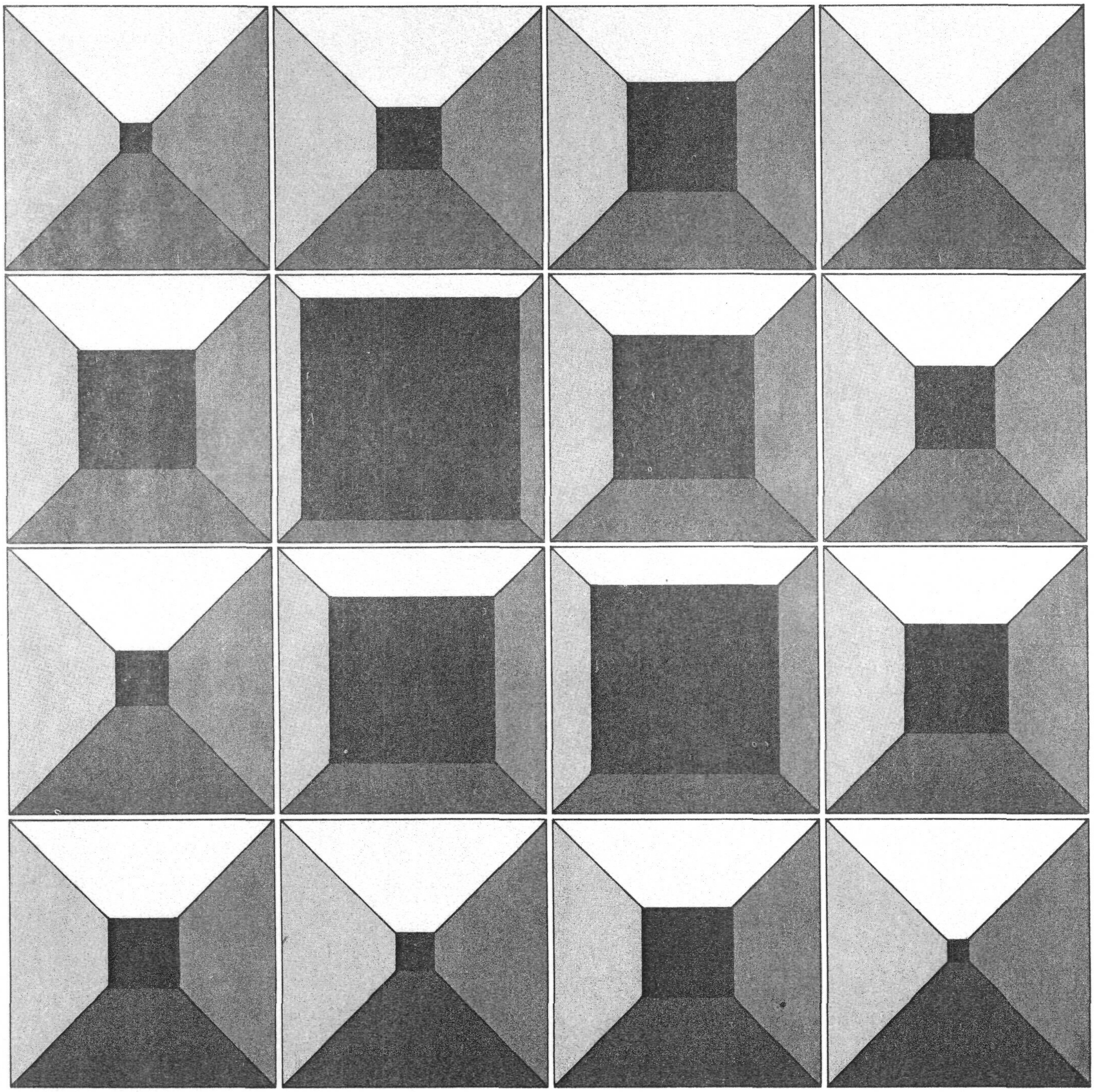
BACKGROUND PAPER

Uranium Enrichment: Investment Options for the Long Term

October 1983

Congress of the United States
Congressional Budget Office



URANIUM ENRICHMENT:
INVESTMENT OPTIONS FOR THE LONG TERM

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NOTES

Except where noted, all dates are expressed in calendar years.

All sums are expressed in 1983 dollars except as noted.

PREFACE

The Congress has already begun to invest in developing advanced processes for producing enriched uranium fuel for domestic and foreign power reactors. As these efforts proceed, the Congress faces major decisions regarding further investment in uranium enrichment--decisions to be made in the context of larger strategic choices for the U.S. role in international nuclear fuel. Choices of technologies are further complicated by a dynamic world market for enrichment services. Once monopolized by the United States, that market has now been made highly competitive by non-U.S. concerns with sizable capacity of their own and more planned for the future.

One consideration in these Congressional decisions is the cost effectiveness of the investment options. At the request of Chairman Pete V. Domenici of the Senate Committee on the Budget and Marilyn Lloyd, Chairman of the House Committee on Science and Technology, Subcommittee on Energy Research and Production, the Congressional Budget Office has analyzed the long-term costs of several technological approaches. In keeping with CBO's mandate to provide objective analysis, the paper offers no recommendations.

The analysis was prepared under the direction of John Thomasian by Gary Mahrenholz and Mollie Quasebarth, of CBO's Natural Resources and Commerce Division under the supervision of David L. Bodde and Everett M. Ehrlich. The authors wish to acknowledge the contributions of Robert Civiak of the Congressional Research Service, John D. Mayer and Jeffrey W. Nitta of CBO, Gene Schmidt and Howard Huie of the Department of Energy, Jim Davis of the Lawrence Livermore National Laboratories, and Alice M. Rivlin, former Director of CBO. Johanna Zacharias edited the manuscript, and Deborah Dove typed the several drafts and prepared the paper for publication.

Rudolph G. Penner
Director

October 1983

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SUMMARY

The U.S. government supplies a major portion of the enriched uranium used to fuel most of the nuclear power plants that furnish electricity in the free world. As manager of the U.S. uranium enrichment concern, the Department of Energy (DOE) is investigating a number of technological choices to improve enrichment service and remain a significant world supplier. The Congress will ultimately select a strategy for federal investment in the uranium enrichment enterprise. A fundamental policy choice between possible future roles--that of the free world's main supplier of enrichment services, and that of a mainly domestic supplier--will underlie any investment decision the Congress makes.

THE UNCERTAIN ENVIRONMENT FOR DECISIONMAKING

Several important trends and uncertainties complicate that choice.

- **The outlook for nuclear power.** Whether demand for electricity and reliance on nuclear power will continue to grow as they have in the past is unclear.

- **Competition in the world market.** The monopoly the United States once held in the world market for this product has begun to slip--to 60 percent by 1983. Up to now, the United States has sought to dominate the world supply of enriched uranium to assure the peaceful use of nuclear fuels. This goal is made explicit in the Nuclear Nonproliferation Act of 1978, but competition from abroad makes it increasingly difficult to achieve. Mounting competition from non-U.S. enrichment suppliers--relative newcomers to this expanding market--shows clear signs of becoming stiffer.

- **The current technology's high cost.** The process by which the United States has thus far produced enriched uranium fuel--begun after World War II for the weapons program and called gaseous diffusion--is now old. Although the plants have recently been upgraded, they are highly energy intensive and expensive to run, and they promise to become increasingly so.

- **Current overcapacity and oversupply.** At present, the United States and foreign suppliers of enrichment services have more

than sufficient capacity to meet anticipated demand and both suppliers and users have overstocked inventories of enriched fuel. Whether future requirements will warrant sizable investment of federal dollars in new enrichment capacity is uncertain.

- **Pricing.** Federal statute requires DOE to recover from sales the full costs of its enrichment services; foreign suppliers, in contrast, have greater latitude to alter prices to adapt to shifting market conditions. While foreign suppliers now sell enrichment services at prices between $100 and $120 per Separative Work Unit (the SWU is the standard in which these services are measured), the current U.S. charge must be set at $140 per SWU to recover the full cost of processing.

Thus, with many factors likely to influence the world enrichment market, the Congress faces decisions about achieving nonproliferation policy objectives and about investing in future technologies in a highly uncertain market. One important consideration is cost effectiveness--any overall strategy should consider the effects on the federal budget and on the utility companies that purchase uranium enrichment services. To assist the Congress in devising the best enrichment strategy, the Congressional Budget Office has analyzed the cost effectiveness of the principal investment options.

THE FEDERAL ENRICHMENT ENTERPRISE

Utility companies needing enrichment services enter into contracts with DOE. Each supplies DOE with natural uranium feedstock at its own expense. For a fee--at present, the $140 per SWU cited above--DOE processes the uranium feed and returns the enriched fuel to the customer. The total cost to the utility comes to $271 per SWU, when costs of the uranium feed are included. A typical 1,000 megawatt nuclear power plant requires between 80,000 and 120,000 SWUs a year. Translated into the terms of a residential consumer, the total cost of enriched uranium accounts for less than 8 percent of an average household's yearly electricity bill.

