"feed," and in return, they receive the enriched product for a fee. In accordance with federal statute, the DOE charge for processing is set at a level that recovers the full costs--both capital and operating--of the service. 1/ In fiscal year 1983, the government will spend roughly $2 billion in enrichment activities, all of which should be returned in the form of revenue from sales of the product.

The "gaseous diffusion" plants that now produce enriched uranium fuel are old, built originally for the nuclear weapons program in the late 1940s and early 1950s. Because these plants are extremely energy intensive, they are expensive to operate and promise to become more so. To curb future costs and remain competitive as a world supplier of enriched fuel, the United States has been investing in the development and construction of new "gas centrifuge" enrichment facilities. These will temporarily increase U.S. domestic capacity in the early 1990s, but they are designed primarily to replace the existing gaseous diffusion plants with substantially lower-cost production capacity.

## THE IMPLICATIONS OF UNCERTAIN MARKET PROSPECTS

Involving between $400 and $850 million a year in capital outlays alone, investments in the new plants are substantial, and they are being committed in an uncertain market environment that is not entirely favorable for the U.S. enterprise. Foreign enrichment competition has increased. The free world now has more enrichment capacity that it can use. And growth rates of nuclear power have slowed. In the face of this uncertainty, the Congress is considering whether construction of any new capacity at all is necessary, whether current plant construction should be abandoned in favor of more advanced though distant technology, and whether the process now being built will allow the United States to be more competitive in the world enrichment market.

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1. This study assumes that current policy requiring full-cost recovery will continue. Thus, it does not investigate the implications for the enrichment investment decision of alternative pricing strategies. Specifically, it does not examine how changed pricing policies might affect the demand for uranium enrichment. Demand projections used in the CBO's initial analysis were prepared by DOE, which has projected demand as being consistent with the pricing rules stipulated by current policy; sensitivity analysis examining the effects of different demand assumptions is presented in Chapter IV.

## THE ISSUES

To help assess these questions, the Congressional Budget Office has reviewed possible alternatives for supplying enrichment services in the future. Accordingly, this study attempts to answer three questions:

- **Which of the investment options available would supply enrichment service most cheaply to the consumer?**

- **Which would afford the lowest cost to the federal government over the life of the enterprise?**

- **What effect might alternative demand projections for enriched uranium have on choice of technology?**

The results of this study concern the costs of different enrichment technologies and their services. Though cost is certainly an essential element of competition, it does not necessarily indicate an ability to compete successfully in the world market. To treat this issue fully would require more detailed examination of current marketing strategies, of U.S. pricing policies now in force, and of assumptions about foreign countries' commitments to their own domestic enrichment capacities than this study can provide.

Similarly, the study does not treat the fundamental issue of what role--if any--is appropriate for the United States in future enrichment markets. The United States could conceivably withdraw entirely from the enrichment business, effectively conceding the market to foreign competitors and taking the position of buyer rather than vendor. Such a course would have significant implications for both national and international policy. It would run counter to the current objectives of the Nuclear Nonproliferation Act of 1978, which calls for the United States to remain a reliable supplier of nuclear fuel to nations that support a nonproliferation policy. These areas are beyond the scope of this study. The analysis in this paper rests on a premise that the United States will continue to take a major part as a producer of enriched uranium. Accordingly, the analysis focuses on the economic aspects of enrichment technologies to assist the Congress in identifying the most cost-effective choice.

## PLAN OF THE STUDY

Chapter II describes the uranium enrichment technologies now in use and under development and describes the aims and mechanics of the U.S. enrichment enterprise. Chapter III explores the demand for enrichment within and outside the United States and offers two alternative future demand scenarios, taking into account the development of foreign enrichment capacity. Chapter IV presents and compares five investment strategies to supply enrichment at varying costs to the government and the consumer through the year 2025. Appendix A describes the method used to examine the economics of various enrichment strategies, and Appendix B discusses the effects of alternative assumptions on the costs of the five enrichment strategies.

# CHAPTER II. URANIUM ENRICHMENT TECHNOLOGIES AND THE U.S. PROGRAM

The key isotope in the fuel of most nuclear electric utility reactors is U-235. Natural uranium is composed mainly of two isotopes in widely different proportions. Approximately 99.3 percent of natural uranium is made up of U-238 atoms, with the remainder being U-235, except for a trace quantity of U-234. Early reactors and some modern ones are able to use natural uranium, but the great majority now in commercial service require uranium containing a much higher concentration of U-235 than occurs in nature. Uranium enrichment defines those processes that increase the concentration of U-235.

Several uranium enrichment technologies exist and others are under development. This chapter reviews the technologies in use and still being devised by the Department of Energy and examines the objectives of U.S. policy concerning domestic enrichment capacity.

