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NUCLEAR MATERIALS AND FUEL CYCLE SERVICES SOURCES, INVENTORIES AND STOCKPILES

Prepared for

US Arms Control and Disarmament Agency
Under Contract No. AC9NC105

Volume III

September 1979

NUCLEAR ASSURANCE CORP.
PROPRIETARY

NUCLEAR ASSURANCE CORPORATION

DATED MATERIAL

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September 1979

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Section VI

GENERIC DESCRIPTION OF COMMERCIAL ASPECTS OF THE NUCLEAR FUEL CYCLE

1. Introduction

This section provides generic descriptions of commercial aspects of the nuclear fuel cycle. Uranium, UF_6 conversion, enrichment, fabrication and reprocessing are discussed in some detail. Heavy water production is noted only in passing - it is essentially not a commercial (i.e., non-governmental) industry.

The industry is complex. At its most basic level, it rests on the single fact that a reactor requires certain material, products and services to operate. Reactor operators strive to acquire them and other organizations strive to provide them - thus, an industry. But there is much more. The segments of the supply industry impose technical, quantity, scheduling and contractual restraints upon each other as well as the ultimate buyer. The utility has various plans, strategies and policies which affect the quantity and timing of its purchases and even the nationality of the supplier. Sometimes it is not a product or a material that is purchased, but a technology. In some cases, the line between buyer and seller becomes indistinct as utilities and even nations integrate into some supply segments.

Overlaying all of this are national and international strategies and policies. In some cases, these factors are almost totally dominant and the industry actually becomes an instrument of national policy. This is particularly so for non-US reprocessing and to a lesser extent for enrichment and uranium supply.

2. Uranium

The uranium industry developed in the 1940's and 1950's solely to supply the weapons programs of the US and UK. It remained essentially dependent upon these programs until the mid 1960's.

In 1948 the Eldorado Mine at Great Bear Lake in Canada, the Shingolobwe Mine in the Belgian Congo, the gold deposits of South Africa and the vanadium deposits of the US Colorado Plateau were the only known sources of uranium in the free world. US reserves in 1947 were estimated at only 2000 tons of U_3O_8.

The US undertook large scale efforts to stimulate exploration and production - sending teams of geologists into the field, establishing guaranteed prices and offering bonuses. The effort worked. Exploration boomed and by 1960 there were 1,017 operating uranium mines in the US, 26 privately owned uranium mills and US annual production rose to almost 37,000,000 pounds of U_3O_8.

By the early 1960's defense needs had been satisfied and the US government began withdrawing from the market it had previously dominated. It began reducing the prices it would pay (from a high of $12.43 per pound U_3O_8 in 1958 to a low of $5.56 in 1970) and deferring its purchase commitments. Finally, at the end of FY 1970, the US government procurement program ended. During the entire program the US purchased about 312,000 tons of U_3O_8, about 55% from US producers, 24% from Canada and the rest from the Belgian Congo and South Africa.

Since the US had been the dominant purchaser, the period of its withdrawal was particularly difficult. Although General Electric Company (GE) had sold the Oyster Creek reactor in 1963 and a rash of reactor sales occurred in 1966 and 1967, these did not immediately translate into U_3O_8 deliveries. With no real purchaser in the market prices fell, exploration essentially ceased, mills closed and many marginal producers quit. The effect was similar in Canada and South Africa.

Both the US and Canada attempted to lessen the impact upon their producers. Canada established three stockpiles eventually totalling 25.7 million pounds of U_3O_8 over the period 1963-1974. The US passed the 1964 Private Ownership of Nuclear Materials Act. This Act established an effective embargo on the use of non-US uranium in US reactors and a transition to private ownership of nuclear material. The objectives of the Act were to establish new purchasers for US uranium (previously utilities had leased uranium from the US) and to ensure that these new purchasers would buy only from US producers.

The period between 1966 and 1973 saw the transition from a governmental to a commercial market. On the supplier side, the industry rapidly consolidated as inefficient operations were abandoned or combined. Brisk sales occurred, but mostly for future delivery. During the period, about 180,000 tons of U_3O_8 were sold in the US but by the end of 1973 120,000 pounds had yet to be delivered. Some non-US suppliers allegedly formed a "club" or cartel to rationalize exploration, production and sales. By early 1973 exploration and expansion of production capacity had been so discouraged that producers frankly warned of a projected shortage in production capability. Buyers, in contrast, saw the period as a "buyer's market" with adequate supply, stable prices (around \$6.00 per pound U_3O_8) and brisk competition.

From late 1973 through 1975, a series of events changed this situtation.

Perhaps the most significant was the US change from the requirements-type enrichment contract to the long-term fixed-commitment contract (LTFC). This new contract, although not clearly recognized at the time, created a large artificial uranium demand by forcing utilities to fix their minimum uranium requirements 10-18 years prior to the actual need. In response, utilities began trying to secure 10-20 year forward commitments for uranium supply.

A second event was the Arab oil embargo of 1973. This had two impacts; first was growing awareness of the true value of energy resources - including uranium. Secondly, it helped fuel a nuclear buying spree as nations sought to isolate themselves from future oil price increases and embargoes. In the US alone 44 reactors were ordered in 1973.

With the effects of the oil embargo fresh in their minds, both new and old uranium buyers entered the market. In 1973 US utilities' requests for uranium bids were almost triple those of 1972. In late 1973 the Tennessee Valley Authority (TVA), seeking up to 86 million pounds of U_3O_8 for its 1979-1980 needs, failed to receive responsive bids. It re-entered the market in 1974 with a then novel approach, requesting producers to submit their own proposals, rather than bidding to TVA's specifications. No awards were announced, but the effect of a buyer in the market with the ability to tie up all known production capability was striking. Clearly the supply/demand balance was tipping.

During 1974 price began to escalate with prices for future delivery (1978-1982) reported in the $15-17 per pound range. Some new elements were introduced, with producers requesting advance money to secure ore in the ground and to help finance mine/mill construction. In other cases, base prices were subject to 100% escalation.

By mid to late 1974, several major US producers had sold all of their known reserves and/or production capability and withdrew from the market. Henceforth, the price of any new supply would have to support development of new mine/mill facilities.

At the same time, major non-US producers were beginning to face governmental interference. The governments of Gabon and Niger (sources of French uranium) were challenging the prices paid by the French. Canada enacted a policy that reserved uranium for Canadian use, required stiff safeguards, required governmental price approval and required all exports to be in the form of UF_6.

Events seemed to cascade in 1974; some positive, some negative. As prices began to rise, so did exploration drilling. The first new US mine/mill complex in four years was announced. Utilities began to break their dependence upon traditional supply sources by starting exploration efforts on their own, by forming joint ventures with producers or by outright purchase of a producer. This trend has been continued by US and non-US utilities and even non-US governments.

In 1974 the first round of US reactor delays began. But even so, uranium demand did not slip for the utilities were locked into the LTFC enrichment contracts. Tremendous inventories were building. Analyses at that time indicated that for every pound of U_3O_8 projected to be used in a US reactor in 1976, three pounds would be sitting idle in someone's inventory.

Not only did uranium demand not slip, it increased! Even with the inventories, some utilities were uncovered for near-term needs. These utilities found themselves in a bidding war in a very thin market. Small quantities of material had large impacts on prices - indeed, causing an exponential growth. Spot prices for uranium went from about $7.00 per pound in January 1974 to about $15.00 by December. Prices continued upwards in 1975, reaching $25.00 per pound by mid-summer and then stabilizing.

During late 1974, early 1975 traditional sources of supply had virtually disappeared and a new set of economical procurement practices was becoming established. As well as the exploration or joint venture activities previously mentioned, plain buyers were now expected to share the risks of exploration and the development costs of new production facilities. Contracts including unpriced future deliveries were negotiated. The eventual price would be negotiated near delivery on the basis of a "world market price" or a base price plus escalation whichever was higher.

In late 1975 a major market disruption occurred. Westinghouse abrogated its contractual obligation to provide over 60 million pounds of uranium to its customers and claimed that it was excused under provisions of the Uniform Commercial Code. The litigation and negotiations resulting from this action have yet to be completely settled.

The Westinghouse action had two major effects. Short-term, it left several utilities uncovered for 1976-1977 needs and they entered the market in near panic. Prices rose directly to about $35.00 per pound of U_3O_8 and by the end of 1976 to about $40.00 per pound.