The federal government is now contracted with domestic and foreign utilities to supply about 32 million SWUs a year by 1990. But because of power plant delays and cancellations, actual annual demand may fall to roughly 20 million SWUs by that date, rising to only 27 million by the turn of the century. Present U.S. capacity will be able to produce an annual 27.3 million SWUs through the year 2000, or somewhat more than current and likely foreign demand contracts require.

THE TECHNOLOGICAL CHOICES

The DOE now operates three gaseous diffusion plants, one in Kentucky, one in Ohio, and the third in Tennessee. In addition, it has already invested $2 billion in a facility in Ohio that would produce enriched uranium by the gas centrifuge process; this effort may culminate in a stage of technology considerably more refined than its predecessors. Federal dollars also support research in and development of the advanced isotope separation process; this effort is now under way at the Livermore Laboratories in California.

The function of each of these processes is to separate out the relatively heavier U-238 isotope contained in natural uranium and increase the concentration of the lighter U-235 isotope to a point at which the product is usable as reactor fuel. In raw uranium, the ratio of these two isotopes is more than 99 to one; the enrichment process generally increases the U-235 concentration to 3 percent.

Gaseous Diffusion. The gaseous diffusion plants enrich uranium by exploiting the mass differentials of U-235 and U-238 isotopes. The process first converts the natural uranium to a gas (uranium hexafluoride) and then pumps it through several chambers with porous walls. Being lighter, U-235 isotopes pass through the walls more quickly, leaving the heavier U-238 components behind. After several thousand passes through the chambers, the uranium is sufficiently enriched. Substantial electric power is needed to pump the gas through each chamber, resulting in very high operating costs: some 85 percent of this process' cost is attributable to electricity.

Gas Centrifuge. This technology, already in operation abroad and quite far in development in the United States, promises to enrich uranium at substantially lower cost. Like the gaseous diffusion process, this technique separates the U-235 and U-238 isotopes in uranium hexafluoride gas, but it does so more efficiently. The gas is spun in a rotor, and centrifugal force propels the heavier U-238 outward; the lighter U-235 isotope tends to remain in the core of the centrifuge. As in the diffusion processes, enrichment by the centrifuge method requires repeated operations. Nonetheless, the latter uses only 5 percent of the power consumed in gaseous diffusion to produce the same amount of fuel.

For the Gas Centrifuge Enrichment Plant (GCEP) now under construction in Ohio, this technology is being developed in stages, or "sets." The Set IV phase is already nearing completion, and recent advances using different materials have opened the possibility of a Set V technology. This more refined stage, called advanced gas centrifuge (AGC), could double the efficiency of the operation. Though the future costs of the gas centrifuge process, especially those at the Set V stage, are somewhat uncertain, sizable improvements in efficiencies seem possible. Cost estimates now range from between $20 to $80 per SWU (not including uranium feed), with the lower estimates associated with AGC.

Advanced Isotope Separation. Considerably more experimental, this enrichment process uses laser light to separate the isotopes in uranium in a solid rather than a gaseous form. The technique, called the atomic vapor laser isotope separation (AVLIS) process, removes an electron from the U-235 isotope while leaving the others undisturbed. The charged U-235 particles can then be collected separately, affording appreciable enrichment in just one stage. The AVLIS process is estimated to cost between $20 and $30 per SWU, although these figures are uncertain owing to the technology's early stage of development.

INVESTMENT OPTIONS FOR FUTURE ENRICHMENT SERVICES

Planning for future enrichment capacity takes into account both the current availability of gaseous diffusion and the anticipated availability of the new technologies by certain dates. Both DOE and CBO assume different combinations of existing and new enrichment processes when considering an upgraded enrichment enterprise. The technological composition and assumed timetables of five possible courses examined by CBO--a base plan and four alternatives--are recapitulated in Summary Table 1. As its base case, the CBO has taken DOE's recommended program from its most recent operating plan, published in January 1983. In the initial analysis, the CBO has relied on DOE's engineering projections and cost data.

The CBO compared the four options against both the Base/DOE Plan and against each other. The analysis focused on three questions:

- Which investment option would supply the cheapest enrichment service to the consumer?
- Which would cost the federal government the least in direct outlays?
- What effects do alternative demand projections for enriched uranium have on choice of technology?

The projection period examined is 1983 through the year 2025. In its initial analysis, the CBO examined the options with a uniform set of assumptions. Key assumptions include a policy decision to reach annual production levels of 26.5 million SWUs by 1996 to meet a projected high level of demand, attainment of DOE's projected availability schedules for

SUMMARY TABLE 1. COMPOSITION AND TECHNOLOGY TIMETABLE ASSUMED UNDER THE OPTIONS

Options	Gaseous Diffusion	Gas Centrifuge Enrichment Plant	Advanced Gas Centrifuge	Atomic Vapor Laser Isotope Separation
Base/DOE Case	Shutdown of one plant in 1993; remaining two operational through year 2025	Set III machines operational in two buildings by 1988; Set IV machines operating in full eight-building plant by 1997	Not assumed	Not assumed
Option I	Phaseout of all three plants by 1996	Set III machines operational in two buildings by 1988; Set IV machines operating in full eight-building plant by 1997	Not assumed	Two plants in operation as of 1994 and 1995
Option II	Phaseout of all three plants by 1997	Set III machines operating in first two buildings by 1988, to be replaced by Set IV machines in early 1990s; work on remaining six GCEP buildings halted	Not assumed	Three plants in operation as of 1994, 1995, and 1996, producing at full capacity in 1998
Option III	Phaseout of all three plants by 1999	Progress stopped on GCEP plant and project decommissioned in 1983	Not assumed	Three plants in operation as of 1994, 1995, and 1996, producing at full capacity in 1998
Option IV	Phaseout of all three plants by 1999	Set III machines operating in first two buildings by 1988; refined Set IV installed in next four buildings by 1993; AGC (Set V) operating in last two buildings by 1995; all machinery upgraded to AGC level by late 1990s		Not assumed

SOURCE: Congressional Budget Office.

the AGC and AVLIS technologies, and realization of DOE's present cost projections. However, to test the validity of its results from the initial analysis, the CBO also applied less optimistic supply, cost, and schedule assumptions in a sensitivity analysis.

For each option, the analysis examined both federal outlays--that is, annual discounted costs to the U.S. Treasury--and total enterprise costs. The former comprise the costs of delivering enriched fuel, and they include money spent for research and development, capital investment, and operation and maintenance of plants. The latter include these same components plus the price of uranium feed and interest charges on capital.

Results of the Analysis

Several points emerge quite distinctly in the initial analysis. First, the range of total enterprise costs is quite narrow. Over so long a period (43 years), the cost difference of $13 billion between the cheapest and costliest options is not great. Second, the more advanced technologies--AGC and AVLIS--appear to offer the best prospect for an enrichment enterprise with low operating costs. Conversely, prolonged reliance on the costly gaseous diffusion process appears to be the most expensive course, postponing opportunities for lowering enrichment costs. Third, the sensitivity analyses conducted tend to corroborate these findings. Even with their progress slowed and their capital costs inflated by overruns, the more advanced but remote AGC and AVLIS processes appear ultimately to offer the better prospects for a sound long-term investment.

Ranking of the Options on Three Standards. The analysis results in the following ranking of options. In terms of total enterprise costs, Option IV, ultimately relying on AGC for enrichment services, would offer the most economic approach, with costs over the full projection period totaling $123.5 billion (see Summary Table 2). Option III, ultimately relying on AVLIS without GCEP or gaseous diffusion, falls next in the sequence, with enterprise costs of $128.2 billion. Options I and II, involving combinations of the gas centrifuge and AVLIS technologies, follow closely with enterprise costs of $128.7 billion and $129.6 billion. At the bottom of the ranking and markedly more expensive than the other options is the Base/DOE Plan, with enterprise costs of $136.8 billion over the projection period.

Total government outlays over the same period, also shown in Summary Table 2, follow the same pattern. The Base/DOE Plan would require the greatest outlays ($41.4 billion), while building Option IV would require the least ($28 billion). However, the schedule of outlay trends differs over the period 1983 to 2025. Through 1990, Option IV would require $18 billion

SUMMARY TABLE 2. SUMMARY OF DISCOUNTED COSTS AND OUTLAYS UNDER EACH OPTION 1983-2025

	Base/DOE Plan	Option I	Option II	Option III	Option IV
			Discounted Enterprise Costs in Billions of 1983 Dollars		
Gaseous Diffusion	90.9	46.6	53.7	58.5	44.8
Gas Centrifuge a/	45.9	45.9	15.1	1.4 b/	78.7
AVLIS	None	36.2	60.8	68.3	None
Full-Period Total	136.8	128.7	129.6	128.2	123.5
1983-2003 Total	87.4	85.3	86.2	85.4	82.3
			Discounted Federal Outlays in Billions of 1983 Dollars		
1983-1990	17.9	18.7	16.9	15.2	18.2
1991-2000	11.3	10.1	12.1	13.1	7.8
2001-2025	12.2	4.3	5.1	4.7	2.0
Full-Period Total	41.4	33.1	34.1	33.0	28.0
			Costs per SWU in 1983 Dollars		
Full-Period Total Fuel Cost	129.4	121.7	122.6	121.3	116.8
Full-Period Enrichment Charge	39.4	31.6	32.5	31.3	26.7

SOURCE: Congressional Budget Office.

a. Through Option III, data reflect costs and outlays associated with GCEP operation through Set IV technology; include AGC costs and outlays for Option IV only. Because AGC is the culmination of the GCEP project, its associated costs and outlays are not identified separately.

b. Cost to decommission GCEP project.

