implement these criteria by redefining the 10-year campaign period to be 1971-1980 and by estimating SWU demands under the assumption that plutonium recycle would begin in 1974; the 15% contingency, the 5% discount rate, and the use of uninflated cost forecasts were retained from the original \$26/SWU calculation. Using those new assumptions the AEC established a price of \$32/SWU in November, 1971. Although the operating plan was revised during 1971 to reflect a long-term operating tails assay of 0.25% as well as the split tails policy, the \$32 price remained unchanged.<sup>46</sup>

5.1.4 The Initiation of LTFC Pricing and the Creation of an  
REQ-LTFC Price Differential

Once again the desired price stability could not be maintained due to unanticipated increases in electric power costs. In August 1973, concurrent with the initiation of LTFC contracting, the AEC once again increased the SWU price. Because the criteria remained unchanged, the cost-recovery calculation was basically an updated version of the 1971 calculation--the 1971-1980 campaign period and the 15% contingency remained unchanged--with the following exceptions:

1. The discount rate was increased to 5.5%;
2. Natural uranium sold by the AEC as a result of STFS was included as an AEC cost, and evaluated at projected market value;
3. Enrichment prices were automatically inflated at the rate of 1% every six months beginning January, 1974;
4. REQ contract sales were priced at \$2.50 higher than LTFC sales to compensate AEC for the additional risks associated with greater demand uncertainties in the case of REQ contracts rather than LTFC contracts; 47
5. The price ceiling was eliminated for LTFC contracts because, after the declassification and annual publication of AEC diffusion costs and the direct inclusion of cost-recovery

language into the 1954 Act by the Omnibus Bill of 1970, the purpose of the ceiling no longer applied; the price ceiling was retained for REQ customers as it was explicitly written into their contracts;

6. Unlike increases in the REQ SWU price, which became effective 180 days after publication in the Federal Register, LTFC prices could be changed with no advance notice simply by Federal Register publication. "In justifying this change, AEC stated that it was not ordinary commercial practice to give lengthy notice for price increases." <sup>48</sup> In sum, these new calculations yielded a SWU price of \$36/SWU for LTFC customers and \$38.50/SWU for REQ customers.

5.1.5. Further Price Increases and the Inclusion of Additional Costs

Even though the inclusion of the 2% annual escalation factor had laid to rest the myth of stable campaign prices, this scheme alone could not keep pace with rising costs. Therefore, in December, 1974 the AEC raised the prices to \$42.10/SWU for LTFC sales and \$47.80/SWU for REQ sales. These increases were based on the same 1971-1980 cost recovery calculation with the following exceptions:

1. The discount rate was increased once again to 6%;
2. The automatic escalator was raised to 2% every six months;
3. Costs of gas centrifuge R&D were included in AEC costs;
4. LTFC prices were further reduced by \$2.15 from REQ prices to reflect interest on advance payments received from LTFC customers.

Once again, these updated prices failed to keep pace with rising costs and during late 1975 prices were increased to \$53.35/SWU for LTFC sales and \$60.95/SWU for REQ sales. These prices were based on calculations identical to prior cost-recovery calculations, as were the subsequent price increases during 1976 and 1977 detailed in Table 4. The only changes of any significance over the period were an increase in the discount rate to 6.5%, the inclusion of a credit for feed recovered by tails recycle, and the abandonment of the automatic escalation provisions in favor of updating the SWU prices every six months.

#### 5.1.6 Fair Value Pricing

While the official SWU pricing procedure had reached some degree of consistency during the years 1975-1977, ERDA was proposing a

dramatic change in the enrichment criteria which would substitute fair value pricing for cost recovery pricing of LTFC sales. The proposed fair value price would modify the cost recovery pricing formula to include a risk-adjusted, private discount rate, an allowance for corporate income taxes, and "other costs typical of private operation." <sup>49</sup> ERDA's specific assumptions used in determining a June, 1975 fair value price of \$76/SWU are documented in Table 7.

The analysis lying behind these assumptions was as follows: <sup>50</sup>

1. The 12% discount rate had two components: a 10% factor representing the average real before-tax rate of return on private investment, as given by OMB, and a 2% ERDA risk adjustment intended to reflect the "above-average risk associated with uranium enrichment";
2. The 50/50 debt-equity ratio was chosen as reasonably representative of the financing ratios in the electric utility industry;
3. The 15% equity cost of capital was based on Federal Power Commission estimates that a 15% return was needed to attract capital to public utilities;

TABLE 7

ASSUMPTIONS USED IN DETERMINING \$76/SWU FAIR VALUE PRICE

1. Discount rate: 12%
2. Debt-equity ratio: 50/50\*
3. Interest rate on debt: 8.3%\*
4. Return on equity: 15%\*
5. Historical cost amortization period: 16 years
6. New enrichment technology R&D costs: \$25 million/year
7. State & local taxes, and insurance: 1% of gross investment
8. Working inventory of reproduced uranium: 90 days

\* for Federal income tax calculation purposes only.

Source: (18) pp. 457-466.

4. The 8.3% debt cost of capital corresponded to an average interest rate on "certain highly rated bonds" during the years 1970-1974;
5. The allocation of 1% of gross investment for state and local taxes and insurance was estimated by determining the amount paid for these items by two of ERDA's diffusion plant power suppliers-- Ohio Valley Electric Corporation and Electric Energy, Incorporated;
6. The 90-day working inventory of preproduced enriched uranium was based on ERDA calculations presented by Kiser at the 1975 Oak Ridge Enrichment Conferences (25); unlike the ERDA cost recovery scheme which recovers only the interest on the separative work costs of preproduction, the fair value price would include the interest on the natural uranium contained in this working inventory.

A comparison of ERDA's \$53/SWU cost recovery price and the proposed \$76/SWU fair value price is given in Table 8. The use of a higher discount rate and the inclusion of Federal income taxes account for virtually all of the \$23/SWU net difference.

The main point that needs to be made about this fair value price is that it was not intended to represent a commercial charge for

TABLE 8

COMPARISON OF \$53/SWU COST RECOVERY  
CHARGE AND \$76/SWU FAIR VALUE CHARGE

1. ERDA cost recovery price	\$53.35/SWU
2. Less 15% contingency	<u>6.96</u> \$46.39
3. Difference due to discounting at 12% rather than 6.5%	9.69*
4. Federal income tax	12.32
5. Other taxes and insurance	2.15
6. U <sub>3</sub> O <sub>8</sub> contained in 90-day preproduction working inventory	3.36
7. Laser enrichment R&D	<u>2.09</u>
TOTAL	<u><u>\$76.00/SWU</u></u>

\* does not include effect of difference in discount rates in items 4-7; total difference including these items is \$14.17.

Source: (18) pp. 460-462.



enriching services, unlike the AEC's commercial charge of \$28.70/SWU established during the latter half of 1970. The fair value price did include insurance costs, income taxes, and a higher discount rate, but continued to compute depreciation based on the historical acquisition cost of the gaseous diffusion plants, and did not include a provision for return on equity. Therefore, the GAO review of ERDA's fair value proposal concluded that,

"ERDA's proposed (\$76) charge is about midway between its existing cost recovery price of \$53 an SWU for fixed-commitment contracts and the estimated initial (UEA) commercial price of \$100 an SWU." 51

ERDA stated that the purpose of the fair value legislation was to

"eliminate or reduce the difference between the Government's charge for enriching services and those of potential domestic private enrichers...(thereby removing) any barriers that may prevent utilities from entering into enrichment contracts with private industry...and end an unjustifiable subsidy to both foreign and domestic customers." 52

Furthermore, ERDA added that if the \$76 charge was not high enough to encourage utilities to contract with domestic private enrichers, "it planned to add an amount to the fair value charge to meet this objective." 53

The fair value legislation has failed to receive Congressional approval to date. Throughout the intervening three years the fair value price computation has continued to be updated to reflect rising

costs. The fair value price would have been approximately \$90/SWU as of May, 1976 and would have risen to \$100/SWU by October, 1977. 54

#### 5.1.7 The Redefinition of the Cost-Recovery Campaign Period

Despite the disapproval of the fair value legislation, ERDA substantially modified its conventions for pricing SWUs within the confines of the cost-recovery mandate. In September, 1977, ERDA announced that it was changing the definition of its campaign period from 1971-1980 to 1976-1986, in mid-campaign. This change of time horizons and subsequent recomputation was designed to account for the fact that incremental investment in improving and uprating the diffusion barriers, as well as the Portsmouth add-on, planned for the early 1980's, would not be captured during the 1971-1980 campaign and would, therefore, result in a sudden surge in SWU prices during the subsequent campaign.

The effect of this campaign shift was partially blunted by a change in DOE's depreciation method. During all previous cost-recovery calculations the gaseous diffusion base plant was depreciated on a 30-year straight-line basis from 1958-1988, however, because the recent investments in CIP/CUP will not be economically depreciated by 1988, the depreciation schedule was changed to depreciate the entire diffusion complex (the undepreciated portion of the base plant plus CIP/CUP) to the year 2000. The Portsmouth

centrifuge plant will be amortized over 25 years, once plant production begins, and capital expenditures for centrifuge R&D are amortized to the end of 1988.

The net effect of the campaign shift, after allowing for the offsetting effect of stretching out the depreciation schedule on the original base plan, was to increase applicable costs by about 10%.<sup>55</sup> In addition to these two changes, DOE included \$50 million of annual laser enrichment research and development costs for recovery in the SWU price.

The outcome of these changes in the pricing procedure was the establishment of a price of \$74.85/SWU for LTFC sales and a price of \$83.15/SWU for REQ sales. The components of these enrichment charges are summarized in Table 9. The LTFC price went into effect during November, 1977, while the REQ price did not go into effect until March, 1978, and even then the full \$83/SWU price was not realized because it exceeded the prevailing \$77/SWU ceiling charge.

## 5.2 Evaluation of the AEC Pricing Policies

Having described the AEC's enrichment pricing procedures, what generalizations may be drawn about these policies, and how do they relate to our behavioral hypothesis? Our evaluation of the AEC

TABLE 9

## COMPONENTS OF \$74.85/\$83.15 CHARGE

<u>COMPONENT</u>	<u>CHARGE(\$/SWU)</u>
Power	34.94
Other diffusion operating	5.65
Diffusion capital projects (CIP/CUP)	6.18
Centrifuge R&D	3.80
Base plant and working capital	3.25
Split tails feed sales	1.80
Interest on separative work costs of preproduction	6.51
Laser R&D	2.05
Portsmouth add-on costs	<u>2.67</u>
	66.85
Contingency @ 15%	<u>10.03</u>
	76.88
Rounded to	76.90
REQ contracts risk surcharge	6.25
REQ price	<u>83.15*</u>
LTFC contracts	
Advance payment credit	(2.05)
LTFC price	<u>74.85</u>

\* Ceiling charge during first 6 months of 1978 is \$76.82.

Source: DOE pricing representatives

pricing policies shall focus on three general results that come out of the first decade of toll enrichment pricing experience:

- (1) the instability of SWU prices and SWU pricing conventions,
- (2) the underpricing of SWUs, and
- (3) the differential pricing of SWUs,

and seek to show how these results are consistent with our proposition.

#### 5.2.1 Instability in Prices and Conventions

The preceding chronological narrative of AEC enrichment pricing shows quite clearly that the AEC was singularly unsuccessful in maintaining a stable current dollar price for enrichment services over any ten year campaign period. Levelized pricing was originally conceived as a means of dealing with the Government's peculiar situation of abundant excess capacity without discouraging utilities from pursuing nuclear reactor installations. Because of the scale economies in gaseous diffusion facilities, actual production costs were expected to decline over the years of a campaign as excess capacity came into use. Rather than charging utilities for the actual cost of production during each year, for fear of discouraging nuclear power growth during the early campaign years due to higher prices, the AEC chose to establish a price based on average campaign

production costs which would understate forecasted costs during the early campaign years and overstate forecasted costs during later campaign years. <sup>56</sup> Clearly this levelized campaign pricing strategy is consistent with our behavioral hypothesis, because it encouraged the growth of domestic and international nuclear power by reducing toll enrichment prices during the early years of the campaign and providing the stable basis for a long-term utility commitment to nuclear electric generation.

Rising costs and rising political privatization concerns destroyed the AEC's attempts at stable pricing. Beginning with the announcement of the commercial criteria in mid-1970, SWU prices have risen steadily and dramatically; starting with the announcement of the \$32/SWU price in 1971, announced REQ prices have first closely tracked then exceeded the escalating price ceiling, as shown in Table 10. Announcement is defined as the date when the proposed price increase is submitted to the JCAE for review. Due to the 45-day JCAE review period and the 180-day waiting period after Federal Register publication, the effective date of the price increase will be some seven months after the announcement date. Because the announced prices have paralleled or exceeded the REQ ceiling, the effect has been to effectively peg REQ prices to the REQ ceiling price throughout the mid-1970s, as shown in Table 11.

TABLE 10

COMPARISON OF ANNOUNCED REQ PRICE WITH  
ESCALATING PRICE CEILING

<u>DATE</u>	<u>ANNOUNCED <sup>1</sup> REQ PRICE (\$/SWU)</u>	<u>REQ PRICE CEILING (\$/SWU)</u>
11/29/67	\$26.00	\$30.70
06/10/70	\$28.70	\$32.16
12/21/70	\$32.00	\$32.91
02/08/73	\$38.50	\$39.12
06/14/74	\$47.80	\$40.83
06/20/75	\$60.95	\$52.34
06/22/76	\$69.80	\$65.06
09/29/77	\$83.15	\$67.58

<sup>1</sup> "Announcement" is defined as the date when the proposed price increase is submitted to the JCAE for review. Due to the 45-day JCAE review period and the 180-day waiting period after Federal Register Publication, the effective date of the price increase will be some 7 months after the announcement date.

---

Source: (23), pg. 6  
(29), pp. 60-62,  
(20), pg. 360  
(10), pg. 901

TABLE 11

COMPARISON OF EFFECTIVE REQ PRICE WITH  
ESCALATING REQ PRICE CEILING

<u>DATE</u>	<u>ANNOUNCED REQ PRICE (\$/SWU)</u>	<u>REQ PRICE CEILING (\$/SWU)</u>
01/01/69	\$26.00	\$30.83
02/02/71	28.70	34.07
09/06/71	32.00	36.72
08/14/73	38.50	40.59
01/01/74	38.90	40.83
07/01/74	39.30	47.27
12/18/74	47.27	47.27
01/01/75	47.80	52.34
07/01/75	48.80	59.80
12/18/75	59.80*	59.80
01/01/76	60.95	65.06
08/25/76	65.83*	65.83
01/27/77	69.75*	69.75
07/01/77	67.58*	67.58
01/01/78	69.80	76.82
03/29/78	76.82*	76.82

\* denotes effective price = ceiling price

---

Source: (23), pg. 6.



The lessons of these price data are difficult to interpret. At one level the rising prices are simply a reflection of rising AEC costs, including changes in the Government interest rate, and the inclusion of additional unanticipated AEC costs (such as STFS costs and R&D costs) into the cost recovery formula as was appropriate. At another level this explanation is too unsophisticated, because it fails to explain such major changes in AEC pricing procedures as the two-time redefinition of the campaign time horizon, the introduction of an automatic escalator, the levying of a risk surcharge on REQ sales, the adoption of an advance payment credit for LTFC sales, the changeover in depreciation schedules, the elimination of the LTFC price ceiling, the reduction in advance notice for LTFC price changes, the short-lived experiment with commercial criteria, and the fair value pricing proposal.

Each of these actual, or suggested, changes has either increased the SWU prices or opened the way for later increases in SWU prices. The redefinition of the campaign duration, the introduction of an automatic escalator, and the creation of an REQ surcharge are consistent with the proposition that the AEC sought to pin REQ prices at the legal upper limit in order to prepare the international market for the prices that would be charged by a domestic private enricher, thereby reducing the barriers to private entry into the SWU market, as well as encouraging REQ customers to convert to LTFC contracts. As will be described in more detail later, the encouragement of

conversion to LTFC contracts is also consistent with the enrichment privatization policy.

Of course the campaign redefinition and the automatic escalator also brought rising prices for LTFC customers. As before, this trend towards increasing the SWU price is consistent with our behavioral hypothesis because it helps to eliminate the utility preference for Government- supplied, rather than private, enrichment services, solely on price grounds. In addition, the adoption of an advance payment credit and the recent changeover in the base plant depreciation schedules reinforce the differential pricing policy by helping to keep LTFC prices lower than REQ prices.

The reduction in advance notice for LTFC price changes is also consistent with the privatization policy, because it is intended to conform to commercial standards of doing business. The AEC's defense of this change makes this point quite clearly (see section 5.1.4).

Similarly the elimination of the price ceiling for LTFC sales may be seen as a tactical move in the enrichment privatization strategy, because it clears the way for subsequent Congressional passage of some variant of commercial or fair value pricing for LTFC SWUs without recourse for the customer. Presumably if the differential pricing policy had been successful in encouraging all REQ customers to convert to LTFC contracts, whereby the REQ customer gave up his

ceiling price protection in return for an initial reduction in prices, the subsequent transition to fair value pricing for all AEC enrichment services would have been greatly simplified.

Many of the preceding attempts to link the instabilities in AEC SWU prices and procedures with our behavioral hypothesis are highly speculative. The argument that these changes were a reasonable response to rising costs offers an equally good explanation of these events, with two notable exceptions: the adoption of commercial pricing criteria during the last half of 1970, and the push for fair value pricing, beginning in 1975. In these two cases, unlike many of the prior events, the public record clearly shows that the motivation for the pricing changes was not increased costs, but a political effort by the AEC to promote domestic enrichment privatization. The insight into the AEC's motivation in pursuing, or proposing, commercial and fair value pricing strengthens the plausibility of our alternative explanation of the other changes in AEC pricing procedures in light of our behavioral proposition.

The plausibility of our explanation is further augmented when one examines the AEC's motivation for the changeover from REQ to LTFC enrichment contracts. The management of the changeover to LTFC contracts is described in detail in essay #1. The major additional point that needs to be made here is that the prime motivation for this changeover was to foster enrichment privatization. In

announcing the new contract format, AEC Chairman Schlesinger defended the LTFC contracts by arguing that the AEC needed

"to move toward contracts that are firm and business-like and (facilitate) reliable planning for supplying enrichment services on a long-term basis...I believe the improved planning basis will be of value to industry as it moves into this major production activity."57

This position was amplified in correspondence with the JCAE wherein Chairman Schlesinger stated,

"This action (i.e. the initiation of LTFC contracting) by the AEC is part of a coordinated effort to assist and encourage the participation by private industry in the supply of enrichment services, the only portion of the nuclear fuel cycle not yet in the private sector. (emphasis added)"58

This insight into the role of the privatization policy in the changeover to LTFC contracting lends added weight to our supposition that the more subtle changes in the AEC pricing procedure were part of the AEC's "coordinated effort" to encourage domestic enrichment privatization referred to by Chairman Schlesinger.

#### 5.2.2 Underpricing of SWUS

The criticism has frequently been made that the AEC cost-recovery pricing scheme has resulted in a persistent underpricing of SWUs. It is alleged that this persistent underpricing of SWUs represents a

subsidy to users of AEC enrichment services and biases the choice of the operating tails assay downward.<sup>59</sup> This criticism has a long history. As early as 1963, in a discussion of AEC pricing policies prior to toll enrichment, Mullenbach (16) commented on the "hidden subsidy (to the private atomic power industry) in the prices charged by the AEC for fuel."<sup>60</sup> That this policy of subsidization has persisted during the toll enrichment era is reflected in a 1978 study by Moore (9) where he asserts,

"There is little argument that the current pricing formula for enrichment services, which is based on recovery of the government's costs over a reasonable period of time, understates economic costs."<sup>61</sup>

Indeed even the JCAE has long recognized that enrichment services have long been underpriced. A few months prior to the OPEC oil embargo of 1973, one long-standing member of the JCAE was moved to defend the U.S.'s low cost atomic fuel policy as follows:

"The reason they (i.e. U.S. SWUs) are of such lower price (compared to alternative fuels) is the fact that there is a Government policy of making them available at reasonable recovery costs in order to accelerate the industry and get a source of fuel which is domestic in nature...(emphasis added)"<sup>62</sup>

We shall find ourselves in agreement with the assertion that the AEC pricing procedure has long underpriced SWUs, and we shall seek to roughly evaluate the extent of the subsidy that this underpricing entails. In order to more precisely specify the nature of our

agreement and attempt any subsidy calculations, however, we need to consider the ungrammatical question, "Underpriced compared to what?"

In order to respond to this question one is required to imagine an alternative institutional framework, which yields a different pricing scheme, against which the AEC pricing policy may be compared. A favorite point of pricing comparison by economists is marginal social opportunity cost (MSOC), because theoretical welfare economics demonstrates that if a society prices all of its goods and services at their respective MSOC (as would occur in a series of perfectly competitive markets) then the allocation of these outputs will be pareto optimal.

We argue that a comparison between AEC prices and MSOC is a moot point (see footnote 79); instead, we shall draw the more realistic comparison between the price charged by the AEC and that which presumably would have been charged by a series of alternative forms of ownership. These comparisons are fundamentally more revealing because, unlike the creation of a competitive market, they represented viable institutional alternatives to public ownership of enrichment facilities during the toll enrichment era. It is virtually useless to compare AEC toll enrichment prices over the last 15 years with those which would be established by a competitive enrichment industry, simply because the creation of a competitive industry was not feasible. Even if a different private corporation

were to own and operate each of the three gaseous diffusion plants, the structure of the enrichment would be a highly concentrated oligopoly rather than a competitive industry. Although much of the theoretical literature and case study research into the behavior of oligopolistic markets defies sweeping generalizations, it is safe to say that there is broad support for the assertion that highly concentrated oligopolies, such as the aluminum smelting and tin can industries, display significant deviations from the competitive pricing standard of MSOC. The conclusion that a workably competitive enrichment industry was unlikely throughout the first decade of toll enrichment was shared by the 1969 White House Task Force on Uranium Enriching Facilities, headed by the Chairman of the Council of Economic Advisers, Paul McCracken.<sup>63</sup>

Given, therefore that the U.S. government was not in a position to relinquish control of the enrichment industry to a group of competitive sellers, what institutional alternatives to public ownership were plausible, what prices might these alternatives have yielded, and how would these alternative prices have compared to those charged by the AEC? Subsequent sections shall compare AEC prices to:

- (1) accounting costs;
- (2) the prices that might have been charged by a regulated monopolist;

- (3) the prices that would have been charged if ERDA's fair value pricing legislation had been approved;
- (4) the prices that were charged by the AEC's foreign competitors in the enrichment market; and
- (5) the prices that would have been charged by a domestic private enricher upon enactment of the NFAA.

Each of these successive benchmarks will reveal a separate facet of what observers mean by "underpricing" and its attendant "subsidy."

#### 5.2.2.1 Comparison with Accounting Cost

We have found that, despite the 15% allowance for contingencies, AEC prices have consistently failed to keep pace with accounting costs. This failure is the result of a number of influences.

##### 5.2.2.1.1 Lag Factors

First, the AEC REQ SWU pricing procedure is: (1) characterized by a significant "regulatory lag" between the time that price calculations are made and the time that these prices take effect; and (2) is constrained by a backwards-looking escalating price ceiling. These two factors guarantee that during a period of rapidly inflating costs, the AEC price structure cannot hope to keep pace with these costs.



The regulatory lag results from two legal restrictions. By the Atomic Energy Act of 1964 the AEC is required to give the JCAE 45 days to review any changes in the SWU price, and by the provisions of the REQ contracts, any price changes cannot take effect until 180 days after publication in the Federal Register, which succeeds the JCAE review. Therefore there is roughly a 7 1/2 month lag between the time that the AEC announces a price change, and the time that this change goes into effect; this lag is before any allowance for the time it takes the AEC to prepare and review this price internally. Allowing for this additional lag means that approximately one year elapses between the time that the AEC incurs a cost increase and the time that the price begins to reflect this additional cost. During the years 1971 - 1977, when the major component of SWU costs, electric power, was tripling in price, this one year lag was a major source of downward bias in the SWU price, when compared to actual costs.

This downward bias was aggravated by the backwards- looking method for establishing the price ceiling, which provides for escalating the price ceiling for a prospective six-month period based on the labor and power cost experience of the previous six-month period. Obviously this ceiling price will not keep pace with actual costs during an era of rapid inflation, and will bias the SWU price downwards when compared to accounting costs in years when the price

ceiling is binding, e.g. for much of the period 1974 - 1978 (see Table 11).

#### 5.2.2.1.2 The Use of Uninflated Costs

In addition to these lag factors, which play the dominant role in explaining the inability of AEC prices to recover costs, there exist some other systematic tendencies in the AEC pricing procedure which further bias the SWU price downwards. The AEC has always made its cost forecasts in constant dollars with no allowance for cost inflation, as well as other factors.<sup>64</sup> Only during the years 1974 and 1975 was an automatic escalator used in attempt to keep SWU prices in line with inflation, and even these were too modest to be successful. Therefore AEC prices were always in the process of trying to "catch up" with inflation, rather than trying to anticipate it.

#### 5.2.2.1.3 Levelized Pricing

In retrospect the choice of a levelized pricing strategy also biased the SWU price downwards. As explained in Section 5.4, the concept of a stable campaign price meant that the AEC would operate at a deficit in the early years of the campaign and would presumably reap an offsetting surplus in the later years. Because the AEC had a habit of changing the campaign horizon in mid-stream, however, the

original campaigns were never completed, and the offsetting surplusses were never realized.

Although the use of the accumulated income term as an automatic self-correcting mechanism offset the downward bias introduced by the use of uninflated cost projections and the levelized pricing concept, some ex ante downward bias still remains because the income term is only an ex post correction which cannot anticipate the need for further future corrections.