The more major impact was that a very large demand was uncovered. Westinghouse had been following a strategy of offering U_3O_8 (and other services) with their reactors. The price was favorable and many utilities obviously considered the service beneficial. (In fact, one large US utility had bought all of its uranium from Westinghouse.) But at that time, Westinghouse was not a uranium producer, it was an agent. It would cover its commitments with later contracts with various producers. Westinghouse had failed to cover its large 1972/1973 sales quickly and soon the upward price movement of 1974/1975 put them in an untenable position.

The key point was that the industry (particularly the buyers) had failed to note Westinghouse's uncovered position. Only a few analysts recognized that a buyer's commitment to an agent does not represent fulfilled demand until a matching commitment is made to a producer. So, one way or another, the market saw a "new" 60 million pound demand.

From its inception to about 1976/1977 the uranium market was a roller coaster with commercial aspects changing to meet new market demands. At first there was one dominant customer actively stimulating producers. Terms, although clearly acceptable, were as dictated by that customer. When that customer, the US government, satisfied its need and retired from the market there were no significant replacement customers. The production industry essentially disintegrated, even though various governments did make efforts to protect their indigenous producers.

Until about 1973 it was a "buyer's market", but now the buyers were nuclear utilities and a few reactor vendors. Prices remained at about $6 per pound of U_3O_8, spot sales were very frequent and long-term sales contracts were often at fixed prices or modest escalation. Producers often made sales on a marginal cost basis just to maintain survival cash flow. Exploration and production facility investment had essentially ceased.

From 1973 to 1976, the whole situation reversed. Existing reserves and amortized production capability had been sold out. Costs of new reserves and new mine/mill capacity would be much higher. Increased reactor sales, the driving force of the LTFC enrichment contract, the protectionist attitude of several governments, and the Westinghouse abrogation all added to demand pressure. The producer became "King" - and with a vengeance.

Whole new commercial concepts came into being. Short term or spot purchases were frequent - not because the buyers wanted that but because that was all the suppliers were willing to sell. Actual auctions occurred, where buyers competed. Long-term sales (such as there were) were at a "world market price" to be determined and included large doses of front money to support exploration and production capability development. Often entire projects were financed by the buyer. Older, lower priced contracts were renegotiated or abrogated and litigation abounded.

However, even then events were in the making which would lead to a new cycle in the market (the present) and new commercial aspects.

The uranium production industry is characterized by long lead times and large investments. Including everything, it can take from 8 to 10 years to bring a new project into initial production. Just beginning serious exploration can take two years. Thus, there are lag times from the occurrence of a "forcing" event to the results. The results of the 1974/1975 events are just now really appearing. Unfortunately, demand conditions have changed again and the appearing results are somewhat inappropriate to the new market.

It is only a modest overstatement to say that everybody and his brother entered some portion of the uranium supply industry after 1974. US and non-US utilities began their own operations. Some began with grass-roots exploration, some purchased proven reserves, some entered joint ventures with both established and new producers, some are worldwide. Some non-US governments supported such activities - either with direct participation, through subsidies or by establishing national monopolies - for they recognized the strategic energy resource character of uranium. Traditional uranium producers and large energy companies mounted massive programs. New parts of the world - South America, Africa, Asia - are being subjected to intense exploration efforts. All of these take time to bear results, some never will. But, bit by bit, many are. In time, under the correct conditions, an outpouring of U_3O_8 could occur - much of it either wholly controlled by user utilities/governments or by organizations never previously in the market.

Meanwhile, the growth in demand has collapsed. Electricity growth projections in industrialized nations have fallen. Nuclear programs of some Lesser Developed Countries (LDCs) have proven unrealistic or have been interrupted by revolution. Public opposition to nuclear has gained stature in countries and politicians have responded. New regulations have increased the cost and time to construct reactors.

The reactor ordering spree of 1973 is now seen as ill founded. Consequently, even before Three Mile Island (TMI), reactor construction delays were frequent as utilities adjusted commercial operation dates to falling electricity demand growth. Outright cancellations occurred. For political reasons, for reasons of national economy, for reasons of simple cost escalation, or for reasons of lowered load growth - there is an almost worldwide de facto moratorium on new reactor orders.

Further, and of complementary importance, the US has again shifted its basic enrichment contract. But this time, the new contract provides significantly increased flexibility. Thus reactor delays can now, within contractual limits, lead to delays in future uranium demand. Together, all of these events are shaping a new commercial reality.

There has been relative price stability over the last eighteen months in the $43-44 range. Prices have not kept pace with inflation and, thus, have decreased in real terms. The seller's market of several years ago no longer exists and the current market reflects more balance between buyers and sellers. However, a true buyer's market does not yet exist. New procurement activity has been at a lower level than in the 1976-1977 time period. With a large portion of the aggregate near-term requirements covered, buyers are more carefully assessing the market.

This change in the character of the market has affected the types of contracts in existence. Buyers who possess contracts calling for the higher of base-price-escalated or market-prices are attempting to renegotiate these agreements, since escalated prices have been higher than the recent stable prices that have existed. If stable prices continue to be evident in the market, buyers will be able to insist upon a greater voice in the pricing mechanisms that are included in their contracts.

Over the past year and a half, there has been a departure from the market price contracts. Producers are now unable to sign contracts which call for the higher of base-priced-escalated or market-price. Buyers will not accept it. Producers are themselves hesitant to be tied to a world market price which may decline in real terms due to inflation. This departure from market price contracts is more prevalent for contracts involving delivery over the next few years as opposed to long-term contracts.

A large percentage of the contracts announced since January 1978 have been spot sales. Twenty-three of the forty-five announced contracts of the past eighteen month period can be classified as spot sales.

Spot sales have been prevalent for several reasons. A spot sale takes advantage of the prevailing high price levels with essentially no risk. Revenues from a spot sale also make an immediately favorable contribution to the producer's financial position. Uncertainty about the market on the part of buyers is another factor that has contributed to the large number of spot sales. They have been waiting to see if the recent price stabilization continues before signing long-term contracts.

Nearly one-half of the recent spot market sales by US producers have been to non-US buyers. This high percentage can be attributed, in part, to the devaluation of the US dollar. The cost to the non-US buyer is at an effective discount when compared to the cost to a US customer. Sales by US producers to Japanese buyers were especially influenced by the devaluation of the dollar.

A contracting mechanism that has been partially responsible for the apparent trend toward extended delivery periods is the recent emergence of contracts tied to production costs. The Western Nuclear-Union Electric agreement is an example of this type of arrangement. Though enough of these types of contracts have not yet been signed to point to an actual trend, they represent an attempt by producers to remove some of the uncertainty inherent in long-term contracts. By using this type of contract, the producer is assured of receiving a price that is a certain amount above production costs, regardless of the market price at the time of delivery. As a result, the producer can be guaranteed a certain return on investment and profit. However, there is no incentive for the producer to try to keep production costs low, which can be a disadvantage to the buyer.

Phosphate recovery producers have been contracting very actively since the end of 1977. International Minerals and Chemical, Freeport Uranium, and Earth Sciences have signed nine long-term contracts for a total of almost 33 million pounds of U_3O_8. These contracts tend to be long-term due to the nature of the production process. Because the uranium is recovered as a by-product of a chemical process associated with the fertilizer industry, some of the uncertainties associated with long-term contracting from conventional production processes do not exist. Cost increases, declining ore grades, reserve depletion and other factors related to the conventional mining of uranium are not applicable.

Six basic types of contract mechanisms are currently in effect for U_3O_8 purchases. These types of contracts are briefly defined below.

- Fixed Price Contract

  A certain quantity of U_3O_8 is sold for a given price. The price is fixed by the two parties involved and is not subject to escalation. Usually, the fixed-price contract is more commonly associated with spot market purchases. It can apply, however, to contracts for longer term delivery.

- Base Price Escalated Contract

  A base price per pound is specified at the time of contract signing as a starting point for determination of prices in future delivery years. Escalation of the base price begins from a given date which can be before, on, or after the date of contract signing. Escalation is usually determined from a formula based on published escalation indices for labor and materials or other specified indices. This type of contract is associated with both short-term and long-term contracts, and is currently the most common contract type.

- Market Price Contract

  The price paid for U_3O_8 delivered in a given year is the prevailing market price for similar contracts at the time delivery is made. For each delivery, the market price is determined from available information on prices in effect for the given time period. The two parties attempt to negotiate an agreed upon price that is representative of the current market price. If no agreement can be reached, arbitration can occur. This type of contract is usually associated with long-term contracts. Common in 1975-1977, but not now.