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in outlays, roughly equal to the Base/DOE Plan's requirements over that period. Option III, however, would require only $15 billion in capital costs through 1990.

The analysis also indicates that the Base/DOE Plan and all the alternatives would provide relatively low-cost enrichment services as judged by current enrichment prices. All projected enrichment charges would gradually fall well below the current DOE rate of $140 per SWU. If foreign suppliers hold SWU costs at the current levels of $100 to $120 per SWU, the United States would be in a position to compete favorably. As is the case with full enterprise costs, Option IV offers the lowest enrichment charge, $27 per SWU, and the Base/DOE Plan the highest, $39 per SWU.

Sensitivity to Changed Assumptions. Even with changed analytic assumptions regarding the timing of availability and level of demand, the initial rankings hold; although the absolute costs of the options rise. The Base/DOE Plan remains the most costly, while Option IV is the cheapest. When capital cost overrun factors are assigned to the new technologies, the initial rankings remain in all instances but one. The exception involves raising capital costs for AGC beyond current estimates, but using the current estimates for AVLIS. In this instance, Option III becomes $2.0 billion cheaper than Option IV.

The initial ranking holds when the production plans are assumed to be scaled back to meet little more than domestic demand only. In this case, the United States would build to meet demand of 19.6 million SWUs a year instead of 26.5 million after the year 2000. In this situation, Option IV remains the most economic approach, with $93.4 billion in enterprise costs. Again, Option III falls next, involving roughly $96 billion in enterprise costs. The Base/DOE Plan is still the most expensive, with enterprise costs of $99 billion.

In a similar test, the United States is assumed to build full capacity for 26.5 million SWUs but eventually to service only domestic demand and existing foreign contracts--that is, to produce only 19.6 million SWUs a year after 2000. Again, the ranking of the options holds. Option IV is the most economic, while the Base/DOE Plan is the least so. Though the lifetime cost per SWU under Option IV rises from $27 to $32, it remains well below current world prices. These and other sensitivity analyses performed by CBO suggest that, although technical and economic uncertainties do exist regarding the advanced processes, investment in the GCEP facility carried through the AGC stage offers the United States the most cost-effective production plan for sustaining competition in the uncertain uranium enrichment market. At the same time, the overall cost difference between this lowest-cost option and the next best choice--Option III using AVLIS--remains strikingly small.

URANIUM ENRICHMENT:

Investment Options for the Long Term

CHAPTER I. INTRODUCTION

Enriched uranium, much of it processed under the management of the U.S. government, fuels most of the world's nuclear power plants. These plants are the source of between 12 percent and 15 percent of the electricity consumed in the industrialized free world. In the United States, where the Department of Energy (DOE) undertakes all uranium enrichment activity, 13 percent of all electrical energy is produced by uranium, and in several other nations, reliance on nuclear energy is somewhat greater. Thus, the demand for enriched uranium is already sizable, and although the outlook for future energy growth is unclear, that demand is expected to remain large and possibly to grow in the coming several decades. Critical to the United States' future position in the world enrichment market are decisions now before the 98th Congress concerning federal investment in uranium enrichment technologies.

THE U.S. POSITION IN THE WORLD MARKET

What share of the free world's demand for enriched uranium will be met by the United States is uncertain. From 1969 through the 1970s, the United States held a commanding position as the principal provider of enrichment services. Since the late 1970s, however, the United States has been losing its market dominance as other countries have introduced their own enrichment capacity. While the United States still services almost all domestic enrichment demand, it supplies less than 60 percent of the current foreign market demand. Contracts now in effect indicate a continuation of this downward trend, and the U.S. share of foreign markets is expected to fall to less than 35 percent over the next ten years.

THE FEDERAL ENRICHMENT ENTERPRISE

As the nation's sole provider of uranium enrichment services, DOE controls and promotes these activities in accordance with national policies for control of nuclear materials (further considered in Chapter II). At present, the federal government aims to hold a dominant role in the world market to monitor the nuclear fuel cycle and thereby prevent nuclear materials from being diverted for use in weapons. The mechanism by which this service is provided is simple enough. Utility companies needing enriched uranium to fuel reactors supply DOE with unprocessed uranium "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		Foreign Production at 85 Percent of Capacity	Mid-Level World Demand a/	Potential Excess Production	Cumulative World SWU Inventory
	Base Case	Low Case				
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 formula, which now requires full cost recovery; the result could be a partial government subsidization of enrichment services.

Should the Congress choose a course comparable to the lower production scheme, the United States would concede the foreign enrichment market to foreign suppliers. In doing so, the United States could risk losing its potential influence in nuclear nonproliferation by having little control over foreign fuel transactions. Further, it might sacrifice the opportunity to enter the enrichment market once demand picked up after the year 2000, since the cost of restarting development of an enrichment process once terminated would probably be very high. 7/

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7. Building a portion of new enrichment capacity using gas centrifuge or AVLIS, stopping production of the process, and then restarting it to add more capacity several years later would likely involve more expense than originally planned, although how much cannot be predicted. Production lines for both the gas centrifuge and AVLIS processes probably will remain fully operational only so long as the government purchases new equipment. If the government were to stop equipment purchases, the production lines would likely be shut down, requiring some fixed costs to restart them. In this respect, production for the gas centrifuge process might be more expensive to restart overall than AVLIS, because GCEP is more capital intensive.

CHAPTER IV. URANIUM ENRICHMENT OPTIONS FOR FEDERAL INVESTMENT

Cost effectiveness will be a critical factor in the Congress' choice of a uranium enrichment strategy. Even the most cost-effective investment option, however, offers no guarantee of the United States' regaining its once dominant position in the international market for enriched uranium; besides the United States' policy requiring full-cost recovery, many factors unrelated to price can influence future demand for U.S. enrichment services. The outlook for future nuclear power demand is not clear; foreign competition in the enriched uranium market promises to remain stiff; and world capacity to produce that fuel is currently overabundant. In this uncertain environment, the Congress will want to pursue whatever technological approach offers the best prospect for minimizing costs to both the government and the consumer. To help identify that course, this chapter presents a comparative analysis of an array of options.

OPTIONS FOR FEDERAL INVESTMENT

For some time, the U.S. uranium enrichment enterprise will continue to have at its disposal the now old but recently upgraded gaseous diffusion plants. Other processes, in which the government has already invested sizable sums, may be used in the future. These include the Gas Centrifuge Enrichment Plant now in progress in Ohio, the culmination of that effort--the advanced gas centrifuge--and the atomic vapor laser isotope separation process. Though the latter two, AGC and AVLIS, are still far from operational, they are treated in the analysis as available to serve, either in tandem with other technologies or alone, by certain future dates. (See Table 7, which outlines the technological composition and the timetable assumed under each option.) The projection period of the analysis extends from the present to the year 2025, during which time certain new technologies are assumed to begin and the gaseous diffusion plants to be partly or completely phased out. 1/ For a base case, the Congressional Budget Office

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1. Because the energy intensiveness of gaseous diffusion makes the operating cost of this technology so high, both the CBO and the Department of Energy have assumed for purposes of analysis and planning that another technology will be chosen to substitute partly or wholly for gaseous diffusion. The CBO has nonetheless investigated the costs of providing all enrichment services with gaseous diffusion and has found its cost to be some $13 billion higher than the lowest-cost alternative.

