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ENRICHMENT SUPPLY AND TECHNOLOGY OUTSIDE THE UNITED STATES

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For Presentation at the American Nuclear Society Executive Conference on Uranium Fuel Supply at Monterey, California, January 26, 1977

January 13, 1977

UNION CARBIDE

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This review of foreign uranium enrichment capacity and uranium isotope separation technology is based solely on news items and articles in the public literature. It should not be presumed that the inclusion in this presentation of any reported information necessarily attests to its validity.

Foreign Enrichment Capacity

There are currently just four nations, other than the U.S., that have facilities larger than that of a pilot plant for the enrichment of U-235. These are Great Britain, France, Russia and China. All of their existing plants were built initially for the purpose of fulfilling military objectives. Of the four, only Russia has sufficient capacity beyond its own national needs to sell some toll enrichment services abroad.

A strong interest has been developing in many nations in recent years to acquire their own capacity to enrich uranium to fuel grade levels, or at least to share in such an enterprise. The chief motivation for this is the desire to acquire an assured supply of fuel for their nuclear power reactors. In the case of a few nations that possess large, rich deposits of uranium ore, the prime motive is to maximize the economic benefits realizable from the ownership of such a resource by enriching their own uranium and selling the product. There are a few countries that are interested in acquiring uranium enrichment facilities in order to capitalize on the fact that they have sites where large quantities of inexpensive power are, or can be made, available.

In general, commercial scale uranium enrichment imposes such a burden on a nation's resources that most of the nations seeking to develop their own enrichment capability have sought partners to join them in such an enterprise. Two multi-national European consortia that were formed for this purpose and have become well known in recent years are Urenco and Eurodif. Both of these groups currently have sizable enrichment facilities under construction. West Germany and Brazil have formally agreed to a joint enrichment venture, the first phase of which is the construction of a small demonstration plant in Brazil. Japan and Australia and also France and Canada have engaged, for a number of years, in intermittent negotiations regarding joint enrichment ventures with no agreements to date. On the other hand, South Africa has developed independently an isotope separation process it calls unique and has announced plans to apply it in a commercial scale plant.

World-wide plans, outside of the U.S., for the construction of uranium enrichment facilities as they stood at the end of 1976 are summarized in Table 1. For those plans that are listed as definite in this table, there may be some slippage in the year of completion of the full capacity: for example, there is talk that Urenco might decide, depending on market conditions, to stretch its completion date for 10,000 MTSWU/year capacity to 1988, from the original date of 1985. With regard to conditional plans, Coredif, which is an affiliate of Eurodif, intends to expand its capacity beyond the first 5400 MTSWU/year only if the market outlook in the 1980's appears favorable. It is expected that Japan's intention to build the listed facility will be affected by any success it has in lining up a partner for a joint venture.

In March 1970 Great Britain, West Germany and the Netherlands officially formed the tripartite Urenco/Centec Group. These three nations, each of which had been engaged independently in gas centrifuge research and development, formally agreed to pool their technologies and financial resources for the production of nuclear fuel by the enrichment of uranium by centrifugation. Three pilot plants, two at Almelo, each with a capacity of 25 MTSWU/year, and one at Capenhurst with a capacity of 14 MTSWU/year, have been built and are now fully operational. Each of the three partners is testing their own particular machine designs in one of the three plants. Product from these pilot plants has been delivered to utilities in the member nations. Two demonstration plants, one at each site, are currently under construction. Each of these, when in full operation in 1979, will have a capacity of 200 MTSWU/year. It has been reported that the first cascades at each site, representing about one-tenth of the scheduled capacity, are now in operation. Urenco plans call for installation of 1400 MTSWU/year at Almelo and 700 MTSWU/year at Capenhurst by 1982. Original expectations were that these would be expanded to a total of 10,000 MTSWU/year by 1985, but according to some reports this may be stretched out to 1988 because of slower than expected growth in demand. Very recently, Uranit, which is the FRG member of Urenco, announced it will build a 1,000 MTSWU/year centrifuge plant in Germany to be ready about 1985. It is not clear whether this represents an addition to Urenco's capacity plans or a substitution in whole or in part for another installation in its program.