## THE COST OF URANIUM ENRICHMENT

The cost of enriching natural uranium to fuel-grade quality is measured in terms of a standard of energy called the separative work unit (SWU). The SWU represents the cost of increasing the energy content of the enriched uranium over that of the natural feedstock. The amount of SWUs needed to enrich a given uranium feed thus depends on the amounts of U-235 to be contained in the enriched product and to be left in the depleted waste stream, or uranium "tails." Enrichment processes in the United States typically increase the concentration of U-235 roughly fourfold to 3 percent by weight, leaving a concentration of 0.2 percent in the tails. Under these specifications, a 1,000-megawatt nuclear power plant would require from 80,000 to 120,000 SWUs each year to meet its fuel needs, depending on its generating capacity, its use rate, and how often the nuclear fuel is taken out for replacement.

Utilities needing enrichment services from DOE supply their own feedstock and are charged for the amount of SWUs needed to enrich it to fuel grade. On the basis of prices quoted at the beginning of 1983, the average charge per SWU is about $140. The cost of feedstock adds approximately $131, resulting in a total fuel cost to the utilities of roughly $271 per SWU. At that price, the total cost of nuclear fuel and enrichment is small relative to the total delivered charge for electricity. Electricity



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costs attributable to enriched fuel are about 5 mills per kilowatt hour, which is less than 8 percent of the average electricity charge billed to residential U.S. users in 1982. (Enrichment costs alone are less than 5 percent of the total charge for electricity). 1/

## URANIUM ENRICHMENT TECHNOLOGIES

Three major uranium enrichment technologies are now in use or under development in the United States and elsewhere:

- The **gaseous diffusion** process is the only method now in use in the United States, but it is expected to be partly or fully replaced if U.S. enrichment capacity is upgraded,

- The **gas centrifuge** enrichment process, already in use in Western Europe and now under development by DOE, is evolving through several stages of technology refinement, of which the most distant is termed **advanced gas centrifuge** (AGC), and

- The **atomic vapor laser isotope separation** (AVLIS) process, currently under development by the DOE.

In addition, several other processes are being developed abroad. The gaseous diffusion and early gas centrifuge processes, however, are the only tested ones to date; the others are still in the research and development stage and have not been operated commercially. Both AVLIS and AGC are the enrichment processes being most aggressively pursued by the United States.

### The Gaseous Diffusion Process

The United States' three gaseous diffusion enrichment plants now in operation were originally built 30 or more years ago for the nuclear weapons program, but they have since been converted to mostly civilian use. 2/

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1. The average national charge for residential electricity use in 1982 was 68.6 mills per kilowatt hour. See Department of Energy, "Monthly Energy Review," Energy Information Agency (March 1981). The cost of delivered electricity by type of power plant is not collected by DOE, and a comparison to nuclear-generated electricity costs is thus not available.

2. The three gaseous diffusion plants are located in Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio.

Gaseous diffusion separates the U-235 and U-238 molecules by exploiting their different masses. The process first converts the isotopes into a gas (uranium hexafluoride). Being lighter, gaseous molecules containing U-235 move slightly faster than those containing U-238 when forced through a porous medium. When the uranium hexafluoride gas is passed through a series of chambers, each containing a porous wall, the lighter U-235 molecules move more rapidly, producing a concentration differential between the two sides of a chamber. Thus, with each pass through a chamber, the concentration of U-235 increases. Up to 1,500 successive passes through the chambers may be necessary to achieve the enrichment concentration desired.

The pumps used to move the uranium hexafluoride gas require substantial electric power, which accounts for roughly 85 percent of the cost of gaseous diffusion. 3/ In fact, the equivalent of roughly 1 percent of electric power capacity in the United States (6,000 megawatts) is consumed in operating the three plants. Since power costs in general are expected to rise (in real terms) over the next few decades, the cost of enrichment--already high--would be expected to increase if gaseous diffusion remains the dominant U.S. technology used.

## The Gas Centrifuge Technology

Gas centrifuge technology, as its name implies, separates U-238 and U-235 isotopes in gaseous uranium hexafluoride by centrifugal force. Uranium hexafluoride gas is fed through a thin-walled cylindrical rotor, or centrifuge, which is spun at high speed. This causes the heavier U-238 molecules to move toward the outside of the chamber, increasing the concentration of lighter U-235 remaining in the inner core of the rotor. Much as in gaseous diffusion process, a "cascade" principle is used in which the uranium hexafluoride is passed through a series of enrichment stages, and at each stage, it passes the increasingly enriched gas on to the next. The advantage of the centrifuge process over the diffusion technique is that the former uses only 5 percent of the electricity consumed by the latter. At the same time, however, the centrifuge method entails significant capital investment.

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3. The actual enrichment cost of gaseous diffusion is roughly $100 per SWU; the current DOE charge of $140 per SWU includes gaseous diffusion costs as well as charges for research and development, construction of the gas centrifuge enrichment complex, and various overhead associated with the enrichment services.

Early versions of the gas centrifuge technology are now used in West Germany by the Western European nuclear fuel consortium, Urenco. Although small in capacity (one million SWUs a year), the plant has been demonstrated on a commercial scale. The DOE has been developing its own gas centrifuge technology through private contractors. The centrifuge machine models are being developed in various stages, or "sets," although the overall design of the process remains essentially the same. The DOE has completed the Set III technology and is in the process of completing Set IV, which could increase SWU output 50 percent over the Set III machines. 4/ Recent developments using advanced materials indicate the possibility of Set V technology--the advanced gas centrifuge (AGC) process--which could double the efficiency of its soon-to-be-completed predecessor.