- Base Price or Market Price Contract

  The price paid is the higher of base-price-escalated or market-price at the time of delivery. The escalation provisions are usually tied to labor, material or other pertinent indices. The market price is determined by means used under normal market price contracts. This type of contract has been used more often for long-term contracts than it has for short-term ones.

- Cost-Plus Contract

  The buyer pays the cost of production of the material plus an extra fixed amount per pound. The cost of production may include all direct costs related to production as well as some indirect costs. This contract is growing in acceptance.

- Discounted Market Price Contract

  Under a discounted market price contract, material is sold at the prevailing market price minus a discount factor at the time of delivery. This contract usually includes prepayments from the buyer to the seller that are used to bring a facility into production. The discount factor is related to the amount advanced as prepayment and the risk involved.

Tables VI-I and VI-2, reprinted from the Fuel-Trac® Topical Report, "Worldwide U_3O_8 Producer Profiles", January 1979, illustrate the market status of US and non-US producers.

TABLE VI-1

SUMMARY OF CURRENT MARKETING STATUS US U_3O_8 PRODUCERS

Fuel-Trac®
January 1979

Company	Remarks
American Nuclear	Most production committed to TVA.
Anaconda	Essentially committed through 1983, except spot sales.
Atlas	Partially committed through 1982. Some material currently available.
Bear Creek Uranium	Most production committed to Southern California Edison. Some material available on open market.
Bokum Resources	Essentially all production committed to LILCO.
Chevron Resources	All production committed through 1986.
Continental Oil	Existing production 50% committed through 1980.
Cotter	All production committed to Commonwealth Edison.
Dawn Mining	Production essentially committed through 1981.
Earth Sciences	All production committed.
Exxon Company	All production committed to Exxon Nuclear to meet existing contracts and for marketing.
Federal Resources	Most production committed to TVA.
Freeport Uranium	All production committed.
Gardinier	All production committed.
Getty Oil	All production committed through 1983.
Gulf Mineral Resources	Mariano production committed. Mt. Taylor production uncommitted.
Homestake	Production fully committed through 1980, except spot sales.

TABLE VI-1
(continued)

Fuel-Trac®
January 1979

Company	Remarks
Intercontinental Energy	Existing production fully committed.
International Minerals and Chemical	All production committed.
Kerr-McGee	Fully committed through 1982, except for spot sales.
Minerals Exploration	Production 50% committed.
Mobil Oil	Existing production committed but additional unsold production planned.
Pathfinder	Some uncommitted production available through 1981.
Phillips Uranium	Production about 25% committed.
Pioneer Nuclear	All production committed to Philadelphia Electric.
Plateau Resources	All production committed to Consumers Power.
Ranchers	Production essentially committed through 1983.
Reserve Oil/SOHIO	Production about 50% committed.
Rio Algom	All production committed to Duke Power through 1980.
Solution Engineering	All production committed.
Tennessee Valley Authority	All production committed to TVA.
Union Carbide	Some material available through 1981. No commitments past 1981.
United Nuclear	Uncommitted production available pending outcome of General Atomic litigation. Actively marketing.
U. S. Steel	Production about 25% committed through 1983. Actively marketing.
U.S. Steel-Niagara Mohawk	Production committed to Niagara Mohawk.

TABLE VI-1
(continued)

Fuel-Trac®
January 1979

Company	Remarks
Uranium Recovery	Production committed to United Nuclear for marketing.
Uranium Resources	No contract commitments (as of end of 1978).
Western Nuclear	Production from Jeffrey City essentially committed through 1983. Sherwood production uncommitted.
Wyoming Mineral	Production committed to Westinghouse.

TABLE VI-2

SUMMARY OF CURRENT MARKETING STATUS NON-US U_3O_8 PRODUCERS

Fuel-Trac®
January 1979

Country	Company	Remarks
Argentina	CNEA	All production committed to Argentina government.
Australia	Mary Kathleen	Production fully committed.
	Noranda	No contract commitments.
	Pancontinental	No contract commitments.
	Queensland	Existing commitments of 3320 ST U_3O_8. Commitments being met from Australian governments' stockpile.
	Ranger	Existing commitments of 3300ST U_3O_8. Commitments being met from Australian governments' stockpile.
	Western Mining	No contract commitments.
Brazil	Nuclebras	All production committed to Brazilian government.
Canada	Agnew Lake	Production essentially fully committed through 1981.
	Amok	All production committed to COGEMA and Minatome except for 25% which will be retained for Canadian requirements.
	Denison	Most of production essentially committed.
	Eldorado	Most of production essentially committed.
	Gulf Minerals	Production about 50% committed. Currently marketing.
	Madawaska	All production committed to AGIP.
	Rio Algom	Most of production essentially committed.

TABLE VI-2
(continued)

Fuel-Trac®
January 1979

Country	Company	Remarks
France	CFMU-SIMURA	All production committed to COGEMA.
	COGEMA	All production committed to COGEMA.
	Dong-Trieu	Most of production committed to EdF.
	SCUMRA	All production committed to COGEMA.
Gabon	COMUF	All production committed to COGEMA and IMETAL.
Italy	Novazza	All production committed to AGIP.
Mexico	INEN	All production committed to Mexican government.
Niger	COMINAK	All production committed to COGEMA, OURD, and ENUSA.
	Imouraren	No contract commitments except 33% committed to COGEMA.
	SOMAIR	All production committed to COGEMA, AGIP, and Urangesellschaft.
Portugal	ENU	All production committed to Portuguese government.
Spain	ENUSA	All production committed to ENUSA.
	FESA	All production committed to ENUSA.
	JEN	All production committed to ENUSA.
Sweden	Ranstad	All production committed to Swedish government.
South Africa	ERGO	Production fully committed through 1981.
	NUFCOR	Production about 70% committed. Actively marketing.
	Palabora	Production about 50% committed. Rio Tinto markets production.

TABLE VI-2
(continued)

Fuel-Trac®
January 1979

Country	Company	Remarks
S. W. Africa	Rossing	All production committed to Rio Tinto for marketing.
Yugoslavia	Zavod	All production committed to Yugoslavian government.

3. UF_6 Conversion

While there are many U_3O_8 producers, there are only five UF_6 converters in the World Outside of Centrally Planned Economic Areas (WOCA) - two in the US, one in Canada, one in the UK, and one in France. Canada may add another plant and Australia is considering a plant. Brazil and Japan both plan facilities to serve their needs.

The U_3O_8 industry involves a natural resource of unknown ultimate quantity found in various locales and in different forms. In contrast the UF_6 industry involves a highly efficient chemical process meeting extremely rigid product specifications. There is relatively little national policy/political activity surrounding the industry and the industry has maintained an overcapacity condition. While contracts (both spot or bulk, covering requirements over many years) are between the converter and usually the utility (sometimes his agent), the majority of the contract is concerned with allowable impurities in the incoming U_3O_8 and in the product UF_6. Product specifications are imposed by the next, more dominant step in the cycle, enrichment.

The two US suppliers - Allied Chemical and Kerr McGee - have contracted primarily with US customers. Currently over 90% of their future commitments are to US customers. Historically, both have had modest success in the non-US, capturing 14%-24% of the non-US conversion market. However, their future non-US market share is essentially none. Kerr McGee, being also a large U_3O_8 producer, has usually sold its uranium only as UF_6 (thus capturing the value added revenue of the conversion step). Kerr McGee has also added a new circuit to their facility to accept uranium in the form of a wet slurry rather than U_3O_8 only. This is an attempt to capture a market niche by allowing smaller uranium producers to avoid the milling step.

BNFL (essentially owned by the UK government) and Comurhex (French) have essentially captured all of the UK and French market, respectively. Both have heavily contracted with customers in Europe. Together, they have captured the majority of the European market and are strong competitors in Japan.

Eldorado Nuclear can be considered somewhat of an instrument of Canadian policy, since all uranium exported from Canada must be as UF_6. Eldorado's commitments are widely spread among the major nuclear regions. It has captured only a modest share of the US and European market, but the majority of the future Japanese market (because of the large Japanese purchases of Canadian uranium). Canada plans another plant as demand rises.

Australia is now considering following Canada's lead by constructing a UF_6 conversion facility and then requiring all uranium exports to be as UF_6. Australia's goal seems to be the straightforward desire for value added revenue and jobs.