#### 5.2.2.1.4 Demand Overestimation

Third, the AEC revenue forecasts have demonstrated a systematic tendency to overestimate SWU demands and to underestimate the slippage in SWU capacity additions, both of which have biased the SWU price downwards, compared to accounting costs. The tendency of official government forecasts to overestimate demand is documented in essay #1. More recently, the use of enrichment contract data as a source of demand estimates has also yielded unrealistically high forecasts (see essay #1, section 4.4.2). In either case the result has been an overestimation in the denominator of the pricing equation and a resulting downward bias in the SWU price. The magnitude of this bias is difficult to estimate, because to the extent that forecasted demand is not realized there will be some downward bias in the forecasted size of the preproduction stockpile which shall have

an additional effect on the SWU price. In any event, sensitivity tests done by the AEC during 1971 have shown that an unanticipated slippage in demand results in an underestimation of the SWU price, "principally resulting from additional interest costs on reproduced inventories."<sup>65</sup>

Similarly the AEC has demonstrated a systematic tendency to be overly optimistic about the completion dates of the CIP and CUP programs. In their original 1969 estimate, the AEC had planned to complete installation of CIP/CUP by 1978;<sup>66</sup> as of 1978 the most recent estimate of the completion date is 1982.<sup>67</sup> Sensitivity tests reveal that unanticipated slippage in these plant improvements biases the SWU price downwards,<sup>68</sup> because the resulting reduction in the actual amortization costs is more than offset by the decline in SWU production.

#### 5.2.2.1.5 Cost Underestimation

Fourth, the AEC cost estimates have been systematically too low. This effect is most prominent in the forecasting of power costs, where the AEC's standard operating procedure has been to assume a constant power cost throughout the campaign period. For example, during the 1970 computation of the \$32/SWU price, power costs were assumed to remain constant at 5.2 mills/kwh, which was the forecasted average power cost during 1972,<sup>69</sup> while during the most recent

computation of the \$83.15/REQ SWU price, power costs were assumed to remain constant at 16 mills/kwh from 1976-1986. Of course these simplistic forecasts have proven to be underestimates time and again which has contributed to the downward bias in the SWU price. Nevertheless, this standard procedure continues to be pursued; rather than deal explicitly with the uncertainties of a sophisticated forecast, the AEC chose to negotiate a predictable environment by imposing a standard operating procedure and sticking to that procedure despite its flawed record. This is a simple, but illuminating, example of the validity of much of the organizational theory summarized in section 2.0.

Power costs are not the only costs that have been consistently underestimated. AEC engineering estimates of CIP/CUP investment costs have been systematically low,<sup>70</sup> which leads to the supposition that Portsmouth add-on costs are similarly underestimated.

#### 5.2.2.1.6 Minor Factors

Lastly, in addition to these cost underestimates there exist a number of other minor factors which contribute to a downward bias in the SWU price. Not all of these factors are discussed here because their impact on the SWU price is small. For the interested reader, however, Appendix I to essay #2 provides some insights into the

biases present in the AEC pricing formula's treatment of one such minor factor--split tails feed sales. Although the impact of this item on the SWU price is small, the detailed review in Appendix I is interesting because it reveals how the underpricing spirit which permeates the AEC pricing procedure has penetrated to the furthest reaches of the formula's components.

#### 5.2.2.2 Comparison with Regulated Monopolist

One obvious alternative to public ownership of enrichment facilities is government regulation of a private monopolist enricher, making enrichment a public utility similar to electric power utilities and the telephone company. How might the prices established by a regulated monopolist compare to the toll enrichment prices levied by the AEC?

The literature of public regulation is filled with studies of regulatory pricing policies. These policies show some variation over time and across geographic regions, however, during the decade 1965-1975 regulatory procedures tended to have some common features:

1. prices were based on the recovery of average historical costs;

2. prices reflected the utility's weighted average cost of capital, which included both historical debt costs and a return to equity capital.

The inclusion of a company's rate of return on equity in the pricing formula was designed to make utilities "competitive" in obtaining financing in capital markets. A regulated enricher's required rate of return on equity would undoubtedly exceed the government bond rate of 6.5%, due to the risk inherent in the enrichment industry. Presumably a regulatory determination of a private enricher's weighted average cost of capital would yield a result roughly equal to the average rate of return for domestic electric utilities, currently around 12%.

In each year the price would be determined by applying this 12% cost of capital to the undepreciated portion the enricher's rate base and adding in the enricher's operating costs before dividing by the enricher's total utility SWU sales, as follows:

$$\text{Base SWU Price} = \frac{\left[ \begin{array}{l} \text{weighted} \\ \text{average} \\ \text{cost of} \\ \text{capital} \end{array} \right] \times \left( \begin{array}{l} \text{rate} + \\ \text{base} \quad \text{operating cost} \end{array} \right)}{\text{SWU Sales}}$$

Using the data used by DOE in its most recent SWU pricing calculation, and a weighted average cost of capital of 12%, this

calculation yields a SWU price of roughly \$100/SWU as of 1/1/78, which is 30% higher than the AEC inflated base price of \$77 (\$67 before the 15% inflator) as of the same date.<sup>71</sup> Therefore, despite the AEC's 15% inflator which is applied to the base price, the current AEC price is still roughly 30% lower than the price which might be generated by a traditional regulatory proceeding. The price differential arises because although the AEC calculation uses historical asset book values and average debt costs in its pricing calculation, similar to the standard regulatory practice, the AEC does not include the return to equity which is a critical part of the regulatory process.

#### 5.2.2.3 Comparison with Fair Value Pricing

Another obvious point of comparison is with the proposed AEC fair value price, which modifies the AEC price formula as explained in section 5.1.6. A comparison of effective AEC prices and announced fair value prices is provided in Table 12; obviously the fair value price exceeds the cost-recovery price. As explained previously, the AEC price is less than the fair value price because the fair value price uses a higher discount rate and includes income taxes in its calculations.

Students of public finance will be aware of the long literature surrounding the choice of a discount rate, and will recognize the



TABLE 12

COMPARISON OF PROPOSED FAIR VALUE PRICE WITH  
EFFECTIVE LTFC PRICE

<u>DATE</u>	AEC LTFC <u>PRICE</u>	PROPOSED AEC FAIR <u>VALUE PRICE</u>
08/20/75	\$53.35/SWU	\$76/SWU
05/06/76	\$59.05/SWU	\$90/SWU
01/01/78	\$74.85/SWU	\$100/SWU

---

Source: Section 5.1.6 footnotes and SWUCO (23)

AEC's use of the average Treasury bond rate as a measure of the "riskless" interest rate. The traditional justification for using a risk-free interest rate for discounting government projects has been that governments are so large, and have so many projects, that they pool risks better than private corporations; similar to a large insurance company governments achieve a scale economy in risk-pooling, as expressed by the law of large numbers, which permits them to discount at the riskless rate.<sup>72</sup>

Recent developments in capital market theory and empirical research into the efficient markets hypothesis have challenged the traditional choice of a risk-free rate. Current financial theory recognizes two sources of risk associated with any investment project--(1) unsystematic risk: that portion of the variance in project returns which is uncorrelated with general movements in securities markets, and which can therefore be eliminated by diversification; and (2) systematic risk: that portion of the variance which is correlated with stock market fluctuations, and which cannot be reduced by pooling.<sup>73</sup> Therefore, modern capital market theory asserts that a risk-free interest rate is appropriate for discounting only when the systematic risk associated with the project is zero.<sup>74</sup> Further, because tests of the efficient markets hypothesis allow us to reject the null hypothesis that the US securities market is inefficient,<sup>75</sup> financial theory argues that private corporations are able to spread unsystematic risks as

efficiently as the government. Therefore, barring a specific demonstration of a securities market imperfection, or a convincing argument for rejecting the discount rate chosen by the free market, public and private concerns should adopt the same discount rate for evaluating investment projects.

While we do not pretend to be able to explicitly assess the degree of systematic risk in the enrichment market, it is plausible that it is greater than zero if only because electricity demand, and thus SWU demand, is positively correlated with general economic conditions, which in turn correlate with stock market movements. It is presumably on these grounds that ERDA selected a 12% discount rate for use in the fair value pricing calculation. Because forecasted future enrichment revenues grow much more rapidly than forecasted future costs, the effect of using a higher discount rate is to increase the SWU price, since a higher discount rate will reduce the denominator of the pricing equation relatively more than the numerator.

#### 5.2.2.4 Comparison with Foreign Enrichers

Another point of comparison is with the AEC's competition, URENCO and EURODIF. SWUCO, an international enrichment marketing information corporation, reports that the approximate current price for a long-term URENCO contract is \$125/SWU, while the corresponding

price for EURODIF services is \$113/SWU;<sup>76</sup> these are properly compared with the AEC LTFC price of \$75/SWU.

This comparison is important not just because these foreign enrichers are competitors of the AEC, but because national cross-investment and joint public-private participation represented feasible alternative ownership structures for AEC facilities during the first decade of toll enrichment. Presumably the foreign enrichment pricing experience is some reflection of what we could expect from such institutional alternatives in the U.S.

Very few details of foreign enricher pricing procedures are available, however, it is likely that foreign SWU prices exceed AEC prices because:

1. The youth of the foreign plants means that their historical construction cost closely approximates replacement cost, unlike the AEC base plant which was built during the 1940's and 1950's.
2. The presence of national cross-investment (in both consortia) and private participation (in URENCO only) increases the likelihood of including a return to equity in the pricing calculation.
3. Other terms of EURODIF and URENCO long-term enrichment contracts differ from the terms of AEC LTFC contracts.<sup>77</sup>

#### 5.2.2.5 Comparison with UEA

Another point of comparison is the pricing policy suggested by UEA in their proposal which formed the basis for the NFAA of 1975. UEA adopted a forward-looking pricing strategy similar to the pricing policy used by the AEC in implementing the commercial criteria (see section 5.1.2) Using the following assumptions (all figures in 1975 \$):

- (1) capital costs = \$3.3 billion for a 9 MMSWU diffusion plant, to be depreciated over 25 years;
- (2) UEA to be financed 85% by debt and 15% by equity;
- (3) debt cost of capital = 9%;
- (4) after-tax equity cost of capital = 15%;
- (5) full recovery of audited operating costs;

UEA calculated an average SWU price of \$85/SWU (1975 \$) over the life of the plant, at a time when the average AEC SWU price was roughly \$50/SWU. This average price was calculated by dividing the total unescalated capital and operating costs over the entire operating period by the total SWU output at full capacity operation.

Because of the manner in which the debt was to be serviced, the actual price would exceed the average price during the first part of the operating lifetime and would be less than the average price during the latter part of the 25-year period; the posted price would range from \$106-\$60/SWU. The SWU price would be recalculated periodically to reflect actual audited costs during the previous period, and adjustments to customers' fees would be made accordingly.

The components comprising the UEA calculation were as shown in Table 13. If anything, these estimates appear downward biased. Comparison with AEC cost indices for power and labor used in the computation of the REQ price ceiling reveals that these components alone amounted to about \$45/SWU in mid-1975, compared to the 1975 UEA estimate of less than \$35/SWU throughout the 25-year life of the UEA plant. Due to UEA's cost pass-through pricing approach 100% of these increased costs would be borne by UEA customers, thereby raising the average SWU price over \$85/SWU. In sum, the UEA average price of \$85/SWU is most likely a lower bound on the SWU price that would have been established following passage of the NFAA of 1975.

The ballpark size of this price is confirmed by the Electro Nucleonics (2) feasibility study of gas centrifuge enrichment facilities, which resulted in the formation of the CENTAR centrifuge

TABLE 13  
 UEA AVERAGE SWU PRICE  
 (1975 \$)

	<u>\$/SWU</u>	<u>% of Total Price<sup>1</sup></u>
Power	28	33
Operating, Maintenance & General Costs	7	8
Income Taxes	11	13
Royalties	2	2
Equity Return	12	14
Debt Services	<u>25</u>	29
	852	

Source: UEA testimony before JCAE on NFAA, April 6, 1976 Slide #9,  
 (pg. 31A)

- 
1. Figures do not add to 100% due to rounding errors.
  2. Range of SWU price = \$106 - \$60

consortium in response to the NFAA opportunity. The CENTAR study calculated an average price by assuming (all figures in late 1974 \$)

(1) capital costs of \$1.13 billion for the construction of a 3 MMSWU GCP facility, which is to be fully depreciated over a 23-year plant life;

(2) debt cost of capital = 10%

(3) after-tax equity cost of capital = 15%;

(4) plant financed 25% by equity, 75% by debt;

which results in an average price of \$70/SWU (late 1974 \$) of which \$43 (61%) represent financing costs and \$27 (39%) represents operating costs. CENTAR's estimate of the UEA price in comparable late 1974 \$ was \$79/SWU,<sup>78</sup> while the AEC's average price at this time was approximately \$45/SWU.

In sum, the difference between the AEC price and the estimated private price arises because private enrichers, unlike the AEC, include income taxes and a competitive return to debt and equity capital, as well as current enrichment plant replacement costs, in their pricing calculations.<sup>79</sup>



#### 5.2.2.6 Underpricing Summary

These price comparisons are summarized in Table 14. All prices have been put on an even footing by quoting them in 1978 dollars. The price inflation was based on AEC operating experience. 80 The clear implication of this table is that the AEC has underpriced its enrichment services relative to the price that would be yielded by alternative institutional arrangements--including a regulated monopoly, fair value pricing, foreign cross-investment, mixed public-private control, and private ownership. Depending upon which benchmark you choose to adopt, this underpricing is chiefly the result of:

1. The AEC's failure to include a return to equity or income taxes in the cost recovery pricing calculation;
2. The AEC's use of a riskless discount rate rather than a private discount rate as the cost of capital;
3. The AEC's use of book value investment costs rather than replacement investment costs;
4. Systematic downward biases in the AEC SWU pricing formula.

TABLE 14  
PRICE COMPARISON SUMMARY

<u>SOURCE</u>	<u>PRICE (as of 1/1/78 in 1978 \$)</u>
AEC Inflated Base Price	\$ 77
AEC Fair Value Price	100
URENCO Price	125
EURODIF Price	113
UEA Price	103
CENTAR Price	91
REGULATORY Price	100

In sum, Table 14 indicates that the current price subsidy relative to alternative institutional arrangements is roughly \$35/SWU, or approximately 50% of the AEC's inflated base price. Because the cost of enrichment services is roughly 25% of the total cost of nuclear fuel, the removal of this subsidy would only increase total fuel costs by 10%. While this may make the subsidy look comparatively small, it would amount to \$500 MM during 1978, a non-negligible absolute amount.

Having gone to great lengths to establish that AEC toll enrichment services have been underpriced by any measure, we are left to ask how this result reflects on our behavioral proposition. We shall argue that the underpricing of SWUs is consistent with the strategy of subsidizing the international growth of nuclear power while maintaining the U.S. enrichment monopoly, which was pursued with great success from 1954-1970. Obviously, persistent underpricing of enrichment services provides an incentive to over-order SWUs, to overbuild SWU capacity, and to overuse nuclear fuel, while discouraging entry into the commercial enrichment market by foreign suppliers. U.S. guarantees of ample, low priced enrichment services effectively discouraged a French proposal for an independent EURATOM enrichment plant during 1957.<sup>81</sup> In similar fashion the first announcement of a toll enrichment SWU price of \$26/SWU in 1967 was received in Europe as an attempt to undersell prospective foreign entrants into the enrichment industry.<sup>82</sup> That

this European view was not altogether groundless is substantiated by the price series in Table 4. During the era 1956-1968, the record of sharply declining prices (32% in current dollars, 47% in constant dollars <sup>83</sup>) presented a substantial barrier to entry.

As the 1970's approached and the push for enrichment privatization intensified, this declining price trend was sharply reversed, as the AEC moved towards negotiating and pricing its enrichment contracts on a more businesslike basis. During the five years from 1968-1973 REQ prices rose from the low of \$26 to \$32. Then with the introduction of LTFC contracts in September, 1973, REQ prices jumped to \$38.50 while the LTFC price was set at \$36.00. Prices continued to increase from this point, as indicated previously.

During this later period, as argued in Section 5.2.1, the major evidence in favor of our behavioral proposition was not that the AEC intentionally underpriced SWUs, but that they did everything in their power to increase the prices of SWUs as rapidly as possible within the confines of the law. It was not so much the fact of the price subsidy from 1970-1978 as the unsuccessful struggle of the AEC against the confines of the cost recovery mandate which we cite in support of our behavioral model.

### 5.2.3 Differential Pricing of SWUs

The third regularity which emerges out of the narrative history of AEC pricing is that the AEC has priced LTFC SWUs at a discount from REQ SWUs. As described in section 5.1, this price differential has two components:

1. The REQ risk surcharge, which is added on to the inflated base price for REQ sales to reflect "the differences in risks and costs between the two types of contracts;" 84
2. The LTFC advance payment credit which is deducted from the inflated base price "to reflect interest (received by the AEC) on advance payments (made by LTFC contract holders)." 85

This section of the essay shall examine the economic rationale for these two adjustments to the inflated base price, and then discuss the implications of the differential pricing strategy for our central proposition.

#### 5.2.3.1 The REQ Surcharge

As described, the role of the REQ surcharge is to recover from REQ customers the fixed costs that DOE incurs by consistently

overplanning for actual REQ demands based on Appendix A forecasts. There remains a theoretical issue of whether such a surcharge is appropriate at all. Presumably, slippage is one of the realities that lie behind the mysterious 15% across-the-board inflator already built-in to the pricing calculation. The fact that DOE bears the risk of REQ demand slippage is a direct result of the way the REQ contracts are written. The REQ contract requires the submission of SWU demand forecasts on a rolling 5-year basis, for use as a DOE planning tool, but specifically states that these schedules are not legally binding. To turn around and penalize REQ customers for exercising the scheduling flexibility legally available to them is unfair in the sense that it was not anticipated by the provisions of the REQ contract. The pricing policy effectively extends the firm-up period beyond 180 days to include the fixed cost portion of at least a 5-year firm-up horizon.

This penalty is even more paradoxical in view of some other facts. First, REQ customers must demonstrate an actual demand requirement in order to acquire enriched fuel. Therefore, even if they wanted to, they are legally prohibited from accepting deliveries in excess of actual demands. Second, LTFC customers have in fact not been forced to bear the full brunt of slippage risk. DOE has already administered one open season on LTFC contracts during which LTFC customers could readjust their delivery schedules with no attendant termination penalties.

Further slippage since this first open season has resulted in DOE's announcement that it shall grant case-by-case contract relief to overscheduled LTFC SWU customers. While the guidelines for this contract relief have not been established, it appears that the penalties for requesting relief will be substantially less than those written into the LTFC contracts. What these two examples point out is that while DOE is apparently serious about recovering REQ slippage costs through the imposition of a surcharge, they have been less than diligent about forcing LTFC customers to bear the full brunt of demand slippage.

Third, whatever the slippage in REQ demand, the fact is that DOE SWU plants operate at full capacity, preproducing an enriched fuel stockpile. No demand charges or depreciation charges are incurred on idle cascades. Rather, preproduction carrying costs are included in the SWU price, making the REQ surcharge a case of double counting, where the customer pays once for the costs of theoretically idle capacity and again for the carrying costs on preproduction from that idle capacity.

In addition to the broader question of the legitimacy of such a surcharge, there is the practical issue of how such a surcharge is calculated. Returning to the surcharge formula, and recognizing that STFS costs are less than 3% of total costs, we see that basically the surcharge amounts to 9.6% ( $= 1/12 \times 1.15$ ) of the base SWU charge. As

a digressionary note, the STFS cost term is subtracted from the total campaign costs "because the REQ customers didn't ask for the STFS program so DOE feels that it is unfair to penalize them for its existence;" this presents another insight into the contorted and conflicting logic underlying the SWU pricing procedure.

The practical problem with the surcharge calculation is that the factor of 1/12 appears to have no analytical basis, much like the 15% price inflator discussed earlier.<sup>86</sup> Some research into enrichment costs, diffusion power contracts, and REQ delivery data, yields no firm basis for levying a 9.6% surcharge on REQ customers. The data are not available to permit a precise calculation of what this surcharge should be in order to recover DOE's fixed costs, but the following calculations provide some notion of the magnitude of such a surcharge.

DOE representatives put the historical average of REQ demand slippage at 10% of forecasted Appendix A demand. A first cut at an upper bound estimate would be to charge the percentage of total campaign costs allocated to forecasted REQ sales, to 90% of the forecasted REQ sales, yielding a base price of \$74/SWU, or equivalently a surcharge of approximately \$7/SWU.

Of course, this first cut is a gross overestimate because it includes a variety of variable costs which DOE would not incur if REQ



demand was not forthcoming. Most notable of these variable costs are electricity energy charges; presumably only electric demand charges will be incurred on idle cascades. Using estimated 1978 data from the ERDA Budgetary Authorization Request we find that demand charges average less than 25% of total power costs, which in turn represent 55% of the base SWU price. Therefore, at least 75% of the power costs, representing 41% of the total campaign costs, are variable. Factoring this into our calculation yields an upper bound base price of \$71/SWU, or a surcharge of \$4/SWU.

In similar fashion, one can deduct other variable costs associated with the enrichment plants, further reducing the upper bound for the surcharge. In general, the base price should equal

$$\frac{100\% \text{ of fixed costs} \quad + \quad 90\% \text{ of variable costs}}{\text{allocated to REQ sales} \quad \quad \quad \text{allocated to REQ Sales}} \\ 90\% \text{ of forecasted REQ Sales}$$

Using 1977 DOE SWU pricing data for the 1977-1986 campaign yields, a base price of \$70, or a surcharge of \$3 rather than the current surcharge of \$6.

In conclusion, not only does the theoretical basis for this REQ surcharge rest on shaky ground, but the surcharge appears to be overestimated by at least a factor of 2. Testimony before the JCAE by utility nuclear consultants comes to a similar conclusion.

Whatever its magnitude, a surcharge calculation based on a percentage of fixed costs, like that performed above, is more appropriate than the existing surcharge calculation which is effectively based on total costs.

#### 5.2.3.2 The Advance Payment Credit

Similarly there is a question about the propriety of the advance payment credit given to LTFC customers as an offset to the interest forgone on the prepayments made to secure an AEC LTFC enrichment contract. In the simplest sense this refund results in an interest-free loan for utilities. Consider the following possible sequence of events: a utility holding an LTFC contract is faced with the prospect of forwarding a substantial prepayment to DOE, so utility representatives apply to a bank for a loan to cover the prepayment; the bank agrees to provide the loan at a negotiated rate of interest; DOE receives the prepayment and over the contract period credits the interest earned on that prepayment against the SWU price; effectively, DOE pays the utility's interest on the prepayment loan to the bank, leaving the utility as the middleman in the transaction.

More subtly, the precise manner in which the interest is credited implies a series of inter-utility subsidies. In calculating the interest refund, DOE uses the average prepayment date for all utilities holding LTFC contracts. Because utilities actually made

these prepayments at different times, this scheme implies that utilities making payments later than the average date are being subsidized by utilities making payments earlier than the average date; paradoxically, promptness in obtaining a SWU contract is penalized. The data are not publicly available to permit an assessment of the size of this subsidy, but it provides another example of the unintentional subsidies arising out of seemingly simple DOE conventions.

#### 5.2.3.3 Summary of Differential Pricing

The preceding two sections have argued that while some REQ-LTFC price differential may be plausible, though certainly not mandatory, on theoretical grounds, the calculated size of the differential is certainly suspect. A careful reading of AEC testimony during the hearings surrounding the establishment of LTFC contracts, as well as recent confidential conversations with DOE pricing officials, reveals that enrichment privatization objectives were as important as actual cost differences in the motivation behind differential pricing.

Just as the privatization objective revealed itself in the establishment of LTFC contracts, so it was prominent in the creation of a price differential which created an incentive for REQ customers to convert to LTFC contracts. The GAO Report on the AEC's proposed price differential found that,

"According to AEC the proposed price differential will provide substantial incentive for holders of requirements contracts to convert to fixed-commitment contracts...(because) a customer electing not to convert to a fixed-commitment contract would increase his annual operating costs by about 0.4 percent." 87

That this incentive was at least worth considering is revealed by the Statement of Arkansas Power and Light Company, an AEC REQ contract holder, to the JCAE, wherein Arkansas calculates that the penalty which they would incur for continuing to hold their REQ contract would be \$15 million during the term of the contract, and that despite bitter protest about the terms of the LTFC contracts, "it is probable that (Arkansas) will elect to accept the new terms of the contract and avoid the \$15,000,000 penalty." 88 That most utilities did not find that this incentive outweighed the additional risks associated with LTFC contracts is evidenced by the fact that only one utility chose to convert from an REQ to an LTFC contract.

In the face of this failure to achieve a total conversion to the sort of long-term contracts deemed necessary for the establishment of domestic private enrichment, the AEC redoubled its efforts by installing the advance payment credit. Although not part of DOE's original \$36 LTFC pricing scheme, a \$2.15 advance payment credit for LTFC customers was included in the subsequent \$42.10/LTFC SWU price calculation. This additional credit raised the price differential from 7% of the inflated base charge to 13% of the inflated base

charge, but was still unsuccessful in encouraging contract conversion. The reason for this ebb tide of converts was that by the time that this doubling of the percentage price differential had taken effect (1/1/75) the LTFC contracts had turned into a utility nightmare with the utilities pleading for relief from their strait-jacket delivery schedules and the AEC pondering the details of its Open Season. <sup>89</sup> This climate convinced REQ contract customers of the wisdom of not converting to LTFC contracts, despite the increased price incentive.

### 5.3 Pricing and Contracting Conclusion

The evidence presented in our analysis of the AEC's pricing and contracting policies strengthens the support for our central behavioral proposition. Our description of the instabilities in AEC prices and procedures provides a classic example of an organization's attempts to respond to major environmental changes by incremental, isolated responses determined by the existing details of standard operating procedures; it also provides an insight into the complex, confusing, and often contradictory pricing contraption that this short run feedback-react behavior has created. Nevertheless, through it all we have found evidence of the common thread that these procedural changes were founded in a desire to motivate enrichment privatization within the constrictions imposed by the Congress with

the cost-recovery mandate which came in response to the AEC's pursuit of commercial prices.