The U.S. Gas Centrifuge Enrichment Plant (GCEP), now planned to have an enrichment capacity of 13.2 million SWUs a year, is to be an eight-building complex that, if completed, will use centrifuge machines of greater efficiency than those used by Urenco. Almost one-fourth of the eight-building project, located in Ohio, has been completed to date, with completion of the entire project expected in 1994 according to the current DOE operating plan.

The Atomic Vapor Laser Isotope Separation Process

The atomic vapor laser isotope separation process (AVLIS) is still in the development stage. This process uses laser light to remove an electron from gas molecules containing U-235, leaving the molecules containing U-238 undisturbed. The U-235 molecules acquire an electric charge and can then be collected relatively easily. Researchers at DOE believe that enrichment up to 3 percent U-235 can be accomplished in a single stage with appreciable efficiency.

Three separate organized efforts, both public and private, have been devoted to developing the isotope separation process. These were carried out by the TRW Corporation and the federal government's Los Alamos (New Mexico) and Lawrence Livermore (California) laboratories. The DOE helped fund each of the efforts for several years until it could determine the most promising approach. In 1982, the Livermore AVLIS process was chosen to receive further research and development funds, and assistance was withdrawn for the other two processes in fiscal year 1983.

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4. See U.S. Department of Energy, "Uranium Enrichment Operating Plan" (January 1983).

Though most industry analysts agree that the AVLIS process will eventually prove technically feasible for commercial development, considerable uncertainty surrounds when it can be introduced and what the production cost per SWU will be. Present plans involve a commitment to continuing research and development on the process, with full-scale commercial development not yet scheduled.

## THE U.S. ENRICHMENT PROGRAM

Between 1969 and 1979, the United States' gaseous diffusion plants were the only source of enriched uranium outside the Soviet Union, fulfilling between 70 percent and 100 percent of the free world's enrichment needs. Several developments contributed to a loss in the U.S. position of world dominance, however. Early in the 1970s, several European nations had made plans to construct their own enrichment capacity with the goal of diversifying their supply choices. In 1974, the Atomic Energy Commission (DOE's predecessor agency) closed its enrichment order books for four years because future orders had exhausted theoretical capacity. Simultaneously, the OPEC oil embargo of 1973 occurred. In response to these developments, European nations stepped up efforts to achieve greater energy independence, including construction of their own enrichment capacity. Such factors have eroded the United States' role as the dominant world supplier of uranium enrichment.

A prominent goal of the U.S. enrichment program has been to maintain its strong position on the world market. The underlying reason has not been profit--enrichment charges are meant only to recover costs--but rather to control the uses of enriched uranium and spent uranium fuel to prevent their reprocessing for nuclear weapons. Such controls are enacted through joint agreements with the United States and other countries that use U.S. enriched fuel. 5/

### The Current Program to Increase Domestic Enrichment Capacity

In 1978, the Congress decided that additional U.S. enrichment capacity was needed to pursue the policy goal of nuclear nonproliferation, and it included in the Nuclear Nonproliferation Act a statement of national policy to "provide a reliable supply of nuclear fuel to those nations and groups of

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5. See the Nuclear Nonproliferation Act of 1978. See also Thomas Neff and Henry Jacoby, "Nonproliferation Strategy in a Changing Nuclear Fuel Market," Foreign Affairs (Summer 1979).

nations which adhere to policies designed to prevent proliferation." To meet the additional capacity requirements that would be consistent with this policy, the Congress authorized funds in 1978 for the construction of the new Gas Centrifuge Enrichment Plant to be built near Portsmouth, Ohio.

Current plans call for construction of an eight-building GCEP complex using Set III and Set IV technology. One-fourth of the project is well under construction. Set III machines will go into the first two buildings in the late 1980s, and Set IV machines will replace these in the early 1990s and will be placed directly in the remaining six buildings. With the GCEP fully operational, one of the three previous-generation gaseous diffusion plants is to be shut down. The remaining diffusion plants will supply 13.3 million SWUs a year, and the GCEP will supply another 13.2 million SWUs a year when full production is reached in 1997. 6/

The GCEP project requires funds for research and development, capital construction, and operation and maintenance. Funding during construction, not counting costs associated with operating the current gaseous diffusion capacity, will run between $400 million and $800 million a year in constant dollar outlays (see Table 1). The peak year of funding is expected to be 1989, involving $812 million in that year. Current construction and cost schedules remain subject to change, depending on the progress of other elements of the program and budgetary decisions made by the Congress. Thus, as developments occur in the testing of the AGC machines (that is, gas centrifuge Set V technology), the GCEP construction schedule and associated outlays may be modified to include these advanced processes in place of less advanced ones. In addition, further development of AVLIS--perhaps instead of a finished gas centrifuge complex--continues to receive Congressional consideration, although current plans do not call for full-scale commercial development of AVLIS until more is known about it.