Eurodif, the other active multinational consortium, was promoted and organized in 1972 under the leadership of France. The membership and apportionment of shares in Eurodif has been changeable. Presently it is constituted by Belgium and Spain 11% each, Italy 25%, France 28% and Sofidif 25%, which is 40% owned by Iran and 60% by France. By utilizing the tried and proven French gaseous diffusion technology, Eurodif minimized design and development efforts and was thereby able to begin

TABLE 1

ANNOUNCED FOREIGN ENRICHMENT CAPACITY PLANS
AT THE END OF 1976

Nation or Group	Scheduled Capacity, MTSWU/yr	Process	Expected Year of Completion of Scheduled Capacity*
Definite			
Urenco	10,000	Centrifugation	1985
Eurodif	10,800	Gaseous Diffusion	1982
Coredif**	5,400	Gaseous Diffusion	1985
Nuclebras†	180	Separation Nozzle	1981
South Africa	5,000	Stationary-Wall Centrifuge	1986
USSR	3,000††	--	1982
Sub-Total	34,380		
Conditional			
Coredif	5,400	Gaseous Diffusion	1989
Japan	6,000	Centrifugation	1985
Total	45,780		

*Parts of the facilities listed in this table will be in operation and producing prior to the projected completion date.

**Coredif and Eurodif are closely affiliated groups having the same membership but a different arrangement of shares.

†Nuclebras is a joint venture by the FRG and Brazil. The listed installation is a demo plant. Successful operation is expected to be followed by the construction of a commercial scale plant, but there has been no word, as yet, on its size.

††The USSR, which has an existing gaseous diffusion capability, has not announced any plans to increase its enrichment capacity. The 3,000 MTSWU/yr listed here represents only the peak quantity of separative work the Russians will have available for foreign sale, according to reports by prospective purchasers.

construction of its industrial scale plant in July 1974 at Tricastin in France. This plant will have a capacity of 10,800 MTSWU/year (increased from the originally planned 9000) and is now scheduled to be in full operation in 1982. In 1975, another consortium called Coredif with the same multinational membership as Eurodif but a different distribution of shares (Eurodif 51%, France 29% and Iran 20%) was organized to assess future nuclear demand and build a second Eurodif-type plant if the study results justified it. Late last year, the decision was made by Coredif to proceed with a 5400 MTSWU installation to be fully in production in 1985, followed by a doubling of the capacity in the late 1980's. A site for the Coredif plant has not yet been selected.

In addition to its efforts in centrifugation, West Germany has been developing the separation nozzle process for more than a decade. It has made significant progress in making the process a viable one. Reports were circulating a few years ago that a demo plant of about 700 MTSWU/year for the jet nozzle was planned. In 1975, the FRG and Brazil signed a bilateral nuclear accord whereby the FRG will sell its jet nozzle technology to Brazil along with follow-up technical support for the eventual construction of a jointly owned enrichment plant in Brazil. Initial plans by the partnership organized under the name of Nuclebras call for a demonstration plant with capacity of 180 MTSWU/year to be built in Brazil. This will evidently substitute for the demo plant originally projected to be built in Germany. There is no word on the capacity of the commercial scale jet nozzle plant that Nuclebras envisions for the future.

Several years ago the South Africans announced that they had developed a uranium isotope separation process that is different from all those which had hitherto been used or considered, the nature of which they declined to disclose. In 1975, they announced that the process is based on a separating element which is described as a high performance, stationary-wall centrifuge operating on a mixture of UF_6 and H_2 at higher than atmospheric pressure. Many observers, including Becker himself, according to reported comments, have the opinion that the South African process is fundamentally a variation of the Becker separation nozzle. The South Africans have built and are operating a pilot plant testing their process and report that it has fully met all theoretical expectations. An official decision has been made to construct a commercial scale enrichment plant, but its capacity will be determined in 1978 contingent upon the size of enrichment service contracts they can make by then. Present unofficial best estimates for the plant size are 5000 MTSWU/year to be fully on stream in 1986.

Japan has been seeking partnerships, so far unsuccessfully, wherein Japan will furnish most of the financing and the partners supply either the feed uranium or a proven technology or both. Meanwhile, Japan has been developing its own centrifuge design. After having tested machines in very small pilot plants, it is about to begin construction of a large pilot plant comprised, when completed in about 1980, of approximately 7000 machines with a capacity of about 50 MTSWU/year. Successful operation of this pilot plant will be followed by the construction of a full sized centrifuge facility of 6000 MTSWU to be ready in 1985, unless Japan succeeds in making other arrangements in the interim.