Similarly our discussion of the systematic underpricing of AEC SWUs has supported our behavioral hypothesis. Prior to 1970 the AEC was content to concur with the JCAE in the pursuit of an underpricing strategy as a means of subsidizing the growth of nuclear power. With the advent of increased interest in enrichment privatization, the AEC entered an era of conflict with the JCAE on the subject of enrichment pricing. The AEC struggled mightily, although with only partial success, to rapidly increase the price of enrichment services as a means of attracting private investment into the enrichment sector. While the AEC spoke of "commercial" prices as a means of reducing entry barriers and eliminating subsidies, the Chairman of the JCAE took the viewpoint that through price increases,

"...we are going to pick on one industry (i.e., the nuclear industry), a new industry that we are trying to get into being...(by) saying not only should the Government get its cost back, but it should make a profit on it...Should we make a profit on sending out Government pamphlets, and giving the weather service to the airline industry?...Remember, the Government was not set up to operate at a profit. Most of the departments of Government I know anything about operate at a loss." 90

Further, we have indicated that the changeover to LTFC contracts was consistent with the need to pave the way for a private enricher, as was the differential pricing policy which was as much an incentive for REQ customers to convert to LTFC contracts as it was a reflection

of actual cost differences. Indeed, even the Open Season on LTFC contracts was structured to "offer an additional incentive for a customer to seek commitments for his post-1982 enriching services needs from a private domestic enricher." 91 Specifically the AEC stood ready to consider termination without charge, including return of advance payments, for all LTFC customers "who express a desire to be terminated in order to contract with a domestic private enricher." 92 The AEC noted that such termination would permit the customer to avoid the necessity of costly advance feed deliveries that would accompany slippage of AEC LTFC contract demands during the Open Season.

In short, the AEC's pricing and contracting history is consistent with our central proposition that AEC actions are guided primarily by domestic commercial objectives.

In section 6.0 we shall scrutinize this proposition against the evidence of international political attempts at enrichment multilateralization.

## 6.0 SWU TECHNOLOGY TRANSFER

This brief section of the essay documents the influence of the AEC's commercialization objectives, and the accompanying policies of domestic industry protection and enrichment privatization, on the two major U.S. enrichment foreign policy initiatives of the early 1970's. Most of the material in this section is drawn from the political science research of Wonder (32), and the interested reader is referred to the Wonder references for further amplification of the political dimensions of these issues. In the context of this thesis, Wonder's conclusions will be taken as evidence of the predominant influence of US commercial objectives in the formulation of US enrichment foreign policy.

### 6.1 The 1971 Initiative

The two major initiatives referred to earlier were aimed at encouraging multilateral international enrichment facilities as a means of reducing the security risks attending the dispersion of enrichment technology. The first of these proposals came during 1971. Following on several years of unofficial discussions, the U.S. formally offered to assist its allies in constructing a multinational enrichment plant. The U.S. offered access to unclassified information on gaseous diffusion to all interested foreign parties. By encouraging the construction of a diffusion plant, the U.S. hoped



to eliminate the safeguards problems associated with the centrifuge technology;<sup>93</sup> because of the economies of scale in a diffusion plant, its use of a single long cascade, and the enormous power requirements, it is more difficult to maintain a clandestine diffusion facility than a secret centrifuge facility. In addition, a multinational diffusion plant would reduce the number of worldwide enrichment facilities which would ease the materials accounting safeguards burden, reduce the number of competitors to the AEC in the enrichment market, reduce the likelihood of prevailing excess enrichment capacity, and offer U.S. firms an opportunity to tender component bids for the construction of diffusion cascades.

Two preliminary meetings were held in Washington during 1971 to discuss the possibility of multinational cooperation with potential foreign enrichers. At these meetings, the U.S. delegation laid down a set of prospective rules for enrichment technology transfer. These rules may be summarized as follows:

(1) The U.S. demanded technological protection--The exploratory offer was limited to unclassified diffusion technology only. Prior to a final commitment to a multinational project, foreign partners would not have access to classified technology. Therefore, prospective partners would simply have to trust the operation of the "black box" which the AEC was offering for sale, without comparing its technical merits to the French or British diffusion data. In

addition, the U.S. attempted to limit the chances of technological surprise by demanding access to information on all technical development associated with the multinational plant. Therefore, if any European technology was incorporated in the multinational plant, the U.S. would have full access to its progress, thereby insuring a continuous update on the European centrifuges or the British or French diffusion technologies.

(2) The U.S. demanded commercial protection--No AEC enrichment contracts would be terminated to create a market for the new enricher. Diffusion technology would be sold to the new enricher at a commercial price. U.S. firms would have an equal opportunity to tender component bids. There must be no commercial barriers to the importation of enriched fuel from U.S. enrichment facilities.

(3) The U.S. demanded security protection--Involved foreign governments were to be responsible for security arrangements, subject to the approval of the U.S. government. The plant and its product must be subject to IAEA safeguards. The plant would be limited to the production of low-enriched uranium.

These three forms of protection represented the U.S. attempt to reconcile two competing views regarding how the multilateral initiative should be implemented. The protectionist view, championed by the AEC and the JCAE, considered the 1971 initiative in terms of

its impact on U.S. commercial leadership and technological preeminence. It held that any potential transfer must not be a subsidized giveaway, but must be a commercial transaction which provided adequate protection for U.S. commercial interests. The AEC clung to the Eisenhower view that multilateralization was a less effective means of dealing with foreign fears than a policy of strong fuel supply assurances backed by expanded U.S. enrichment capacity.

By contrast the internationalist view, championed by the State Department, held that the construction of foreign enrichment facilities was inevitable. Thus, rather than employing obstructionist tactics to control this development, the correct response was to actively participate in foreign enrichment ventures as a means of channeling development away from the less proliferation-resistant centrifuge technology. 94

As analyzed by Wonder, the protectionist forces dominated the internationalist forces in the implementation of the multilateralization strategy. The resulting scheme for technology transfer was grossly unsatisfactory to the interested foreign parties and there was no follow-up to the preliminary Washington meetings in 1971.

## 6.2 The 1974 Initiative

The environment shifted sharply again following the imposition of the OPEC oil embargo during late 1973. International energy cooperation suddenly attracted top priority, in the person of Secretary of State Henry Kissinger, and led to a reproposal of enrichment multilateralization during 1974.<sup>94</sup> Unlike the UEA proposal, which attempted to achieve multilateralization by attracting foreign equity participation in a private domestic enrichment plant, Kissinger repropose the notion of international technology transfer. Contrary to the 1971 initiative, the Kissinger proposal offered to examine the sharing of U.S. diffusion and centrifuge technologies for the creation of multinational enrichment plants outside of the United States.

Unlike the detailed structure laid out by the 1971 rules, the criteria for the 1974 proposed technology transfer were broader, more flexible, and open to negotiation. Rather than setting out specific ground rules, the U.S. invited foreign countries to initiate discussions on enrichment multilateralization, subject only to a series of guiding principles such as the "orderly introduction of new technologies," the "assurance of supply...(through) multinational investment", "geographic dispersion", non-proliferation, and the inclusion of "developing countries." 96

In fact, within this broad negotiating framework, only one detail was specified; in the present context this specification was of great interest. The U.S. proposal specifically stated that,

"For its part, the U.S. would expect the interested U.S. companies to be the principal channel through which exploratory discussions on technology sharing would be pursued. Proposals developed and negotiated by companies at the private level would be brought back to governments for their consideration and the development of the necessary intergovernmental arrangements." (emphasis added) 97

In short, domestic enrichment privatization was assumed as a necessary prerequisite of international enrichment technology sharing, because a private enricher was to be both the source of such a sharing arrangement, and the eventual conduit for the necessary technology.

### 6.3 Technology Sharing Summary

In this section we have found further evidence in support of our central proposition. Both the 1971 and 1974 multilateralization initiatives bear the stamp of AEC commercial objectives. The predominance of the AEC position is clear in the 1971 initiative's black box and commercial provisions, which sought to protect domestic industry and preserve technological preeminence. Perhaps more revealing, however, is the institutionalization of the enrichment privatization policy as a vital component in the 1974 initiative. Even during this latter era when the forces of internationalism and

the State Department were at their apex, the fact that privatization was taken for granted in the formulation of such a key international proposal is testimony to the continued impact of the AEC's commercial objectives on foreign policy.

The path taken by these two multilateralization initiatives leads Wonder to conclude that in the final analysis, when conflicts arose between the international policy of encouraging multilateral cooperation in building future enrichment plants and the domestic policy of relinquishing responsibility for enrichment to the private sector, "multilateral cooperation ranked lower in priority than successful 'privatization' of American enrichment operations." 98 The influence of the AEC's commercial objectives was evident in both the 1971 and the 1974 proposals, and the top priority accorded these objectives is consistent with our behavioral proposition.

## 7.0 THE DECLINE IN U.S. SUPPLY CREDIBILITY

By examining in some detail the AEC production planning, pricing and contracting policies, as well as the U.S. foreign policy with respect to enrichment technology sharing, we have sought to marshal evidence in support of our central proposition. As stated in Section 3.0, this proposition is:

U.S. enrichment policies may be understood not as the result of a continuous global rebalancing of domestic commercial objectives and international security considerations, but as the result of the AEC's primary emphasis on domestic commercial objectives, often to the neglect of the security implications of the resulting enrichment policies.

We contend that the evidence adduced in Sections 4.0-6.0 substantially confirms the validity of that proposition. We are left to confront the question, "So what?" The implication of this proposition was discussed briefly in Section 3.3. This discussion led in turn to the formulation of a second derivative proposition:

The failure of U.S. enrichment policy to achieve a balance between commercial and security objectives contributed to the decline in U.S. credibility as a reliable enrichment supplier,

which had negative impacts in both commercial and security domains.

The present section of the essay shall present the evidence in support of this second proposition. We shall seek to integrate many of the broad results of the previous sections into a chronological narrative aimed at tracing the decline in U.S. supply credibility to the sole pursuit of commercial objectives. Stated another way, we shall trace the creation of the "enrichment crisis" and much of the concern about enrichment supply assurance to the failure of the U.S. government to anticipate the negative international impacts of domestic enrichment privatization.

#### 7.1 The Changing International Environment Confronted by the Enrichment Privatization Policy

Prior to the late 1960s U.S. nuclear policy commercial and security objectives had been dovetailed neatly into a consistent strategy which subsidized the growth of international commercial nuclear power, and along with it the domestic uranium and reactor industries, while retaining monopoly control of the weapons-producing enrichment technology. Low enrichment prices and building enrichment capacity well in advance of demand were characteristic of AEC policy.



By 1970, however, the international environment had been altered dramatically. Despite the successful discouragement of the proposed EURATOM enrichment plant during 1957, and the subsequent security classification of German, Dutch, and British enrichment research at American request during 1960-61, the Treaty of Almelo in 1970, which created URENCO, clearly signaled that the U.S. monopoly of commercial enrichment technology was a thing of the past.

This signal was not without warning. The rapid growth of civilian nuclear power in Germany, France, and Japan made continued dependence on the U.S. as the sole source of enrichment services unacceptable. Nuclear power figured mightily in the energy supply plans of these foreign industrial powers, who depended more critically on imported energy supplies to fuel growing economies. Any delays in the expansion of U.S. enrichment capacity could result in a painful setback for economic expansion programs. Many foreign market participants feared that the U.S. monopoly might be exploited for political purposes or for commercial purposes, by coupling sales of enrichment services to U.S. reactor vendors, or by favoring U.S. vendors, as it was the custom for the reactor supplier to contract for fuel supply as a service to the customer. Each of these foreign nations recognized that U.S. reactor vendors were securing nearly 90% of all reactor export orders, and that their domestic reactor industries must break the U.S. domination of the reactor market to

realize the scale economies necessary to compete in international markets.

These observations combined to suggest the need for commercial enrichment facilities in Europe. The revival of European interest in enrichment is described succinctly by Wonder:

"The French (CEA) was contemplating the construction of a commercial-scale diffusion plant to serve European needs. FORATOM, the European nuclear industry organization, had released a report recommending the construction of European enrichment facilities. The European Community...in 1968, had declared its support for some measure of European enrichment autonomy and had begun developing concrete proposals to accomplish this. This revival coincided with growing European alarm at the Atlantic 'technology gap' and the 'American challenge.' European technological independence was seen as the necessary response to remedying an unacceptable situation where American technical and scientific superiority could mean the economic and political subordination of Europe."<sup>99</sup>

## 7.2 The Momentum Grows For Privatization

It was into this changing environment that the long-smoldering iron of domestic enrichment privatization was thrust. The chain of events set in motion by the Atomic Energy Act of 1954, and accelerated by the legislative creation of toll enrichment in 1964, began to bear fruit during the first Nixon Administration. In 1968 the Atomic Industrial Forum, a domestic nuclear industry group, published the results of a study which argued for the transfer of the gaseous diffusion plants to the private sector. The JCAE asked the

GAO to evaluate the sale of the plants to the private sector; the GAO's report was generally negative toward the idea. The AEC staff as well as a White House task force chaired by Paul McCracken of the Council of Economic Advisors outlined the strengths and weaknesses of various alternative courses of action. The result of this flurry of activity was the creation of a position within the Nixon Administration advocating the sale of the existing diffusion plants to the private sector. This proposal failed to survive strong congressional opposition, nonetheless, it alerted foreign and domestic observers to the vitality of the privatization objective.

### 7.3 The Failure of the 1971 Initiative

Meanwhile in the international sphere, the U.S. was proposing strategies for the multilateralization of enrichment as a means of reducing the security risks of the dispersion of enrichment technology. As described in the preceding section, the first of these proposals came during 1971, and was an abysmal failure.

In theory this proposal simultaneously satisfied security and commercial objectives. However, the strategy failed in its assessment of European technological and political realities, and the resulting implementation backfired badly. Primary dissatisfaction surrounded the differentiation applied by the AEC in its treatment of foreign and domestic firms on the issue of technology transfer. On

the one hand, the AEC excluded the U.S. centrifuge technology from the 1971 proposal, and asked foreign parties to make a firm commitment to the black box GDP technology prior to access to classified information. On the other hand, the AEC invited domestic firms to examine classified data on both U.S. centrifuge and diffusion technologies with no prior commitment to an enrichment venture. The exclusion of the U.S. centrifuge from the 1971 offer was inconsistent with the European technical realities, as evidenced by the Treaty of Almelo, and the preferential treatment of domestic firms inflamed foreign suspicions that the true purpose of the U.S. initiative was to limit potential competition and retain political control of the international nuclear markets.

Foreign parties showed little interest in the 1971 U.S. offer, and instead intensified their own development of enrichment technology. Rather than discouraging the spread of enrichment technologies, the failure of the 1971 offer encouraged the subsequent commercial enrichment plans of URENCO, EURODIF, UCOR, TECHNABSEXPORT, and PNC. As summarized by a U.S. official,

"It (the 1971 initiative) definitely caused Europe to establish an enrichment capacity before they would have otherwise. We probably lost out involving ourselves in some business sense in European plants by our policy of being so restrictive on the technology."100

In addition to this simultaneous failure in security and commercial objectives, the upshot of the 1971 fiasco was a shaken foreign perception of U.S. integrity, and the credibility of official U.S. nuclear policy. The encouragement of domestic enrichment privatization, and the accompanying implication that enrichment was no longer a special case requiring government ownership but was now a conventional industrial technology, was inconsistent with an international policy which sought to obstruct the construction of foreign enrichment plants on non-proliferation grounds, or to at least limit the technologies and competitive opportunities for these plants. The handling of the 1971 offer implied to foreign firms that domestic objectives, rather than international security objectives, were dominating U.S. nuclear policy.

#### 7.4 Intensified Pressure For Privatization and the Negative Impacts of LTFC Contracting

Despite tangible evidence of the pitfalls of simultaneously pursuing privatization and multilateralization, these two policies persisted. As described in essay #1, the pressures for privatization intensified during 1972 and 1973. Spurred by OMB's desire to transfer a large appropriations burden to the private sector, and the AEC's conviction that U.S. technical superiority and supply reliability should be exploited by private enrichers, U.S. SWU prices continued to rise and LTFC contracts were advanced to replace REQ

contracts. Despite the cool reception given privatization by domestic corporations,<sup>101</sup> President Nixon reiterated the government's commitment to privatization in April, 1973.

The reaction of both foreign and domestic utilities, as well as the JCAE, to the LTFC contracts was harsh. The sharp differences in opinion between the testimony of AEC representatives and the views of utility representatives led one member of the JCAE to comment, "If you can get a fusion reaction as hot as this room is today, we are in good shape."<sup>102</sup> Donald Allen, appearing on behalf of the Edison Electric Institute, the principal domestic association of privately held electric utilities, characterized the new LTFC contract criteria as,

"criteria which have been stripped of virtually every protective provision, and which have been transformed into a charter for future unilateral contract changes and price increases in the Commission's sole discretion,"<sup>103</sup>

and likened the execution of an LTFC contract to signing "a blank check."<sup>104</sup> Allen and other utility witnesses lamented the fact that they had no opportunity for advance consultation with AEC about the provisions of the LTFC contracts and therefore were totally unprepared for the Commission's package.

The JCAE was also chagrined by the new LTFC criteria because they felt confronted by a "fait accompli" which they frankly could not

adequately review during the required 45-day period.<sup>105</sup> The following exchange between Mr. Allen and Representative Holifield, Chairman of the JCAE, indicated the JCAE's concern that these new criteria would substantially weaken JCAE control over AEC contracting activities:

"Representative Holifield:...What control do you feel the Joint Committee will have over the essential terms and conditions of this or any other contract for enriching services under the new criteria?

Mr. Allen: None

Representative Holifield: Thank you. I came to the same conclusion."<sup>106</sup>

Utility representatives also made it quite clear that a near certain impact of LTFC contracting would be overordering by utility customers. A representative of Toledo Edison summarized these contentions:

"The new criteria would indeed provide a fixed schedule of demand for enrichment services...(which) could be used for planning...additional enrichment capability. Such a schedule would, however, inflate the real demand for enrichment services by requiring each nuclear plant owner to commit to purchase feed material and enriching services well ahead of his need. (No nuclear utility)...could take the risk of not contracting on the long-term basis proposed by the AEC, if that is the only option realistically available...

The net result may be certainty for planners of enrichment capability to the detriment of consumers of electricity who will bear the unnecessary cost...the goal of a reliable planning base may be achieved but it will not likely be a realistic planning base."<sup>107</sup>

This extended quotation eloquently foreshadows the problem of artificially inflated demand that has plagued nuclear markets since the LTFC contracting rush closed the AEC order books in 1974.

Furthermore, domestic and foreign utilities alike attacked the inflexibility of the rolling 10-year LTFC firm commitment period. Sidney Stoller, President of S. M. Stoller Corporation, the nuclear consulting subsidiary of Arthur D. Little, Inc., argued that if one major motivation for the LTFC contracts was to create an enrichment contracting structure "which is harmonious with commercial contracting practice" at other stages of the nuclear fuel cycle, then LTFC contracts were much too inflexible. Drawing on examples of existing commercial contracts both for U<sub>3</sub>O<sub>8</sub> resources and fabrication services, Mr. Stoller provided evidence of contractual flexibility which contrasted sharply with the proposed firm LTFC delivery schedules.<sup>108</sup>

Foreign utilities also questioned the wisdom of the LTFC criteria. Although the criticism was offered in a slightly more polite and cautious manner, the LTFC contracts were characterized as "extremely and unexpectedly severe."<sup>109</sup> The major concern of foreign utilities was the extended lead time associated with the execution of the LTFC contracts. The LTFC contracts required a lead time of 8 years prior to the delivery of the first core, while the entire lead time for foreign reactor construction was only 5-6



years. Therefore, foreign utilities would be forced to firm up an AEC enrichment contract as much as 2-3 years before they began reactor construction. As diplomatically as possible, a representative of the Japanese Atomic Industrial Forum, stated,

"Accordingly, we are afraid that we may be forced to conclude an enrichment contract too early, resulting in a possible significant gap between the predetermined plan and the actual outcome in the future."<sup>110</sup>

On these grounds the Japanese representative asked for a reduction in the leadtime, "to the extent possible, down to no longer than around 4 years."<sup>111</sup> The difficulties associated with the disparity between SWU contract leadtimes and foreign reactor construction leadtimes were echoed by representatives of Swedish and German utilities.<sup>112</sup>

In addition the German representative made reference to the European fear that because AEC was the only current enrichment services supplier, foreign utilities would be forced to contract well in advance of actual demands and, "there would be no room left for further contracts with the additional (enrichment) capacities to be built in Europe."<sup>113</sup> This reinforces the sentiment uncovered by Wonder during a series of European interviews during 1975. He found that the difficult LTFC contract terms were seen as an attempt to squeeze Europe into guaranteeing a post-1980 market for a U.S. private enricher; a French atomic energy official observed, "The AEC

has made a strictly imperialist move in the grand tradition of economic colonialism."<sup>114</sup> Indeed the LTFC lead times were longer and supply schedule flexibility substantially less than the contracts subsequently offered by EURODIF and URENCO, which had 5 year lead times between contract execution and the first enriched fuel delivery and permitted moderate ( $\pm 10\%$ ) flexibility in SWU quantities until 2 years before the delivery date.<sup>115</sup>

Despite the obvious misgivings of both foreign and domestic utilities, as well as the JCAE, the AEC went forward with the LTFC contracts after a few concessions. Specifically: (1) the AEC postponed the effective date of the new criteria to allow time to explain the criteria in more detail to industry representatives; (2) the AEC proposed an additional contracting approach which would provide for variations in SWU quantity at increased cost with additional feed;<sup>116</sup> (3) at the suggestion of EURATOM, contracts were rewritten to permit free exchanges of enriched product as a means of permitting the free market to offset the tendency to overorder.<sup>117</sup> In retrospect these alterations did not satisfy the demands of the utility industry, as evidenced by the ensuing contracting glut.

The European response to LTFC contracts was to accelerate plans for indigenous enrichment capacity, while turning to the Soviet Union as an alternative source of enrichment services. This acceleration

is clearly documented in JCAE testimony. During July, 1973, prior to the initiation of LTFC contracts, an AEC representative summarized the status of foreign enrichment operations as follows:

(1) URENCO's most optimistic investment plans called for a 2 MMSWU/yr. capacity by the end of 1980, growing to 10 MMSWU/yr. by year-end 1985;

(2) With the withdrawal of Australia and the URENCO nations from EURODIF feasibility studies, "hopes for realization of a multinational diffusion plant based on French diffusion technology by the late 1970's seem to have dimmed," although the French reiterated their intention to build a 6 MMSWU/yr. diffusion plant, "even if they have to 'go it alone.'"118

(3) The U.S.S.R's role as a potential supplier of SWU services was still not clearly defined. Even though some Western nations had evidenced increasing interest in TECHNABSEXPORT contracts, "aside from the enrichment services for the Russian-built Finnish nuclear power plant and the initial core of the French Fessenheim plant, there have been no other known enrichment contracts consummated with non-bloc countries."119

Only a year later, July, 1974, immediately after the closing of the AEC order books, a representative of the General Electric-Exxon

joint centrifuge venture (CENGEX) summarized the foreign situation as:

(1) URENCO had announced a firm expansion schedule identical to its earlier most optimistic case of 2 MMSWU/yr. in 1980 and 10 MMSWU/yr. in 1985; because "it has already booked orders for more than 10 million S.W.U.'s from British, Dutch, and German utilities" due to its more flexible, shorter leadtime contract terms at a price (\$48/SWU) only slightly higher than the prevailing AEC price;<sup>120</sup>

(2) EURODIF's future was no longer questionable. The French had announced a construction schedule beginning in 1974 with planned outputs of 3 MMSWU/yr. in 1979, 6 MMSWU/yr. in 1980 and 10 MMSWU/yr. in 1981. "EURODIF has largely sold out its capacity...under contracts from French, Spanish, Italian, and Belgian utilities...and has signed a firm contract with Japan for 1 million S.W.U.'s per year for a 10-year period 1980-89."<sup>121</sup>

(3) The U.S.S.R. had become an established enrichment supplier. "Firm orders have been booked with Finland, France, Germany, Austria, Sweden, Belgium, Italy, and Spain,...(and) they have offered to supply 100 percent of Japan's needs from 1975 through 1980."<sup>122</sup>

(4) The Japanese were giving consideration to the construction of a 6 MMSWU/yr. centrifuge plant by 1985, instead of their previous

plans which had called for an 0.5 MMSWU/yr. demonstration plant in 1985;123

(5) The South Africans were putting a pilot enrichment plant on line during 1974 and were conducting feasibility studies with West Germany contemplating the expansion of this plant to 7 MMSWU/yr. by the mid-1980's;124

(6) Two groups in Canada, plus EURODIF, were considering the construction of a 10 MMSWU/yr. Canadian diffusion plant by the late 1980's;125

(7) Finally, Australia was holding preliminary discussions with URENCO regarding the use of the centrifuge technology to have an Australian plant on stream by the mid or late 1980's.126

In short, the onerous LTFC contract terms, which resulted from the push for enrichment privatization, hastened the decline in the perceived credibility of U.S. supply assurances precipitated by the 1971 cooperative initiative.127

#### 7.5 The Failure of the 1974 Initiative and the Weakness of Privatization

As with the 1971 initiative, the 1974 cooperative proposal failed to achieve its purpose. Discussions with foreign enrichers during 1974 revealed the difficulty of any technology transfer. The progress in EURODIF and URENCO in the three years since 1971 led the Europeans to challenge the U.S. presumption of technical superiority and to suspect that these new negotiations were a thinly veiled attempt to preserve U.S. market domination by disrupting formative European supply arrangements. U.S. supply credibility was lessened by the stipulation that technology transfer would be channeled through a private enricher, in view of the absence of a firm commitment on the part of domestic industry to private enrichment.

This perceived weakness of the privatization program had long been an issue of concern to the JCAE. As early as 1970 Representative Hosmer, criticizing the implementation of commercial pricing criteria as a stride towards the Nixon concept of privatization, which revolved around the sale of the existing diffusion plants, concluded that "(Privatization) was an idea whose time has not come." 128 He chastized the AEC which

"has pushed the further investigation into private ownership...in a total vacuum concerning the possibility for implementing this private ownership." 129

He concluded that this "vacuum" existed because,

"Whereas at the first of 1969 the...(industrial)...people were all hot for hiring a priest and raffling the plants off...By the

time they reached November 10, 1969, when a statement was finally made downtown, it was quite apparent that there was money absolutely no place in sight...that could possibly finance a purchase of these plants." 130

Despite the shift of the privatization initiative from the sale of existing diffusion plants to the construction of incremental enrichment capacity by private firms, suspicions about the viability of the privatization policy continued. In March, 1973, JCAE member Jackson said that,

"(Due to financial circumstances) I have real doubts in my own mind as to whether industry will really participate (in enrichment privatization)...(and if these doubts are realized) you (i.e., the AEC) have real problems as to the predicate on which you are going to do your future planning." 131

In August 1973, JCAE Chairman Holifield criticized the shallowness of the privatization policy saying,

"It is really disgraceful that someone in the Nixon Administration ambiguously said that private enterprise will provide the next increment of enrichment. No one knows who said it, and apparently that person went away. This prophecy has been self-fulfilling since that time. Now we come to the hard part when we have to really massage this question thoroughly in all its aspects instead of taking it as an offhand decision. And, we find ourselves doing so in a climate of urgency because of the time limits..." (emphasis added) 132

Clearly these informed observers were of the opinion that the privatization policy was unrealistic; it is not unlikely, therefore, that this opinion was shared by some foreign utilities and governments, which served to lessen the credibility of the 1974 initiative.