## Funding Uranium Enrichment Services

The cost of constructing the new gas centrifuge facility is funded initially through the U.S. Treasury, but it is expected to be offset by revenue from sales of enrichment services. As stated in Chapter I, U.S. uranium enrichment services are designed to recover the cost of capital investments as well as operating expenses. The experience to date in recovering costs is mixed, however, and the net cost to the government of

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6. The current plan does not call for full-scale construction of the AVLIS technology, although research and development for AVLIS probably will continue at a cost of between $50 million to $100 million a year.

TABLE 1. CURRENT OUTLAY SCHEDULE FOR THE GAS CENTRIFUGE ENRICHMENT PLANT, TO 1994
(In millions of constant 1983 dollars)

| Year | Capital | Research and Development | Operation and Maintenance | Total |
|---|---|---|---|---|
| 1983 | 600 | 76 | 15 | 691 |
| 1984 | 625 | 77 | 35 | 737 |
| 1985 | 600 | 74 | 61 | 735 |
| 1986 | 600 | 57 | 72 | 729 |
| 1987 | 600 | 50 | 101 | 751 |
| 1988 | 600 | 40 | 128 | 768 |
| 1989 | 600 | 57 | 155 | 812 |
| 1990 | 575 | 51 | 179 | 805 |
| 1991 | 500 | 36 | 203 | 739 |
| 1992 | 490 | 36 | 228 | 754 |
| 1993 | 387 | 36 | 244 | 667 |
| 1994 | 150 | 36 | 247 | 433 |

SOURCE: Congressional Budget Office from DOE information.

NOTES: Years shown indicate peak period of construction activity only. Funding for operation and maintenance of the GCEP facility is to continue after 1994. See Appendix A for more details.

projects currently funded will depend on the ability to recover expenditures from future sales.

The DOE sells enriched uranium at a price set according to the provisions of the Atomic Energy Act of 1954, as amended. This price includes charges for depreciation and interest on the capital portions of the investment. The income from the sale of enriched uranium currently goes into the general funds of the Treasury. Like the majority of federal spending, the funds needed to operate the enrichment enterprise must then be authorized and appropriated by the Congress.

Until 1971, sales or leases of enriched uranium were priced to provide "reasonable compensation to the government." Table 2 shows the funding history of the U.S. uranium enrichment enterprise since 1971. In that year, the Atomic Energy Act Amendments became effective, requiring enrichment prices to be set for "recovery of the government's costs over a

TABLE 2. FEDERAL EXPENDITURES FOR AND REVENUES FROM URANIUM ENRICHMENT, 1971-1982

| Fiscal Year | Total Outlays | Revenues | Net Revenues |
|---|---|---|---|
| 1971 | 439.0 | 516.2 | 77.2 |
| 1972 | 553.7 | 408.8 | -144.9 |
| 1973 | 689.7 | 538.5 | -151.2 |
| 1974 | 838.3 | 1,410.6 | 572.3 |
| 1975 | 1,082.8 | 1,007.2 | -75.6 |
| 1976 | 1,940.4 | 1,137.1 | -803.3 |
| 1977 | 1,759.7 | 1,059.4 | -700.3 |
| 1978 | 1,885.7 | 1,448.7 | -437.0 |
| 1979 | 1,741.3 | 1,679.5 | -61.8 |
| 1980 | 1,334.8 | 1,407.4 | 72.6 |
| 1981 | 1,555.4 | 1,495.7 | -59.7 |
| 1982 | 1,509.9 | 1,998.8 | 488.9 |
| Total | 15,330.7 | 14,107.9 | -1,222.8 |

SOURCE: Congressional Budget Office from data in Robert L. Civiak, "Uranium Enrichment Technology and Policy," Congressional Research Service, Issue Brief Number IB82061 (June 1982), and the Department of Energy Budget Book, Fiscal Year 1984.

NOTES: Minus signs denote a net shortfall. Transition quarter included in 1976 data.

reasonable time." The table shows that enrichment outlays exceeded revenues in eight of the 11 years from 1971 to 1982, and that the total deficit (in 1983 dollars) during that period was roughly $1.2 billion ($650 million in nominal dollars). The government also has spent more than $3 billion (in nominal dollars) on improving existing plants and constructing the GCEP facility. During the 1971-1982 period, however, the government has built up its inventory of enriched uranium to more than 24 million SWUs, a supply worth $2.6 billion at current world prices. If in future the United States can sell the SWUs now in its inventory and recover current construction costs, revenues will meet outlays. If demand for U.S. enrichment services continues to fall as it has in recent years--as market trends suggest may be the case--then revenues may not cover all the costs that have been and will be incurred for the GCEP project.

## CHAPTER III. WORLD SUPPLY AND DEMAND FOR U.S. ENRICHMENT SERVICES

The United States is constructing new uranium enrichment capacity in a highly uncertain market environment. How much and how quickly nuclear power capacity will grow are unclear, and continued stiff competition from foreign enrichment services is likely. Both projected demand (measured in separative work units) and the United States' ability to compete against foreign suppliers are important considerations in deciding what approach the United States should take in providing future enrichment services. To help understand these issues, this chapter describes the United States' and other supplying nations' enrichment capacities, factors motivating the growth of foreign capacity, and what can be expected concerning the relationship between world supply and demand.