The USSR, which has never revealed the capacity of its existing uranium enrichment facilities nor any plans for expansion, has been in the market as a seller of enrichment services. There have been reports, however, from other than official USSR sources, that it is in the process of increasing its enrichment capacity in order to take care of its growing domestic requirements and to expand into the world market for toll enrichment services. The capacity quantity shown for Russia in Table 1 merely represents outsiders' estimates of how much separative work it will have available for foreign sale annually. What relationship this bears to the actual expansion, if any, of its uranium isotope separation facilities is unknown.

A number of nations, in addition to those already mentioned, are considering the feasibility of building commercial scale enrichment facilities. A current list of these are Australia, Canada as specifically represented by its province of Quebec, India, Sweden and Zaire. None of these have plans sufficiently advanced which would warrant their inclusion in the table.

Portions of the projected capacities listed in Table 1 will be in operation prior to the final project completion date shown. Accordingly, we have constructed a schedule, shown in Table 2, of the approximate expected growth in enrichment capacity outside of the U.S. based on the various pronouncements we have seen to date. This tabulation omits the conditional capacity plans listed in Table 1. This schedule is probably optimistic since there are some reports of possible slippage in on-stream dates. According to some sources, for example, Urenco's two demo plants originally expected to be in full operation in 1978 will probably be completed in 1979, the 2100 MTSWU capacity scheduled for completion in 1982 will probably not be finished until 1983, and the planned attainment of a capacity of 10,000 MTSWU scheduled for 1985 may be stretched out to 1988. With respect to this table, the recently announced Uranit plan (the FRG member of Urenco) to build a 1000 MTSWU plant in Germany is treated as a re-allocation of, rather than an addition to, planned capacity.

The numbers shown for Russia in Table 2 do not represent a growth schedule of separative work capacity but rather one of separative work available for foreign sale. The sources of these numbers are evidently prospective purchasers of future Russian toll enrichment services.

Sales of Separative Work

All of the global demand for current toll enrichment services is being met by the U.S. and the USSR, with the U.S. being the larger supplier by far. Eurodif and Urenco have entered the market by selling contracts for future delivery of separative work services during the next decade. A summary of the sales contracts signed by foreign suppliers to date is presented in Table 3.

TABLE 2

APPROXIMATE SCHEDULE OF FOREIGN ENRICHMENT CAPACITY GROWTH

Year	National or Group Capacity Increment						Total Increment for Year	Cumulative Capacity Increase
	Thousands of MTSWU/Year							
	Eurodif	Coredif	Urenco	USSR*	Nuclebras	S. Africa		
Thru 1976			0.1	0.4			0.5	0.5
1977			0.2	0.4			0.6	1.1
1978			0.2	0.2			0.4	1.5
1979	3.0		0.4	0.5			3.9	5.4
1980	3.2		0.4	0.5			4.1	9.5
1981	2.3		0.4	0.5	0.2		3.4	12.9
1982	2.3		0.4	0.5			3.2	16.1
1983		2.7	2.3				5.0	21.1
1984		2.7	2.6			1.6	6.9	28.0
1985			3.0			1.6	4.6	32.6
1986						1.8	1.8	34.4
TOTAL	10.8	5.4	10.0	3.0	0.2	5.0	34.4	

*For the USSR this is a schedule in growth of foreign sales availability and not that of capacity expansion.

TABLE 3

SALES OF ENRICHMENT SERVICES BY
FOREIGN ENRICHERS TO OUTSIDERS

Enricher	Buyer	Total SWU, MT	Delivery Period
Eurodif	FRG	600	1981-84
	Japan	10000	1981-90
	Switzerland	920	1981-90
	TOTAL	11520	
Urenco	Brazil	2000	1984-94
	Ireland	570	1981-90
	Switzerland	850	1983-90
	TOTAL	3420	
Russia	Austria	1260	1978-87
	Belgium	1300	1979-85
	Finland	620	1978-86
	France	3500	1979-83
	FRG	6220	1976-90
	Italy	3920	1976-83
	Spain	5100	1978-86
	Sweden	600	1979-82
	United Kingdom	1000	1981-90
	TOTAL	23520	

The participating states in the two consortia, Eurodif and Urenco, which have sizable enrichment facilities either under construction or on the drawing boards are expected to take the greater part of the production of their consortium. Each member nation will purchase, on an indefinitely continuing basis, a fraction of the available production roughly in proportion to its financial share in the enterprise. There will be some production, however, in excess of the total requirements of the member states, which will be available for sale to outsiders. Only sales by a consortium to non-member states are listed in Table 3.