Japan has developed a unique process to go directly from ore to UF_6, skipping the U_3O_8 milling process. Current plans are to use it only for the small indigenous uranium production.

Brazil, towards its goal of self-sufficiency in the LWR fuel cycle, plans to build a small UF_6 conversion facility, using French technology. Both it and Japan's plant are for national use only.

4. Enrichment

Enrichment services are provided (or offered for sale) by four organizations today: USDOE, Urenco, Eurodif and Techsnabexport. USDOE and Techsnabexport (USSR) are government organizations; Eurodif is a French corporation with ownership resting in five governments; and Urenco is a partnership owned by the UK, Netherlands and the FRG, with some private participation. In addition, there are enrichment projects in Brazil, Japan and South Africa developing to meet indigenous needs. The latter two have reached pilot plant stage, the eventual implementation of the Brazilian project is questionable.

US enrichment capability began in order to meet nuclear weapons needs. Three major plants, at Oak Ridge, Paducah and Portsmouth, were constructed over the period 1943-1955. Production peaked in FY61 at about 17 million separative work units (SWU) and then, as defense needs were satisfied, fell to a low of 6 million SWU in FY70. As a point of reference, FY81 requirements were estimated at 13-14 million SWU.

With excess capacity, the US decided to provide enrichment to commercial customers in support of nuclear generated electricity. At first, the US would lease the enriched uranium, with the customers paying for what it used (use charge) and a lease payment. After enactment of the Private Ownership of Nuclear Materials Act in 1964 the US began toll enrichment, wherein the customer provides natural uranium feed and USDOE enriches the feed to the desired level. Except for a very few emergency cases, this is the universal mode of operation.

The US soon achieved an absolute monopoly on commercial enrichment services - it had the capacity, its price was good, its contract terms were favorable and it built a superb reputation for performance.

Matters proceeded thusly until December 8, 1972 when the US put a freeze on any new contracting (extending eventually to September 11, 1973). During this period the US developed its new contract type - the Long-Term Fixed-

Commitment Contract. While the previous requirements contract was very flexible - the US would supply the customer's requirements with very short notice lead times for fixing the requirements - the new contract called for fixing deliveries for a ten-year rolling period, with the initial delivery fixed as much as eight years prior to reactor startup.

The freeze, the new contract, and following period to mid-1976 during which the US seemed totally unable to effectively decide how (if) to add new capacity - can now be seen as the "chink" providing the initial opportunity for other enrichment suppliers to enter the market.

Three major suppliers (the French through Eurodif, a consortium of the UK, FRG and Netherlands through Urenco, and the USSR through Techsnabexport) entered the market during this period and captured respectable portions of it.

The Russians - with perhaps some excess capacity, seeing a market vacuum and desiring hard currency - initially entered the Western market in 1973, capturing a long-term agreement with an FRG utility. Since then they have contracted with FRG, UK, Austria, Italy, Spain, Sweden and France. Usually they offered to meet US terms, with perhaps a slight (5%) discount in price. Their market capture is not insignificant, reaching 13%-15% in 1979/1980 and averaging 6% over the period 1973-2000. They have developed a reputation for reliability, but potential customers must accept this upon faith, for very little is known about their operations. The contract terms and conditions of the major enrichment suppliers are shown in Tables VI-3 and VI-4.

Urenco (Uranium Enrichment Company) was formed as a result of the March 4, 1970 Treaty of Collaboration between the UK, FRG, and Netherlands (often

TABLE VI-3

NON-USA ENRICHMENT SUPPLIER CONTRACT TERMS AND CONDITIONS

Fuel-Trac®
September 1979

	EURODIF	COREDIF	URENCO		
Contract Features			Requirements	Previous Fixed Commitments	New Contract
Time from contract signing to first delivery	5 years	8 years	5-10 years	5-10 years	5-10 years
Designated Reactor	No	No	Yes	No	Yes
Restricts additional deliveries (other sources)	No	No	Yes	No	Yes, Urenco first option to deliver
Can SWU be used in another facility?	Yes, with consent	Yes, with consent	Yes	Yes	Yes
Reduce SWU requirements of facility by taking other deliveries	No	No	No	No	No
SWU limits set by:	Contract	Contract	Reactor plus contract	Contract	Reactor plus contract
Quantities:					
Lead time prior to initial delivery to set quantities	Upon contracting	Upon contracting	4 Years prior to each delivery	Upon contracting	4 years prior to first delivery
Firm period	Contract	Contract	4 years	10 years	10 years
Commitment period	10 years	10 years	10 years	10 years	10 years

TABLE VI-3
(continued)

Fuel-Trac®
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	EURODIF	COREDIF	URENCO		
Contract Features			Requirements	Previous Fixed Commitments	New Contract
SWU quantity flexibility within commitment period	4 years notice - moderate adjustment 6 months - 1 year notice minor adjustment. All flexibilities include and are related to tails flexibility	2 years - moderate All flexibilities include and are related to tails flexibility	2 years - moderate	4 years - major 2 years - moderate	4 years - major 2 years - moderate
Timing flexibility	Can delay SWU by paying an interest penalty on cost of SWU, delivery feed and paying storage costs	Can delay SWU by paying an interest penalty on cost of SWU, delivery feed, and paying storage costs	Customer may have to deliver feed, and pay a penalty based on loss to Urenco, including cost of capital and storage cost	None without penalty	None without penalty
Assay flexibility	2 years - moderate 1 year - minor		2 years - major	2 years - major	2 years - major
Variable tails range	.20 - .30%	Unknown	None	None	Unknown
Variable tails notice	4 years	2 years	None	None	4 years prior to initial delivery
Estimated or reference tails	.25%	.20%	.3%	.3%	As set by customer

TABLE VI-3
(continued)

Fuel-Trac®
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	EURODIF	COREDIF	URENCO		
Contract Features			Requirements	Previous Fixed Commitments	New Contract
Penalty for late delivery of product	Yes	Yes	Yes		
Price, present	Jan. '74 - 350 FF	Jan. '77 - 520 FF	Jan. '78 - $120	Jan. '78 - $120	Jan. '78 - $120
Price adjustments	Escalation	Escalation	Escalation	Escalation	Escalation
Ceiling price	No	No	No	No	No
Contract terms	10 yrs. with options	10 yrs. with options	10 years of deliveries with options	10 years of deliveries	10 years of deliveries
Advance payments	5 payments at about 15% of the 10 year commitment. Credit spread over 5 years. Around $16 M.	5 payments at about 15% of the 10 year commitment. Credit spread over 5 years. Around $16 M.	Typically around $10 M. Credited against first deliveries. Paid 4 yrs. prior to the first delivery	Typically around $10 M. Credited against first deliveries. Paid 4 yrs. prior to the first delivery	Small payment on contracting and a major payment 4 years in advance of the initial delivery
Unexcused Termination by customer	Notice Given — % SWU Charge 0-1yrs. — 100% 1-2yrs. — 60% charges decrease with increasing notice periods. No charge at 9 years notice.	Notice Given — % SWU Charge 0-1yrs. — 100% 1-2yrs. — 60% charges decrease with increasing notice periods.	No plant requirements 1 year notice, 80-100% 2 year notice, 75% 3 year notice, 50% 4 year notice, 25% plus 10% on additional deliveries terminated	No provision (100%)	Small fee with 4 years advance notice of reactor is cancelled otherwise 100% of SWU price

TABLE VI-3
(continued)

Fuel-Trac®
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	EURODIF	COREDIF	URENCO		
Contract Features			Requirements	Previous Fixed Commitments	New Contract
Supplier termination	Default by buyer	Default by buyer	Default or bankruptcy of buyer		
Retransfer (sales) restrictions	Not with consent	Not without consent	Subject to government agreements		
Force Majeure	Yes	Yes	Yes, customer may terminate if supplier is delayed a certain period		
Method of settling disputes	Arbitration	Arbitration	Arbitration	Arbitration	Arbitration
Assignment provisions	Only with consent	Only with consent	Only with consent	Only with consent	Only with consent
Limitations on contracting	Only countries that agreed to IAEA safeguards				