### CAPACITY, COMPETITION, AND DEMAND

Although contracts for the purchase of enriched fuel are generally made many years in advance of actual need, actual demand for enriched uranium is determined largely by the number of nuclear reactors in operation. At present, the United States' three gaseous diffusion plants can supply 27.3 million SWUs a year. The majority of this capacity is available for civilian purposes, with less than two million SWUs a year needed for the Navy's power reactors and an undisclosed but very small amount needed for the U.S. weapons arsenal. 1/ The gaseous diffusion capacity now available should suffice to fill U.S. contracts through the end of this century.

The federal government, through the Department of Energy, has contracts to supply both domestic and foreign utility company customers with about 28 million SWUs a year in 1985--an amount somewhat in excess of the 27.3 million SWUs now available--and with about 32 million SWUs a year in 1990. Because numerous planned power plants holding enrichment contracts have been cancelled or delayed in the past few years, however,

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1. The weapons program of the Department of Defense has made no withdrawals from the U.S. enriched uranium inventory since 1964. The weapons program relies mainly on plutonium instead of uranium, and it already has a stockpile of highly enriched uranium from obsolete weapons.



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projected actual demand is below contracted levels. In a report issued in January 1983, DOE projected that, between 1985 and the year 2000, actual annual demand for U.S. enrichment services from foreign and domestic utilities will rise gradually from 18.7 million SWUs to 26.8 million SWUs. All of this could be serviced by existing capacity. 2/ (Roughly 60 percent to 65 percent of total DOE SWU demand over this period will involve domestic customers, with the remainder being foreign contracts.)

With current gaseous diffusion capacity apparently adequate to meet the demand for another two decades, cost is an important factor motivating construction of new enrichment plants. The existing plants are old, and although the three plants have undergone some efficiency improvements, they will become increasingly expensive to run as their lifetimes are extended and energy prices escalate. To improve the United States' competitive position in the world enrichment market, curbing costs will be crucial. Completion of the new gas centrifuge or AVLIS processes promise eventually to cut enrichment costs to at least one-half their present level given current cost estimates. By becoming more competitive in the world market, the United States would be in a better position to regain a larger share of world sales, which could help further the goals of nuclear nonproliferation.

But factors other than the price of enriched uranium affect sales of U.S.-produced SWUs in the complex world market. Foreign producers may not readily yield their market positions in the face of lower U.S. SWU prices, and the United States cannot afford to invest in capacity that will not be used. To make investments in new capacity worthwhile, the United States must be relatively assured that the SWUs it produces will have buyers. Foreign SWU production affects the sales of U.S.-enriched fuel on the world market, and the United States must base its decision on new plants taking into account similar decisions in other nations.

## THE U.S. POSITION IN A COMPETITIVE MARKET

Many non-U.S. customers have firm "take or pay" contracts with foreign suppliers, in which a certain quantity of SWUs must be bought each year. Utilities not needing their full contract allotments are selling SWUs to other customers in a "secondary" market. Moreover, many non-U.S. enrichment services can sell SWUs at prices below production costs because of more flexible pricing policies allowed by their governments. Thus the

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2. See U.S. Department of Energy, "Uranium Enrichment Operating Plan" (January 1983).

United States--seeking to regain or maintain a large market share--faces formidable competition.

## The Emerging Competition Abroad

European governments first began providing enrichment services through consortia of several nations. The first consortium was Urenco, which began operation in 1977. Urenco was established as an enterprise owned jointly by the governments of Great Britain, the Netherlands, and West Germany. It operates the gas centrifuge technology with a modest capacity of one million SWUs a year. (Table 3 enumerates all existing and planned world capacity.)

In 1978, Eurodif, with one non-European partner, emerged as the second major consortium. Its members are Belgium, France, Iran, Italy, and Spain. France is the dominant partner, controlling more than 40 percent of the enterprise. Using the gaseous diffusion technology, Eurodif began with an initial annual capacity of 2.6 million SWUs and has since expanded to 10.8 million SWUs a year. Eurodif's output equals roughly 40 percent of current U.S. capacity, which makes this consortium the world's second largest supplier of enriched uranium and by far the largest non-U.S. source. Other foreign suppliers of enrichment include Japan and South Africa (each producing less than one million SWUs a year) and the Soviet Union (roughly three million SWUs a year). At the end of 1982, foreign enrichment capacity devoted to serving non-Communist countries totaled an annual 14.9 million SWUs.

Enrichment capacity outside the United States will probably increase by roughly 1.5 million to 2.5 million SWUs a year by 1990. The largest growth is expected for Brazil, Japan, South Africa, and Urenco. The Soviet Union will probably reduce its SWU exports by roughly one-third, and the Eurodif consortium is expected to maintain its current capacity of 10.8 million SWUs a year. (The amount of enrichment the Soviet Union will export through the end of the century may rise if it chooses to supply SWUs as a means of raising revenue.) By the year 2000, Australia also may enter the enrichment market with a modest capacity of one million SWUs a year.