Equally clearly, the impression that privatization was a dead end gained further prominence during 1974. In his June, 1974 JCAE hearing remarks, Representative Hosmer lamented the religious fervor of privatization proponents by demanding rhetorically,

"Are we to conclude that 'stonewalling' in the form of repetition of the (call for privatization) will magically make it so? Are we to become becalmed in a semantic sea, then told we will cross that sea by some magic power, with OMB's divine guidance and by the spiritual inspiration of the five wise persons of Germantown (i.e. the AEC), and be brought to a heavenly place when even plates and candlesticks are made of enriched uranium?" 133

The subsequent withdrawal of Union Carbide from the UEA consortium, and the likely withdrawal of Westinghouse from UEA 134 led Representative Hosmer to state in August, 1974 correspondence with OMB that "Your UEA group is in tatters and CENGEX would be if it knew what UEA has been able to learn about the situation," and went on to characterize OMB, UEA and CENGEX as "obstinate holdouts against reality." 135

#### 7.6 The Closing of the Order Books Further Tarnishes AEC Credibility

If the perceived weakness of privatization was not enough to torpedo the 1974 initiative, the closing of the AEC enrichment order books guaranteed its demise, and fueled the growing foreign suspicions of U.S. commercial motives. Many foreign utilities suspected that the closing of the order books was an artificial



crisis intended to force Congressional approval of enrichment privatization.<sup>136</sup> The immediate reaction of European nations was the further acceleration of indigenous enrichment plans, which could "pose a serious threat to the current U.S. position as chief world supplier of enriched uranium."<sup>137</sup> One European official was moved to comment that it was "particularly ludicrous" that the U.S. had brought this problem on themselves through the pursuit of a misguided nuclear foreign policy.<sup>138</sup> As described in essay #1, this acceleration in plans did indeed occur. During 1975, COREDIF, UCOR, and NUCLEBRAS put forth plans for additional foreign enrichment capacity.

In addition to the step-up in foreign enriching plans, the foreign utilities reacted with great trepidation regarding the AEC's likely management of the contracting process. Testifying before the JCAE, the Director General of the EURATOM Supply Agency stated,

"I have to say quite frankly that the customers in the community have been shocked by the absolutely unexpected decision of the U.S. AEC...to suspend signing contracts, and more so, as all publications and statements of the preceding 2 months indicated that the limit of contracting capability would be reached at a later point in time than previously forecasted." (emphasis added)  
139

This position was reiterated by a Japanese utility representative who stated that the AEC's action in closing the order books "came to us as a surprise and a shock."<sup>140</sup>

Both foreign utility representatives found themselves in the uncomfortable position of having submitted a large number of signed LTFC enrichment contracts, along with advance payments, to the AEC well in advance of the June 30, 1974 deadline, only to find that the AEC had imposed the contract moratorium after honoring only a percentage of those requests. <sup>141</sup> Both representatives emphasized the need for an early resumption of AEC enrichment contracting to prevent fuel supply shortages for those reactors requiring fuel deliveries beginning in 1978, <sup>142</sup> and both expressed concern that they, as foreigners, might not receive fair and nondiscriminatory treatment from the AEC.

This latter question of non-preferential treatment for all AEC customers arose due to the AEC's treatment of the LTFC requests made by Egypt, Israel and Iran. As summarized by the EURATOM representative,

"Serious concern and criticism has been brought to the attention of (EURATOM) that, while our contracts, introduced in due time, were not signed, the United States entered into new enrichment contracts with Egypt, Israel and Iran up to the very last day of June 30, 1974." <sup>143</sup>

EURATOM indicated that this preferential treatment of "people who are completely new in the nuclear field" at the expense of those who "have (had) an agreement for cooperation with the AEC from 1958 on," violated the AEC's nondiscriminatory traditions, and attributed this

AEC abuse to "political reasons." 144 The AEC later testified that

"the sole exception (to the closing of the order books)...was related to contracts with Egypt, Israel and Iran...(where) a Presidential commitment of supply had previously been made on behalf of the U.S. Government." 145

If the management of the contract moratorium displeased many utilities, the AEC's conditional contracting solution to the problem only aggravated this concern. At the time of their signing, the AEC conditional contracts were quite speculative, so that President Nixon's personal guarantee that the conditional contracts would be honored failed to satisfy foreign customers.<sup>146</sup> In large measure, this failure was also the result of the declining credibility of the Nixon Administration; Nixon's guarantee was given on the day that he resigned.

In addition, the shuffling of the conditional contract queue, to the disadvantage of the Japanese utilities, raised further concerns about the reliability of the U.S. policy of non-discriminatory supply. On August 6, 1974, the AEC testified regarding how it would satisfy the backlog of requested contracts. At the time of contract suspension, the AEC had countersigned 273 GWE of enrichment contracts. It subsequently determined that it could execute firm LTFC contracts up to 320 GWE of capacity and would offer conditional contracts for the additional 44 GWE of requested contracts. Basically, the AEC proposed to execute these additional firm and

conditional contracts in the chronological order in which they were submitted to the AEC for countersignature. AEC Chairman Ray noted that,

"Without further adjustment, however, this chronological approach would result in an imbalance, obviously inequitable, in the resulting actions in that Japan would receive 25 standard contracts as related to 27 requests, and Western Europe would receive 1 standard contract as related to 33 requests.

Following consultation with the Department of State on this matter, it was determined that a degree of redress of this situation would be appropriate...

The conclusion was reached that the chronological position of six Japanese reactors should be interchanged with two from France, two from Germany, one from Spain, and the one from Puerto Rico. The chronological position of the other 81 reactors would not be altered." 147

The upshot of this reshuffling of the contract queue was to guarantee that all domestic requests received firm contracts (the Puerto Rico request would otherwise have received a conditional contract), and that Western Europe received more firm contracts, both at the expense of the Japanese utilities; the Japanese were understandably miffed.

Wonder concludes that, "the Atomic Energy Commission's handling of the (contract moratorium) situation was embarrassing and the lack of interagency coordination was alarming."<sup>148</sup> Certainly the entire incident did nothing to bolster declining foreign confidence in U.S. enrichment supply reliability. In July 1974, Representative Hosmer summarized these sentiments,

"Frankly, the AEC has not done much for its credibility over the past year or so...we have found a great fluctuation in the date when their contracting capability was to be used up, and every time somebody at the AEC had to make an important speech about that matter, the facts seemed to change to accomodate whatever would be desirable in a public relations way to be said on the platform on that particular date.

Then with very little, if any, preparation or explanation the guillotine dropped on the contracting on July 2 (1974)..."<sup>149</sup>

Although eventually all the customers holding conditional contracts were given the option of firming up these LTFC contracts, made possible largely by extensive reactor slippage and by cancellation from those customers already holding firm contracts, this process took more than four years and "was more a fortuitous situation than a method which could be relied upon again." <sup>150</sup>

In the midst of this confusion, U.S. enrichment policy appeared to be floundering without direction. Many observers echoed Representative Hosmer's condemnations of the feedback-reactor behavior displayed by the AEC, in the absence of any long-run strategic planning,

"There has been no forward planning; there has been no overall concept of management here as a business...

As a consequence, the needs of that kind of management each year have bent to the necessities of the particular year's budget, and it has been OMB which has operated this thing on a hand-to-mouth basis..."<sup>151</sup>

"...the uranium enrichment business carried on by the U.S. Government is carried on not in the interest of that business and its customers, but the extraneous interests of the U.S. Government which largely are the current year's fiscal crisis, of which there is always one."<sup>152</sup>

"We get a hearings week and get a rush...Everything all of a sudden seems to happen at once, just before a hearing, or during one.

I am not at all happy that this very vital function (i.e. enrichment)...either receives the (constant) attention or the organizational emphasis required to carry it successfully through a very difficult period." 153

## 7.7 Subsequent Events Deepen Reigning Confusion

During January 1975, at the time these additional firm and conditional contracts were being executed, the AEC ceased to exist, and its responsibilities were assigned to ERDA and NRC. Foreign and domestic customers did not know what to expect from the new organization, nor did the JCAE. Having long derided the "parade of virgins" and "Johnny-come-latelies" produced by the constant turnover of AEC commissioners,<sup>154</sup> Representative Hosmer took stock of the situation as the ERDA reorganization loomed on the horizon,

"What do we have? We have ourselves in the middle of an impeachment...We have new people in all the top executive offices where they make any decisions...people who don't know a thing about this business...

Right now we are in one gigantic mess because...we got ourselves into a situation with many of our friends overseas whom we had assured that there would always be nuclear fuel from the United States, and now it 'ain't' coming...

The members of this (JCAE) many of them were around here...when the Eisenhower 'atoms for peace' declarations were being made. But there is nobody downtown in a policymaking position that is still around (who seems to remember those decisions)."155

Despite the tumultuous history of the privatization initiative, ERDA, backed by the Ford Administration and OMB, continued to carry the privatization torch to the Congress in the form of the 1975 Nuclear Fuel Assurance Act (NFAA). Citing the urgent need to open the order books as a justification for enrichment privatization, rather than allowing that the reason that the order books had been closed so suddenly was the pursuits of privatization via LTFC contracting, ERDA asked the Congress to authorize ERDA to negotiate agreements with UEA and other potential private domestic enrichers, for the sale of Government enrichment technology as well as the establishment of a series of Government guarantees. Despite continuing evidence from domestic and foreign utilities alike that UEA was offering an unacceptable enrichment contract,<sup>156</sup> the privatization juggernaut lurched forward.

Meanwhile the order books remained closed. Foreign concern was further heightened by the March, 1975 suspension of all fuel exports by the NRC, pending case by case evaluation of physical security measures. The European Community protested vigorously because the resulting delivery delay threatened to slow reactor start-ups and shut-down some operating reactors. The European nations were "openly questioning the integrity of American treaty commitments...The only alternative was the Soviet Union (and)...many European governments considered such dependence politically undesirable." Even so, the United States began to appear little more attractive as a source.

The Economist observed: "...'American suppliers...have proven unreliable in the past and are now turning awkward again'"<sup>157</sup>

Subsequent events described in essay #1 further tarnished the U.S. image and revealed the consequences of this loss of credibility. Four years after the closing of the U.S. enrichment contract order books, they remained closed. The intermediate delays in designing a new enrichment contract, the death of the NFAA, and the postponement of the Portsmouth add-on solidified foreign suspicions about the level of confusion in U.S. nuclear policy. Meanwhile the artificial surge in demand created by LTFC contracts contributed to the rapid price increase in uranium markets which, in conjunction with uncertainties about the future management of DOE's STFS policy, advance feed policy, and enrichment contracting policy,<sup>157</sup> and the subsequent Westinghouse incident, threw the international uranium market into a state of confusion from which it has yet to recover. Lastly the decline in U.S. credibility led to still further entry by potential foreign enrichers, as well as the expansion of capacity plans by previously announced foreign enrichers. This in turn has led to a circumstance of excess enrichment capacity which will continue to prevail through much of the 1980's. This inability to rationalize capacity expansion could lead to stiff competition in the enrichment market, which may have undesirable security implications if it results in any compromising of safeguards standards.



## 7.8 Conclusion

This section of the thesis has attempted to scrutinize the proposition that the single-minded pursuit of AEC commercial objectives in the form of enrichment privatization contributed mightily to the loss of U.S. credibility as a supplier of enrichment services. This tarnished credibility in turn accelerated the spread of commercial enrichment technologies in foreign nations, which increased the fears of further weapons proliferation, and aggravated already grave uncertainties in uranium markets. This combination of events, and the chain reaction that emanated outwards from them, created much of the prevailing concern surrounding "nuclear fuel assurance" which currently occupies the attention of nuclear policymakers. One proposed solution to the assurance problem is the focus of our third essay.

It is difficult to substantiate the contention that the sort of organizational behavior posited in our first proposition led the sort of negative impacts as posited by proposition two. We have relied almost exclusively on the public record to weave the narrative which suggests the plausibility of this cause-effect relationship. Obviously we cannot conduct a controlled scientific experiment and hold all other variables constant to verify our contention. Therefore we find that while the weight of the evidence in support of our second proposition is not absolutely conclusive, it is too

substantial to be dismissed out of hand without an equally well defended alternative.

We have cited extensively from the public record to demonstrate both the commercial motivations of the AEC and the negative ramifications of the actions undertaken in response to the commercial objecties. To demonstrate that these actions were pursued in the absence of an interdependent analysis of the international political implications of these actions, we appeal to the deafening silence of the record in this regard. It is indicative that the AEC chose not to consult with the State Department about the international implications of price increases <sup>159</sup> or the closing of the order books <sup>160</sup> until after the fact. More to the point, despite the anti-proliferation thrust of the two multilateralization initiatives of 1971 and 1974, the AEC and the JCAE continued to conceptualize the international implications solely in terms of the balance of payments.<sup>161</sup>

It is only in February, 1976, that the testimony on international implications finally recognizes the non-proliferation aspects of enrichment policy. At this late date, as the Administration's final witness in support of the NFAA, Secretary of State Kissinger touched on the interdependencies between domestic enrichment policy and international non-proliferation policy.<sup>162</sup> Nevertheless, he finally admitted that the State Department's primary reason for supporting

the NFAA, "was that additional enrichment capacity should be provided as rapidly as possible," and that, "from the point of view of foreign policy it is not of decisive consequence whether (incremental enrichment capacity comes from) a governmental plant or private plant." 163 Indeed his only defense of the battered privatization policy was,

"I was impressed by the arguments -- though they are not primarily in my area of jurisdiction or in my field of competence -- that this was the time to move the enrichment capacity into the private field if we were ever going to do it." 164

## 8.0 SUMMARY

This essay has suggested an institutional model of U.S. enrichment policy, and looked at two propositions which flow from this model. Drawing on the historical privatization theme, as revealed in essay #1, we have offered an organizational argument for presuming that AEC commercial objectives, particularly enrichment privatization, will predominate over security objectives in the formulation of U.S. enrichment policy. Enrichment privatization is an old idea, whose roots may be traced directly to the Atomic Energy Act of 1954 and which has long enjoyed AEC support at the Commission level. It was the next logical step in the progressive commercialization of the nuclear fuel cycle, following on the subsidization of civilian reactor installations, the creation of a privately held uranium industry, and the removal of legal barriers to the private ownership of nuclear fuel.

This proposition has been tested by examining U.S. enrichment policy with respect to production, pricing, contracting, and technology transfer. In each arena we have found significant evidence of the dominance of privatization initiatives; in most cases policy choices were made in an attempt to pave the way for a private enricher.

In the area of SWU production we have revealed the commercial origins of the AEC's production strategy and explained how the resulting cost-minimizing computer calculation justified the choice of operating tails assays, the desirable size of the preproduction stockpile, and the tails recycle program. In addition, we have shown how these production decisions were made in the absence of any analysis of their interaction with security objectives, by demonstrating that the inclusion of a vanishingly small stockpile security premium may dramatically alter the pursuit of the tails recycle program.

Furthermore, having established the rationale for these production policies, we have explained the subsequent course of AEC production policies as a sequence of short-run responses to short-run external budgetary and political pressures. These responses have been determined by AEC "standard operating procedures" of enrichment privatization, uranium industry protection, and the pursuit of preproduction stockpiling and tails recycle. This incremental decision-making mode, which has replaced long-run strategic planning, ties back to the notion of bounded rationality which forms the foundation for our organizational model.

In the area of SWU pricing we have uncovered a sequence of regularities in the pricing formula. Consistent with the promotional theme highlighted in essay #1, we have recounted the historical

underpricing of AEC enrichment services as a subsidy to buyers of nuclear electric energy and a vehicle for fostering domestic industrial and foreign trade interests. In addition, we have documented the struggle of the AEC to escape from the confines of the underpricing mandate throughout the 1970's, as a means of lowering the barriers to the entry of domestic private enrichers. This attempt, which was explicit in the abortive attempt to adopt commercial pricing during 1970, has revealed itself, both in the continual shifts in AEC pricing procedures, which have resulted in the maintenance of AEC prices at or near the legal ceiling price, and more recently in the AEC push for fair value pricing as a transitional compromise measure. Along the way we have once again sought to tie back our pricing discussion to our organizational model by describing the evolution of the pricing formula as a sequence of accumulated conventions chosen in response to short-term problems rather than long-run goals. The resulting pricing formula, which we have characterized as the accretion of a myriad of confusing, and often conflicting incremental decisions, is a classic example of the output of this feedback-react decision-making mode.

We have also seen how SWU contracting has borne the stamp of enrichment privatization. There is little dispute that a major motivation for the changeover from REQ to LTFC enrichment contracts was to provide for a smooth transition to private enriching. Indeed, the AEC pricing formula sought to further promote this changeover by

the creation of a differential pricing strategy for REQ and LTFC SWUs. Although by some interpretations this differential price is founded in actual differences in AEC costs associated with the two types of contracts, our research reveals that the encouragement to REQ customers to convert to LTFC contracts was equally important in the adoption of the differential pricing approach.

Finally, in the area of international technology transfer, we have demonstrated the domination of AEC commercial objectives in the two U.S. foreign policy proposals for enrichment multilateralization during 1971 and 1974. In the implementation of the 1971 initiative the protection of domestic commercial interests and the attempted preservation of technological preeminence were evident, while in 1974 the predication of the transfer policy on the creation of a private enricher was explicit.

Having argued the validity of the model's basic commercial predominance proposition, we next turned to an examination of the international implications of this behavior. We have traced the failures of the 1971 and 1974 foreign policy initiatives to the preeminence of the privatization policy over international multilateral policies, and the failure to reconcile the inconsistencies between these two policies. These inconsistencies link back to the minor theme of political-market tension identified in essay #1. We have also traced the closing of the order books and

the subsequent confusion in uranium and enrichment markets, exacerbated by the mishandling of the conditional contracting process, to the institution of LTFC contracts which we have already seen to be motivated by the privatization policy. This uncertainty links back to the second minor theme identified in essay #1.

The result of these foreign policy and enrichment contracting failures has been the destruction of U.S. credibility as a reliable supplier of enrichment services. This decline in U.S. credibility led to a foreign concern about nuclear fuel supply assurance and a resulting proliferation of foreign enrichment projects. This untoward result has defeated both the U.S.'s commercial and security objectives and created a circumstance of grave uncertainty in international enrichment and uranium markets which continues to plague today's policymakers.

With the advent of the Carter Administration has come increased White House pressure for the placement of security objectives above commercial objectives in the formulation of U.S. nuclear policy. International enrichment cooperation has replaced enrichment privatization at the head of the nuclear policy agenda. The commissioning of a government-owned Portsmouth centrifuge plant and the prospective reopening of the enrichment order books, subject to a more flexible enrichment contract, are seen as the first strides in attempting to restore U.S. supply credibility. Whether this



rehabilitation of U.S. image and the reordering of nuclear priorities will be successfully accomplished remains to be seen. The results of this essay lend a deeper perception to the difficulty of this task and the price of a failure to complete it.

## APPENDIX I

### BIASES IN THE AEC PRICING OF SPLIT TAILS

#### FEED SALES (STFS)

The highly complicated accounting treatment of the STFS program appears to impart a downward bias to the SWU price. The assumption that STFS will end in 1981 as the basis for the pricing calculation is inconsistent with DOE's current public position regarding the STFS program. DOE has indicated that 1981 is the earliest date that STFS will be terminated, and most internal DOE calculations consider three future STFS scenarios where the program extends until 1981, 1985, or 1990. Given recent demand slippages, STFS will not exhaust DOE's natural uranium stockpile until after 1990. The selection of the first scenario as the basis of the pricing calculation understates the size of the uranium sales from the DOE stockpile, relative to the two extended STFS scenarios.

Not only is the magnitude of the STFS probably underestimated, but the use of an average market price as a value of  $U_3O_8$  probably underestimates the value of uranium sold through STFS. Research into uranium prices reveals the price series data to be sparse and suspect. Standard microeconomic theory would value uranium at its market price, which would equal the social opportunity cost of the marginal source of supply, but under current circumstances it is

extremely difficult to identify the market price. Presumably the relevant market is the long term contract market, rather than the spot market which is subject to short-run fluctuations. The distinction between the spot and the contract market is an important one because the current average spot price is around \$45/lb. while the current price for delivery today under a long-term contract averages \$20/lb.

Even within the long-term contract market there are problems in defining the price. DOE collects market survey data on prices but these data are not publicly reported in separate long-term and spot contract categories, so the price data show a broad range. Private conversations with DOE representatives reveal that even within the long-term contract market there exists a broad range of prices. This broad price band is a function of many factors, including: (1) the differing ages of the contracts, some being negotiated when the government support price  $U_3 O_8$  was \$6/lb., and others being negotiated after the Westinghouse incident when spot prices topped \$40/lb.; (2) the differing terms of the contract, some being arms-length agreements and others involving prepayments or an equity position in a joint venture not reflected in the transaction price; and (3) lack of standardization in the price inflators built into the contracts, some being tied to an undefined world market price or to the as-yet unknown actions of a national pricing board, while some

are linked via complicated formulas to indices of mining cost or general price level which are difficult to forecast.

In any event, the price picture is one of broad uncertainty and lack of standardization. While DOE has one of the world's premier data sources in its commercial price survey, our discussions reveal that this survey relies almost exclusively on utility buyer forecasts of delivered uranium prices with little cross-checking against U<sub>3</sub>O<sub>8</sub> seller price forecasts. Because DOE takes these buyer forecasts at face value, with minimal inquiry into the forecasting methodology, it is difficult to assess the data's validity. Beyond that, we do not know how DOE processes these data to arrive at the average market price. Operating on the assumption that DOE merely averages the delivery prices under all long-term contracts for each year, we conclude that this will underestimate the price at the margin because the average will be depressed by the older, low-priced contracts and the implicit costs not reflected in the transactions price. The more interesting figure would be the annual average delivery price for new long-term contracts signed during the past few years, where the delivery price is adjusted to reflect the implicit cost of prepayments or joint venture involvements.

The inclusion of the tails recycle credit in the calculation of STFS costs obviously reduces the SWU price. Setting aside for now the manner in which the tails are valued, one must inquire whether

such a credit is appropriate at all. While it is true that the 0.3% tails came from toll enrichment customers it is not obvious that fairness dictates a tail recycle credit for current SWU customers. All of DOE's REQ and LTFC SWU contracts contain a provision specifying the customer's option, exercisable upon written notice to DOE at least 90 days prior to the scheduled delivery of enriched uranium, to acquire tails material from DOE. The maximum quantity of tails material (kg U) is equal to the difference between the total quantity of uranium supplied in the feed and the total quantity of enriched uranium returned as final product. With the exception of handling charges, no charge will be made in connection with furnishing tails material to the customer.

There is, however, a catch in this option to acquire tails material. The customer is not guaranteed the tails material resulting from the processing of the feed material that he furnished, rather, the U-235 assay of the tails material delivered to the customer is within the sole discretion of DOE. Effectively, this insures that any customer exercising his tails option, which happens less than 1% of the time, will receive 0.2% tails. This tails material will have value to the customer only if: (1) laser enrichment technology becomes available, which permits him to strip those tails to a near-zero tails assay, or, (2) DOE agrees to accept tails material as feed, which they currently do not do, and is operating at a tails assay below 0.2%. At present both of these are

distant, opportunities, which explains why so few customers choose to acquire tails material.

Is this "fair"? We argue that fairness should be defined with respect to a set of agreed-upon ground rules, not with respect to a test of economic efficiency or social morality. Therefore, because utility acceptance of this contract provision implies its acceptance as a ground rule, the effective ownership of all tails material by DOE is fair. The contract goes on to state, "The customer shall receive no credit for tails material subject to its option but not taken." This statement flatly contradicts the tails recycle credit contained in the SWU pricing formula, rendering the SWU price "unfairly" low. In fact, this reading of the contract would argue that DOE should charge customers for  $U_3O_8$  recovered from DOE-owned tails and resold through the STFS program, rather than offer a credit to them. DOE's neglect of the SWU contract provisions results in roughly a \$40 MM subsidy of nuclear power by U.S. taxpayers over the campaign period. This subsidy is comparatively minor; the elimination of the tails recycle credit would increase the SWU price by about .03%.

Even if the DOE notion that the customer should be compensated for the residual uranium in the tails material were borne out by the SWU contract, the DOE pricing scheme rewards not those customers who supplied the uranium in the first place, but those customers who

happen to buy SWUs during the campaign when tails recycle is in effect. Finally, even if the tails recycle credit were appropriate, DOE's valuation of the tails material is inconsistent with the  $U_3O_8$  prices used in the STFS calculation and the SWU price produced by the pricing calculation. The method for tails valuation is summarized in Table 15. Using market prices for uranium and enrichment services yields a tails value of 29¢/kg. U. Obviously if a value more closely approximating the marginal costs of SWUs were used in the valuation formula, the value of tails material would be negative. We conclude that DOE's valuation of tails material at \$22/kg U is both an overestimate of its value and one which is inconsistent with the other valuations in the pricing calculation.

In sum, the use of a lower bound for STFS sales, the under-valuation of the uranium sold through this program, and the improper conclusion of an overstated tails recycle credit, combine to understate STFS costs relative to long-run marginal costs. It could be argued that this understatement is relatively unimportant in view of the minor role of the STFS cost component in the final SWU price; during the last two price calculations STFS costs have accounted for less than 1% of the SWU price. We have examined these biases in great detail not because of their significant impact on the SWU price, but because they are indicative of the internal inconsistencies, misinterpretations and inappropriate conventions that plague the DOE base price formula and result in the underestimation of SWU price.