TABLE 7. COMPOSITION AND TECHNOLOGY TIMETABLE ASSUMED UNDER THE OPTIONS

Options	Gaseous Diffusion	Gas Centrifuge Enrichment Plant	Advanced Gas Centrifuge	Atomic Vapor Laser Isotope Separation
Base/DOE Case	Shutdown of one plant in 1993; remaining two operational through year 2025	Set III machines operational in two buildings by 1988; Set IV machines operating in full eight-building plant by 1997	Not assumed	Not assumed
Option I	Phaseout of all three plants by 1996	Set III machines operational in two buildings by 1988; Set IV machines operating in full eight-building plant by 1997	Not assumed	Two plants in operation as of 1994 and 1995
Option II	Phaseout of all three plants by 1997	Set III machines operating in first two buildings by 1988, to be replaced by Set IV machines in early 1990s; work on remaining six GCEP buildings halted	Not assumed	Three plants in operation as of 1994, 1995, and 1996, producing at full capacity in 1998
Option III	Phaseout of all three plants by 1999	Progress stopped on GCEP plant and project decommissioned in 1983	Not assumed	Three plants in operation as of 1994, 1995, and 1996, producing at full capacity in 1998
Option IV	Phaseout of all three plants by 1999	Set III machines operating in first two buildings by 1988; refined Set IV installed in next four buildings by 1993; AGC (Set V) operating in last two buildings by 1995; all machinery upgraded to AGC level by late 1990s		Not assumed

SOURCE: Congressional Budget Office.

has used the operating plan currently being followed by the Department of Energy's Office of Uranium Enrichment and Assessment. The alternatives would combine the four extant and developing technologies in various ways. The options are described in greater detail below. The analytic method is detailed in Appendix A.

Each of the options analyzed in this chapter--the Base/DOE Plan and four alternatives--is examined first in terms of the higher production projections reviewed in Chapter III and later, in terms of the lower production scenario. The former reaches an annual U.S. production level of 26.5 million separative work units in the year 2001, the latter, a production rate of 19.6 million SWUs in the same year. Each option is also tested for its sensitivity to other variables, notably financial and cost conditions, and schedule changes. (Appendix B provides detail on the sensitivity analyses.)

The Base/DOE Plan--Operate Full-Scale Gas Centrifuge Process, Continue Gaseous Diffusion

The last DOE enrichment operating plan, issued January 1983, is treated here as current policy. 2/ The January plan calls for full completion of the eight-building GCEP complex with Sets III and IV gas centrifuge machines; it also specifies shutdown of one of the three gaseous diffusion plants in 1993, with the other two operating through the year 2025. Gas centrifuge production would begin in 1988, providing 0.4 million SWUs from the first two buildings; these machines would be upgraded to the Set IV level within a few years. The Set IV centrifuges would be installed in the remaining six buildings when they are completed. By 1997, GCEP production would reach a maximum annual capacity of 13.2 million SWUs, and the continuing two gaseous diffusion plants would provide the balance of 13.3 million SWUs a year.

The DOE operating plan outlines the U.S. enrichment program over a 20-year period, and includes only technologies that are reasonably assurred of providing production over that timespan. Thus, the Base/DOE Plan does not include the more advanced technologies still in the early development

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2. See U.S. Department of Energy, Uranium Enrichment Operating Plan (January 1983). The estimated cost and project development schedules for the AGC and AVLIS processes are currently under revision by the DOE. The CBO will examine the effect of these revisions on the analysis when the official DOE data are available.

stages.[3] The base plan is thus quite conservative in its assumptions about available technologies. Without the AGC and AVLIS processes, the production burden on the two remaining gaseous diffusion plants would be sizable through the year 2025.

Option I--Operate Full-Scale Gas Centrifuge Plus AVLIS, Phase Out Gaseous Diffusion

This option assumes completion of the eight-building GCEP complex according to the same schedule in the Base/DOE Plan--that is, DOE's operating plan as of this past January. Again, to produce 13.2 million SWUs, the gas centrifuge process would be taken through Set IV, stopping short of the Set V, or AGC, technology. In addition, two AVLIS plants would be constructed, eventually supplying an additional 13.3 million SWUs a year; one would come on-line as of 1994 and the other in 1995. The three gaseous diffusion plants would be closed down for commercial operation by 1996. Compared to the Base/DOE Plan, introduction of the AVLIS plants with the GCEP facility would result in substantial energy and cost savings, since replacement of all three of the energy-intensive and hence costly gaseous diffusion plants would become possible in the late 1990s. The savings in operating costs realized by this approach would have to be weighed against the initial large capital expenditures entailed in introducing the newer technologies.

Option II--Operate Partial Gas Centrifuge Capacity, Phase Gaseous Diffusion Out, Phase AVLIS In

This option calls for completion of only the first two of the eight GCEP buildings now planned; the AVLIS process would make up the remaining SWU capacity. Late in the 1980s, Set III centrifuge machines would be placed in the two GCEP buildings now nearing completion. More efficient Set IV GCEP machines would replace these in the early 1990s, providing a maximum annual production rate of 3.3 million SWUs by 1996. As in the Base/DOE Plan and Option I, the more advanced Set V AGC machines would not be pursued. Dovetailing with the phaseout of gaseous diffusion facilities, the AVLIS process would be introduced to make up for GCEP capacity not built, and eventually it would replace the gaseous diffusion plants. Three AVLIS plants, with potential output of 23.2 million SWUs, would be constructed. AVLIS production would begin in 1994 and

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3. The current DOE plan does, however, continue to allot some research and development funds for the AGC and AVLIS processes.

1995 and would reach full capacity by 1998. All three gaseous diffusion plants would be shut down for commercial operation by 1997. Capital costs for completing only two of the eight GCEP buildings now planned would be cut accordingly. But the need to continue relying for some years on the costly gaseous diffusion plants would to some extent offset the savings in GCEP costs.

Option III--Halt GCEP, Phase Gaseous Diffusion Out, Phase AVLIS In

This option represents a commitment to the AVLIS process in place of GCEP and the gaseous diffusion plants being phased out. The GCEP project would be halted at the end of 1983, involving a one-time-only expense for decommissioning the project. 4/ Three AVLIS plants would produce the full complement of 26.5 million SWUs a year. Production from the first plant would start in 1994. The gaseous diffusion plants would be decommissioned by 1999. Discontinuing the GCEP project would prolong reliance on the gaseous diffusion plants, resulting in higher power costs in the 1990s. By the year 1999, AVLIS would constitute the full enrichment enterprise.

Option IV--Phase Gaseous Diffusion Out, Phase Advanced Gas Centrifuge In

A reversal of the approach taken in Option III, this option calls for pursuing the GCEP project through the Set V, or AGC, stage but not proceeding with AVLIS. As in the Base/DOE Plan and Option I, the full-scale eight-building GCEP complex in Ohio would be built, but the operation would differ with respect to some of the machinery installed in succeeding buildings. In 1988, Set III production would begin in the first two buildings. Buildings three through six would use slightly improved Set IV centrifuges (actually further refinements of the Set IV machines envisioned in the Base/DOE Plan and Options I and II). Further advanced machines, AGCs, would be placed in buildings seven and eight when they are completed. Late in the 1990s, the machines in buildings one through six would be retrofitted with AGC technology. (The efficiency of the AGC machines is assumed to be triple that of the Set III machines and double that of the Set IV machines. The 100 percent efficiency gains of the AGC machines compared to the Set IV are consistent with the official DOE operating plan assumptions.) Production from AGC would reach a maximum annual capacity of 26.5 million SWUs by 1999. At that time, gaseous diffusion production would

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4. The cost in outlays for closing out the GCEP project from 1983 on is estimated to be $1.4 billion; $442 million of these outlays were obligated but not spent before fiscal year 1983.

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end, putting a halt to that high and escalating operating cost. The risks in this option are the same as in any other approach relying heavily on still unproven technology, namely those of overruns in capital costs and production schedule delays.

THE ANALYSIS--CONCLUSIONS, CAUTIONS, AND METHOD

The CBO's analysis (detailed below) points to the general conclusion that the total cost differences among the options, reflecting both capital investment and operating expenses, are rather small. Most costly would be the option that makes prolonged use of gaseous diffusion and continues the GCEP project, as defined in the Base/DOE Plan; this is so because of the long-term reliance on gaseous diffusion, the most costly of all production methods. All the alternatives share the advantage of avoiding this long-range operating cost to differing degrees. At the other end of the scale, the most economic would be the approach that culminates in full-scale operation of AGC, Option IV. The next best alternative would be Option III, relying principally on the AVLIS process. Options I and II rank third and fourth after the AVLIS option.

The results also show that the enrichment costs under all the plans examined would be very competitive in today's market. Under either the Base/DOE Plan or Option IV, enrichment costs--at $39 and $27 per SWU, respectively--would be substantially lower than the current DOE charge of $140 per SWU. They would also fall well below the current foreign market price of roughly $100 per SWU. These projected enrichment costs, however, represent lifetime processing charges for each option; they would therefore be reached gradually over the projection period. For example, the enrichment cost under the least expensive program, Option IV, would be roughly $107 per SWU in 1990 and $61 per SWU in 2000. By comparison, enrichment costs for Option III would be $107 per SWU in 1990 and $68 per SWU in 2000.

Cautions. Several cautions about these conclusions should be noted, however. First, the conclusions assume that the technologies still in relatively early stages of refinement, AGC and AVLIS, would not experience significant cost revisions from those now projected by DOE. Experience suggests, though, that such overruns cannot be ruled out. In fact, both technologies have already undergone adjustments in their estimated costs, and another round of reestimates is under review by DOE as of the publication of this study. Second, the schedules according to which the new technologies would be operable are assumed to be realistic, but already the development timetables for these processes have been altered, and future changes are not implausible. Thus, the potential for both higher costs and project delays must be taken into account in the Congress' consideration of uranium enrichment options.