TABLE VI-4

USSR AND USA ENRICHMENT SUPPLIER CONTRACT TERMS AND CONDITIONS

Fuel-Trac®
September 1979

	TECHSNABEXPORT	U. S. DOE		
Contract Features		Requirements	Long-Term Fixed Commitment	Adjustable Fixed Commitment
Time from contract signing to first delivery	Not designated	N/A	8 years	6 - 10 years
Designated Reactor	No	Yes	Yes	Yes
Restricts additional deliveries (other sources)	No	Yes	No	Yes
Can SWU be used in another facility	Yes	Yes, after SWU order is placed	Yes	Yes
Reduce SWU requirements of facility by taking other deliveries	Yes	No	Yes	No
SWU limits set by:	Contract	Requirements of facility plus contract ceiling	Contract	Reactor plus contract
Quantities:				
Lead time prior to initial delivery to set quantities	Upon contracting	Upon contracting set ceilings	2 years after contract signing, or 30 days after filing for a CP, whichever is later, but in no event later than 4 years after contract signing	6 years and 3 months prior to first FY of requirement

TABLE VI -4
(continued)

Fuel-Trac®
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Contract Features	TECHSNABEXPORT	U. S. DOE		
		Requirements	Long-Term Fixed Commitment	Adjustable Fixed Commitment
Firm period	Life of contract	180 days	Rolling 10 years	Rolling 5 years
Commitment Period	Not specified	30 years from signing contract	Up to 30 years from initial delivery	10-30 years from start of initial delivery period
SWU quantity flexibility within commitment period	Major - 9 months prior to year of delivery	Upper limit only	Fixed	3 years firm; ± 10% variation in 4th year; ± 20% variation in 5th year of rolling 5 year period
Timing flexibility	Mutual agreement; customer will pay an unspecified penalty	Order 180 days before need	One-time reload delay with delay in issuance of construction permit	Schedule can be adjusted by paying schedule adjustment charges
Assay flexibility	None	Any assay in standard table of enriching services	Any assay in standard table of enriching services	Any assay in standard table of enriching services
Variable tails range	.20 - .35%	None	None	As published in the Federal Register
Variable tails notice	9 months prior to the year of delivery	N/A	N/A	As published in the Federal Register
Estimated or reference tails	.25%	0.2%	0.2%	0.2%

TABLE VI -4
(continued)

Fuel-Trac®
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	TECHSNABEXPORT	U. S. DOE		
Contract Features		Requirements	Long-Term Fixed Commitment	Adjustable Fixed Commitment
Penalty for late delivery of product	Yes	None	None, contract provides for delayed shipment	None, contract provides for for delayed shipment
Price, present	DOE price (in first contracts DOE price less 5%)	$78.20 (ceiling)	$74.85	$74.85
Price adjustments	As changed by DOE	Cost recovery up to ceiling	Adjusted periodically for cost recovery	Adjusted periodically for cost recovery
Ceiling price	No	Yes	No	No
Contract term	Not specified	Up to 30 years from date of signing	30 years of enriching services	10-30 years of enriching services
Advance payments	None	None	$3.3M per thousand megawatts in 3 installments	$3.3M per thousand megawatts in 3 installments or $4,656 million at time of firm-up
Unexcused termination by customer	100% of SWU price	No penalty if 5 year notice; up to 40% if within 5 years	Entire contract prior to issuance of construction permit; penalty is advance payments. Otherwise charge dependent on notice period: Notice Given — % SWU Charge* 0-1 yrs. — 56.9 9-10 yrs. — 23.9	Termination prior to firm-up loss of advance payments. Termination charges dependent on notice given. If reactor is cancelled, penalty only on 5 years of deliveries, otherwise the penalty is on 10 years of deliveries

TABLE VI-4
(continued)

Fuel-Trac®
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Contract Features	TECHSNABEXPORT	U. S. DOE Requirements	Long-Term Fixed Commitment	Adjustable Fixed Commitment
Supplier termination	Safeguards control and guarantee provisions infringed, default by customer	1) Failure to have license to possess material 2) Failure to meet contract obligations 3) Buyer Bankruptcy 4) Termination of agreement for cooperation	1) Failure to have license to possess material 2) Failure to meet contract obligations 3) Buyer Bankruptcy 4) Termination of agreement for cooperation	1) Failure to have license to possess material 2) Failure to meet contract obligations 3) Buyer Bankruptcy 4) Termination of agreement for cooperation
Retransfer (sales) restrictions	Cannot be re-exported without approval, retransfer within the country is allowed	Retransfer approval required to another agreement for cooperation	Sales by customer; retransfer approval to another agreement for cooperation	Sales by customer; retransfer approval required to another agreement for cooperation
Force Majeure	After certain period either party may terminate. Includes prohibitions on export and import	Neither party liable for damages beyond control and without fault or negligence of either party so failing to perform	Neither party liable for damages beyond control and without fault or negligence of either party so so failing to perform	Neither party liable for damages beyond control and without fault or negligence of either party so failing to perform
Method of settling disputes	Arbitration	Arbitration	Arbitration	Arbitration

TABLE VI-4
(continued)

Fuel-Trac®
September 1979

	TECHSNABEXPORT	U. S. DOE		
Contract Features		Requirements	Long-Term Fixed Commitment	Adjustable Fixed Commitment
Assignment provisions	Only with consent	Assignment with consent for same facility	Assignment with Government consent	Assignment with Government consent
Limitations on contracting	Only those who have signed NPT and agree to IAEA safeguards	N/A	Agreement for Cooperation 1) MWe ceiling 2) Safeguards Up to capability of existing facilities, as improved, fully powered and authorized capacity	Agreement for Cooperation 1) MWe ceiling 2) Safeguards Up to capability of existing facilties, as improved, fully powered and authorized capacity

known as the Treaty of Almelo). This treaty, recognizing that centrifugal enrichment was technically feasible, that the centrifuges and support equipment could be manufactured reasonably, and that centrifuge reliability was acceptable, joined the three countries' efforts to create an economically viable entity. This was the result of R & D work begun in the late 1950s and continued in a classified manner throughout the 1960s. The treaty also included a second company, CENTEC, responsible for the development, design and manufacture of centrifuges and plants.

Initially three pilot plants (one for each member country) were located at Capenhurst (UK) and Almelo (FRG and Netherlands). The initial combined capacity of these plants was only 55 MTSWU per year - but they did work. In 1973, two 200 MTSWU per year production plants were commissioned, one each at Almelo and Capenhurst. They came into operation in 1978.

Urenco's initial offering terms were very attractive - essentially requirements type contracts, but with relatively short lead times for large changes in quantity. In fact, a contract between Urenco and a US utility was negotiated in 1974 but failed when the utility cancelled the reactors it was to have serviced.

The original contract flexibility appeared to backfire on Urenco - most of the reactors covered suffered significant slippages and deliveries were delayed. In a protective action (and noting the similar US action) Urenco went to a fixed-commitment contract, but this was unattractive. A later contract (see Table VI-3) appears to be somewhat between the two earlier contracts.

Urenco's market success came mainly in its owners' countries. There were some foreign sales (notably to Brazil, but this is in support of the large FRG contract), but in total Urenco's market position was poor and its essential viability questioned.

In 1978 and 1979, the FRG took a series of steps to change this situation. The FRG, reacting to the potential of a US embargo of enriched material and Dutch reluctance to approve the Urenco/Brazil relationship, became determined to have significant enrichment capability within its national boundaries. According to the treaty, it could not until the Almelo and Capenhurst plants reached a total of 600 MTSWU per year. The FRG also realized that, with the then foreseeable enrichment market, Urenco would not become viable unless major new markets were captured.

The first FRG step was to force decisions to increase the Almelo and Capenhurst plants to at least 600 MTSWU per year and to announce plans to build a plant on German soil. The next step was to provide a load for these plants by cancelling several US contracts, swinging the contract requirements to Urenco, and by convincing the UK to contract their AGR requirements with Urenco.

At this point Urenco serves primarily the UK and FRG (the Dutch market is negligible), and Brazil. It aggressively markets, mainly searching for special situations where it has an advantage (such as a package in conjunction with FRG reactor sales, or a country seeking diversification from US supply).

Eurodif was founded by the French recognizing their need for indigenous enrichment capability to support their growing LWR nuclear program. Electing to use the diffusion process, they knew that a large facility would be needed for economic operation; larger than could be justified by French needs alone. Following their established policy, they invited other nations to join in the project as both owners and customers. Eventually the ownership included France, Italy, Iran, Belgium and Spain. France would own about 43% of Eurodif.