TABLE 15

SHADOW PRICING OF TAILS MATERIAL

We begin with two equivalent means of producing 1 kg U 3% enriched product:

<u>using natural feed</u>	<u>or</u>	<u>using 0.3% tails feed</u>
5.96 kg U natural feed		55 kg U tails feed
+		+
3.81 SWUs		7.63 SWUs

Next we compute the cost of these alternatives, using market prices of \$75/SWU and \$18/kg U as  $U_3 O_8$

$$(5.96 * 18) + (3.81) * 75 = \frac{\$588}{\text{kg U}} \quad \text{or} \quad 55 \text{ kg U} * \text{value tails} \\ + 7.63 * 75$$

Because these two final products are identical we can solve for value tails = \$0.29/ kg U



ESSAY #2

FOOTNOTES

- 1 (33), pg. 21
- 2 (10), pg. 1444
- 3 (25), pg. 35
- 4 (25), See Figure on pg. 37
- 5 (11), pg. 45
- 6 (11), pg. 46
- 7 IBID, pg. 46
- 8 IBID, pg. 47
- 9 Exact value = \$1,023.85
- 10 (28), pg. 106
- 11 (30), pg. 81
- 12 (29), pg. 7
- 13 (20), pg. 486
- 14 (8), pg. 18
- 15 IBID, pg. 17
- 16 (20), pg. 20
- 17 IBID, pg. 138
- 18 (20), pg. 652
- 19 (20), pg. 335
- 20 (10), pp. 572-573
- 21 (25), pg. 43

22 IBID, pg. 2  
23 IBID, pg. 4  
24 IBID, pg. 60  
25 IBID, pg. 60  
26 (26), pg. 32  
27 (21), pg. 5  
28 (8), pg. 107  
29 (10), pg. 735  
30 (8), pg. 107  
31 (10), pg. 50  
32 (26), pg. 36 Note figure on pg. 36 does not include  
working inventory of 7 MMSWU.  
33 (13), pg. 27  
34 (24)  
35 (12)  
36 (21), pg. 15  
37 (21), pg. 9  
38 For more on the pitfalls of preproduction stockpile  
measurement see Essay #3. Appendix I  
39 (30), pg. 522  
40 (28), pg. 105  
41 IBID, pg. 107  
42 IBID, pp. 2-3  
43 IBID, pg. 5

- 44 IBID, pg. 12
- 45 (29), pg. 4
- 46 (20), pg. 46
- 47 IBID, pp. 362-364
- 48 IBID, pg. 340
- 49 (18), pg. 169
- 50 IBID , pp. 457-466
- 51 IBID, pg. 458
- 52 IBID, pg. 269 and pg. 458
- 53 IBID, pg. 465
- 54 (12), pg. 450 and  
(23), pg. 8
- 55 IBID, pg. 8
- 56 (29), pp. 40-41
- 57 (20), pg. 265
- 58 IBID, pg. 267
- 59 (15), pg. 12
- 60 (31), pg. 553
- 61 (15), pg. 12
- 62 (20), pg. 14
- 63 (28), pg. 111
- 64 (29), pg. 31
- 65 (20), pg. 466
- 66 (29), pg. 78

67 (5),  
68 (20), pg. 466  
69 IBID, pg. 473  
70 Compare (29), pg. 72 and (5)  
71 In performing this mock regulatory calculation the  
DOE rate base was defined as:  
rate base = diffusion plants + CIP/CUP + investment  
in preproduction inventory + working capital + GCP  
construction work in progress  
72 (2)  
73 (22)  
74 (1). This does not challenge the use of a risk-free  
discount rate for life insurance corporations  
because to a first approximation the probability of  
death is uncorrelated with stock market fluctuations.  
75 (6).  
76 (23), pg. 8, 10  
77 (4), pp. 10-12  
78 (7), pp. 13-17  
79 Because the UEA pricing calculation uses current  
costs of debt and equity capital, as well as current  
investment costs, the UEA price is a good estimate  
of the marginal social opportunity cost (or its  
practical equivalent, the long-run marginal cost:  
see Kahn (14), pg. 85), of enrichment services with

one glaring exception--the price of electric power, a major determinant of SWU costs. The UEA calculation uses a power price of 12 mills/KWH, which equals the estimated transactions price between the electric utility supplier and UEA. Because this transactions price is calculated via a regulatory price formula which uses a historical cost rate base and a historical embedded debt cost, it substantially underestimates the opportunity cost of electric power. To crudely approximate the size of this underestimation, we adopt the Ford-MITRE 1976 estimate of the minimal long-run marginal cost of nuclear power as 40 mills/Kwh; ((17), pg. 126). This selection is reasonable in view of the fact that the operation of the UEA facility would necessitate the commissioning of additional base-load nuclear generating capacity in Alabama. Substituting this 40 mills/Kwh figure into the UEA calculation, appropriately deflated by 7%, yields a long run marginal cost estimate of \$150/SWU in 1975 dollars, which equals \$185/SWU in 1978 dollars. We reiterate that the difference of more than \$100/SWU between this price and the AEC base price is a moot point, because utility price regulation guarantees that no private enricher will have to pay the full opportunity cost of his power demand.

80 (23), pg. 10 estimates cost inflation at 7%/yr.  
81 (33), pg. 22  
82 (32), pg. 8  
83 Implicit GNP price deflator equals 62.9 for 1956 and  
82.6 for 1968 (1972 = 100)  
84 (20), pg. 678  
85 (10), pg. 904  
86 Assertion based on private conversations with DOE  
pricing officials during 1977.  
87 (20), pp. 339-340  
88 (20), pg. 553  
89 (10), pp. 798-799, 804-807  
90 (28), pg. 60  
91 (20), pg. 804  
92 IBID  
93 (32), pg. 15  
94 IBID, pp. 17-19  
95 (18), pp. 520-521  
96 IBID  
97 IBID  
98 (32), pg. 3  
99 (32), pg. 11  
100 IBID, pg. 25  
101 IBID, pp. 30-32

- 102 (20), pg. 53
- 103 IBID, pg. 71
- 104 IBID
- 105 IBID, pg. 75
- 106 (20), pg. 83
- 107 IBID, pg. 139
- 108 IBID, pp. 403-407
- 109 IBID, pg. 122
- 110 IBID, pg. 123
- 111 IBID
- 112 IBID, pp. 170-171, 132
- 113 IBID, pg. 171
- 114 (32), pg. 33
- 115 (4), pp. 10-12
- 116 (13), pp. 422-424
- 117 IBID, pg. 162
- 118 (8), pg. 81
- 119 IBID, pg. 82
- 120 (10), pg. 423
- 121 IBID, pg. 431
- 122 IBID, pg. 430
- 123 IBID, pg. 431
- 124 IBID
- 125 IBID, pg. 432

126 IBID  
127 (32), pg. 33  
128 (28), pg. 12  
129 IBID  
130 IBID  
131 (20), pg. 16  
132 (8), pg. 120  
133 (10), pg. 6  
134 (10), pg. 568  
135 IBID, pg. 567  
136 (32), pg. 60  
137 (10), pg. 1203  
138 IBID  
139 IBID, pg. 234  
140 IBID, pg. 343  
141 IBID, pg. 241, 343  
142 IBID, pg. 238, 343  
143 IBID, pg. 235  
144 IBID, pg. 243  
145 IBID, pg. 516  
146 (32), pg. 60  
147 (10), pg. 520  
148 (32), pg. 60  
149 (10), pg. 226



- 150 (32), pg. 60
- 151 (10), pg. 538
- 152 IBID, pg. 733
- 153 IBID, pg. 557
- 154 (10), pg. 556
- 155 IBID, pg. 449
- 156 (10), pg. 292 and (18), pg. 542
- 157 (32), pg. 61
- 158 (10), pg. 306
- 159 (29), pg. 21
- 160 (10), pg. 520
- 161 (8), pp. 148-152 and (5), pg. 227
- 162 (19), pp. 2-5
- 163 IBID, pg. 6
- 164 IBID, pg. 7

## ESSAY #2

### REFERENCES

1. Bailey, M.J. and Jensen, M.C. "Risk and the Discount Rate for Public Investment" reprinted in M.C. Jensen (ed.) Studies in the Theory of Capital Markets. Praeger, London, 1972.
2. Baumol, W. J. "On the Discount Rate for Public Projects" reprinted in R.H. Haveman and J. Margolis, Public Expenditures and Policy Analysis. Markham, 1970
3. Cyert, R. and March, J. A Behavioral Theory of the Firm. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1963.
4. "DOE Compares Enrichment Supplier Contract Terms and Conditions." Nuclear Fuel May 24, 1978, pp. 10-12.
5. Department of Energy, "DOE Quarterly Report on Capacity Expansion of the Gaseous Diffusion Plants." June, 1978.
6. Dyckman, Thomas R., Downes, David H., and Mager, Robert P. Efficient Capital Markets and Account: A Critical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J. 1975.
7. Electro Nucleonics, Inc., Tennessee Valley Authority, Burns and ROE Industrial Services Corp., A Feasibility Study of Gas Centrifuge Enrichment Facilities: Unclassified Executive Summary. September, 1975.
8. Future Structure of the Uranium Enrichment Industry Hearings before the Joint Committee on Atomic Energy, Phase I; July 31 and August 1, 1973.
9. Future Structure of the Uranium Enrichment Industry Hearings before the Joint Committee on Atomic Energy, Phase II; October 2, 3 and 4, 1973.
10. Future Structure of the Uranium Enrichment Industry Hearings before the Joint Committee on Atomic Energy, Phase III; June 25, 26 and 27; July 16, 17, 18, 30, 31; August 6; November 26; and December 3, 1974. Two volumes.
11. Hatch, D. E. and Levin, S. A. "Enriched-Uranium Production Planning." Nuclear Applications and Technology. Vol. 7. July, 1969, pp 44-54.

12. "Industry Fumes Over Delay In Uranium Enrichment,"  
Energy Daily May 11, 1978, Volume 6, No. 92. pp. 1-3.
13. Jacoby, Henry D. "Uranium Dependence and the  
Proliferation Problem" Technology Review, Vol. 79, No. 7.  
June, 1977, pp. 18-29.
14. Kahn, Alfred E. The Economics of Regulation, Volume I.  
John Wiley & Sons, Inc., New York, NY, 1970.
15. Moore, Thomas Gale. Uranium Enrichment and Public  
Policy. American Enterprise Institute for Public Policy  
Research, Washington, D.C., 1978.
16. Mullenbach, Phillip. Civilian Nuclear Power.  
Twentieth Century Fund, New York, NY, 1963. pp 71-73,  
166-175.
17. Nuclear Energy Policy Study Group. Nuclear Power  
Issues and Choices. Ballinger Publishing Company,  
Cambridge, Mass. 1977.
18. Nuclear Fuel Assurance Act of 1975. Hearings before  
the Joint Committee on Atomic Energy, December 2, 3, 4, 9  
and 10, 1975.
19. Nuclear Fuel Assurance Act of 1975. Hearings before  
the Joint Committee on Atomic Energy. Part 2. February 6,  
March 23, April 6 and 7, 1976.
20. Proposed Changes in AEC Contract Arrangements for  
Uranium Enriching Services. Hearings before the  
Subcommittee on Energy of the Joint Committee on Atomic  
Energy. March 7, 8, 26; and April 18, 1973.
21. Schwennesen, Jarvis L. "Uranium Enrichment Policies".  
Compiled in Proceedings of 1977 Grand Junction Uranium  
Conference. Department of Energy, Washington D.C. October,  
1977.
22. Sharpe, William F. Portfolio Theory and Capital  
Markets. McGraw-Hill, New York, NY, 1970.
23. SWUCO Report No. 9, October 1, 1977.
24. "TVA Loses a Third of its Capacity", Energy  
Daily. December 12, 1977, Volume 5, No. 238 pg. 1.
25. United States Energy Research and Development  
Administration, Uranium Enrichment Conference, Oak Ridge,  
Tennessee, February 13 & 14, 1975. Conf-750209.

26. United States Energy Research and Development  
Administration, Uranium Enrichment Conference, Oak Ridge,  
Tennessee, November 11, 1975. Conf-751134.
27. United States Energy Research and Development  
Administration "Survey of United States Uranium Marketing  
Activity." May, 1977. ERDA 77-46.
28. Uranium Enrichment Pricing Criteria. Hearings before  
the Joint Committee on Atomic Energy. June 16 and 17, 1970.
29. Uranium Enrichment Pricing Criteria. Hearings before  
the Joint Committee on Atomic Energy. Part 2. February 25,  
1971.
30. Uranium Enrichment Pricing Criteria and Related Matters  
Hearings before the Joint Committee on Atomic Energy.  
August 2, 3, 4, 16 and 17, 1966.
31. Wilcox, Clair. Public Policies Toward Business. Fourth  
Edition. Richard D. Irwin, Inc. Homewood, IL 1971.
32. Wonder, Edward F. Nuclear Fuel and American Foreign  
Policy. Westview Press, Boulder, Colo. 1977.
33. Wonder, Edward F. "On Comparing Nuclear Export  
Policies: Seeking the Determinants of International  
Control." Prepared for delivery at the 1977 Annual Meeting  
of the American Political Science Association. Washington,  
D.C., September, 1977.

ESSAY #3:

A CRITIQUE OF A MEDIUM-TERM NUCLEAR FUEL BANK  
PROPOSAL

1.0 INTRODUCTION

The following press release summarizes the remarks by President Carter at the opening of the INFCE Conference (see Essay #1, Section 2.4.3) in Washington during October, 1977:

"President Carter called yesterday for the creation of an international nuclear fuel bank as one means of discouraging the spread of technology that can be used to fashion nuclear weapons.

The President's proposal would be an attempt to assure a worldwide supply of nuclear fuels and thus reduce pressure on other nations to develop their own advanced nuclear technology, which might lead to the production of nuclear weapons.

Addressing the opening of a three-day nuclear fuel cycle conference at the State Department, Carter said the United States would be willing to contribute "our own technical ability and our own portion of the enriched uranium supplies" to such an international fuel bank.

The proposal was the Administration's latest step in an effort to halt the spread of nuclear weapons."<sup>1</sup>

This fuel bank proposal is part of the Administration's three-tiered plan for improving enrichment supply assurance, as contemplated by the Nuclear Non-Proliferation Act of 1978 (see Essay #1, Section 2.4.4):

- (1) "The first tier deals with steps the U.S. can take independently to re-establish its credibility as a reliable

supplier of enrichment services."<sup>2</sup> These steps include the re-opening of the U.S. enrichment contract order books, closed since mid-1974, and the expansion of DOE's enrichment capacity by building the Portsmouth centrifuge plant.

- (2) "The second tier of our approach will be to promote strengthened cooperation on the multilateral level to improve existing fuel assurance arrangements."<sup>3</sup>
- (3) "The 'third tier' is envisioned as an instrument for enhancing the credibility of both unilateral and bilateral contractual terms and conditions governing uranium feed and enrichment supply."<sup>4</sup>

This rather tortured language about the "third tier" of assurance is generally taken to refer to a stockpile, also known as a fuel bank, as proposed in President Carter's remarks.

Our purpose in this third essay is to analyze one variant of this fuel bank proposal aimed at providing supply assurance during the next 5-30 year period (which we refer to as the medium term). The essay shall begin by stepping back to explain the broad logic of the fuel bank, before performing some simple calculations of the potential magnitude of such a bank and examining the details of a specific stockpiling proposal.

## 2.0 THE MOTIVATION FOR A MEDIUM-TERM FUEL BANK

As indicated in the previous press release, a nuclear fuel bank represents an attempt to satisfy prevailing concerns about supply assurance as a means of reducing the proliferation of nuclear weapons. This section of the essay offers a more precise definition of medium-term nuclear fuel assurance fears and the role of a fuel bank in alleviating these concerns.

### 2.1 A Definition of Medium-Term Assurance Fears

In seeking a definition of medium-term nuclear fuel assurance, we draw on a larger project on the topic of nuclear fuel assurance, of which the author is a member.<sup>5</sup> The research of this project summarizes medium-term assurance concerns as fears about supply access and stability during the next five to thirty year period (1983-2008). During this period consumer concerns center around the availability and sanctity of standard long-term contracts for uranium and enrichment services. Consumers are heard to voice the fear that they will be unable to get a contract. We interpret this to mean that they will be unable to get a contract at an acceptable political and economic cost.

This concern is clarified by considering various sorts of economic and non-economic costs. Economic costs include not merely

the price paid for the final product; advance payments, equity positions and bartered goods must be considered as elements of price. Political (non-economic) costs are much more difficult to measure. Examples of these costs include:

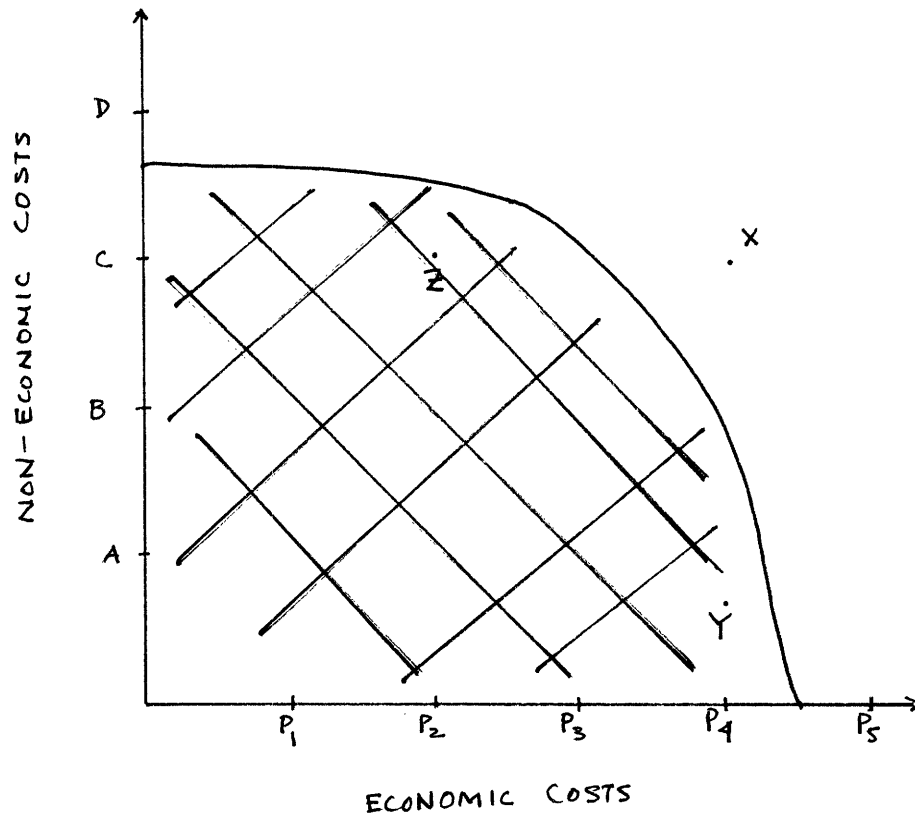
- (1) non proliferation standards--for example, an agreement to give the supplier unilateral veto power over the retransfer or reprocessing of spent reactor fuel;
- (2) dependence on political enemies--e.g. reliance on the U.S.S.R. as a major source of enrichment services;
- (3) exclusive dealing agreements--e.g. restrictions on the choice of trading partners imposed as part of a far-reaching nuclear pact, such as the Germany-Brazil treaty, which included German sales of reactors, enrichment and reprocessing technologies in return for preferential access to Brazilian uranium resources.<sup>6</sup>

Taken together, these two types of costs define a two-dimensional region of "contract acceptability" as shown in Figure 3. It should be emphasized that the shape of this curve is purely hypothetical and is chosen only for discussion purposes.



FIGURE 3

THE REGION OF ACCEPTABLE CONTRACTS



The abscissa of this graph represents economic costs, calibrated in dollars. The ordinate represents an ordinal ranking of non-economic costs corresponding to various future states of the world. The tradeoff between these two types of cost defines a boundary. Every point lying in the cross-hatched region represents an acceptable combination of economic and non-economic costs associated with a given contract, while every point outside the diagram represents an unacceptable contract.

The point labelled X, corresponding to a generalized contract price  $P_4$  and a political state of the world C, is an unacceptable contract. Notice however that if the political cost is lowered to State A, leaving price unchanged, the total contract moves from point X to point Y which lies within the range of acceptability. Similarly, if the contract price is reduced to  $P_2$ , leaving political costs unchanged, the contract moves from point X to point Z and becomes acceptable. Such a tradeoff is not always possible as indicated by observing that a price  $P_5$  is considered a prohibitive economic cost, irrespective of the political state of the world, while non-economic cost D is unacceptable, no matter what contract price is offered.

## 2.2 Two Polar Models of the Evolving Allocation System

In discussions with consumers expressing medium-term assurance

fears, the following model of the evolution of the world's nuclear fuel allocation system is revealed:

The World of Exclusive Dealing -- In this world, political relationships predominate. Nuclear fuel suppliers and consumers are constrained by an overlaid web of bilateral and multilateral national nuclear trade agreements, which bind buying and selling nations together, along the lines of the Germany-Brazil Treaty. What is important is not what price a buyer is willing to pay, but what supplier nations have reliable trade agreements with his host country.

Clearly a world of political exclusive dealing agreements would not effectively resolve assurance concerns. By its very nature, exclusive dealing implies an absence of supply diversity. Therefore, the extent to which a buyer's assurance fears are reduced by dependence on a single seller is a function of the strength of the political ties at the national level; even though contracts may be available, the sanctity of those contracts will always be open to doubts. In addition to these assurance fears which plague nations who participate in this web of political agreements, one must consider those nations (most likely developing countries) who are outside of this fabric. Because the vast majority of nuclear supply would be rigidly committed along politically negotiated lines, these residual nations will have only a very thin market in which to

purchase fuel cycle services. They are most certainly worse off in a world of exclusive dealing.

By contrast, consumers and suppliers who disparage the validity of medium-term assurance fears implicitly accept a polar model of the evolution of the nuclear fuel allocation system:

The World of Smoothly Functioning Markets -- In this world, price, not political ties, is the determining factor. International nuclear markets are filled with homogeneous, competing suppliers who are not encumbered by exclusive trade agreements or "most favored nation" preferences. Most sales are made under standard long-term contracts, although this mechanism is supplemented by the operation of a spot market. Price fluctuates narrowly around long-run marginal cost, and information about price and contract terms is widely disseminated, to permit potential buyers to make intelligent decisions.

In this second world, the presumption is that smoothly functioning nuclear markets will virtually eliminate medium-term assurance concerns, as for example happens in the international coal market, where standard long-term coal contracts are available from a variety of competing sellers at a well-defined price whose historical trajectory is fairly predictable and fairly closed linked to long run

marginal costs. This is not to say that coal buying utilities have no problems with fuel supply assurance. Our most recent domestic experience with striking coal miners revealed why most U.S. utilities maintain a 3-month stockpile of coal as insurance against short-term supply interruptions. Unlike nuclear utilities, however, coal utility buyers are rarely heard to voice concern about the impossibility of obtaining a long-term contract for coal delivery, because the availability of diverse, alternative sources of supply eliminates fears of contract nonavailability.

Therefore, the critical issue in analyzing the seriousness of consumer medium-term assurance fears is the extent to which smoothly functioning international nuclear markets will develop. The link between consumer assurance fears and supplier concerns comes through nuclear weapons proliferation. In the name of fuel assurance, a variety of nations are pursuing a series of actions which increase the risk of nuclear weapons proliferation, and this increased risk imposes an external cost on the world at large. Some of the events which have substantial proliferation overtones, and which are at least partially justified by fuel assurance arguments, include:

- (1) the acquisition or sale of domestic enrichment capacity, as a means of reducing sole dependence on the U.S. as a source of enrichment services (Germany-Brazil, URENCO, EURODIF, UCOR, PNC);

- (2) the acquisition or sale of domestic reprocessing capacity, as a means of extending the uranium resource base, and diversifying the sources of uranium supply (Germany-Brazil, France-Pakistan);
- (3) the pursuit of breeder R&D as an expansion of the resource base (France, Germany, U.K., U.S.S.R., Japan).

### 2.3 Trends

These two polar models of the evolving allocation system reflect the political-market tensions identified in essay #1. Furthermore, the difficulty in identifying whether the current trend is in the direction of a market system or an exclusive dealing system is aggravated by the prevailing uncertainties noted in essay #1. As described in our first essay there have been some incidents (e.g. the Canadian and Australian embargoes, and the closing of the U.S. order books) which have heightened consumers' medium-term assurance fears. Some consumers have reacted to these assurance concerns by trying to achieve supply assurance by negotiating exclusive dealing arrangements.

The German-Brazilian Treaty is the leading example of a movement towards a world of exclusive dealing. Subject to this \$4 billion agreement, Germany will transfer enrichment and reprocessing

technology to Brazil, in return for which Brazil will purchase two German reactors, take an option on six more, and give Germany preferential treatment regarding purchase of Brazilian uranium. In effect Brazil will receive the means for eventual energy self-sufficiency while Germany will create a market for reactor exports and acquire a captive uranium supply.<sup>7</sup> Both parties to this agreement have argued that it was necessitated by the need to achieve independence from the insecurities in the uranium and enrichment markets.<sup>8</sup>

On the other hand, there are other less obvious indications that the market system is attempting to function to allocate risks through the contracting process. DOE is in the process of proposing the AFC enrichment contract which will allow the customer more scheduling flexibility than the LTFC contract, thereby sharing some of the risks of slippages in reactor demand. Uranium contracting has created a series of utility-mining company joint ventures aimed at sharing the risks of uranium exploration and production. Utilities and national governments have begun to accumulate stockpiles of natural and/or enriched uranium as an assurance measure. EURODIF and URENCO are examples of enrichment consortia which offer a guaranteed percentage of the consortium's output in return for equity participation. Similarly there exists substantial supranational investment in foreign mining operations as a means of guaranteeing supply and reducing the risk of expropriation.

## 2.4 The Role of a Medium-Term Fuel Bank

In sum, the role of a medium-term fuel bank is to reduce the perceived degree of political control over the nuclear marketplace by offering an alternative to reliance on a few national suppliers who have proven unreliable in the past and whose future policies are still highly uncertain. Presumably, this attempt to "take the politics out of nuclear fuel" will restore international confidence in the international nuclear market system, thereby reducing the incentives both for the negotiation of exclusive deals, which frustrate the ability of the market to provide supply assurance, and for the assurance-motivated pursuit of proliferation-prone technologies.



### 3.0 THE MARKET ENVIRONMENT WITHOUT A MEDIUM-TERM FUEL BANK

Section 2.0 of this essay has outlined what might be loosely referred to as the theoretical basis for a medium-term fuel bank. As described there, the notion certainly makes logical sense. To appreciate the actual impacts of such a fuel bank, however, one must understand the status quo market situation with which the fuel bank is to be compared. The description of this baseline alternative is the purpose of this third section of the essay. Using some simple international stockpile forecasts we shall demonstrate that the operation of the enrichment market, without the addition of a fuel bank, will result in the accumulation of large, geographically disperse stockpiles of enriched fuel during the next decade which should substantially mitigate medium-term assurance concerns.