Method. The technique for analyzing each option uses a computer-based model that calculates annual and cumulative discounted costs. In the simulation, SWU production is assigned on a "least-cost" basis. 5/ Estimates of annual costs are used as the best measure of actual expenditures incurred during the life of each program. These include expenditures for research and development, capital, operation and maintenance, feed and power costs, and costs for decommissioning the gaseous diffusion plants. 6/ The DOE Office of Uranium Enrichment and Assessment was the primary source of the cost and engineering data.

The analysis concentrates on three categories of information:

- **Enterprise costs**--the total present-value cost of each program, including uranium feed costs and interest on capital, based on meeting the assigned SWU demand schedule over the projection period; enterprise costs represent the combined costs to both DOE and its customers.

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5. Certain assumptions are made in assigning SWU production levels to meet overall demand. The DOE SWU inventory is drawn down as needed to meet annual requirements, after assuring that it could provide at least one-third of the next year's requirements. Production from gaseous diffusion is assigned only as needed to meet demand not satisfied in the inventory by the other technologies (see Appendix A).

6. The amount of feed required to produce the enriched uranium product depends on the U-235 concentration left in the depleted uranium waste stream after the enrichment process. For this analysis, this concentration, called the tails assay, is consistent with that used in the DOE official operating plan analysis--prior to 2000, all technologies operate at a tails assay of 0.2 percent; from 2000 to 2025, all technologies would operate at a tails assay of 0.25 percent. It has been argued, however, that both the AVLIS and AGC technologies would operate more efficiently at a lower tails assay, which would require less feed but necessarily produce more SWUs to obtain the same amount of enriched uranium product. An analysis of AVLIS and AGC programs assuming a tails assay of 0.1 percent from 2000 on is presented in Appendix B.

- **Government outlays**--the total present-value cost to the government (excluding uranium feed and interest charges) of each program over the projection period.

- **Total SWU and enrichment costs**--these are identical to the enterprise costs, except that they are expressed on a "per SWU" basis; in addition, total SWU costs include uranium feed, representing total fuel costs, while enrichment costs do not. The enrichment cost is the measure that best represents the price DOE would charge to its customers. 7/

Except as noted, the analysis uses certain baseline assumptions. All costs are expressed in constant 1983 dollars and outlays made before 1983 ("sunk costs") are excluded. 8/ Cumulative production for each option is assumed to be 1.06 billion SWUs. A real discount rate of 4 percent is applied to all yearly expenses to obtain a total present value, and a real capital recovery factor of 4 percent is applied to new capital charges (fully depreciated over 25 years) when calculating enterprise and total SWU costs and enrichment charges. A real escalation rate for electricity is assumed at 0.5 percent. In addition, each option is examined under two enrichment demand schedules (a base and lower case). Later in the chapter, the options are subjected to sensitivity analyses involving changes in the basic set of financial, engineering, and production assumptions. 9/

INITIAL ANALYSIS OF THE OPTIONS

Comparison of the choices examined reveals the greatest cost difference among them over the full 43-year period of analysis to be only $13 billion, a relatively small sum over so long a period (see Table 8). Involving

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7. The actual DOE SWU price would be different from the reported enrichment cost, since the former is designed to recover the full costs of the enrichment program over a ten-year period, while the enrichment cost averages total program costs on a per SWU basis over the full analysis period. In addition, the DOE SWU price would include outlays made before 1983 and DOE's administrative costs.

8. The cost data used in the CBO analysis were supplied by DOE in constant fiscal year 1984 dollars. The CBO reports these data as constant dollars as of the end of calendar year 1983.

9. More detailed discussion of the method is presented in Appendix A. Appendix B provides summary tables showing the effects of alternative assumptions.

TABLE 8. SUMMARY OF DISCOUNTED COSTS AND OUTLAYS UNDER EACH OPTION, 1983-2025

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	90.9	46.6	53.7	58.5	44.8
Gas Centrifuge a/	45.9	45.9	15.1	1.4 b/	78.7
AVLIS	None	36.2	60.8	68.3	None
Full-Period Total	**136.8**	**128.7**	**129.6**	**128.2**	**123.5**
1983-2003 Total	87.4	85.3	86.2	85.4	82.3
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	17.9	18.7	16.9	15.2	18.2
1991-2000	11.3	10.1	12.1	13.1	7.8
2001-2025	12.2	4.3	5.1	4.7	2.0
Full-Period Total	**41.4**	**33.1**	**34.1**	**33.0**	**28.0**
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	129.4	121.7	122.6	121.3	116.8
Full-Period Enrichment Charge	39.4	31.6	32.5	31.3	26.7

SOURCE: Congressional Budget Office.

a. Through Option III, data reflect costs and outlays associated with GCEP operation through Set IV technology; include AGC costs and outlays for Option IV only. Because AGC is the culmination of the GCEP project, its associated costs and outlays are not identified separately.

b. Cost to decommission GCEP project.

$137 billion in enterprise costs, the most expensive option is the Base/DOE Plan, relying on continued use of gaseous diffusion and construction of the GCEP project. The least expensive alternative is Option IV, which eventually relies solely on the most refined stage of gas centrifuge technology, AGC; this would entail $123.5 billion in enterprise costs. The next lowest-cost plan is Option III, relying heavily on AVLIS, which would cost $128.2 billion. This would be followed closely by Options I and II, the alternatives that would combine GCEP and AVLIS in different proportions.

The quite small cost difference between the two least expensive options, only $4.7 billion over the analysis period, must be considered with the uncertainty of cost projections for such experimental technologies in mind. If, under the AGC program, research and development funding for AVLIS were continued through 1995 at its fiscal year 1984 appropriation level of $103 million, the discounted cost would add roughly $1.1 billion to the $123.5 billion cost of Option IV. Thus, this program would still be less expensive than the $128.2 billion AVLIS program under Option III.

As shown in Table 9, the gas centrifuge program that stops at the Set IV level of technology is by far the most capital intensive on a per SWU production basis; capital costs of the eight-building GCEP facility would be about $14 per SWU.[10] Because of greater output, capital investment in AGC would cost roughly $8 per SWU. At roughly $4 per SWU, the capital costs of AVLIS would still be lower. The operating costs of the AGC, however, would average just $11 per SWU--one-half the projected costs of operating the AVLIS plants. (The $11 per SWU operating cost for AGC includes operating the Set III and improved Set IV machines in the first six GCEP buildings in the early years of production as stated in the outline of Option IV.) The operating costs for AVLIS--$22 per SWU--include the $11 per SWU cost of converting uranium feedstock from a gaseous state into a

10. Current discussion of the performances of the advanced technologies generally focuses on undiscounted system costs. These costs are therefore not comparable to the discounted option enrichment charges reported in Table 8. The discounted costs, however, using a real discount rate of 4 percent, show the same relative trends between technologies: discounted capital costs are about $12 per SWU for the full GCEP, $7 per SWU for AGC, and $2 to $3 per SWU for AVLIS. The discounted operating and maintenance projections are roughly $9 per SWU for the current GCEP plan, $5 per SWU for AGC, and $8 per SWU for AVLIS, compared to estimates of about $50 to $82 per SWU for gaseous diffusion under the different options.

TABLE 9. UNDISCOUNTED ENRICHMENT COSTS UNDER THE OPTIONS, BY TECHNOLOGY, 1983-2005
(In constant dollars per separative work unit)

Cost Components	Base/DOE Plan	Option I	Option II	Option III	Option IV
			Gaseous Diffusion		
Capital Charge	2.14	3.08	2.66	2.58	3.58
Operating and Maintenance (Including power costs)	95.99	100.58	99.89	101.24	99.88
Subtotal	98.13	103.66	102.55	103.82	103.46
			Gas Centrifuge		
Capital Charge	14.15	14.15	22.96	None	7.69
Research and Development	1.40	1.40	5.36	None	1.25
Operating and Maintenance	20.85	20.85	44.80	None	10.90 a/
Subtotal	36.40	36.40	73.12	None	19.84
			Atomic Vapor Laser Isotope Separation		
Capital Charge	None	3.92	3.68	3.59	None
Research and Development	None	1.78	1.44	1.27	None
Operating and Maintenance	None	22.00	22.00	22.00	None
Subtotal	None	27.70	27.12	26.86	None
			Option Production Costs (Combined averages)		
Capital Charge	7.22	8.09	5.57	3.34	6.95
Research and Development	0.59	1.28	1.54	0.95	1.02
Operating and Maintenance	64.19	36.35	42.20	41.87	27.00
Total	72.00	45.72	49.31	46.16	34.97

SOURCE: Congressional Budget Office, based on data from DOE, Office of Uranium Enrichment and Assessment.

a. Includes operating cost associated with the Set III and improved Set IV machines that are used initially in the first six GCEP process buildings until the Set V AGC machines replace them in the late 1990s.

solid metal. 11/ The gaseous diffusion and gas centrifuge processes, using uranium feedstock in a gaseous form supplied directly by the customers, entail no such conversion costs.