Projecting very rapid nuclear growth, a second organization - Coredif - was formed to construct and operate a second, later facility. Coredif would be owned 51% by France, 25% by Iran and the remainder by Italy, Belgium and Spain through Eurodif.

Because of the owner-customer relationship, 90% of the Eurodif production is committed to its owners (and conversely, its owners are committed to take that production) and the rest to utilities in Germany, Switzerland and Japan. Coredif would have followed a similar policy, reserving 60-80% of production for its customers and selling the rest on the open market.

Of the original Eurodif owners, only France's nuclear program remains strong. Iran's program has essentially disappeared, Italy's can be considered as almost stopped, Belgium's faces serious constraints (lack of sites and no need for new plants), and Spain's is only now emerging from a period of replanning. As a result, Coredif can be considered indefinitely delayed. Eurodif exists and has started production.

France will ensure that the facility continues, but the roles of the other owners is unclear. Both Italy and Iran have attempted to sell their shares and Italy also offers to sell SWU (thus creating a secondary market).

Unlike other fuel cycle components, many contractual arrangements for assuring supply and demand are incorporated in the contract between supplier and customer.

While terms and conditions vary, as shown in the previous tables, in general, key features of enrichment contracts are as follows:

- Contracts are executed 5 to 10 years prior to initial delivery and commit the suppliers to provide certain enrichment services. This contractual term provides the enricher with a firm foundation for financing expansion, upgrading, etc.

- Separative work deliveries are scheduled 4-10 years in advance and are subject to adjustments on the order of up to ± 20%. This contractual term allows the enricher to perform production planning and gives the customer a certain degree of flexibility in adjusting SWU deliveries to match reactor requirements.

- Commitment periods are for 10 years or longer, usually with options to extend. This contractual term allows the enricher to run a facility at near optimum capacity with a committed output and binds the purchaser to take this output.
- Advance payments are on the order of 15% or less of the base contract value. This provision more firmly commits the buyer to the enricher since failure to take delivery under the terms of the contract means forfeiture of the advance payment.

- Termination changes are dependent on how long in advance of delivery the customer gives notice. Generally, these charges are significant if given less than 4 to 5 years in advance of the delivery schedule. These provisions are designed to further bind the purchaser to the enricher, to take delivery and to protect the enrichers' investments.

- Tails levels are generally very firmly referenced, although some customer flexibility in setting the tails assay is becoming the trend. It is necessary for both the supplier and customer to know the tails assay level in advance since the feed delivery, SWU production, power consumption, cash flow, and general plant operation are determined by this parameter.

- Feed delivery requirements in enrichment contracts are rather inflexible. Although delivery of feed in advance of enrichment could be expensive for the customer depending upon the degree to which his actual needs slip, the enricher is assuring himself adequate feed levels for smooth and efficient operation. (Allowing slippage of feed deliveries could perturb the near-term uranium supply market.) Relief from this provision has been the subject of discussion for many years. USDOE has taken a few steps to alleviate the perceived hardship.

In general, the enrichment exports of individual suppliers are not subject to any restrictions other than those related to capacity limitations or non-proliferation conditions. Also, individual supplier nations share comparable and common non-proliferation policies with some important differences.

The US, UK, FRG, Netherlands and the USSR are parties to the NPT and as such undertake not to assist non-nuclear weapons states in the manufacture or development of nuclear weapons. The NPT also obligates these countries to require, as a condition of export, the application of International Atomic Energy Agency (IAEA) safeguards on the supply of enriched material and facilities to non-nuclear weapons states. Such safeguards can be implemented in a number of ways.

5. Fabrication

For LWR fuel the term fabrication generally includes all manufacturing processes from receipt of the fuel material as enriched UF_6 to delivery of finished fuel assemblies. For non-LWRs using natural uranium fuel the definition is similar, except that the fuel material is received as natural uranium in the proper chemical form from a converter.

LWR fuel fabrication actually includes four major sub-processes and the industry initially formed about these. When enriched UF_6 is received, the first step is to convert the material to UO_2 powder. This is primarily a chemical engineering process, and since the fuel material is very pure, the primary concern is simply to avoid contaminants.

The next major step involves using the fuel powder to make fuel pellets. This is a fairly complex mechanical/chemical engineering process involving pressing the powder to pellet shape, sintering it in a high temperature furnace and finally grinding it to dimensions. Very careful control of density, impurities and dimensions are required and the process involves a sophisticated combination of pressing techniques, atmosphere control, firing time, firing temperature and grinding techniques. Since it was recognized very quickly that fuel pellets were an important determinate of ultimate fuel performance, the major fuel fabricators quickly moved to include pellet manufacture in their scope of supply.

The third process includes manufacture of the fuel cladding (now primarily zirconium alloys for LWR fuel) and the other hardware (end fittings, fuel rod end plugs, fuel rod spacer grids, springs, nuts, etc.) needed to join the rods together to form a fuel assembly. Zircalloy clad manufacture was (and still is) a relatively high technology tubing effort undertaken by a few specialty companies and a few major fuel fabricators. Even for the major fuel fabricators, the clad manufacture is usually undertaken as a separate manufacturing operation. The remaining hardware can easily be procured and the manufacture/purchase decision is almost inevitably one of straight economics.

The final step is called assembly wherein the various fuel components are brought together to make the finished fuel assembly. Usually this involves loading the pellets and internal hardware into the fuel clad; welding the end plugs in place (and depending upon the design, purging the interior volume or pressurizing it with helium); building the assembly skeleton of spacer grids, tie rods, and the bottom end plate; inserting the fuel rods into the skeleton and attaching the upper end fitting. This is generally a very high skill hand operation done under carefully controlled environmental conditions, but much automation is appearing in the fuel pellet loading, end plug welding and QC/QA stages.

For most of the national non-LWR reactors (the UK and French Magnox and the UK Advanced Gas Reactors) fabrication is provided by national companies and there is little if any competition. CANDU fuel is provided to Canadian reactors primarily by two manufacturers (Canadian General Electric and Westinghouse Canada) although Combustion Engineering is attempting to enter the market. The fuel is provided to specific AECL design and generally various utilities/ reactors seem aligned with specific fabricators. Initial fuel for export CANDUs is almost always provided by a Canadian manufacturer, but usually the purchasing country quickly establishes indigenous fabrication capability (the technology is relatively straightforward and self-sufficiency is often a primary reason for a CANDU purchase).

US LWR fuel supply has evolved through two commercial stages and now seems settled into a stable third stage. Initially all fuel for US LWR reactors (whether sold to US or non-US utilities) was manufactured by the US reactor vendor. There were very simple reasons for this arrangement - nobody else knew how to make the fuel and the fuel design/manufacture was intrinsic to the reactor/fuel warranties.

About 1970 this evolved into a second-brief-stage. In this stage various US companies - Exxon, Gulf Oil, Getty Oil, United Nuclear among them - perceived the reactor/fuel business as equivalent to the razor/razor blade business. They would let others make the reactor and the initial fuel, but they would then provide the later reload fuel. Concurrently, the US utilities felt that they understood fuel sufficiently that the risk of new fuel suppliers would be low and they welcomed the competition.

The competition was indeed brisk - PWR fuel previously priced at $100-120 per kilogram of uranium was offered for as low as $30-$35 per kilogram of uranium. But such could not last. By late 1973 (early 1974) vendors had abandoned the market to the point that only the reactor suppliers (General

Electric Company, Westinghouse, Babcock & Wilcox, Combustion Engineering) and Exxon Nuclear remained. (Ironically, when United Nuclear Company (UNC) left the market it had a larger contract backlog than Combustion Engineering (CE). But CE's was concentrated and at relatively high prices while UNC's was spread out and at lower prices).

The third stage appears to be relatively stable. The reactor suppliers each supply at least the initial fuel load for their reactors. Matters of licensing, interface and reactor/fuel warranties make any other supply arrangement virtually impossible. Each vendor is highly integrated from design through final assembly (although only General Electric and Westinghouse make fuel clad). Prices are again sufficient to support the extensive required licensing and quality efforts. Warranties have in general simplified to materials and workmanship.

There is still reasonable competition for reload fuel with Exxon Nuclear competing across the board. Only rarely do the reactor vendors compete for fuel for other than their reactors. Fabrication contracts now can be for a few yearly reloads (generally uneconomic because of high fixed engineering costs) or as long as 10 to 15 years. Rarely do the contracts include anything more than fabrication, although the vendors will act as agents (on a cost-plus basis) to handle U_3O_8 and/or enrichment.