#### 3.1 Stockpile Forecasts

In this section of the essay we shall use publicly available data on enrichment supply and demand to compute a base case aggregate stockpile forecast which indicates the cumulative excess enrichment capacity available for private or public stockpiling from now through 1990, and we shall test the sensitivity of our estimates to variations in our input assumptions. Lastly we shall comment on how these estimates relate to any medium-term fuel bank proposal. Next using data on enrichment contract deliveries we shall estimate how

this aggregate stockpile is likely to be allocated between suppliers and consumers in five geographic regions of the Non-Communist World--U.S., EURODIF nations, URENCO nations, Japan, and Other nations.

### 3.1.1 Demand Projections

In order to compute stockpile forecasts, we require, as one input, the demand for nuclear-generated electricity, in terms of annual forecasts of GWE installed capacity by region and by reactor type. For our demand forecasts we have chosen to use the most recent OECD projections, published in December, 1977, as given in Table 16.

Table 16 estimates reflect the substantial slippage in reactor installations in recent years. The OECD world estimate for the year 2000 is now 1,000 GWE nuclear, which is one-half of the "low" estimate of 2,005 GWE reported in the 1975 version of this report. In addition these estimates are significantly lower than the official estimates of many countries; assuming the realization of the ambitious goals of official national nuclear programs would yield an installed world nuclear capacity of 1890 GWE by the year 2000.

Even with these drastic reductions in capacity forecasts, the OECD/IAEA estimates are likely to remain upward biased. This bias is the result of all the problems in demand estimation cited in essay

TABLE 16

OECD/IAEA FORECAST OF NON-COMMUNIST WORLD  
 INSTALLED LWR NUCLEAR CAPACITY (GWE)<sup>9</sup>

<u>END OF CALENDAR YEAR</u>	<u>USA</u>	<u>EURODIF1 NATIONS</u>	<u>URENCO2 NATIONS</u>	<u>JAPAN</u>	<u>OTHER</u>	<u>TOTAL</u>
1977	48	5	10	8	6	77
1978	50	9	13	12	10	94
1979	55	16	18	13	12	114
1980	60	23	20	15	15	133
1981	68	28	22	17	17	152
1982	77	35	24	19	19	174
1983	88	43	26	22	20	199
1984	101	49	30	24	24	228
1985	115	57	33	27	27	259
1986	130	66	37	31	32	296
1987	146	77	46	35	35	339
1988	162	88	51	39	41	381
1989	178	100	57	44	48	427
1990	194	111	62	50	53	470

SOURCE: OECD and IAEA, "Uranium: Resources, Production, and Demand", December 1977. Derived from Table 8, page 28, and Table 9, page 31.

- 1 France, Spain, Italy, Belgium and Iran
- 2 United Kingdom, West Germany, Netherlands

#1. This upward bias is confirmed by comparing the OECD/IAEA estimates with the most recent independent DOE, and IEA estimates, as done in Table 17. Nevertheless, we have chosen to use the OECD/IAEA estimates because they are the most recent publicly available data series which is disaggregated both by region and by reactor type. Due to the likely residual bias we shall interpret these demand data as providing an upper bound on demand.

Assuming a tails assay of 0.25%, a steady state reactor load factor of 65%, and no uranium or plutonium recycling, one can convert the GWE forecasts of Table 16 into the SWU demand forecasts shown in Table 18.

### 3.1.2 Supply Projections

Similar to the demand side of the market, there are problems in forecasting the supply of commercial enrichment services that serve as the second major input into the stockpile simulations. Just as official national demand forecasts have consistently overestimated reactor installations, there is a tendency for SWU suppliers to overstate the size of their capacity expansion forecasts, and to understate the delays inherent in operationalizing capacity additions. This overstatement is motivated by commercial gamesmanship, national prestige, and engineering optimism. An example of the sorts of delays that have been experienced is offered

TABLE 17

COMPARISON OF WORLD LWR CAPACITY ESTIMATES

	<u>1990</u>	<u>2000</u>
OECD/IAEA	504	1,000
DOE <span style="display: inline-block; vertical-align: middle; font-size: 1.2em;">{</span> "Low"	405	915
DOE <span style="display: inline-block; vertical-align: middle; font-size: 1.2em;">{</span> "Base"	420	1,012
IEA	410	960

TABLE 18

FORECASTS OF ENRICHMENT DEMAND  
 DERIVED FROM OECD/IAEA GWE FORECASTS (MMSWU)10

<u>YEAR</u>	<u>USA</u>	<u>EURODIF NATIONS</u>	<u>URENCO NATIONS</u>	<u>JAPAN</u>	<u>OTHER NATIONS</u>	<u>TOTAL</u>
1977	4.7	1.2	1.5	1.5	1.4	10.3
1978	5.7	2.3	2.3	1.3	1.3	12.9
1979	6.1	3.0	2.0	1.6	1.7	14.4
1980	7.2	3.2	2.2	1.8	1.8	16.2
1981	8.1	4.0	2.4	1.9	1.9	18.3
1982	9.3	4.9	2.6	2.3	1.9	21.0
1983	10.8	5.2	3.2	2.4	2.6	24.2
1984	12.2	6.2	3.3	2.8	2.8	27.3
1985	13.7	7.1	3.8	3.2	3.4	31.2
1986	15.2	8.3	5.3	3.6	3.5	35.9
1987	16.7	9.3	5.3	4.0	4.5	39.8
1988	18.2	10.6	5.9	4.7	5.2	44.6
1989	19.6	11.4	6.3	5.3	5.4	48.0
1990	<u>21.0</u>	<u>12.4</u>	<u>6.7</u>	<u>5.9</u>	<u>5.8</u>	<u>51.8</u>
TOTAL	168.5	89.1	52.8	42.3	43.2	395.9

- \* No recycling
- \* 0.25% tails assay
- \* 65% equilibrium load factor
- \* GWE data from Table 16

by the U.S. experience in the construction of 9 MMSWU of additional enrichment capacity. Originally scheduled for completion as a privately owned Alabama-located gaseous diffusion plant in 1983, the incremental SWU capacity is now scheduled as a government owned, Portsmouth, Ohio, centrifuge facility to be completed by 1988. Given that the completion date is 10 years away, and contracts for much of the construction have not yet been let, even this 1988 completion date may be hopelessly optimistic.<sup>11</sup>

Once again, we rely on the publicly stated capacity expansion plans of current and potential SWU suppliers. Even here, however, it is possible to draw distinctions between the degree of firmness associated with different capacity expansion plans based on a careful monitoring of the nuclear trade literature and discussions with veteran nuclear market participants.

The firm category of enrichment supply includes the most recent publicly announced expansion plans of DOE, EURODIF, URENCO, and TECHNABSEXPORT (U.S.S.R.). DOE's plan to expand the current (1977) domestic SWU capacity of 17 MMSWU has three components:

(1) The Cascade Improvement Program (CIP), currently ongoing at the three government-owned enrichment facilities at Oak Ridge, Tennessee, Paducah, Kentucky, and Portsmouth, Ohio. Initiated in 1973, CIP is intended to implement technological improvements in

existing diffusion barriers and pumping units, which will increase the total SWU capacity by 5.7 MMSWU at a cost of \$320 MM. With the exception of a 15 - week strike at Portsmouth, CIP is on schedule and is targeted for completion in 1982; it is presently 60% completed.

12

(2) The Cascade Upgrading Program (CUP), also currently ongoing. Unlike CIP, which modifies existing equipment to improve its efficiency without adding new barriers or requiring more power inputs, CUP is designed to add additional barriers to the diffusion complex which will increase the total SWU capacity by 4.8 MMSWU. Initiated in 1975, with a total cost of \$250 MM, CUP is currently on schedule and is targeted for completion in 1985; it is presently 60% complete. The upgrading of the 4140 CUP stages will require increasing the power input into the diffusion complex from 6100 MWE to 7400 MWE. Power contracts have been signed <sup>for</sup> 100% of the additional 1300 MWE.

(3) The Portsmouth gas centrifuge plant (GCP), currently in the contract-letting stages for planning and design. The current schedule calls for construction to begin during 1979, with the 8.8 MMSWU capacity coming on line as shown in Table 19.13



Because the centrifuge process is so much less energy-intensive than the diffusion process, only 100 MWE will be required to operate the GCP; this power is currently under contract.

The combined effect of these three programs is to increase DOE's SWU capacity as shown in Table 19. This rated capacity assumes that all firm power is delivered as contracted; although DOE holds interruptible power contracts, no interruptible power deliveries are assumed.

EURODIF is a multinational consortium headed by France (43%), including Spain (11%), Italy (25%), Belgium (11%) and Iran (10%). The French Government supplies the gaseous diffusion technology and operating skills, while the other partners supply equity investment. The non-French partners do not share in the development of the technology or the operating decisions; in return for their capital funds these other partners are guaranteed a percentage of the enriched output proportional to their equity holdings, and likewise are able to vote their shares on marketing decisions such as contract terms and pricing. EURODIF is presently building a gaseous diffusion enrichment plant at Tricastin, France; commercial sales are scheduled to commence in 1979, with the full scale production level of 10.8 MMSWU being reached by 1982. Total engineering, plant and equipment costs are estimated at \$10.7 billion (1975 dollars), and construction, initiated in 1974, is currently on the schedule

TABLE 19

## DOE ENRICHMENT CAPACITY

<u>END OF CALENDAR YEAR</u>	<u>BASE PLANT</u>	<u>CIP</u>	<u>CUP</u>	<u>GCP</u>	<u>TOTAL</u>
1977	14.4	2.3	1.9	--	18.7
1978	14.0	3.6	3.1	--	20.7
1979	13.9	4.7	3.9	--	22.5
1980	13.2	5.5	4.5	--	23.2
1981	13.0	5.7	4.8	--	23.5
1982	13.0	5.7	4.8	--	23.5
1983	14.5	5.7	4.8	--	25.0
1984	16.5	5.7	4.8	--	27.0
1985	17.5	5.7	4.8	--	28.0
1986	18.5	5.7	4.8	1.2	30.2
1987	18.4	5.7	4.8	4.1	33.0
1988	18.0	5.7	4.8	7.2	35.7
1989	17.2	5.7	4.8	8.8	36.5
1990	<u>17.2</u>	<u>5.7</u>	<u>4.8</u>	<u>8.8</u>	<u>36.5</u>
TOTAL	219.3	73.2	61.4	30.1	384.0

SOURCES: (4), and DOE Power Contracts

reflected in Table 20. This capacity may be considered firm as almost 95% of EURODIF's SWU capacity is under contract, and the balance is being aggressively marketed worldwide.

URENCO is also a multinational consortium comprised of the United Kingdom (1/3), West Germany (1/3), and the Netherlands (1/3). The organization of URENCO is more complicated than that of EURODIF, because in the URENCO consortium the three partners share in the development and operation of the enrichment technology, as well as the marketing of the enriched product; this structure is described in detail by Allday (1).

Two URENCO enrichment plants are now operating, and their first commercial contract deliveries were made during 1977; they are due to be expanded to 2.1 MMSWU by 1982, in accordance with the schedule shown in Table 20. This expansion may be considered firm, as roughly 75% of the cumulative production is under contract and the balance is being offered for sale worldwide. Although we consider the size of this expansion as firm, the location of this expansion is as yet undetermined, and the timing of the expansion may be delayed as much as three years.

TABLE 20

## FIRM FOREIGN ENRICHMENT CAPACITY

END OF <u>CALENDAR YEAR</u>	<u>EURODIF</u>	<u>URENCO</u>	<u>USSR</u>	<u>TOTAL</u>
1977	-	0.2	2.1	2.3
1978	--	0.4	2.0	2.4
1979	2.6	0.8	3.4	6.8
1980	6.3	1.2	3.4	10.9
1981	8.4	1.6	3.4	13.4
1982	10.8	2.1	3.0	15.9
1983	10.8	2.1	3.6	16.5
1984	10.8	2.1	2.6	15.5
1985	10.8	2.1	2.7	15.6
1986	10.8	2.1	2.6	15.5
1987	10.8	2.1	3.1	16.0
1988	10.8	2.1	3.1	16.0
1989	10.8	2.1	2.5	15.4
1990	<u>10.8</u>	<u>2.1</u>	<u>2.5</u>	<u>15.4</u>
TOTAL	114.5	23.1	40.0	177.6

SOURCES: (2), pg. 11 modified to eliminate URENCO expansion beyond 2.1 MMSWU.  
USSR data based on DOE estimates of contracts as reported by Newman (9).

Little hard data are available regarding the commercial enrichment plans of the Soviet supplier, TECHNABSEXPORT. Unconfirmed reports have estimated U.S.S.R. enrichment capacity to be about 7 - 10 MMSWU, of which 4 - 7 MMSWU could conceivably be available for civilian nuclear power programs. As a rule of thumb, the U.S.S.R. offers about 3 MMSWU per year to the Non-Communist World market. This capacity may be considered firm, as TECHNABSEXPORT has committed 90% of this cumulative capacity under contracts with West Germany, France, Italy, Sweden, Austria, Belgium, Finland, Great Britain, and Spain, and is contacting utilities in nations such as Australia, the United States, and Japan for the purpose of additional sales.<sup>15</sup> Table 20 estimates of U.S.S.R. capacity are derived directly from U.S.S.R. contracts data reported by Newman (9).

In addition to this firm foreign SWU capacity, three SWU sellers have announced future expansion plans which we have classified as potential capacity. The first of these sellers is COREDIF, a multinational consortium created by the EURODIF participants, with the following ownership structure:

EURODIF	51%
Iran	20%
France	29%

COREDIF was organized in May, 1975, and is contemplating the construction of 10.8 MMSWU of gaseous diffusion enrichment capacity by 1989. The COREDIF facility will only enrich fuel to 1.3%, with

the balance of the enrichment done by EURODIF. The COREDIF site has not yet been chosen, but France, Belgium, or Italy, are all candidate locations. Financing of the \$2.2 billion plant will not be sought, nor any contracts offered, until engineering studies have been completed. Current expansion plans are catalogued in Table 21. COREDIF's shareholders have already spoken for 4 MMSWU of the 5.4 MMSWU capacity planned for 1985; the subsequent expansion to 10 MMSWU by 1989 will be a function of market response, particularly from U.S. utilities.<sup>16</sup>

URENCO has also announced enrichment capacity expansion plans, although their current reading of the market is much different from COREDIF's optimistic assessment which forecasts a shortfall of worldwide enrichment capacity in the mid-1980's. Originally, URENCO planned to have 10 MMSWU of enrichment capacity operational by 1985, yet their recent market experience has failed to support these expectations and URENCO is adjusting its schedule to delay the 10 MMSWU capacity until 1987 or 1988; this revised schedule is reproduced in Table 21.

A third potential source of commercial enrichment services is South Africa's Uranium Enrichment Corporation (UCOR). South Africa officially announced in 1975 that it intends to build a commercial SWU facility using its domestically developed stationary-wall centrifuge process. Currently UCOR is operating a centrifuge pilot

plant, and during 1978 it confirmed its plans for a commercial plant. Although no official public statement has been offered detailing the size and timing of the plant, unofficial South African sources estimate a 5 MMSWU facility will go on stream in 1986; this expansion plan is reflected in Table 21.

Beyond firm and potential foreign enrichment capacity, there are a series of proposed ventures that we have classified as "speculative" SWU sellers. The first of these is NUCLEBRAS, a joint venture of Brazil and West Germany created by the Brazil-Germany Treaty of 1975. Current plans are to build an 0.2 MMSWU demonstration plant in Brazil during the early 1980's using the German-supplied Becker nozzle technology. A successful pilot test will presumably be followed by a commercial enrichment plant, although the timing and size of such a facility remain unspecified. The pilot plant construction is proceeding very slowly, as Brazil appears to attach higher priority to other fuel cycle stages than enrichment.

Another speculative foreign enricher is the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC). PNC is planning to construct a gas centrifuge test plant with a capacity of 0.05 MMSWU in 1980. If successful, this test plant will be followed by a demonstration plant of roughly 0.5 MMSWU for completion during the late 1980's. Finally, plans call for the construction of a 4

TABLE 21

## POTENTIAL FOREIGN ENRICHMENT CAPACITY

<u>END OF CALENDAR YEAR</u>	<u>COREDIF</u>	<u>URENCO</u> <sup>1</sup>	<u>UCOR</u>	<u>TOTAL</u>
1977	--	--		
1978	--	--	--	
1979	--	--	--	
1980	--	--	--	
1981	--	--	--	
1982	--	--	--	
1983	1.8	1.3	--	3.1
1984	3.6	2.6	1.6	7.8
1985	5.4	4.0	3.2	12.6
1986	7.0	6.0	5.0	18.0
1987	8.0	8.0	5.0	21.0
1988	9.0	8.0	5.0	22.0
1989	10.0	8.0	5.0	23.0
1990	<u>10.0</u>	<u>8.0</u>	<u>5.0</u>	<u>23.0</u>
TOTAL	54.8	45.9	29.8	130.5

1 in addition to firm URENCO capacity listed in Table 20.

SOURCES: (2) pg. 11 and various issues of Nuclear Fuel



MMSWU commercial centrifuge plant from 1990 - 1995. Meanwhile, Japan has been actively seeking partnership in joint enrichment ventures, where Japanese financing can complement a partner's enrichment technology and uranium feed; these negotiations have been extensively pursued with Australia, which has developed its own version of the centrifuge technology, although no official agreement has yet been concluded.

Beyond these two speculative enrichment ventures, a host of other nations have evidenced an interest in pursuing a commercial enrichment technology. Even without Japanese participation, Australia has expressed confidence in its ability to build a commercial facility using its domestic technology. Although Canadian plans for a domestic plant as a joint venture with EURODIF are now in abeyance, this interest could revive if the market picks up. Portugal is conducting negotiations with Germany in an effort to create a nuclear pact modelled on the German-Brazilian agreement. Sweden has expressed interest in acquiring an established enrichment technology for use in a domestic enrichment plant. Other nations expressing interest in acquiring enrichment capability include India, Iran, and Zaire.

### 3.1.3 Aggregate Stockpile Forecast

Using the demand estimates of Table 18 and the firm supply estimates of Table 20, we can compute the worldwide cumulative excess

enrichment capacity potentially available for stockpiling programs. The results of this base case calculation are given in Table 22, measured both in:

(1) MMSWU--defined as the separative capacity used to create the stockpile, and,

(2) GWE-yrs.--defined as the amount of electrical energy that could be generated if the stockpiled fuel were used to reload standard LWRs.

Because the SWU is not a measure of physical output, but of thermodynamic potential (see essay #1, section 1.2) the physical size of any stockpile will be a function of the feed assay, tails assay, and product assay with which this separative capacity is used. Therefore, in quantifying stockpile size we have used both a measure of separative capacity available for stockpiling (MMSWU), and a measure of possible physical output (GWE-yrs.). For more on the pitfalls and intricacies of stockpile accounting, the interested reader is referred to Appendix I of this essay.

Table 22 includes the initial DOE stock of 21.5 MMSWU, as of 1/1/77, and the initial Japanese stock of 8.9 MMSWU, as of 1/1/77, created by the Japanese Advance Sale (JAS) during 1973. Under the terms of the JAS a group of Japanese utilities purchased part of the

TABLE 22

## WORLD BASE CASE STOCKPILE FORECAST

END OF CALENDAR YEAR	POTENTIAL WORLD STOCKS (MMSWU)	ANNUAL WORLD LWR DEMAND (MMSWU)	POTENTIAL WORLD STOCKS (GWE-YRS) <sup>1</sup>	INSTALLED WORLD LWR CAPACITY (GWE)
1977	38	10.3	418	77
1978	47	12.9	516	94
1979	60	14.4	659	114
1980	74	16.2	813	133
1981	90	18.3	989	152
1982	107	21.0	1176	174
1983	122	24.2	1341	199
1984	134	27.3	1472	228
1985	144	31.2	1582	259
1986	152	35.9	1670	296
1987	160	39.8	1758	339
1988	165	44.6	1813	381
1989	168	48.0	1846	427
1990	166	51.8	1824	470

<sup>1</sup> - converted at 91,000 SWU/GWE-YR. (See Appendix I)

\* no recycle

\* 0.25% tails assay

\* 65% equilibrium load factor

\* demand data from Table 18, supply data from Table 20

\* includes initial stocks (as of 1/1/77) of DOE = 21.5 MMSWU

JAS = 8.9 MMSWU

\* includes U.S. non-power SWU demand of 1.5 MMSWU/YR.

ERDA preproduction stockpile. The fuel from this advance purchase is held on-site at DOE production facilities, and is used to satisfy a portion of Japanese DOE enrichment contract deliveries. Table 22 assumes that the JAS stock is drawn down at the rate of 0.9 MMSWU per year over the 10-year period 1977 - 1986. Aside from these initial DOE and JAS stocks, no additional initial stockpiles are assumed to exist. Table 22 also reflects DOE's estimate of the U.S. non-power SWU demand of 1.5 MMSWU/yr., the great bulk of which is used to produce fuel for research reactors and naval submarines.

The calculation in Table 22 reveals that excess commercial enrichment capacity will prevail throughout the 1980's, thereby creating an opportunity for the construction of worldwide stockpiles able to satisfy between three and four years of forward demands. Of course the magnitude of these stocks is a function of our assumptions, but it is safe to say that the conclusion that enough excess enrichment capacity will exist to create gigantic stockpiles is a robust result. Table 23 indicates the sensitivity of the 1990 stockpile to changes in the input assumptions. Obviously our base case forecast is a conservative calculation because it uses an upper bound for demand and a lower bound for supply. Only a reduction in the tails assay, an increase in reactor operating efficiency, or a delay in expansion plans will sharply cut back the potential stockpile, while a number of events, including plausible further

TABLE 23

SENSITIVITY OF 1990 STOCKPILE TO INPUT ASSUMPTIONS

Base Case 1990 Stockpile = 166 MMSWU = 1824 GWE-YRS.

Changes in Demand:	<u>STOCK</u>
1. increase load factor to 70%	-16 MMSWU
2. decrease tails assay to 0.20%	-38 MMSWU
3. increase tails assay to 0.30%	+55 MMSWU
4. have demand slip 10%	+40 MMSWU
5. recycle uranium and plutonium beginning in 1985 <sup>1</sup>	+51 MMSWU

Changes in Supply:

1. delay Portsmouth past 2.2 MMSWU	-7 MMSWU
2. include potential foreign enrichers	+130 MMSWU
3. recycle entire DOE stockpile of 0.3% tails <sup>2</sup>	-32 GWE-YRS. <sup>3</sup>

1 assumes 20% SWU savings due to recycle (Nuclear Fuels Policy pg. 115). This is actually an upper bound.

2 DOE stockpile of 0.3% tails = 42,281 MT U as of 7/1/77.

3 Unlike the other sensitivity tests, tails recycle will have no effect on the size of the stock calibrated in SWUs, but it will reduce the physical mass of reactor fuel as calibrated in GWE-YRS. (See Appendix I).

slippage as well as entry by potential foreign enrichers, could increase the magnitude of the potential stock.

#### 3.1.4 Contracts Data

Given, therefore, that the potential for extensive worldwide stockpiles does indeed exist, we next inquire as to how these stocks are likely to be distributed across geographic regions in future years. Knowledge of the deliveries to be made under currently existing enrichment contracts provides the link that is required to disaggregate the worldwide stockpile by region.

DOE compiles data on U.S. and foreign enrichment contract deliveries based on Appendix A of its current enrichment contracts. Using these data, Table 24 calculates DOE's contractual commitments assuming an 0.25% operating tails assay and a 75% contract load factor. Recall that as discussed in essay #1, and as confirmed in conversations with DOE contract personnel in Oak Ridge, enrichment contract load factors significantly exceed expected load factor experience, which we earlier estimated at 65% for purposes of our aggregate stockpile calculation. Oak Ridge officials estimate that most SWU contract load factors are between 70% and 80%, therefore, we have chosen 75% as a representative load factor.

TABLE 24

## DOE ENRICHMENT CONTRACT DELIVERIES (MMSWU)

<u>CALENDAR YEAR</u>	<u>U.S. UTILITIES</u>	<u>EURODIF UTILITIES</u>	<u>URENCO UTILITIES</u>	<u>OTHER UTILITIES</u>	<u>JAPAN UTILITIES</u>	<u>TOTAL</u>
1977	6.5	1.0	0.9	1.3	1.6	11.3
1978	7.8	1.4	0.8	1.6	1.6	13.2
1979	9.6	1.4	1.0	1.8	1.9	15.7
1980	11.4	1.9	1.5	2.4	2.1	19.3
1981	13.2	1.8	1.9	3.3	1.9	22.1
1982	15.0	1.9	1.8	3.2	3.2	25.1
1983	17.5	2.0	1.7	3.7	4.6	29.5
1984	18.9	1.9	1.7	3.4	4.2	30.1
1985	20.7	1.9	1.6	3.4	5.2	32.8
1986	20.8	1.9	1.6	3.6	5.6	33.5
1987	22.1	1.9	1.6	3.5	5.0	34.1
1988	21.2	1.9	1.6	3.5	5.0	33.2
1989	21.9	1.9	1.6	3.5	5.0	33.9
1990	<u>21.5</u>	<u>1.9</u>	<u>1.6</u>	<u>3.5</u>	<u>5.0</u>	<u>33.5</u>
TOTAL	228.1	24.7	20.9	41.7	51.9	367.3

0.25% tails

75% contract load factor

SOURCE: DOE Enrichment Contract Appendices

Similarly, DOE uses a variety of sources to compile a data series for enrichment contract deliveries by foreign enrichers. Tables 25-27 provide these data for EURODIF, URENCO, and TECHNABSEXPORT contract deliveries.

### 3.1.5 Disaggregated Stockpile Forecasts

Using the demand, supply, and contract delivery data of Tables 18-20 and 24-27 we can compute the disaggregated base stockpile forecast given in Table 28 in MMSWU and plotted in Figure 4 in GWE-yrs. These results reveal that not only is there a worldwide aggregate cumulative excess enrichment capacity, but that there is excess capacity within each region. The allocation of the stockpile between utilities and enrichers within each region depends on whether current contract deliveries are actually made, or whether utilities get relief from their over-contracted position. To the extent that relief is granted some of the stocks will shift back to the enrichers, but in any event this contract relief will have no effect on the size of the aggregate potential stockpile; it merely determines who holds what portion of the potential stocks.