The undiscounted total cost of the AGC technology would be roughly $20 per SWU, compared to about $27 per SWU for AVLIS and $36 per SWU for the full GCEP project through Set IV. In comparison, the total cost of running the gaseous diffusion plants on the basis of production schedules specified under each option would average roughly $100 per SWU; most of this is attributable to power costs.

Options using the gas centrifuge process in its present stage of development (Sets III and IV) are more expensive than options using either AGC or AVLIS alone. The analysis also suggests that, if AGC does not perform according to current projections, a better course would be to halt GCEP construction and proceed immediately with AVLIS, assuming that AVLIS can hold to its current project schedule and meet its efficiency goals.

Federal Costs Over the Near- and Mid-Term

Of more immediate concern to the Congress than costs over the full span of the CBO projection may be the options' federal costs over shorter periods. To put the analysis in the context of the budget, the CBO has prepared a short-term analysis covering the period 1983-1990 and, as shown in Figure 1, a mid-term analysis ending in the year 2003. (For illustrative purposes, the figure includes a projection of the 20-year costs of continuing to meet all enrichment capacity with gaseous diffusion technology.) Interestingly, the results of examining these two periods do not fully reiterate those of the long-term projection, and the ranking of options emerges somewhat changed.

Federal Costs Through 1990. Between 1983 and 1990, the costliest choice in terms of federal outlays appears, at $18.2 billion, to be Option IV, the program that would ultimately depend on AGC for enrichment services; over the full 43-year projection period, however, this same option becomes the least expensive. Option III, relying on AVLIS--in the full projection, ranking second in savings--ranks at the top in the 1983-1990 timespan, with federal outlays of $15.2 billion. Timing of capital investments accounts for

11. Appendix B presents an analysis of the AVLIS and AGC programs under a tails assay of 0.10 percent from 2000 to 2025. The cost of converting the uranium feed in the AVLIS process falls to $5.60 per SWU under this lower tails assay assumption.

these shifts in the rankings. The major portion of AGC would be built between now and 1990, while the AVLIS program would entail sizable capital outlays later.

Federal Costs to the Year 2003. Around the year 1990, the relative positions of these two options would reverse (see Figure 1). As in the full 43-year projection, Option IV emerges as the most cost effective, with 20-year outlays reaching $26.3 billion. Option III (AVLIS) follows, with 20-year outlays of $29.1 billion. Most conspicuous is the high potential cost of continuing to rely on gaseous diffusion. This process would entail some $36.6 billion over 20 years, or some $5.3 billion more than the most expensive alternative, the Base/DOE Plan.

SENSITIVITY ANALYSIS--THE EFFECTS OF CHANGED ASSUMPTIONS

Though the cost projections and options' rankings noted above were derived from what CBO regards as the most plausible set of assumptions, the options were also subjected to various changed assumptions. Such "sensitivity analysis" can reveal what might occur if conditions in certain areas develop in ways other than assumed in the initial analysis. The options were compared against one another and against the Base/DOE Plan with several possibilities assumed, including:

- Project delays,
- Cost overruns,
- Changed real discount rates, and,
- A higher electricity inflation rate.

Two other analytic changes were also considered: the relative costs of running each option at less-than-full capacity, and the costs of scaling down production to meet a low-demand schedule. To keep the comparisons consistent and compatible with the initial analysis, the same 1983-2025 projection period was examined, and except for the final items in the sensitivity analysis, annual capacity was assumed to remain constant at 26.5 million SWUs. 12/ (More detail on the sensitivity analysis is given in Appendix B.)

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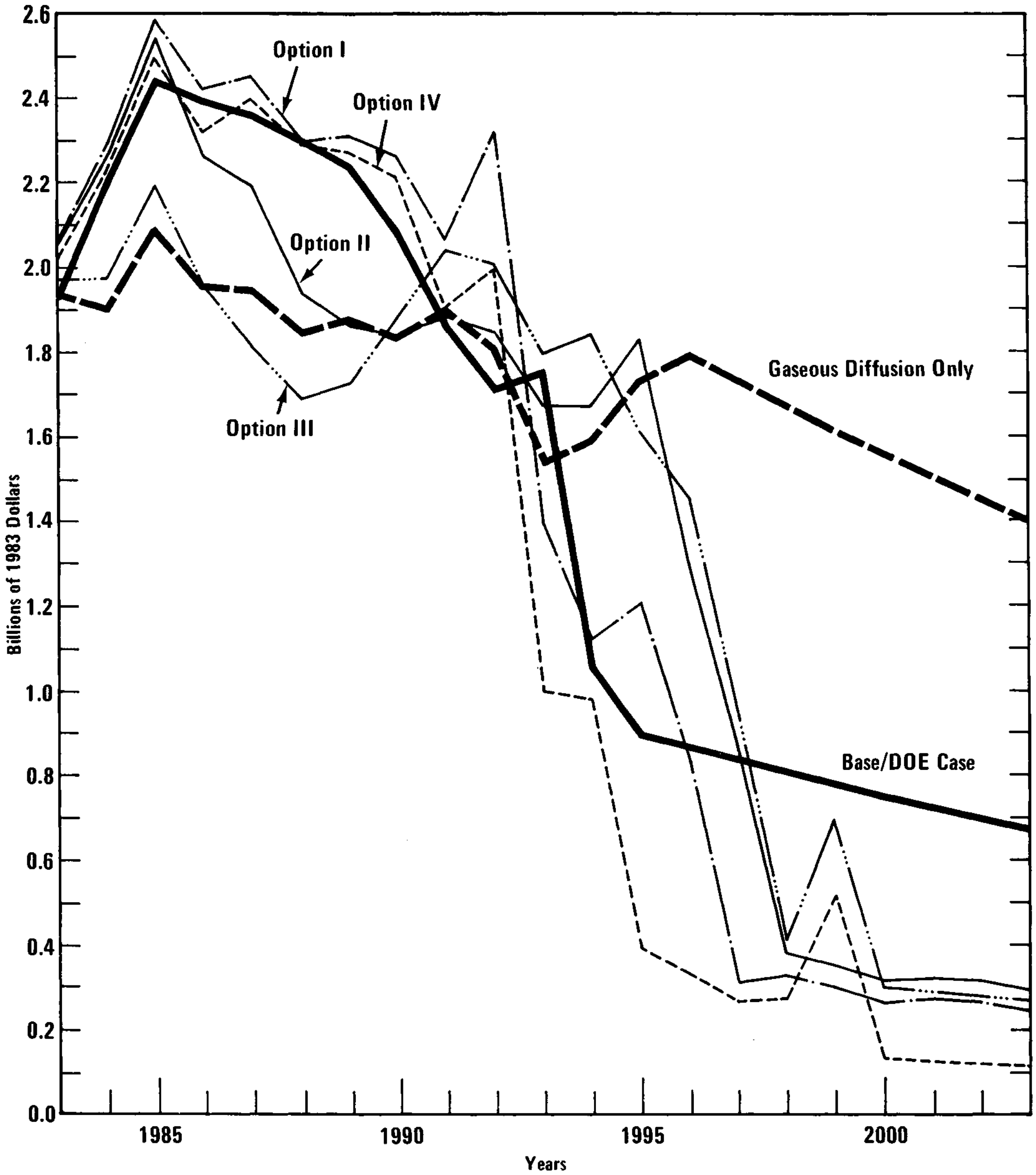
12. An analysis was also done comparing the costs two programs, using AGC and/or AVLIS technologies, under a lower tails assay assumption past 1999. Detailed examination of the tails assay issue and its implications for projected enrichment costs is given in Appendix B.

Figure 1.

Annual Federal Outlays for Base/DOE Plan, Four Options, and Continued Reliance on Gaseous Diffusion, 1983-2003

(In billions of discounted 1983 dollars)



SOURCE: Congressional Budget Office.

With the exception of capital cost overruns, all these sensitivities result in relative cost trends among the less expensive options unchanged from the initial analysis. Option IV, relying on AGC, remains the most cost effective, followed closely by Option III, relying on AVLIS. 13/

Project Delays

The effect of a three-year project delay in the cost of both AVLIS and AGC does not change the order of results. 14/ On a delayed schedule, Option IV, depending on AGC alone, would still incur the lowest enterprise cost--$125.9 billion, rather than the $123.5 billion projected on the schedule assumed in the initial analysis. Next in order would be Option III, the option consisting mainly of AVLIS, which would have its enterprise costs increased from $128.2 billion to $132.2 billion. The Base/DOE Plan would remain the most expensive course, with enterprise costs remaining unchanged from $136.8 billion. Thus, even with a three-year delay, both Options III and IV would nonetheless prove more cost effective than the Base/DOE Plan, which itself would undergo no cost change because of reliance on technologies already in operation or nearing completion. This ranking also holds with costs translated into charges per SWU, with those under Option IV being $29.1, under Option III $34.9, and under the Base/DOE Plan $39.4.