According to Eurodif, 97% of the rated capacity of its Tricastin plant has been contracted out through 1990. It has sold about 11,500 MTSWU to outsiders, deliverable in the 1980's, most all of it to Japan. According to Urenco the entire capacity of about 2,100 MTSWU/year it expects to have on stream in 1982 or 1983 has been committed. Sales to non-member states total about 3,400 MTSWU with more than half of it to Brazil. Russia has contracted to deliver a total of about 23,500 MTSWU through 1990 to nine European countries on this side of the "Iron Curtain", five of them members of Eurodif or Urenco. Russia is known to be seeking a contract with Australia whereby Australian uranium would be enriched in Russian plants. It has also been reported that Russia is interested in selling separative work services to utility companies in Japan and the U.S.

Price of Separative Work

After some reluctance to disclose its separative work price, Eurodif declared, toward the end of 1976, that it is about $100/SWU plus a cost escalation factor to non-member states, with the price somewhat less to partner nations. Urenco announced in early 1975 that its current separative work contract price is the order of $100/SWU plus an escalation factor that is related to the degree of price inflation and to certain market conditions. The South Africans claimed initially that their process will be able to perform separative work at a price 20% less than that of U.S. gaseous diffusion. Lately, it has said that its process enrichment costs compare favorably with that for an advanced centrifuge plant, that is, the order of $100/SWU. The South Africans have indicated that they are about ready to write contracts for the future delivery of separative work. None such have yet been reported. Thus, three prospective commercial enrichers, Eurodif, Urenco and UCOR (South Africa), each with a different process, have in effect come up with essentially the same enrichment costs.

While on the subject of enrichment cost, a comparison of its major components for these processes would be of interest. Such a comparison is made in Table 4. Though no plans for a commercial scale plant have been announced or a probable SWU market price conjectured for it, West Germany's separation nozzle process is included in this table since it may be an economically viable process with potential future industrial scale application. In this tabulation each of the processes is compared with respect to unit capital investment costs, unit power costs, and other operating unit costs with those for gaseous diffusion. The comparisons are based

TABLE 4

COMPARISON OF PROCESS ECONOMICS

Process	Unit Capital Investment	Unit Power Cost	Unit Operating Costs for Other Than Power
Centrifuge: Urenco	>	<	>
Stationary-Wall Centrifuge: South Africa	≃	≃	NE
Separation Nozzle: FRG	<	>	≃

Definition of Symbols:

≃ approximately equal to diffusion

>,< greater than, less than diffusion, respectively

NE no estimate

on estimates made by the process developers. Note should be taken of the fact that the unit power cost for the centrifuge is less than, and for the separation nozzle process greater than, that for gaseous diffusion in reflection of their relative specific power consumption. For the South African process, the specific power consumption is greater than that for diffusion but its unit power cost is given as roughly equal to that of diffusion because of low cost power asserted to be available at the projected plant site.

Foreign Technology

There are many nations which have active research and development programs on uranium isotope separation. Some of these nations are seeking to develop their own version of a technology already developed by others in order to acquire an uninterruptable and independent means of obtaining nuclear fuel. Other countries, which already have a viable enrichment technology or even an operating large scale facility, are working on improving their present process and are simultaneously investigating other processes which promise to be economically superior. A summary of the known major R&D activities outside the U.S. is presented in Table 5. This tabulation does not offer a complete list of the processes that are being investigated or necessarily a complete list of countries with an R&D program in uranium enrichment. Other aerodynamic processes being investigated in France and Germany, and plasma-based processes being researched in Australia, West Germany and the Netherlands, have been omitted since the work thus far is either mainly of a preliminary nature or there is some question whether there will be a continuing effort.