It is important to emphasize that these are potential stockpiles which are forecasted on the assumption that all of the available excess enrichment capacity is used for preproduction purposes. In view of the staggering magnitude of the stocks that accumulate from



TABLE 25

## EURODIF ENRICHMENT CONTRACT DELIVERIES (MMSWU)

	<u>JAPAN</u> <u>UTILITIES</u>	<u>URENCO</u> <u>UTILITIES</u>	<u>OTHER</u> <u>UTILITIES</u>	<u>EURODIF</u> <u>UTILITIES</u>	<u>TOTAL</u>
1977	--	--	--	--	--
1978	--	--	--	--	--
1979	--	--	--	2.8	2.8
1980	--	--	--	6.1	6.1
1981	1	0.2	0.1	7.1	8.4
1982	1	0.2	0.1	7.8	9.1
1983	1	0.2	0.1	8.6	9.9
1984	1	--	0.1	9.3	10.4
1985	1	--	0.1	9.6	10.7
1986	1	--	0.1	9.6	10.7
1987	1	--	0.1	9.6	10.7
1988	1	--	0.1	9.6	10.7
1989	1	--	0.1	9.6	10.7
1990	<u>1</u>	<u>--</u>	<u>0.1</u>	<u>8.5</u>	<u>9.6</u>
TOTAL	10.0	0.6	1.0	98.2	109.8

SOURCE: Estimates compiled by DOE Office of International Security Affairs

TABLE 26

## URENCO ENRICHMENT CONTRACT DELIVERIES (MMSWU)

	<u>OTHER UTILITIES</u>	<u>URENCO UTILITIES</u>	<u>TOTAL</u>
1977	--	0.3	0.3
1978	--	0.5	0.5
1979	--	1.1	1.1
1980	--	1.5	1.5
1981	0.1	1.8	1.9
1982	0.1	2.0	2.1
1983	0.2	1.9	2.1
1984	0.4	1.7	2.1
1985	0.4	1.7	2.1
1986	0.4	1.7	2.1
1987	0.4	1.7	2.1
1988	0.4	1.7	2.1
1989	0.4	1.7	2.1
1990	<u>0.4</u>	<u>1.7</u>	<u>2.1</u>
TOTAL	3.2	21.0	24.2

SOURCE: Estimates compiled by DOE Office of International Security Affairs

TABLE 27

## U.S.S.R. ENRICHMENT CONTRACT DELIVERIES (MTSWU)

	<u>EURODIF</u> <u>UTILITIES</u>	<u>URENCO</u> <u>UTILITIES</u>	<u>OTHER</u> <u>UTILITIES</u>	<u>TOTAL</u>
1974	230	170	0	400
1975	0	295	0	295
1976	98	262	0	360
1977	713	1,183	160	<u>2,056</u>
1978	748	702	620	2,070
1979	1,693	1,479	230	3,402
1980	2,208	1,131	70	3,409
1981	1,843	<u>1,273</u>	290	3,406
1982	1,573	1,115	290	2,978
1983	2,018	1,115	512	3,645
1984	1,195 <sup>1</sup>	1,115	292	2,602
1985	1,195 <sup>1</sup>	1,115	410	2,720
1986	1,125 <sup>1</sup>	1,115	410	2,650
1987	1,650 <sup>1</sup>	1,112 <sup>2</sup>	410	3,172
1988	1,650 <sup>1</sup>	1,112 <sup>2</sup>	410	3,172
1989	1,050	1,112 <sup>2</sup>	410	2,572
1990	<u>1,050</u>	<u>1,112<sup>2</sup></u>	<u>410</u>	<u>2,572</u>
TOTAL	20,039	16,518	4,924	41,481
	(3,000 Option)	(500 Option)		(3,500 Option)

1 = 600 on option

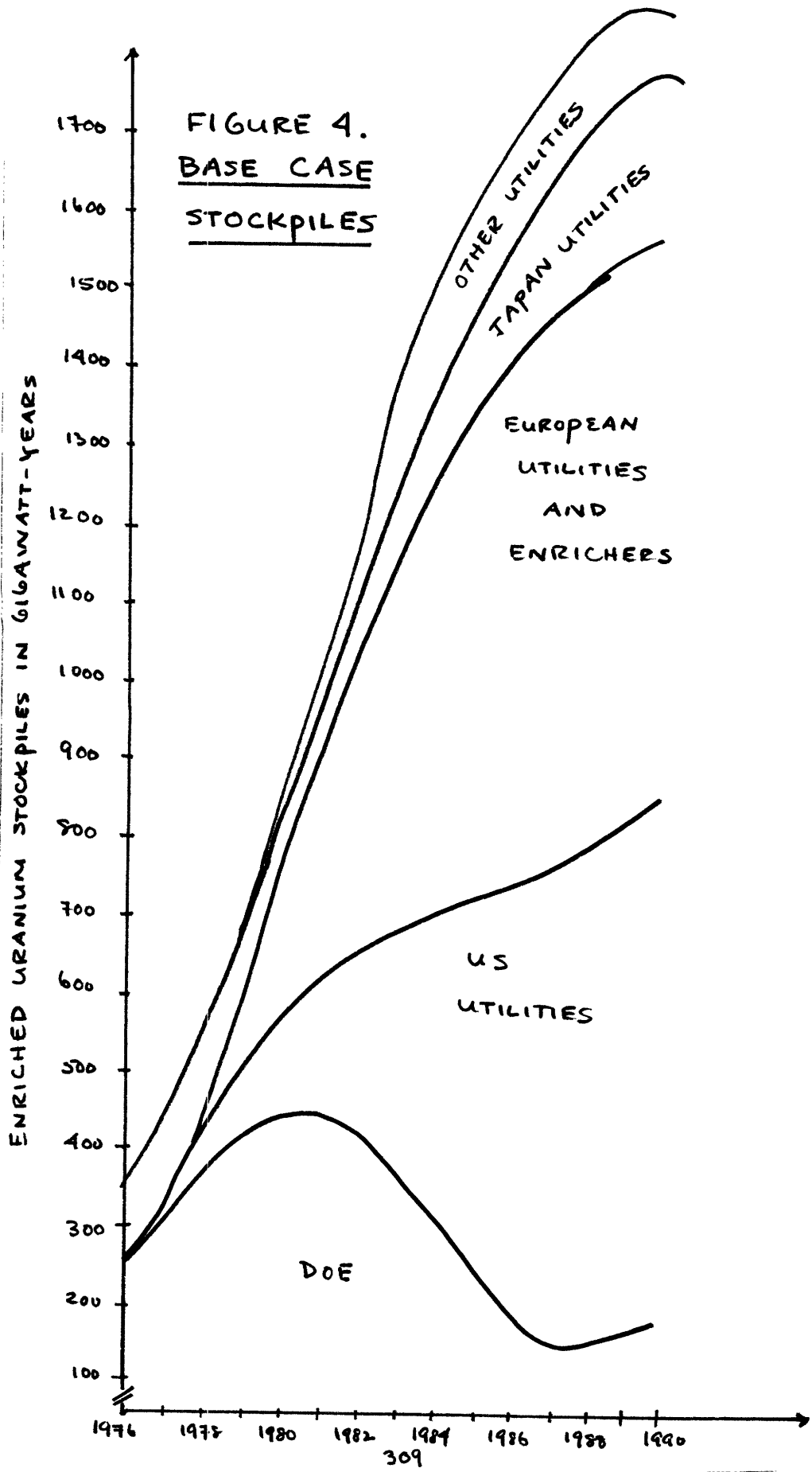
2 = 125 on option

Source: (8) pp. 76 - 77

TABLE 28  
DISAGGREGATED BASE CASE STOCKPILE FORECAST  
(MMSWU)

END OF CALENDAR YEAR	U.S. UTILITIES	DOE	EURODIF UTILITIES	EURODIF	URENCO UTILITIES	URENCO	JAPAN UTILITIES	OTHER UTILITIES	TOTAL
1976	--	21.5	--	--	--	--	8.9	--	30.4
1977	1.8	27.4	0.5	--	0.6	0.2	8.1	0.1	38.7
1978	3.9	33.4	0.3	--	(0.2)	0.6	7.5	1.0	46.5
1979	7.4	38.7	3.2	(0.2)	0.3	1.4	6.9	1.3	59.0
1980	11.6	41.1	10.2	0	1.3	2.0	6.3	2.0	74.0
1981	16.7	41.0	16.9	0	3.2	2.6	6.4	3.9	90.7
1982	22.4	37.9	23.3	1.7	5.0	3.3	7.4	5.7	106.7
1983	29.1	31.9	30.7	2.6	6.1	3.7	9.7	7.8	121.6
1984	35.8	27.3	36.9	3.0	6.9	4.1	11.2	9.2	134.4
1985	42.8	21.0	42.5	3.1	7.5	4.1	13.3	10.1	144.3
1986	48.4	16.2	46.8	3.2	7.1	3.6	15.5	11.1	151.9
1987	53.8	13.6	50.6	3.3	6.3	3.6	17.5	10.9	159.6
1988	56.8	14.6	53.1	3.4	5.2	3.3	18.8	10.0	165.2
1989	59.1	15.7	54.2	3.5	3.7	3.0	19.5	8.9	167.6
1990	59.6	17.2	53.2	4.7	1.8	2.7	19.6	7.4	166.2

SOURCE: Derived from Tables 18-20, 24-27



pursuing this strategy, it is likely that national budgetary pressure will be brought to bear in an effort to encourage contract relief which will permit nations to defer proposed additions to SWU capacities as a means of reducing the inventory carrying costs on these substantial stockpiles. In the U.S. these pressures are already evident in the DOE decisions to offer contract relief to LTFC customers, to delay the proposed Portsmouth expansion, to idle a percentage of existing SWU capacity by accepting reduced power deliveries from TVA, and to consider delays in the completion of the CIP/CUP programs. The preceding potential stockpile analysis suggests that this pattern may soon reveal itself in foreign nations as well.

### 3.2 Summary

This section has sharpened the focus of our critique of any medium-term fuel bank proposal. We have demonstrated that even in the absence of any fuel bank, the normal operation of the enrichment market will result in the creation of large, geographically disperse stocks of enriched fuel during the next decade. This excess capacity result follows from the combination of utility over ordering, as an insurance measure under long term contracting, and the continuing slippage in reactor demand forecasts. Although the concern during the early 1970's centered around the enrichment crisis and the shortage of enrichment capacity, it is now obvious that the

prevailing condition in enrichment markets during the 1980's will not be one of crisis shortages, but of a glut of excess capacity.

Therefore we must recognize that in contemplating the establishment of a medium-term fuel bank the appropriate comparison is between a condition of geographically disperse stocks whose disposition will be determined primarily by market forces, and a condition of a larger, centralized fuel bank stockpile whose disposition shall be governed primarily by politically-determined institutional rules. We emphasize that it is inappropriate to compare a nuclear fuel bank with a world in which no other stockpiles exist. The reader must bear this point in mind during the balance of this essay.

It should be pointed out that the preceding forecasts have dealt solely with the circumstances in the enrichment market, with no mention of the uranium market. Essay #1 has indicated that the issue of nuclear fuel assurance is tied not only to the reliable behavior of the enrichment market, but to the stability of the uranium market as well. Obviously without readily available uranium feed, the enrichment capacity cannot be used for stockpiling. The adequacy of uranium reserves, the performance of the uranium market, and the implications of enriched fuel stockpiles for the performance of the uranium market, are complex topics beyond the scope of this essay. The reader desiring more analysis of the uranium market is referred

to the larger MIT Nuclear Fuel Assurance Project, of which the author is a member. For our present purposes it is sufficient to observe that publicly available forecasts of uranium supply indicate that the availability of uranium will not constrain the accumulation of base case enriched uranium stockpiles. A simple calculation confirming this observation is included as Appendix II to this essay.



#### 4.0 A SPECIFIC MEDIUM-TERM FUEL BANK PROPOSAL

Now we are ready to consider a specific proposal for a medium-term fuel bank. Unfortunately no specific official proposals are in the public domain, although an entire INFCE task force is being devoted to the study of nuclear fuel assurances. Nevertheless, discussions with DOE and State Department officials, as well as reports in the nuclear press, have suggested enough of the outline of such a fuel bank proposal to permit us to offer the following hypothetical medium-term fuel bank, for use as a subsequent focus of criticism.<sup>17</sup>

The fuel bank would be held under the international auspices of the International Nuclear Fuel Authority (INFA) contemplated in the Nuclear Non-Proliferation Act of 1978 (see essay #1, section 2.4.4). As such, it would be jointly owned and managed by supplying and consuming nations. The INFA would seek to stabilize the uranium market, and to create greater supply assurance in the enrichment market by participating in the siting, operation, and ownership of new enrichment facilities.

In order to offer effective supply assurances, the INFA would require widespread voting representation of both consumers and suppliers. This system of checks and balances would be achieved by patterning the voting structure after the three-tiered INTELSTAT

structure.<sup>18</sup> First, INFA would have a universal membership body operating on a one nation/one vote basis; this would be the forum for deciding on general non-proliferation policy issues. It would serve to reduce the perceived likelihood of unilateral discriminatory supply restrictions by giving all nations participating in the INFA a voice in the operations of the fuel bank.

Second, the INFA would have a board of governors exercising direct oversight of the system. This board would be the forum for reviewing financial and operating decisions. Investing nations would contribute enriched uranium,  $U_3O_8$ , or cash, as a means of gaining membership on the INFA Board, and would receive voting power proportional to their investment. This weighted voting scheme would encourage contributions from suppliers by offering some greater degree of control in return for their assumption of greater financial risks as a result of their proportionally larger investments. Consumer representation on the INFA Board would ensure wide geographic representation in order to prevent domination by a single supplier nation.

Finally, the INFA would have an international administrative and technical staff, under a director-general, responsible for making day-to-day decisions under the guidance of the board. Presumably the INFA would draw its staff from different national atomic energy commissions, as well as enrichment contractors and mine operators.

The INFA fuel bank would be held in a single, centralized location. It would consist of 3.2% enriched uranium, as this is the highest enrichment required for fueling an LWR, and lower assays may be achieved by diluting this fuel with natural uranium. Initially stocks would be amassed by contributions from enrichment supplier nations, such as the roughly 10 MMSWU of the DOE preproduction stocks which has been proposed as the U.S. contribution to such a bank. For later stockpile increments, the INFA would purchase enriched fuel from SWU suppliers at market prices, or participate directly in the ownership of enrichment facilities. The costs of building and holding these stocks would be shared proportionately by INFA Board members.

The purpose of the INFA fuel bank would be to act as a supplier of last resort. Nations unable to obtain long-term contracts for enriched fuel at acceptable political and economic costs, or nations experiencing an interruption in fuel supply, could purchase enriched fuel directly from the INFA stockpile. In order to discourage capricious use of these stocks, INFA sales would be made at a slight premium, say 5%, over the prevailing market price for enriched fuel. Nations which would draw on the INFA bank need only agree to IAEA safeguards on the shipments received from the INFA stockpiles; no other non-proliferation conditions would be attached because this would prohibit universal access to the fuel bank.

As stated earlier, this INFA proposal is our best effort at reconstructing the Congressional intent in suggesting a fuel bank. As such, this large international fuel bank will be the primary focus of our subsequent discussion. We note here, however, that the suggestion has also been made that a small emergency reserve fuel bank, of say 5 MMSWU, is a more appropriate strategic response to the fuel assurance problem than the large INFA bank. For now, we only wish to draw the distinction between this emergency reserve fuel bank, which is part of a scheme of restrained market intervention, and the proposed INFA fuel bank, which represents a massive market intervention. After critiquing the INFA strategy, we shall return to say a few words about the emergency reserve approach.

## 5.0 A CRITIQUE OF THE FUEL BANK PROPOSAL

As the starting point for our critique of this proposal, we recall the discussions in section 2 of this essay where we established that the role of a medium-term fuel bank should be to reduce the perceived degree of political control over nuclear markets, thereby fostering the development of a smoothly functioning international market. Therefore, we must ask whether the proposed fuel bank is likely to achieve both, or indeed either, of these objectives.

### 5.1 Depoliticization

Will this proposed fuel bank effectively insulate nuclear markets from the vagaries of political change? We think it unlikely. The success of the fuel bank as a mechanism for resolving some of the prevailing political uncertainties which hamper the development of nuclear markets will be a function of:

1. the details of the INFA voting structure, and
2. the conditions of stockpile access.

As described by Skolnikoff (12) the success of INTELSAT in persuading countries to depend solely on an international organization for the operation of an essential technical service is

largely attributable to its innovative three-tiered structure, which provides both political control and operational efficiency. While the success of the INTELSAT experience is reassuring evidence of the viability of an international high technology corporation, certain stark differences between the nuclear fuel cycle and communication satellite technologies call into question the transferability of the INTELSAT experience to the INFA.

First, in 1964, at the time of the creation of INTELSAT, the U.S. had a technological monopoly on space communications capability. Furthermore, there were substantial economies of scale to be realized by deploying the satellite technology worldwide and making maximum use of the technical advances. In 1978, the United States enjoys less than a monopoly position in enrichment technology. The existence of competing technologies, and some years of vigorous competition, makes the selection of a preferred technology for constructing enrichment plants to be owned and operated by the INFA a highly contentious choice. Also, the economies of scale in enrichment are not so large as to encourage worldwide participation to take advantage of them. Lastly, the uranium enrichment technologies, as well as much of the data on national stockpiles, are surrounded by military classification barriers that will make international conferrals extremely sensitive; although communications capability is an essential aspect of a nation's economy, a

communications satellite is less transparently usable as a weapon of war than a uranium enrichment plant.

Whatever the parallel with INTELSAT, it becomes obvious that the negotiation of an INFA agreement will be orders of magnitude more complicated than is implied by our fuel bank proposal. An elaborate set of rules must be agreed upon in order to represent competing interests. Voting rules must be structured so that not only can no single nation dictate INFA policy, but no easily foreseeable alliances (SWU suppliers-DOE, EURODIF, URENCO; uranium producers-U.S.A., Canada, Australia, South Africa; militant non-proliferators-Canada, Australia, U.S.A.) can dominate corporate proceedings.

Further, it remains to be seen whether a set of voting rules can be devised which effectively reduces the perception of political control by creating a stable consensus of INFA participants regarding the non-proliferation terms and conditions of access to the INFA stockpile. Our fuel bank proposal blithely assumes that only minimal proliferation conditions will be attached to fuel bank sales. While these minimal conditions may satisfy European nations, and simultaneously permit broad, non-discriminatory access to INFA stocks, the acceptance of these minimal conditions would represent a major concession on the part of proliferation-conscious suppliers like Canada, Australia, and the U.S., who would prefer that nations

agree to forgo the acquisition of domestic enrichment and reprocessing capabilities, and to accept full-scope safeguards on all of their nuclear activities, in return for stockpile access. Under some interpretations of the Nuclear Non-Proliferation Act, the U.S. would not be able to make a contribution to the INFA bank in the absence of a veto right over subsequent retransfer of spent fuel for reprocessing purposes. On the other hand, the French have made it clear that they find such retransfer restrictions unacceptable, and in view of their commercial reprocessing industry, both they and other European nations are likely to balk at any restrictions on spent fuel reprocessing and subsequent plutonium recycle.

In addition, other consumer and supplier nations, such as India and South Africa, may find these additional proliferation conditions unacceptably restrictive, and determine that access to the INFA stocks under those terms is an insufficient incentive to forgo enrichment and reprocessing technologies. The result of a failure to include these other nations in the fabric of an INFA agreement would be the segmentation of the nuclear fuel market; in the INFA-serviced segment, consumers could have access to fuel supplies at lower transactions prices in return for the acceptance of tougher proliferation conditions, while in the other segment, consumers would pay a price premium to receive fuel with no proliferation strings attached. Obviously the creation of such a side-by-side market structure is contrary to the purpose of a fuel bank.



These disagreements regarding access restrictions, which we foresee arising during the INFA negotiations, are rooted in two different perceptions of the proliferation problem. These differing perceptions were the focus of the 1977 World Peace Foundation Conference on Managing in a Proliferation - Prone World, as reported by Dunn (5). This Conference highlighted two theories of why nations "go nuclear." The "supply-push" hypothesis, which lies at the root of current U.S. policy, holds that the continuing spread of civilian nuclear technology, including possibly reprocessing and breeder technologies, creates scientific and bureaucratic momentum which culminates in a slow drift towards nuclear weapons. Although a home-grown weapons program was a difficult task in the past, "imminent destabilizing technological developments (such as) the adoption of the plutonium fuel cycle" will drastically reduce the barriers to weapons acquisition. Therefore, advocates of the supply-push hypothesis hope to reduce the temptation to go nuclear by controlling the spread of sensitive technologies through explicit agreements to forgo these technologies in return for fuel bank supply assurances.

By contrast, the "demand-pull" hypothesis, championed by the European nations, argues that possession of a nuclear weapons capability does not predetermine the decision to use that capability, as proven by the decisions of Canada, Sweden, Switzerland and others, not to pursue weapons construction. Instead demand-pull proponents

stress the factors that produce a growth in security as well as status-related incentives for the proliferation of nuclear weapons. As such, access to the INFA fuel bank should not be predicated on restrictive supply-side provisions, whose only effect will be to discourage use of the stockpile with a resulting increase in the incentives to acquire domestic enrichment and reprocessing technologies. Rather, easy fuel bank access will reduce the demands to go nuclear and slow the drift towards proliferation, without the need for costly confrontations or potentially discriminatory technological restrictions.

Disagreement about the relative emphasis given to these two hypotheses about the driving forces behind proliferation, which has prevailed since the early negotiations of the NPT, and has persisted through the London Suppliers Conferences and the first INFCE meetings, resurfaced at the World Peace Foundation Conference. Dunn concludes that the Conference demonstrated that, "the current American view of the new nuclear consensus could be realized only, and if then, with the use of considerable coercion"<sup>19</sup> and that, "it is becoming increasingly necessary that the United States should begin to consider which modifications of its preferred image of the future world nuclear energy system would have an acceptable marginal risk of proliferation."<sup>20</sup> Dunn recommends that,

"(U.S.) policy should shift from internationally unacceptable efforts to restructure completely other countries' domestic nuclear energy programs to a more limited, but potentially more successful, attempt to influence at the margin the characteristics of these programs."<sup>21</sup>

As an example of an "internationally unacceptable" U.S. policy, Dunn selects President Carter's efforts to preclude spent fuel reprocessing. Given that the U.S. does not retain absolute leverage over foreign nuclear programs, Dunn suggests the evaluation of compromise arrangements such as multinational fuel cycle centers, spent fuel buy-back agreements, or reprocessing only in nuclear weapons states. Similarly, we can interpret the results of the last decade's attempt to reach a modified nuclear consensus as mandating a compromise of the stringent U.S. access conditions in order to create a workable fuel bank.

We do not pretend to resolve this conflict in this essay. We merely indicate that it does exist and that the difference of opinion is both significant and long-standing. The creation of the INFA will not short-circuit this conflict; rather, it must confront it head-on. The same considerations which prohibited the supplier nations from reaching a satisfactory consensus on commercial proliferation conditions in the Zanger Committee and at the London Conferences (see essay #1, section 2.2.2) will surface during the INFA negotiations. Because consumer nations will also participate in the INFA negotiations the scope of this ideological rift will be

further broadened and amplified. In sum we are not sanguine about the political prospects for reaching an INFA agreement which guarantees the universal participation in the fuel bank program necessary to depoliticize the nuclear fuel market. Indeed, if such an agreement could be reached, the creation of a stockpile might be unnecessary.

## 5.2 Market Stimulation

Having argued that the INFA is unlikely to achieve the goal of depoliticization, can we at least commend it as an effective support system for encouraging the development of a smoothly functioning nuclear fuel market? We think not. In fact, there are indications that its actual effect may be the opposite of its desired effect.

For example, stockpile pricing will have a strong effect on both fuel bank consumers and suppliers. Some fuel bank proposals have naively assumed that the impact of the stocks on the marketplace can be eliminated simply by making stockpile sales at prevailing market prices. This assumption is improper because it fails to recognize that, due to the magnitude of INFA stocks, the prevailing market price will necessarily reflect the stockpile price. In fact, if the posted INFA stockpile price exceeds a competitive market price, it is likely to become a focal point for the coordination of supplier pricing policies. This form of tacit collusion will clearly reduce

supply diversity and slow the development of a smoothly functioning market. Conversely, if the INFA price is lower than a competitive price, the result may be the disappearance of spot markets because other sellers are unable to match the INFA price. Again, the result is decreased, rather than increased, diversity. Problems of the interactions between INFA prices and market prices are particularly crucial in the SWU market, because the high degree of concentration makes for a gaming environment.

Similarly, INFA pricing policies will impact entry and capacity expansion plans. The INFA could consciously pursue a limit pricing strategy aimed at deterring entry, however, if INFA prices are too low, existing suppliers will have no incentive to expand operations and supply diversity will decline. INFA prices which are too high may actually encourage entry and the resultant proliferation of enrichment technology.

In addition, rather than stabilizing uranium markets, the size of the INFA stocks overhanging the market may instead create additional uncertainty about future market prices by broadening the diversity of expectations about future events.

A contrary approach, which involves pricing stockpile sales on a cost recovery rather than a market price basis, also has significant disadvantages. This scheme would theoretically establish stockpile

prices such that fuel bank suppliers fully recover their costs of production, yet fuel bank consumers pay a price low enough to insure that sellers do not realize windfall profits from stockpile sales. Our second essay's description of DOE's SWU pricing procedure reveals, however, that the idea of cost recovery is vague enough to leave much latitude in establishing prices. Our insights there warn us of the endless bureaucratic complexity that would accompany the administering of a cost recovery pricing policy, and the subsidies that may result from its misapplication.

## 6.0 SUMMARY

The conclusion of this essay can only be a partial one. The results presented in this essay do not permit us to draw a policy conclusion in favor of, or opposed to, stockpiling as an instrument of nuclear fuel assurance. The policy problem is too large, and too complex, to be dealt with in the context of this essay. Nevertheless, a variety of partial conclusions do emerge from this essay.