The introduction of foreign competition in the world enrichment market has had a significant effect on the United States. From a virtual monopoly on enrichment services throughout most of the 1970s, the U.S. share of foreign demand had diminished to less than 60 percent by the end of 1982. This decline has been hastened by such actions as Eurodif's undercutting of the United States' SWU price for the first time in 1982, an

TABLE 3. EXISTING AND PLANNED ANNUAL WORLDWIDE URANIUM ENRICHMENT CAPACITY, BY NATIONALITY, TO 1995

| Enterprise Nationality | Type of Technology | (In millions of separative work units) 1983 | 1985 | 1990 | 1995 |
|---|---|---|---|---|---|
| United States | Gaseous Diffusion | 27.3 | 27.3 | 27.3 | 18.0 |
| | Gas Centrifuge | -- | 0.2 | 3.1 | 13.2 |
| U.S. Total | Both above | 27.3 | 27.5 | 30.4 | 31.2 |
| | **Non-U.S. Enrichment Enterprises** | | | | |
| Eurodif Consortium | Gaseous Diffusion | 10.8 | 10.8 | 10.8 | 11 |
| Urenco Consortium | Gas Centrifuge | 1.0 | 1.0 | 2.0 | 2 to 10 b/ |
| Soviet Union (for export) | Gaseous Diffusion | 3.0 | 3.0 | 2.0 | 2 to 5 b/ |
| Japan | Gas Centrifuge | a/ | a/ | 1 to 2 b/ | 2 |
| South Africa | Other | a/ | 0.3 | 0.3 | 1 |
| Brazil | Other | -- | -- | 0.2 | 1 |
| Australia | Undetermined | -- | -- | -- | 1 |
| Non-U.S. Total | All above | 14.8 | 15.1 | 16.3 to 17.3 | 20 to 31 |
| World Total | All above | 42.1 | 42.6 | 46.7 to 47.7 | 51.2 to 62.2 |

SOURCE: Congressional Budget Office from Congressional Research Service, Issue Brief IB 82061 (Updated March 3, 1983).

NOTE: The capacity figures listed are plant maximums. Actual production may be lower because of plant shutdowns or reductions in power levels. For example, the DOE plans to produce only 9.8 million SWUs in 1983, which is almost two-thirds below current U.S. capacity of 27.3 million SWUs a year.

a. Less than one million SWUs a year.

b. Full plans for additional capacity are currently not known.

advantage the consortium continues to enjoy. 3/ This was attributable partly to appreciation of the U.S. dollar and depreciation of other currencies, notably the French franc; part can also be ascribed to the still unquantifiable government subsidization by France. Such support has included low-interest loans on capital and may also include a commercial pricing scheme that, unlike the enrichment services operated by the United States, does not attempt to recover all capital costs. 4/ In fact, low foreign SWU prices have begun to penetrate the U.S. domestic market: several utilities have recently purchased SWUs from the overseas secondary market. Whether this has set a precedent for domestic utilities to begin contracting for lower-priced foreign enrichment services is unclear.

## The Prospect for Further Foreign Capacity Growth

To assess whether non-U.S. enrichment capacity will continue to expand, it is necessary to understand how it has grown so quickly since 1979. Several factors prompted other countries to take an interest in establishing their own enrichment capacity--an interest that began to take material form early in the 1970s with the establishment of the Urenco and Eurodif consortia. A critical stimulus was the OPEC oil embargo of 1973, which led many oil-importing nations to seek a greater degree of energy independence and a diversified base of energy production. Another was a perception that the United States was an unreliable source of enriched uranium fuel, a suspicion raised by DOE's closing of its order books in 1974 because outstanding contracts exceeded U.S. production capacity. (The DOE accepted no new orders for four years.) Also influential was a mounting

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3. As recently as March 1981, DOE's enrichment price was considerably below that of Eurodif. At that time, DOE charged $110 per SWU for its most common type of contract, while the Eurodif price was about $180 per SWU. In August 1982, DOE increased its price to $139 per SWU, and the Eurodif price had fallen to about $100 per SWU by that date. The decrease in the Eurodif price was partly due to a 30 percent decline in the value of the French franc compared to the dollar. Urenco's basic price for sales within the three partner countries is roughly $160 per SWU; however, the price is negotiated separately for other customers, and some buyers may receive substantial discounts. In the past, the Soviet Union has set its price at the U.S. price minus 5 percent. See Congressional Research Service, Issue Brief IB 82061 (Updated March 3, 1983).

4. See Nuclear Assurance Corporation, "Economic and Price Analysis of Eurodif" (Grand Junction, Colorado: 1980).

objection to the United States' restrictions on the enriched uranium it sold to foreign buyers, as U.S. policy moved toward the Nuclear Nonproliferation Act of 1978. Together, these several factors heightened foreign nations' interests in developing their own enrichment facilities. Future growth of foreign competition will depend largely on how forceful these factors continue to be. It will also depend on what pricing policies the United States and its competitors pursue.

In general, the foreign enrichment consortia and other producers have more flexible pricing policies at their disposal than does DOE. Though the goal of foreign producers certainly is to recover costs, most are not required by statute to do so. Nor are they generally prohibited--as the U.S. enterprise is--from offering special rates to certain customers. Moreover, in the case of the consortia, many strong commitments were made by future customers at the time capacity was being built, ensuring future sales. For these reasons, factors other than price still may bind a foreign customer to its consortium-based producer, even with a prospect of potentially lower SWU prices elsewhere on the world market.