TABLE 5

FOREIGN R&D ACTIVITIES ON URANIUM ISOTOPE SEPARATION

Process	Country or Consortium	Status
Centrifugation	Australia	R&D since 1965; mainly single machine studies with some theoretical and experimental cascade work. Construction of a pilot plant is under consideration.
	France	R&D since 1960. First 3 generations of machines indicated centrifugation at least twice as expensive as gaseous diffusion. Now looking at 4th generation design, which is a supercritical machine.
	India	Report in 1972 that Indian AEC was setting up a study program. No reports since.
	Italy	Work in progress since 1969. Was testing 2nd generation machine in 1975.
	Japan	A 180-machine cascade in operation since 1973 and a cascade of 250 improved machines completed and running in 1976. Pending official authorization a 50 MTSWU demo plant consisting of about 7,000 machines planned for completion in 1979. An industrial scale facility of 6,000 MTSWU/yr for start-up in 1985 is under consideration.
	Sweden	Basic studies since 1971.
	Urenco	Initially independent efforts by FRG, Netherlands and UK, combined into joint program. Operating 3 pilot plants. Portions of two demo plants in operation.

TABLE 5 (continued)

FOREIGN R&D ACTIVITIES ON URANIUM ISOTOPE SEPARATION

Process	Country or Consortium	Status
Gaseous Diffusion	China	Operating plant of unknown but presumably small capacity.
	Eurodif	Has a large commercial scale facility under construction. Participants are Belgium, France, Iran, Italy and Spain. R&D is mainly in France with some activity in Italy.
	France	Has operating plant of about 400-600 MTSWU at Pierrelatte. Is providing its technology to Eurodif. Ongoing R&D program.
	Italy	Barrier and compressor testing for Eurodif.
	Japan	Has developed and done experimental work with barrier made of alumina and teflon. Has built small pilot plant (13 stages) for testing barrier, and flow loops for testing seals and compressors with UF_6. R&D is continuing.
	Russia	Has operating plants of undisclosed capacity. (Some outside sources report that the capacity is 7,000-10,000 MTSWU/year.)
	UK	Has operating plant of about 400-500 MTSWU per year at Capenhurst. No reports of any continuing R&D program.

TABLE 5 (continued)

FOREIGN R&D ACTIVITIES ON URANIUM ISOTOPE SEPARATION

Process	Country or Consortium	Status
Chemical & Ion Exchange	Australia	Some bench scale ion-exchange measurements and a conceptual design study. Concluded particular process cannot be competitive.
	France	Experimental work on ion and chemical exchange systems. Has not found a system with separation parameter values needed for an economically viable process.
	Japan	Single column and multi-column experiments in 1960's. Have studied numerous exchange systems and performed many single column and multi-column experiments. R&D is continuing though evidently at a reduced level.
	Russia	Has reported successful efforts on isotopes of elements other than uranium. It must be presumed that there has been and may still be some R&D on uranium.

TABLE 5 (continued)

FOREIGN R&D ACTIVITIES ON URANIUM ISOTOPE SEPARATION

Process	Country or Consortium	Status
Separation by Laser Radiation	Australia	Theoretical assessment in 1970-1971. Experimental program since. Have demonstrated enrichment on the milligram scale.
	France	Development work since 1960. Recent report that highly enriched U has been produced in small quantities.
	FRG	Small-scale R&D program since 1971.
	Israel	May have R&D program.
	India	Report has it that India is investigating a new technology, possibly involving lasers.
	Japan	Small R&D program initiated in 1975.
	Russia	Known to be engaged in general laser isotope separation work. Though no reports have been issued on work on uranium isotopes, it must be presumed that an R&D program on uranium is being pursued.
	UK	Small-scale R&D program started in 1975.

TABLE 5 (continued)

FOREIGN R&D ACTIVITIES ON URANIUM ISOTOPE SEPARATION

Process	Country or Consortium	Status
Separation Nozzle	FRG-Brazil	Process conceived and developed in FRG. Proponents hold it is or will shortly be economically competitive with gaseous diffusion. Demo plant under construction in Brazil.
Stationary-Wall Centrifuge	South Africa	Proponents claim it is more economical than gaseous diffusion. Pilot plant in operation. Intent to build industrial scale announced.