In non-US countries the fabrication industry has evolved somewhat differently, but the current situation is similar. At first, fuel was supplied by the US reactor vendors. Then, as the major European nations (France and the Federal Republic of Germany) and Japan developed solid indigenous industries (generally through licensing of US technology), they began to provide their own fuel fabrication. Generally government/industry cooperation is close in these countries and the situation quickly rationalized so that there is one national supplier of fuel in France, one national supplier of fuel in FRG (although Exxon Nuclear competes in the FRG), and one BWR and one PWR fuel supplier in Japan (there is an independent supplier also in Japan, but it has had little success). BNFL supplies all UK non-LWR fuel. There were (and to some extent, still are) numerous smaller suppliers in Italy, Belgium, Sweden, Spain and the FRG. While some are quite technically interesting (particularly in the areas of mixed-oxide or U^{233} fuel), they are negligible from a commercial point of view.

6. Reprocessing

History

All initial reprocessing capability, US and non-US, was created to fulfill military needs. As such the capability existed in only three countries, the US, the United Kingdom (UK), and France. (Throughout this section USSR reprocessing capability, while recognized, is not discussed. NAC has no indication that USSR reprocessing capability will be available to non-COMECON countries except as part of a fuel supply contract for USSR supplied reactors). Initial facilities were developed at Hanford and Savannah River in the US, at Windscale in the United Kingdom and at La Hague in France. Each of the facilities was predominately devoted to the recovery of plutonium from low-burnup, metallic fuel.

In the 1950s and 1960s, as nuclear power for electricity generation was introduced into these countries, the government-owned reprocessing facility was always the reprocessor. As the other countries (mainly in Europe) made initial commitments to nuclear power, they tended to look to the original nuclear countries for needed reprocessing. Still, reprocessing remained entirely under the mantle of governments.

Next, a series of nuclear research facilities sprang up in various countries, often including pilot plant size oxide fuel (UO_2) reprocessing facilities (CNEN in Italy; WAK at Karlsruhe, Federal Republic of Germany; and Eurochemic in Mol, Belgium for example). While these were no longer generally involved in military matters or under total government control, they were research facilities and attracted very little public attention.

Encouraged by the apparent successful operation of the initial government facilities, the progress in LWR reprocessing at the research facilities, and noting the growth of LWR oxide fuel reactors, planners - both government and private industry - saw the need to establish large scale LWR fuel reprocessing facilities. There was, of course, little indication at that time of restrictive environmental regulations or adverse public concern. It is doubtful that such matters warranted more than cursory consideration in those plans.

These plans culminated in:

- NFS, authorized in 1963, beginning commerical operations in 1966 at West Valley, New York, with a capacity of 300 MTU per year, but ceasing operations in 1972 and abandoning commercial reprocessing in 1976.

- BNFL adding an oxide fuel chop-leach head-end to its existing solvent extraction system at Windscale, UK in 1972 (the facility had initiated commercial operations in 1964 with natural uranium MAGNOX metal fuel), but shutting it down in late 1973 after a small explosion.

- France deciding in 1969 to add a similar oxide fuel head-end to its existing facilities at La Hague and moving all metal fuel operations to Marcoule. The new head-end has now begun initial operation.

- Japan planning and constructing an LWR oxide fuel reprocessing plant at Tokai-Mura, beginning operation in late 1977 but then closing down for extensive repairs after reprocessing only 19 MTU.

- India building and operating a 60 MTU per year capacity natural uranium oxide reprocessing plant at Trombay in 1966, and also constructing a 100 MTU LWR oxide fuel reprocessing plant near Tarapur.

- General Electric designing and constructing a 300 MTU per year capacity facility at Morris, Illinois but eventually determining that it was inoperable.

- Atlantic Richfield (ARCO) planning a large (~ 1,500 MTU/year capacity) reprocessing plant at Leeds, South Carolina, but abandoning the effort in 1971 when it could not attract sufficient utility contracts.

- Allied General (AGNS) planning and constructing (~ $250 million) a 1,500 MTU per year reprocessing plant at Barnwell, South Carolina, but now unable to operate the plant.
- BNFL, now recognizing the impracticality of upgrading 1950 facilities to 1970's standards and learning from the 1973 explosion, now plans a new 1,200 MTU per year facility known as THORP and scheduled for 1987 operation.
- COGEMA (France) also planning two new plants at La Hague - UP3A and UP3B - each of 800 MTU per year capacity. When these plants begin schedule operation in 1987 and 1989, the total La Hague capacity would be ~ 2,400 MTU per year.
- EXXON planning a large (1,500 MTU per year initial capacity with possible expansion to 2,100 MTU per year) plant located near Oak Ridge, Tennessee. The initial licensing procedures were enjoined and Exxon has essentially abandoned the project.
- Belgium considering revamping and reopening the Eurochemic plant, possibly as early as 1983/1984.

If the initial military oriented metal fuel facilities are considered as the first phase of reprocessing, the small research LWR oxide fuel facilities as the second, and the large commercial LWR oxide fuel facilities as the third phase, it is apparent that - at least to date - the third phase has been unsuccessful.

Why has this transition to large, commercial LWR oxide fuel reprocessing been so difficult? With the vision of hindsight two factors appear paramount; one technical, one socio-political.

The highly favorable early metal fuel reprocessing gave plant designers confidence that a transition to LWR oxide fuel could be readily achieved. However, as is now recognized, oxide fuel - especially high burnup LWR fuel - is not like low burnup metal fuel. The much higher radiation rapidly degraded previously acceptable solvents. The highly sintered oxide fuel proved difficult to completely dissolve and carryover led to unexpected radiation concentrations. The LWR oxide fuel head-end process has been proven to involve considerable mechanical, gaseous effluent, and clad hull complications.

These factors combined to cause the earliest third phase plants - NFS in the US and BNFL in the UK - to operate at much less than design throughput. GE at Morris, attempting to gain superior economics from a newer technology, apparently failed to adequately proof-test all portions of the technology nor did they properly recognize the requirements of remote maintenance.

These factors all, however, are engineering problems and as such, are subject to rational solutions at some cost. Presumably, the new planned facilities - AGNS, PNC, BNFL, THORP, COGEMA - have been able to learn from these problems and do incorporate design solutions. (Note, however, there has been but scant large scale operating experience. Thus, even the THORP, and UP3 plants scheduled for the late 1980s are being designed without an operational background; no doubt other now unknown technical problems exist).

Nevertheless, it must be recognized that the technical problems are not the prime factor in large scale LWR reprocessing. Rather, social and political factors loom as the central issues. These, unfortunately, are much more complex and cannot always be expected to have rational solutions.

Current Status

Light water reactor spent fuel reprocessing is presently non-existent in the US and proceeding only in very halting steps throughout the rest of the World Outside Of Centrally Planned Economic Areas (WOCA).

United States

The status of US reprocessing plants can be summarized as:

NFS - The facility has not operated since 1972 and its owners (Getty Oil Company and Skelly Oil Company), announced in late 1976 abandonment of commercial reprocessing. Their stated reason was the projected high cost (~ $600 million) of modifications required to meet current regulations. Approximately 165 MTU of spent fuel are stored at NFS, but the company does not accept additional fuel for storage. Under terms of its license, NFS is attempting to turn responsibility for the plant to the state of New York. In turn, the state of New York contends that ultimate responsibility rests with the US government. The major question revolves around responsibility for the estimated 615,000 gallons of high level liquid waste (with most of the plutonium concentrated in ~ 30,000 gallons of sludge) in tanks on the site.

G.E. - The G.E. Morris facility has never operated as a reprocessing plant, and probably never will. In an attempt to develop economic small scale reprocessing facilities, G.E. undertook major departures from the Purex process. After several years of plant checkout, G.E. concluded in 1974 that the facility was inoperative in its current state and that the cost of modification was not warranted.

The plant has now been renamed as the Midwest Storage Facility, and is now utilized solely for storage of unprocessed spent fuel. Current capacity is approximately 700 MTU and an application to construct another pool (~ 1,100 MTU capacity, operation in 1982), was submitted in May, 1977 but later withdrawn after the US announced its AFR plans. G.E. states that the storage capacity is available only for G.E. - owned fuel and for reactors which previously held G.E. reprocessing contracts.