Cost Overruns

To estimate cost overruns unrelated to schedule delays--not uncommon for new technologies--the CBO assumed that current estimates of the AVLIS and the AGC technologies are equally uncertain but that data for the current GCEP technology (Sets III and IV) are more reliable, since the project is now under construction and in the demonstration and testing

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13. The analysis using the assumption of a lower (0.10 percent) tails assay from 2000 through 2025 indicates that the most cost-effective program would involve operation of two AVLIS plants in addition to the eight-building AGC facility, providing a combined capacity of 42 million SWUs a year. (See Appendix B.)

14. The delayed AVLIS program assumes that production would begin in 1997 rather than in 1994 as in the current schedule (Option III). Delaying the AGC technology assumes that production from early GCEP technology would still begin in 1988 with 0.4 million SWUs, but incorporation of the AGC technology would be delayed by three years.

phase. 15/ The cost escalation factors for AVLIS, GCEP, and AGC are as follows:

- o An 8 percent cost overrun factor was applied to the centrifuge machine and building costs for the current GCEP project; 16/
- o A 100 percent cost overrun factor was applied to the capital plant and equipment portion of AVLIS; and
- o A 100 percent cost overrun factor was applied to the AGC machines (which account for 85 percent of the AGC capital costs), and a 60 percent factor was applied to the building costs of the full eight-building gas centrifuge facility carried through the Set V (AGC) stage.

Even with project cost overruns, Option IV would remain the least expensive alternative, entailing $130.2 billion in enterprise costs. With enterprise costs of $137.5 billion, the Base/DOE Plan, using gaseous diffusion and GCEP, would remain the most expensive. After that, however, the options' ranking would change. Compared against the Base/DOE Plan, Option I, combining GCEP and AVLIS, would be roughly $2 billion cheaper than Option III. Cost overruns would have a relatively greater impact on the AVLIS program under Option III, because this option would use three AVLIS plants rather than the two to be built under Option I.

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15. The probability of individual projects' exceeding their current expense estimates cannot be determined at this point. Given the current stage of development for both AGC and AVLIS, it is likely that present cost estimates for each project are roughly equal in accuracy. To date, the GCEP project has not exceeded its cost projections. No comparable history exists for the AVLIS or the AGC process.

16. While these cost overrun figures seem to favor GCEP and AGC, they are consistent with the historical record of overruns in comparable projects. In a study by the Rand Corporation, new technologies often were found to experience cost overruns ranging from 10 to 200 percent, depending on stage of development. See W. Merrow, Kenneth E. Phillips, and Christopher Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, prepared for the Department of Energy, R-2569-DOE (September 1981). The building and machine costs for GCEP (Sets III and IV) were assumed to have lower escalation potential because of their advanced stage of development. (See Appendix A for more detail.)

On the other hand, should the AGC technology experience cost overruns but AVLIS not, then Option III would become the cheaper of the two--$128.2 billion versus $130.2 billion for Option IV--in fact, the cheapest in the series. Again, though, the cost overruns calculated for the advanced technologies do not affect their ranking with respect to the Base/DOE Plan: the capital costs for the AVLIS and the GCEP/AGC complexes would have to be 445 percent and 230 percent greater under Options III and IV, respectively, to produce enterprise costs equal to the Base/DOE Plan's $136.8 billion.

Changed Real Discount Rates

A real discount rate--an analytic device designed to translate future monetary sums into their present-day values--tends to make expenditures planned far ahead appear less costly in current terms. This tendency increases as projections extend farther into the future. Thus, a capital project such as AVLIS, with major investments to be made ten years hence, would be expected to appear less burdensome than one such as GCEP and even AGC, involving sizable expenditures sooner.

For the sensitivity analysis reported here, beside the initial discount rate of 4 percent, the options were tested with both a higher rate of 6 percent and a lower rate of zero percent. The results show no change in the ranking of options. Again, Option IV, with total enterprise costs of $92.9 billion under a 6 percent real discount rate, remains the lowest-cost approach.

With the higher rate used, Option III, relying on the more distant AVLIS process, remains the second most cost-effective choice, with total enterprise costs of $96.4 billion, $3.5 billion more than the AGC program under Option IV. In contrast, the Base/DOE Plan would involve $101.4 billion in enterprise costs. The enrichment charges using the 6 percent discount rate would be $22.60 per SWU for Option IV, $25.90 per SWU for Option III, and $30.60 per SWU for the Base/DOE Plan.

Total cost projections using a zero percent real discount rate also indicate that Option IV would offer the least costly investment strategy. With discounting effectively disregarded, total enterprise costs are $257.6 billion for Option IV, compared to $268.6 billion for Option III, and $295.1 billion for the Base/DOE Plan.

Higher Real Inflation Rate for Electricity

Whereas the initial analysis assumed an annual increase in power costs of 0.5 percent, for the sensitivity analysis, that rate was quadrupled to 2 percent, with no significant change in the results. If real power costs were to rise at this higher rate, Option IV would again offer the least expensive choice, having an enterprise cost of $124.5 billion. Options I and III would cost approximately the same--both about $5.5 billion more than Option IV.

A still higher power escalation factor would affect the costs of Option III more relative to those of Option I, because of later retirement of the gaseous diffusion plants specified in Option III. Thus, Option III would lose its cost advantage over Option I, which would phase out gaseous diffusion earlier. Enrichment charges assuming the higher power escalation factor of 2 percent would be $27.70 per SWU for Option IV, $32.70 and $33 per SWU for Options I and III, respectively, and $45.60 per SWU for the Base/DOE Plan.

Lower Production with Full Capacity

The CBO also examined the effect of building enrichment capacity to meet the full-production goal of 26.5 million SWUs but scaling down operations to meet a lower level of demand. This scenario might reflect the loss of a significant share of foreign market demand in the late 1990s. The U.S. enrichment program would still initially produce at full capacity, but starting in 1996, when demand might slack off, production would be slowed to 25 million SWUs a year, eventually leveling off to an annual rate of 19.6 million SWUs after the year 2004. In this situation, only 75 percent of the enrichment capacity would be used.

The effect on program costs of lower realized SWU demands does not change the rankings of the options. Option IV, with enterprise costs of $102.5 billion, remains the least expensive. The next most economic choice would be Option III, having a discounted enterprise cost of $106.0 billion. Option I would fall next, with costs of $106.5 billion. Moreover, in all cases, average enrichment charges over the full operating life of enrichment facilities would still fall well below the current world market SWU price that ranges from $100 to $120.

Planning for Lower Capacity Production Schedule

The study also examined the consequences of designing a smaller future enrichment service to meet a lower goal of annual SWU output. In this scenario, new enrichment plants would be tailored to supply only 19.6 million rather than the full 26.5 million SWUs a year after the year 2000. Such a low-demand scenario reflects a situation in which the federal government expected to lose or not to seek a significant portion of the foreign market, and it would thus plan for less new capacity. This approach, being smaller in scale, would naturally involve less capital investment.

As in the other sensitivity analyses, the ranking of options changes little from that established in the initial analysis. Again, Option IV emerges as the lowest-cost approach, with enterprise costs over the projection period totaling $93.4 billion. Option III follows closely, with enterprise costs of $95.8 billion. 17/ In terms of federal outlays, Option IV also entails the lowest cost: these would come to $25.4 billion through the year 2025, or $2.6 billion less than the $28.0 billion in federal outlays projected for this option under the high-production scenario. Further, since most of these federal outlays would be capital costs and hence made relatively early, a major share--roughly 95 percent, or $23.9 billion--would have been spent by the year 2003. This implies that the longer-term economies to be achieved by this option could be significant, as costs would be composed mainly of the relatively low operating charges associated with AGC.

Concluding Observations

In generally corroborating the results of the initial analysis, the sensitivity studies also point to two similar overall observations for the long term. First is that, unless energy costs should fall in an unprecedented way, long-term reliance on gaseous diffusion will obviate all prospects for a low-cost U.S. enrichment service. Second, those technologies now farthest from the demonstration stage, AGC and AVLIS, appear to offer the best promise for an economic enrichment enterprise and a strong position in the world market. Finally, with the cost of differentials between the competing advanced technologies relatively small and the bases underlying long-range cost projections subject to much uncertainty, the choice between the two is not clear-cut.

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17. A separate calculation was made that involved all demand under the lower production schedule being met through 2003 using existing gaseous diffusion. Outlays and enterprise costs over the period were estimated to be $28.5 and $74.7 billion, respectively--higher than the Base/DOE Plan or any option.