The same factors that spurred the initial growth of foreign capacity prevail today. Between the late 1970s and 1983, foreign enrichment capacity rose from practically nothing to more than 14 million SWUs a year. Between 1983 and 1995, annual foreign capacity will probably grow by about five million SWUs, and it could rise by as much as 16 million. 5/ However, the current oversupply of SWUs in the world market, lower forecasts of nuclear growth, and current excess enrichment capacity will encourage a lower rate of growth.

Even without substantial growth in capacity, foreign enrichment services are adequate to meet most overseas demand. Although the United States has attempted to regain the confidence of foreign customers and to recapture its supremacy in the world market, it has not been successful. Since it reopened its order books in 1978, DOE has obtained only three new enrichment contracts--these have been made with Egypt, for three planned nuclear reactors.

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5. The technology applied in new non-U.S. capacity likely will not exceed the efficiency of that being developed by the United States today, according to current enrichment plans. But foreign producers may still be able to achieve lower SWU prices than the United States through other means.

World Enrichment Demand--Two Scenarios

As in the past, future world demand for enriched uranium will depend on how many nuclear reactors that use the fuel are in operation. Because no definite prediction of such demand is possible, the Congressional Budget Office has examined two illustrative scenarios (see Table 4). Under one scenario, yearly world demand for enriched uranium is seen to increase more than three-fold, rising from today's 19.4 million SWUs to 60.8 million. (Each gigawatt of power generated is assumed to require 120,000 SWUs a year when plants are operating under normal baseload conditions.) Under the other, demand growth is appreciably more modest, rising to 46.5 million SWUs, or just more than twice current demand. The higher case is based on DOE's mid-level growth case for foreign and domestic nuclear capacity. It specifies a total of 133 gigawatts (133,000 megawatts) of domestic and 350 gigawatts of foreign nuclear capacity by the year 2000, all using enriched

TABLE 4. TWO PATHS OF PROJECTED WORLD URANIUM ENRICHMENT DEMAND, TO YEAR 2025
(In millions of separative work units a year)

| | Higher | | | Lower | | |
|---|---|---|---|---|---|---|
| Year | U. S. | Foreign | Total | U. S. | Foreign | Total |
| 1983 | 8.4 | 11.0 | 19.4 | 8.4 | 11.0 | 19.4 |
| 1985 | 11.2 | 14.1 | 25.3 | 10.3 | 12.4 | 22.7 |
| 1990 | 14.4 | 22.1 | 36.5 | 13.7 | 17.9 | 31.6 |
| 1995 | 15.0 | 31.6 | 46.6 | 13.7 | 25.0 | 38.7 |
| 2000 | 16.2 | 44.6 | 60.8 | 13.9 | 32.6 | 46.5 |
| 2025 | 16.2 | 42.8 | 59.0 | 13.9 | 31.6 | 45.5 |

SOURCE: Congressional Budget Office partly from DOE data.

NOTES: The SWU demand figures are adjusted to reflect the additional SWUs required in the initial core loading of new reactors. Several nuclear gigawatt projections were used to generate the SWU demand estimates: the higher demand case is based on DOE's 1983 medium-level domestic nuclear growth and free world nuclear growth projections. The lower demand case represents a combination of the CBO low domestic nuclear growth case and the EIA's 1983 lower free world nuclear growth projections. All projections are adjusted to take account of reactors not requiring enrichment services.

uranium. This much nuclear capacity translates into an annual SWU demand of 16.2 million in the United States and 44.6 million by all other free world users combined, for a total SWU demand in the year 2000 of 60.8 million.

The higher case, based on DOE's 1983 mid-level SWU demand projections, represents a reasonable upper bound, although it reflects inclusion of a number of new reactors that may eventually be cancelled or delayed. 6/ The lower case is based on a survey conducted by CBO on the status of domestic reactors and on DOE's lower-growth scenario for foreign reactors. Only new reactors that are licensed and under construction are included in this lower projection, which specifies a total of 114 gigawatts of domestic capacity and 259 gigawatts of foreign capacity by the year 2000. Again, in terms of enriched uranium requirements, this much capacity would call for 13.9 million SWUs in the United States and 32.6 million by the other foreign users together, for a total worldwide demand in the year 2000 of 46.5 million SWUs.

### The World Enrichment Supply and Demand Balance

The large amount of domestic and foreign enrichment capacity now in place will be more than sufficient to meet world demand through at least 1995. Like the United States, the world market in general is in a state of oversupply, with projected actual SWU demand levels significantly lower than contracted ones. As late as 1982, contracts worldwide called for 43 million SWUs in 1985 and 47 million in 1990. As Table 4 indicates, however, actual annual demand will probably not exceed 36.5 million SWUs. When the range of expected world demand is compared with available world capacity, the potential for overproduction and continuation of a highly competitive market becomes clear.