<u>AGNS</u> - The separations plant and UF_6 conversion facility are complete at the Barnwell, South Carolina site. Waste solidification and plutonium conversion (to PuO_2) facilities have yet to be designed or constructed. (In fact, the basic US government criteria for the facilities have yet to be established.) The plant license proceedings are held up and plant operation cannot be foreseen. AGNS is vigorously attempting to sell the entire plant to the US government.

Two factors - the regulatory climate and governmental reprocessing policy - overlay all US reprocessing activities, and can be expected to do so for the indefinite future. The regulatory climate, although replete with socio-political happenings, primarily involves ever-tightening of existent regulations and ever-delay of needed new regulations, rulings, or criteria (e.g. - GESMO, waste solidification, plutonium conversion). The result is greatly increased costs (the projected cost of modifying the NFS plant rose from ~ \$15 million to ~ \$600 million in five years, and the estimated cost of a new 1,500 MTU facility is now at least \$2.5 billion), extended time periods to construct (now estimated to approach 10 years), and sharply heightened uncertainty that any reprocessing plant could even be completed (regulations could well escalate faster than plant construction proceeds).

The second, and much more serious factor affecting US reprocessing is the governmental policy of "indefinite deferral" of US reprocessing and recycle. This policy has the rather obvious effect of stopping all reprocessing plant projects while it remains in force. When considered in the context of the public's and government's characterization of nuclear energy, the policy discourages even the planning of reprocessing projects, and its effects will probably be long lasting. The net result is that - considering the total impact of the regulatory climate, the indefinite deferral policy, and the "last resort" attitude - resumption of commercial US LWR fuel reprocessing must be considered only for the very distant future, if at all.

Non-US

The status of non-US reprocessing differs in detail from country to country. In no country can reprocessing be said to be proceeding smoothly.

In general, the major industrialized nations of Europe and Asia do not have large indigenous non-nuclear energy supplies. Neither do they have large quantities of uranium. These facts lead to two pragmatic planning conclusions:

- These nations feel a strong need for nuclear power; LWRs now and FBRs later, and
- these nations feel an equally strong need for reprocessing and recycle; to conserve natural uranium resources and to lead to FBRs.

These planning conclusions inevitably lead to conflict with US policy. The technical aspects of this difference have been the subject of the INFCE exercise; no doubt political and diplomatic matters will be considered even after INFCE is officially closed.

United Kingdom

British Nuclear Fuels Ltd. (BNFL) was incorporated in 1971 (wholly owned by the United Kingdom Atomic Energy Authority) to undertake the non-military activities of the UKAEA. Reprocessing is among these activities.

As noted earlier, the first BNFL oxide fuel reprocessing capability occurred in 1970 when a "chop-leach" head-end was added to the existing Windscale Purex facility. (One cycle of Butex extraction was interposed between the chop-leach head-end and the existing Purex solvent extraction lines in order to reduce the oxide fuel fission product content to match that of the metallic fuel.)

Investigations after the failure of the facility in 1973 (after reprocessing some 120 MTU of oxide fuels), indicated that the approach of adding an oxide fuel head-end to an older metallic fuel extraction line would not be satisfactory for long-term operation.

While the head-end will be extensively refurbished and is expected to yield some oxide reprocessing capability, testimony at the Windscale inquiries indicated that:

- reprocessing Magnox fuel is the top priority for the current facility,
- the head-end will not be designed as a production facility, and

- because of that and because of inability to meet stringent, long-term environmental requirements, the head-end oxide reprocessing capability will be limited to 3-4 years of operation.

With this in mind, the primary BNFL plans have shifted to an entirely new oxide reprocessing plant (to be known as THORP-1, THermal Oxide Reprocessing Plant-1). The plant is currently scheduled for initial operation in 1987 with a capacity of 1,200 MTU per year and a contracting limit of 6,000 MTU over the first 10 years of operation (about 400-500 MTU for UK requirements and the remainder for Japanese and other non-UK contracts).

The proposed plant design appears fairly conventional, well thought-out, and with a thorough pilot program. The most salient point is that its schedule is consistently slipping.

France

Cogema, formed in late 1976 by the CEA to handle commercial nuclear fuel cycle activities, operates the La Hague and Marcoule reprocessing plants.

La Hague, now designated as the plant to handle all LWR oxide fuel, is in the startup phase for its oxide head-end addition to the existing UP-2 natural uranium plant. This process has been underway since late 1976, the plant has operated but sporadically and there has been some industry speculation concerning operational problems. Presuming eventual successful operation, the head-end would be expanded to 800 MTU.

Two new plants, UP-3A and UP-3B, of 800 MTU capacity each, are presently planned for operation in 1987 and 1989.

While the French reprocessing effort would appear to be much more successful than its UK counterpart, three points must be considered:

(1) The agressive French position naturally leads to a strong contracting stance,

(2) France is not yet subject to the virtually endless UK hearings, and

(3) La Hague has yet to successfully demonstrate large scale commercial LWR reprocessing.

Federal Republic of Germany

After considerable planning, the FRG embarked on a three-phase program. The first involved contracts with Cogema to store and reprocess 1705 MTU, the second involved a temporary spent fuel storage facility (1500 MTU capacity) at Ahaus for operation about 1985, and the final phase involved a very large storage/reprocessing/recycle/waste disposal facility at Gorleben.

The recent refusal of the local government to permit the reprocessing/recycle plant at Gorleben and the reiteration of Ahaus authorities that their facility is only temporary (i.e. -implying the existence of Gorleben) have effectively destroyed the FRG plans. The nation may de facto be forced to adopt a plan similar to the US - intermediate storage followed by eventual disposal or reprocessing.

Japan

Japan has three sets of large reprocessing contracts with BNFL and Cogema and may succeed in bringing the PNC 210 MTU plant back to operation. However, this is not sufficient to meet their long-term needs. Consequently planning, financing and property acquisition for a large (1400-1500 MTU capacity) plant is now beginning. Initial operations are stated for the late 1980s, but delay into the early 1990s is probable.

Commercial Aspects

Initial reprocessing contracts varied considerably to meet the needs of the customer. They were postulated on either a certain specific quantity of fuel or all fuel discharged over a certain period. The latter contractual method often had serious consequences for the reprocessor - as the reactor schedule slipped after the entire contractual load drifted away. Prices (US) were on the order of $30-35 per kilogram of uranium for reprocessing and waste disposal. Transportation added another $5-10/kg of uranium. The final products were uranyl nitrate and plutonium nitrate.

In the European area such an overabundance of reprocessing capacity was perceived in the early 1970s that United Reprocessors was formed between France, the UK and the FRG to "rationalize" reprocessing capacity plans and contracting.

That has now dramatically changed, with the single most salient fact being that unless a nation is presently contracted (with Cogema or BNFL) for reprocessing or plans to build its own plant, it cannot reasonably expect to reprocess in this century.

Cogema, following the standard French policy, requires that non-French customers provide the capital for the new La Hague plant in proportion to their desired use of it. The price (including spent fuel storage, reprocessing and interim storage of recovered products and wastes) is estimated at $400 per kilogram of uranium or more. (The terms state that customers will pay all costs plus a fee.) Transportation ranges from $50-125 per kilogram of uranium depending upon the distance/method of shipment. Customers have the option to supply their own casks and transport, but the casks must meet Cogema acceptance criteria. The price does not include ultimate waste disposal and the customers may be required to take back the waste for indigenous disposal.

The present UP-2 facility is devoted initially to non-France needs (French LWRs simply have not discharged much fuel yet). When UP-3A operates, it will be devoted to non-French needs but UP-2 will become oriented towards French fuel. UP-3B is for French fuel. In any case of plant delay or operational problems, French fuel has priority. If additional capability becomes available (either through better than anticipated operation or continued operation after the initial ten years) it will be offered to the existing customers on a pro-rata basis. Considering only the current planned facilities (UP-2, UP-3A and UP-3B) the plant is backlogged with contracted non-French fuel until the late 1990s. By the mid-to late-1990s French fuel alone could utilize the entire La Hague capacity.

The BNFL situation is similar to Cogema, with the primary exception that Japan is virtually the only non-UK customer of any significance. The plant is rated at 1200 MTU per year, but based upon experience, the UK has stated the throughput to be 600 MTU per year with only 300 MTU per year available for non-UK reprocessing. The current contracted backlog should not be worked off until almost the year 2000.

The FRG facilities (if ever) are to be avilable only for FRG fuel and it is believed that Japan's facilities may be also so reserved.