Section 2 of the essay revealed that there are two diametrically opposed routes that may be pursued as a solution to the nuclear fuel assurance problem. The first route is the market approach, which consists of supplementing the existing market processes in an attempt to deal with the elements of non-economic costs that lie beyond the ken of the current market structure. The market approach rests on the belief that a smoothly functioning market system, unimpacted by political factors, will provide sufficient medium-term nuclear fuel supply assurance, just as the functioning of the international coal market deals with problems of coal fuel supply assurance.

The second route is the political approach, which seeks to replace much of the existing market structure with an administrative process created by political negotiations. The political approach rests on the belief that a wisely constructed universal political

agreement which draws all interested parties into its web, and which makes it unacceptably costly to violate the agreement, is the proper means for achieving nuclear fuel assurance.

Which of these approaches is adopted is a function of one's analysis of the current performance of the nuclear market, as well as one's fundamental faith in the effectiveness of the market process. If one sees the current nuclear market as a system in hopeless disrepair, where buyers and sellers are driven by gigantic uncertainties to take actions which may have dangerous proliferation implications, and where the market has proven incapable of dealing with these uncertainties, then the creation of a universal political agreement is the preferred alternative. On the other hand, if one sees the existing nuclear market as a desirable tool for resolving most of the prevailing risks, where buyers and sellers are acting through the market process to deal with these risks, but where residual political factors are inhibiting the ability of the market to perform efficiently, then the market approach is the desired alternative.

These two assurance strategies, the market approach and the political approach, translate into two different stockpile strategies. The design of a limited scope fuel bank whose pricing policies and access conditions are chosen to make the fuel bank a supplement to, rather than a replacement for, market processes, may



be consistent with the market approach. The creation of an expanded fuel bank under the direction of an INFA, which envisions the construction of an administrative process as a proxy for the market process, is consistent with the political approach.

Section 3 of the essay further focusses this disagreement by demonstrating that the operation of the enrichment market, even in the absence of any fuel bank, will result in the creation of large, geographically disperse stocks of enriched fuel during the next decade. Therefore, the relevant policy choice in the medium term is not between stockpiling and no stockpiling, but between the market's management of disperse international stocks and an administrative agency's centralized management of international stocks.

Having more precisely defined the two policy alternatives, section 4 offers a hypothetical proposal for an international fuel bank, and section 5 offers some criticisms of this proposal. This criticism finds that while the INFA fuel bank strategy is theoretically comprehensive enough to offer a complete solution to the assurance problem, consistent with non-proliferation policies, some thinking regarding the practical details of this scheme leads us to forecast implementational problems, such as:

(1) a potential political impasse, or at best a time-consuming negotiation, in the achievement of a consensus regarding the details of the INFA voting structure and the conditions of stockpile access;

(2) the undesirable potential market feedback effects of stockpile pricing policies, such as the reduction in supply diversity or the encouragement of cartel behavior.

In sum, the INFA strategy certainly carries greater costs, both direct and indirect, than a strategy of relying on a small fuel bank as a supplement to the market process. Appendix III to this essay estimates the net present value of the direct costs of an international fuel bank to be \$23.4 billion. Stated another way, the carrying charge (at 10%) on one GWE-yr. of reactor fuel is \$2.4 million, which amounts to 0.4 mills per kilowatt-hour for each year's worth of stock held in reserve. This amount is relatively small when compared to total fuel cycle costs (3 to 5 mills per KWH), nevertheless, the large absolute magnitude of this cost portends a difficult negotiation surrounding the distribution of these costs among INFA participants.

In return for these costs the INFA strategy offers potentially greater non-proliferation benefits by proposing a comprehensive solution to the fuel assurance problem. We have not attempted to estimate these benefits; instead we have been satisfied to

demonstrate that the choice of a fuel bank strategy hinges on one's assessment of the likely future performance of the nuclear markets compared to the likely performance of the administrative process which would replace it.

As stated earlier some observers have argued that the emergency reserve fuel bank referred to at the end of section 4.0, is the appropriate strategic response. Its proponents suggest that the limited fuel bank strategy has several advantages which make it easier to implement:

1. Because it is less comprehensive than the INFA bank, it will be easier to negotiate, and can be established more rapidly;
2. Because it will represent a smaller stockpile commitment, it requires a smaller front end investment, thus simplifying the negotiation of a cost sharing agreement;
3. Because it leaves much of the market system unperturbed, it minimizes undesirable feedback into the market's pricing and entry decisions.

Our research, however, suggests that even this emergency reserve strategy faces substantial implementational problems. Even though an emergency reserve bank is an order of magnitude smaller than the INFA

bank, it is not far wrong to suggest that its creation must confront virtually the same political impasse which threatens the INFA strategy. Our stockpile forecasts have shown that a 5 MMSWU bank is paltry compared to the stocks which are likely to exist around the world during the 1980's. As such a small fuel bank can only have value if: (1) the political conditions of access are fundamentally different from those offered by the individual suppliers; and (2) all the proliferation-prone consumers that one is worried about have access to the bank. It is virtually tautological, however, that if a political consensus can be achieved which satisfies these two conditions, then proliferation-prone consumers would have access to individual supplier stocks as well, and there would be no need for an emergency bank. Therefore, although the limited fuel bank strategy acquits itself well in the dimension of preserving the ability of the market to function, the political hurdles which it faces lead either to the conclusion that it will fail to achieve an effective resolution of medium-term fuel assurance fears, or, in achieving such a resolution, will render itself obsolete.

During the early years of its life, the nuclear fuel allocation system was clearly a politically dominated process. The system was created to serve military needs and as a result most transactions occurred at the level of national governments. Our discussions in essay #1 have recounted the change in emphasis from military to civilian objectives, and the slow emergence of a fledging market

allocation process during the late sixties and early seventies. The second essay highlighted how the blind pursuit of U.S. domestic commercial objectives, at the expense of international security objectives, backfired and hampered this transition from a political regime to a market system. The third essay warns of the possibility of this failure in reverse. The blind pursuit of international security objectives, by improving nuclear fuel assurance through the mechanism of an extensive international fuel bank, may backfire by inhibiting the functioning of the market system thereby aggravating, rather than ameliorating, the assurance problem.

## APPENDIX I

### STOCKPILE ACCOUNTING CONVENTIONS

As will soon be demonstrated, there are many ways of stating the size of a stockpile of enriched fuel. While there exists no uniquely right or wrong way to measure stockpile size, a failure to appreciate the strengths and weaknesses of the various stockpile accounting conventions has created widespread confusion in the interpretation of stockpile forecasts. This Appendix identifies a set of stockpile accounting conventions and alerts the reader to the pitfalls in trying to compare stockpile forecasts based on different conventions.

The problem of comparability arises because the unit of enrichment capacity, the separative work unit (SWU), is not a measure of physical output, like tons/year, but a thermodynamic measure of available work; the physical output of an enrichment plant is a function of how this thermodynamic potential is used. Stated another way, the relationship between excess enrichment capacity and the physical output going into the stockpile, cannot be calculated without specifying the operating tails assay of the enrichment plant, as well as the feed assay used and the product assay produced. Therefore, whenever one encounters a stockpile forecast measured in

SWUs, one must discover what assay assumptions lie behind the calculation before it can be compared to alternative forecast results.

Historically, DOE has stated the size of the U.S. preproduction stockpile in SWUs at a reference tails assay. The details of the DOE accounting conventions are clarified by appealing to a simple numerical example. Suppose that during some year, the DOE enrichment capacity equals 25 MMSWU, and DOE's contracted SWU deliveries equal 15 MMSWU; therefore, DOE's excess SWU capacity equals 10 MMSWU. Assuming that the enrichment plants operate at full capacity, what will be the increment to the preproduction stockpile, as measured in SWUs?

The simplest answer, and the answer adopted by Jacoby (6) in his Technology Review article, is 10 MMSWU. Clearly no matter how wisely, or stupidly, this enrichment capacity is used, the stockpile increment will represent the expenditure of 10 MMSWUs of effort. The Jacoby measure is an ex ante convention, in the sense that the SWU increment to the stockpile is measured before the excess SWU capacity is used for preproduction; as a result we shall refer to this stockpile measure as before-SWUs, e.g., the size of the stockpile increment would equal 10 million before-SWUs.

The DOE stockpile accounting convention, on the other hand, attempts to measure the amount of reactor fuel added to the

preproduction stockpile, rather than the effort expended to produce this additional fuel. The calculation begins by assuming that the excess 10 MMSWU is applied to natural uranium feed ( $x_f = .00711$ ), to produce 3% enriched product ( $x_p = .03$ ) at the current operating tails assay of 0.25% ( $x_t = .0025$ ). Next the question is asked, "Given that I have preproduced a measurable mass of 3% product, how many SWUs would it have taken to produce this product mass at a reference tails assay of 0.3%?" This amount of SWUs is taken as DOE's measure of the stockpile increment. This calculation is an ex post calculation in the sense that the stockpile increment is conceptually computed after the excess SWU capacity is used for preproduction; as a result, we shall refer to this measure as after-SWUs, e.g., the size of the stockpile increment in this case equals 9 million after-SWUs.

The preceding discussion reveals the source of confusion in comparing stockpile forecasts. Although both the Jacoby and DOE forecasts state their stockpile increments in SWUs, they are clearly not measured in the same units. Two different SWU conventions are being used, before-SWUs and after-SWUs, and a reader trying to compare stockpile forecasts must be aware that these units are related by the formula:

$$\text{After-SWUs} = \frac{(\text{SWUs per unit product at reference assay}) * \text{before-SWUs}}{(\text{SWUs per unit product at operating assay})}$$



In the case where the operating assay equals 0.25%, and a reference assay of 0.3% is chosen, the conversion formula yields, after-SWUs = 0.9 \* before-SWUs.

This 10% difference due to accounting conventions has a greater than 10% effect on the stockpile forecasts. Looked at from another perspective, the after-SWUs/before-SWUs conversion formula states that the effective annual DOE SWU capacity is reduced by 10% when an after-SWUs stockpile measure is used. Cumulated over the next decade, this 10% difference equals approximately 25 million before-SWUs which represents a substantial fraction of the Jacoby forecast of 60 MMSWU as the 1985 DOE preproduction stockpile.

Having seen the importance of the variations in stockpile accounting conventions, what can be concluded about the relative merits of before-SWUs vs. after-SWUs as measures of stockpile size? The advantage of the before-SWUs measure is its independence from arbitrary choices regarding feed assay, product assay, and tails assay relevant to preproduction. Before-SWUs are best interpreted as a measure of the potential available for building a stockpile. Before-SWUs are also a simple measure because they correspond directly with the unit of measurement of enrichment capacity, SWUs. Transparently, one SWU equals one before-SWU, so that when we speak of DOE's SWU capacity as being 35 MMSWU in 1985, we mean 35 million before-SWUs.

Given the mathematical identity between SWU and before-SWUs, why would anyone dream up a convoluted measure like after-SWUs? The answer, of course, is that the excess SWU potential is in fact used to preproduce reactor fuel, and the disadvantage of the before-SWUs measure is that without data giving the feed assay, tails assay, and product assay relevant to preproduction, the mass of stockpiled reactor fuel cannot be determined. Using the after-SWUs stockpile measure one can easily compute the mass of preproduced reactor fuel without a detailed operating history of the tails, feed, and product assays. The after-SWUs measure serves this purpose well, provided that it is interpreted properly.

The basic problem with the after-SWUs measure is that it is not properly understood by analysts outside of DOE, including members of the Congress and the OMB, and is subject to easy misinterpretation. Since the advent of the preproduction stockpile program, DOE has consistently reported stockpile data, in Congressional testimony, using a reference tails assay of 0.3%. This was all well and good while the enrichment plants were operating at a tails assay of 0.3%, from July 1, 1971, through July 1, 1975, because before-SWUs and after-SWUs are equivalent measures when the operating tails assay equals the reference tails assay. After July 1, 1975, however, the operating tails assay was reduced to 0.25%. In order to preserve historical comparability without necessitating the recomputation of 4 years of data, DOE chose to continue to report at a reference tails

assay of 0.3%. This convention had the added advantage of keeping the stockpile forecasts smaller than they would have been if a reference assay of 0.25% were used, thereby reducing the visibility of the DOE stockpiling program below what it would have been if the stockpile forecasts had taken a quantum leap due to a change in conventions.

One fallacy in interpreting the DOE stockpile forecasts arises when analysts try to compare the size of the DOE stockpile with the DOE enrichment capacity. This is a tempting comparison to make, because both of these entities are measured in SWUs, but it is an improper comparison, because while the DOE stockpile is measured in after-SWUs, the DOE enrichment capacity is measured in before-SWUs. It is often suggested, for example, that the DOE stockpile forecast of roughly 25 MMSWU in 1985 shows that we will have a relatively small stockpile compared to projected 1985 enrichment capacity of 27 MMSWU. In fact the relevant measure for such a comparison would state the 1985 DOE stockpile at 45 million before-SWUs which properly reveals a stockpile equal to nearly two years of DOE SWU production capacity.

That JCAE members have had a difficult time interpreting the AEC's conventions is revealed in the following statement by Representative Hosmer,

"I do not expect (the AEC) to come up here with the same measuring units or other parametrics that have been used in the past and with which we are familiar. I expect to be called upon to make an instant translation of what will be said today into units with some commonality with those used in the past. Of course, that will be impossible now, as it was on previous occasions."

and seconded by the sarcastic remarks of JCAE Chairman Holifield who greeted an AEC witness, saying, "I thought you spent all your time changing the units on which you testified."

Although we have been critical of the potential for misuse of the after-SWUs measure, we hasten to reaffirm its usefulness as a measure of preproduced reactor fuel. We have sought to capture this advantage, while reducing the potential for misinterpretation, by constructing a stockpile measurement in gigawatt-years (GWE-YRS). This measurement is designed to indicate the number of GWE-YRS. of electrical energy that one could expect to generate using a stockpile of enriched uranium. It can be compared to the installed LWR electrical generating capacity, in GWE, as a means of determining approximately how many years worth of reactor fuel are held in preproduction stockpiles.

Of course the construction of this GWE-YR. index requires a series of assumptions about:

- (1) the feed assay and tails assay used for stockpile production;

- (2) the spectrum of stockpile product assays; and
- (3) the efficiency with which stockpiled fuel is converted into electrical energy.

We shall assume that natural feed is used at an 0.25% operating tails assay to produce LWR reloads, 2/3 of which are designed for PWRs and 1/3 of which are designed for BWRs, both of which function at a 65% steady-state load factor. Subject to these assumptions one can derive the conversion equation:

$$1 \text{ GWE-YR} = 0.091 \text{ MMSWU}$$

In conclusion, we recommend the simultaneous use of two measures of stockpile size: SWUs and GWE-YRs. The SWU measurement should be interpreted as an index of the potential available for stockpile production, and is calibrated for comparison with installed enrichment capacity as an indication of the cumulative excess enrichment capacity. The GWE-YR. measurement should be interpreted as an estimate of how this excess capacity will be converted into physical material, and is calibrated for comparison with installed electrical generating capacity as an index of the number of years' supply of stockpiled reactor fuel. We do not recommend the use of the DOE reference tails assay convention because it lends itself to

easy misinterpretation and manipulation in circumstances where the chosen reference tails assay differs from the operating tails assay.

APPENDIX II  
THE IMPACT OF URANIUM SUPPLY ON THE FEASIBILITY  
OF INTERNATIONAL STOCKPILING

The body of Essay #3 has intentionally focused on the limits to stockpiling introduced by the availability of enrichment capacity. This focus has neglected to consider whether the foreseeable limits of uranium production capacity further constrain the attainable size of a medium-term fuel bank. This appendix attempts to fill some of this gap.

In part, this omission is due to the complexity of the problem. This appendix will only consider the issue of uranium supply constraints at its most aggregated level. Specifically we shall compute the effective uranium demand with and without the forecasted base case stockpiles and compare these demands with uranium supply estimates to see if any bottlenecks exist. Table 29 performs such a calculation. This calculation reveals that although the complete use of excess enrichment capacity for stockpiling purposes increases cumulative uranium demand by 25% over actual needs during the next decade, projected cumulative uranium supplies are sufficient to permit the building of these base case stockpiles. Annual supplies exceed annual demands for each of the years 1981-1990, and although supplies are slightly less than demands during the years 1976-1980,

the cumulative shortfall of 27,000 MT  $U_3O_8$  is substantially lower than worldwide  $U_3O_8$  stockpiles at the start of 1976<sup>22</sup>.

As observed, this is purely an aggregate result. Constraints may exist at lower levels of aggregation where individual consumers or suppliers of enrichment services may have inadequate access to enough uranium to permit enriched fuel stockpiling. This disaggregated issue goes beyond the scope of the current essay; it can only be answered by extensive data-gathering in the area of uranium supply contracts and by further disaggregated simulations. For further results regarding these constraints the interested reader is referred to the work of the MIT Nuclear Fuel Assurance Project, of which the author is a member.



TABLE 29

URANIUM SUPPLY AND DEMAND COMPARISONS (103 MT U<sub>3</sub>O<sub>8</sub>)

DURING CALENDAR YEAR	OECD U <sub>3</sub> O <sub>8</sub> DEMAND(1)	INCREMENTAL U <sub>3</sub> O <sub>8</sub> FOR STOCKPILING(2)	TOTAL U <sub>3</sub> O <sub>8</sub> DEMAND(3)	ESTIMATED U <sub>3</sub> O <sub>8</sub> SUPPLY(4)
1976	18.9	16.4	35.3	26.2
1977	23.7	23.9	47.6	38.9
1978	26.5	25.7	52.2	49.5
1979	29.8	29.4	59.2	55.4
1980	33.7	31.2	64.9	62.5
1981	38.6	27.6	66.2	71.9
1982	44.5	18.2	62.7	90.8
1983	50.2	22.0	72.2	96.7
1984	57.4	14.7	72.1	103.8
1985	66.0	14.7	80.7	108.5
1986	73.2	9.2	82.4	113.2
1987	82.1	5.5	87.6	117.9
1988	88.3	-	88.3	122.6
1989	<u>95.3</u>	<u>-</u>	<u>95.3</u>	<u>127.4</u>
Cumulative	728.2	238.5	966.7	1185.3

(1) derived from Table 18 assuming additional 1 year mining lag and  $1.84 \times 10^3$   $\frac{\text{MT U}_3\text{O}_8}{\text{MMSWU}}$  (see OECD (10), pg. 32, Table 10)

(2) assumes stockpiles consist of LWR reloads, produced at 0.25% tails assay, used at 65% load factor. Derived from Table 22 assuming 2 year lag and  $167 \frac{\text{MT U}_3\text{O}_8}{\text{GWE-yr.}}$

(3) sum of previous two columns.

(4) OECD/IAEA (10), pg. 24, interpolated for years 1986-1989, does not include U.S. or foreign U<sub>3</sub>O<sub>8</sub> stockpiles.

### APPENDIX III

#### THE DIRECT COSTS OF AN INTERNATIONAL STOCKPILE

The calculation of the cost of building stocks for a fuel bank is a complicated and uncertain one. We shall attempt only a rough calculation aimed at showing the order of magnitude of the applicable costs. Following Jacoby (6), we shall make a series of assumptions:

1. The fuel bank would hold only 3.2% enriched uranium, as this is the highest enrichment required for fueling an LWR and lower assays may be produced by diluting this fuel with natural uranium,
2. The cost of the fuel bank will be compared to the "no stockpile" option where the total stock held within and outside the U.S. is assumed to remain at its 1977 level,
3. The cost of enriched fuel is calculated to include the marginal cost of uranium, conversion, and enrichment services. Enrichment services are valued at \$100/SWU, uranium is priced at \$40/lb.  $U_3O_8$ , and conversion is assumed to cost \$4.15/kg U. Therefore, the cost of adding 1 GWE-yr. to the fuel bank, assuming an equilibrium load factor of 65% and an 0.25% operating tails assay, is \$24.5

million, and this cost is assumed to remain constant over the period of the calculation.

Using these assumptions, we can calculate the annual cost of our base case stockpile forecast through the year when the base case stockpile peaks. As of this date, the stockpile will have some security value, which we do not attempt to estimate; instead we assume the terminal value to be zero. The 1977 present value of these costs, at a 10% interest rate, is \$23.4 billion.

ESSAY #3

FOOTNOTES

1 Boston Globe, October 20, 1977

2 (11), pg. 15.

3 Ibid.

4 (9), pg. 2.

5 (8).

6 (7).

7 Ibid.

8 (13).

9 Assumptions made to derive Table 17 include--

1. include SGHWR, AGR, HTR, and FBR capacity as part of LWR totals,

2. assume all HWR capacity resides in other nations,

3. divide GCR capacity equally between EURODIF and URENCO nations,

4. estimate Iranian capacity at:

<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>
1.2	1.2	2.4	3.0	3.9	4.9	6.3	8.0

- 10 Technical data used in deriving Table 19:  
for the no-recycle LWR fuel cycle,
- first core requires 213 MTSWU/GWE-Yr.
  - reload core requires 140 MTSWU/GWE-YR. at 100% load factor
  - there is a one-year lag in the enrichment process from  
enrichment in to reactor in

Technical source: (10) Table 10, pg. 32

Table 19 also relies on author's estimate of first-core demands for 1990 which assumes they are identical to first-core estimates for 1989.

- 11 Since the writing of this paragraph the scheduled  
Portsmouth expansion has indeed been slipped, as reported in  
Energy Daily May 11, 1978 Vo. 6, No. 92, pp. 1-3.

The new expansion schedule is:

<u>End of Calendar Year</u>	<u>MMSWU Capacity</u>
1987	1.1
1988	2.2

- 12 (8).  
13 see footnote 11

- 14 (2). pp. 46-51
- 15 (2). pg. 14
- 16 (2). pg. 30
- 17 See "International Nuclear Fuel Authority Sought". Nuclear Fuel Vol. 2, No. 15. July 25, 1977 pp. 1-2 and "Washington Sharply Eyes Concept of Fuel Bank and its Organization", Nuclear Fuel Vol. 2, No. 19, September 19, 1977 pp. 7-8
- 18 (12).
- 19 (5), pg. 7
- 20 (5), pg. 18
- 21 Ibid.
- 22 As of 1/1/76 cumulative government stockpiles in the U.S., Canada and Germany alone exceeded 75,000 MT  $U_3O_8$ .

ESSAY #3  
REFERENCES

1. Allday, C. "Some Experiences in Formation and Operation of Multinational Uranium Enrichment and Fuel Reprocessing Organizations." Reprinted in Chayes and Lewis (3), pp. 177-189.
2. Blumkin, S. "Survey of Foreign Enrichment Capacity, Contracting and Technology: January 1976 - December 1976." ERDA Report K/OA-2547 Part 4. April 18, 1977.
3. Chayes, Abraham, and Lewis, W. Bennett International Arrangements for Nuclear Fuel Reprocessing. Ballinger Publishing Company, Cambridge, Massachusetts 1977.
4. DOE Quarterly Report on Capacity expansion of the Gaseous Diffusion Plants. June, 1978.
5. Dunn, Lewis A. "The Proliferation Policy Agenda: Taking Stock." Report of the World Peace Foundation Conference on Managing in a Proliferation-Prone World. December 9-11, 1977.
6. Jacoby, Henry D. "Uranium Dependence and the Proliferation Problem" Technology Review, Vol. 79, No. 7 June, 1977, pp. 18-29.
7. Lowrance, William W. "Nuclear Futures for Sale: Issues Raised by the West German-Brazilian Nuclear Agreement." Reprinted in Chayes and Lewis (3), pp. 201 - 223.
8. MIT Nuclear Fuel Assurance Project, "The Definition of Nuclear Fuel Assurance Concerns". December, 1977.
9. Newman, Wendy. "Politics of Energy in the Soviet Bloc." MIT Center for International Studies. June, 1978.
10. OECD and IAEA. "Uranium: Resources, Production, and Demand." December, 1977.
11. Schwennesen, Jarvis L. "Uranium Enrichment Policies." Presented at the 1977 DOE Grand Junction Conference. October, 1977.

12. Skolnikoff, Eugene B. "Relevance of Intelsat Experience for Organizational Structure of Multinational Nuclear Fuel Cycle Facilities." Reprinted in Chayes and Lewis (3), pp. 223-231.
- 13 Von Keinlin, A. "Problems Jeopardizing the Security of Supply for Consumer Countries Without Uranium Reserves." December, 1977.



GLOSSARY OF ACRONYMS

AND

ABBREVIATIONS

<u>Acronym/ Abbreviation</u>	<u>Full Name/Definition</u>
AEC	Atomic Energy Commission
AFC	Adjustable Fixed Commitments Enrichment Contract
CEA	Council of Economic Advisers
CENGEX	Centrifuge enrichment partnership: Exxon and General Electric
CENTAR	Centrifuge enrichment partnership: Electro-Nucleonics, Inc. and Atlantic-Richfield Company
CIP	Cascade Improvement Program
COREDIF	Enrichment Consortium: France, Italy, Spain, Belgium, Iran
CUP	Cascade Upgrading Program
DOE	Department of Energy
ERDA	Energy Research and Development Administration
EURATOM	European Atomic Energy Community
EURODIF	Enrichment Consortium with same membership as COREDIF
GAO	Government Accounting Office
GCP	Gas Centrifuge Process

GDP	Gaseous Diffusion Process
GWE	Gigawatts of Electricity
IAEA	International Atomic Energy Agency
INFCE	International Nuclear Fuel Cycle Evaluation
JCAE	Joint Committee on Atomic Energy
KG U	Kilogram of Uranium Metal
KWH	Kilowatt Hours
LTFC	Long Term Fixed Commitments Enrichment Contract
LWR	Light Water Reactor
MMSWU	Million Separative Work Units
MT	Metric Ton
MWE	Megawatts of Electricity
NFAA	Nuclear Fuel Assurance Act of 1975
NPT	Non-Proliferation Treaty
NRC	Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
OMB	Office of Management and Budget
OPEC	Organization of Petroleum Exporting Countries
PNC	Japanese Power Reactor and Nuclear Fuel Development Corporation
R&D	Research and Development
REQ	Requirements Enrichment Contract
STFS	Split Tails Feed Sales

SWU	Separative Work Unit
SWUCO	Separative Work Unit Corporation
TECHNABS- EXPORT	U.S.S.R. Enrichment Corporation
TVA	Tennessee Valley Authority
UCOR	South African Uranium Enrichment Corporation
UEA	Uranium Enrichment Associates, a diffusion consortium headed by Bechtel whose participants at various times have included Union Carbide, Westinghouse, Goodyear.
URENCO	Centrifuge enrichment consortium: United Kingdom, Germany, Netherlands.