## THE U.S. ROLE IN THE FUTURE ENRICHMENT MARKET

To date, the worldwide inventory of SWUs has shown few signs of adjusting to demand. Between 1972 and 1983, it has risen by the annual equivalent of 30 percent. In the face of the projected worldwide enrichment supply and demand balance (see Table 5), the Congress must decide what

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6. The General Accounting Office (GAO) has raised a number of objections to DOE's justification of its enrichment investment plan, and this rather high demand projection is one of GAO's criticisms. See General Accounting Office, Issues Concerning the Department of Energy's Justification for Building the Gas Centrifuge Enrichment Plant (May 25, 1982).

TABLE 5. PROJECTED WORLDWIDE DEMAND AND CAPACITY FOR URANIUM ENRICHMENT, TO YEAR 2025 (In millions of separative work units a year)

| Year | Demand Lower | Demand Higher | U.S. Capacity | Foreign Capacity | Potential Excess Capacity Worldwide a/ |
|---|---|---|---|---|---|
| 1983 | 19.4 | 19.4 | 27.3 | 14.8 | 22.7 |
| 1985 | 22.7 | 25.3 | 27.5 | 15.1 | 17.3 to 19.9 |
| 1990 | 31.6 | 36.5 | 30.4 | 16.8 | 10.7 to 15.6 |
| 1995 | 38.7 | 46.6 | 31.2 | 25.5 | 10.1 to 18.0 |
| 2000 | 46.5 | 60.8 | 31.2 | 25.5 | -4.1 to 10.2 |
| 2025 | 45.5 | 59.0 | 31.2 | 25.5 | -2.3 to 11.2 |

SOURCE: Congressional Budget Office from information supplied by the Congressional Research Service (Issue Brief IB 8-2061) and DOE.

NOTES: Lower and higher demand paths derived from Table 4. Minus signs denote insufficient capacity.

a. Foreign capacity based on average range shown in Table 3.

role the United States should plan to play in the world enrichment market. Essentially, it has two choices. The United States could continue with its plan to build a large volume of new capacity in hope of lowering SWU production costs and thus possibly regaining a large share of the market. This is the course assumed in current DOE planning. As an alternative, however, the United States could scale down the amount of new enrichment capacity planned, with the goal of servicing only domestic U.S. demand and any existing or likely foreign requirements. For analytic purposes, the first production role can be considered a base case and the second a low case. Table 6 shows the potential outcome of both U.S. production scenarios. The analysis assumes that non-U.S. producers operate at 85 percent of their maximum possible capacity, and the world demand presented is the single average of the range shown in Table 4.

If production continues unabated and the world SWU inventory therefore grows as it has over the last several years, a glutted world market could continue through the rest of the century. Competition would be very



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TABLE 6. PROJECTED WORLDWIDE SUPPLY AND DEMAND BALANCE IN URANIUM ENRICHMENT, TO YEAR 2025 (In millions in separative work units a year)

| Year | Potential U.S. SWU Production: Base Case | Potential U.S. SWU Production: Low Case | Foreign Production at 85 Percent of Capacity | Mid-Level World Demand a/ | Potential Excess Production | Cumulative World SWU Inventory |
|---|---|---|---|---|---|---|
| 1983 | 9.8 | 9.8 | 12.6 | 19.4 | 3.0 | 56.0 |
| 1985 | 16.7 | 12.1 | 12.8 | 24.0 | 0.9 to 5.5 | 58.9 to 65.8 |
| 1990 | 19.8 | 17.0 | 14.3 | 34.1 | -2.8 to 0 | 52.4 to 76.8 |
| 1995 | 24.4 | 17.1 | 21.7 | 42.7 | -3.9 to 3.4 | 35.1 to 87.0 |
| 2000 | 28.5 | 16.5 | 21.7 | 53.7 | -15.5 to -3.5 | -19.2 to 83.3 |
| 2010 | 28.5 | 18.0 | 21.7 | 52.3 | -12.6 to -2.1 | -158.3 to 56.0 |
| 2025 | 28.5 | 18.0 | 21.7 | 52.3 | -12.6 to -2.1 | -347.3 to 24.5 |

SOURCE: Congressional Budget Office from DOE information.

NOTES: Enrichment production and demand projections in this table do not include estimates of military SWU needs. Consequently, U.S. production schedules shown in this table are somewhat lower than those given in Appendix A, which include military SWU demand in addition to civilian demand. For comparative purposes, all SWU projections are based on a 0.2 percent operating tails assay. In practice, DOE plans after 2000 to operate using a 0.25 percent tails assay, producing the same amount of fuel but using only 26.5 SWUs. See Appendix C for a discussion of the effect of tails assay on SWU needs. Minus signs denote production or inventory deficits.

a. Represents average of high and low demand shown in Table 5.

strong--particularly under the base case--and the United States would need to compete aggressively in the world market to assure sales of the SWUs it produces.

Risks would be associated with pursuing either SWU production role. Under the base case (that is, DOE's current plan), the United States could face a situation in which, to ensure sales, it would have to sell produced SWUs at a cost below that of either foreign producers or secondary markets. Depending on demand, this could entail altering DOE's current pricing