APPENDIXES

APPENDIX A. DESCRIPTION OF ANALYTIC METHOD AND ASSUMPTIONS

To project total enterprise costs and outlays for the Base/DOE Plan and the options examined, the Congressional Budget Office used an accounting model for each of the three technologies--gaseous diffusion, both the gas centrifuge enrichment plant and advanced gas centrifuge, and the atomic vapor laser isotope separation process. The costs included those associated with research and development, capital investment, operation and maintenance, and uranium feedstock. Those corresponded with each technology's production schedule under the options. The total costs and SWU production figures from each technology were combined in a larger model, which reports on total option costs and production schedules.

As described in Chapter IV, the initial analysis applied a SWU production level designed to meet the Department of Energy's medium-level demand projections. Each option thus provides a cumulative production of 1.06 billion SWUs over the period 1983 to 2025. For each option, the production schedule for the technologies was assigned as follows:

- The three gaseous diffusion plants would be relied on only while production from the advanced technologies is insufficient to meet demand, and they are phased out of commercial operation as soon as the new processes can be brought on-line to replace them.

- For the Base/DOE Plan and Option I, production from the eight-building GCEP complex is based on the deployment schedule outlined in the DOE's operating plan (January 1983), beginning in 1988 at 0.4 million SWUs a year, eventually operating at full capacity of 13.2 million SWUs a year, through 2025.

- For Option II, production from the two-building GCEP complex (as under Option I) would also begin in 1988, producing 0.4 million SWUs, and would eventually run at maximum capacity of 3.3 million SWUs from 1997 through 2025.

- For Options I, II, and III, AVLIS plants would be brought on-line in consecutive years as required to phase out the gaseous diffusion plants, either with or without the GCEP. The AVLIS technology would be first introduced in 1994 at an annual rate of 0.9 million SWUs.

- For Option IV, production from the GCEP/AGC complex would begin in 1988 at 0.4 million SWUs, using the Set III machines and, in 1990, improved Set IV machines. Set V centrifuges would be phased in beginning in 1994, eventually providing a maximum capacity of 26.5 million SWUs per year from 1999 to 2025.

- The DOE SWU inventory is used as needed in meeting annual SWU requirements, after assuring that it could provide at least one-third of the next year's requirements. Under all options, the stockpile is drawn down from its 1982 level of 24.7 million SWUs to 8.8 million SWUs by the year 2002, where it remains through 2025. The drawdown from the DOE inventory is not accounted for in enterprise costs, since the stockpile is considered a "sunk cost," while enterprise costs consist only of yearly outlays expended over the period 1983 through 2025. 1/

Under all options, total enterprise costs represent the feed and system costs of enriching uranium. In determining enterprise costs, the real interest rate on capital was assumed to be 4 percent, and initial costs were fully depreciated over 25 years. The capital recovery factor accounts for the interest and depreciation on capital investment that would be reflected in the SWU prices charged to DOE customers. The federal outlay schedules for each option were also calculated; these do not include feed costs nor capital interest and depreciation expenses, since the actual appropriation levels would be made each year.

The amount of natural uranium feed each technology requires ranges between 1.3 and 1.6 kilograms of uranium (kgU) per SWU produced. 2/ Since

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1. Total enterprise costs represent the combined option costs both to the DOE and to the enrichment customers, including depreciation and interest on capital, and feed charges. Not included in enterprise costs are the still unrecovered outlays expended before 1983, costs associated with carrying the existing DOE natural uranium feed and SWU inventories, and the administrative costs of running the DOE enrichment program. These costs would be reflected in actual DOE SWU prices, however, since by law all costs associated with the federal enrichment program must be recovered from sales.

2. The amount of natural uranium feed required to produce a given amount of enriched product is dependent on the U-235 concentration in the feed, enriched product, and depleted uranium waste stream left after enrichment. The concentration remaining in the depleted uranium tails, called the tails assay, is an operating tool set by the (Continued)

equal cumulative SWU production levels would be produced under all options, the costs of natural uranium feed are not a decisive factor in determining the least-cost enrichment program. However, the feed costs under each option are included in total enterprise costs, which represent the combined enrichment costs both to the DOE and to its customers. 3/ The unit price for natural uranium used in the CBO analysis--$134 per kgU through the year 2025-- was the price set by the DOE in its program cost analyses as published in the January 1983 operating plan.

The three algorithms that calculate the costs of uranium enrichment under the different technologies are described below.

The Gaseous Diffusion Subroutine

The gaseous diffusion model calculates the annual costs of operating the three gaseous diffusion plants at given SWU production levels. The costs include feed, operating and maintenance, power, capital, and plant decommissioning costs.

The DOE has power contracts with the following utility companies for operating the gaseous diffusion plants: the Tennessee Valley Authority (TVA) for the Oak Ridge (Tennessee) and Paducah (Kentucky) plants; Electric Energy, Incorporated (EEI) for the Paducah plant; and the Ohio Valley Electric Corporation (OVEC) for the Portsmouth (Ohio) plant. In 1983, the unit power charges to the DOE were 4.11 cents per kilowatt hour for TVA, 2.79 cents per kilowatt hour for EEI, and 2.96 cents per kilowatt hour for OVEC. Future power costs were determined using a DOE schedule that estimates yearly total power cost projections for different gaseous diffusion production levels. This schedule incorporates DOE's current and projected contract commitments with the three utilities, and includes

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2. (Continued)
DOE. All technologies are assumed to operate under the same tails assay at the same time. Until 2000, all technologies operate at a tails assay of 0.2 percent; from 2000 to 2025, all technologies are assumed to operate at a tails assay of 0.25 percent. This is consistent with the tails assay assumptions in the DOE's current operating plan. Appendix B contains the results of an analysis of program costs assuming that all technologies operate at a tails assay of only 0.10 percent from the year 2000 to 2025.

3. The feed costs are not included in the federal outlay figures or enrichment charges for each option.

demand penalties that the DOE would incur for using less than the full committed power levels under the current contracts. For each option, power charges are adjusted upward using a 0.5 percent real annual rate for electricity. Over the 1983-2025 period, the combined operating and power costs for this process range from $50 to $82 per SWU, varying with the production schedule for gaseous diffusion assumed for each option. 4/

The capital expenditure projections for maintaining the three gaseous diffusion plants were obtained from DOE, totaling roughly $600 million under all options except the Base/DOE Plan, the only program that would continue to use gaseous diffusion through the year 2025. The estimated capital expenditures associated with maintaining the gaseous diffusion plants through the year 2025 in the Base/DOE Plan are $760 million.

The last cost item in the gaseous diffusion subroutine is the decommissioning cost incurred in the year production is discontinued for each plant. The DOE does not currently provide a specific figure for closing down the gaseous diffusion plants, but it has estimated a wide range of costs. The model assumes a mid-range estimate of $700 million for each plant closed down. Whatever portion of the plant is not fully depreciated at the time of decommissioning is still included in enterprise costs.

The GCEP Subroutine

The cost of the GCEP program includes research and development, capital, feed, and operating and maintenance. The system costs used in the GCEP subroutine are based on projections prepared at the Oak Ridge Laboratory where the development and performance testing for this project are under way. Cost estimates were provided for the eight-building GCEP (Set III-Set IV) complex (Base/DOE Plan and Option I), the two-building GCEP (Option II), and AGC (Option IV). 5/

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4. The outlays for the operating and maintenance costs, in addition to the power costs, were obtained from the DOE Office of Uranium Enrichment and Assessment. The cost figures cited in this Appendix represent discounted outlays in constant 1983 dollars assuming a real discount rate of 4 percent.

5. The GCEP and AGC cost data were in part reported in the DOE operating plan. The rest were obtained from the DOE Office of Uranium Enrichment and Assessment.

The discounted operating costs for the GCEP/AGC complex average $5 per SWU over the analysis period, including the operating costs of the less advanced Sets III and IV machines before the introduction of the Set V (AGC) advanced machines. This $5 per SWU average is about one-half the cost per SWU of operating the eight-building GCEP complex. The total discounted capital costs for the GCEP and AGC programs are very similar, $5.5 billion and $5.7 billion, since both would use the same eight buildings; the incremental capital costs for AGC are associated with the more efficient Set V machines. The discounted research and development costs for the AGC process are $0.8 billion, more than 50 percent higher than research costs for GCEP. It is important to note that there is still a large degree of uncertainty concerning the advanced centrifuge machine design, performance, and project costs; thus, total AGC costs could be much higher.

There is a significant trade-off between the two-building GCEP proposal (Option II) and the eight-building GCEP project (Base/DOE Plan and Option I). Through the capital costs for the two-building GCEP ($2.6 billion) would be about 53 percent lower than those for the full eight-building plant ($5.5 billion), the operating costs per SWU would be more than twice as high. Furthermore, before AVLIS became operational in the early 1990s, a two-building GCEP complex would require greater reliance on the gaseous diffusion plants, further increasing total production costs.

If the GCEP program were discontinued entirely after 1983, as in Option III (AVLIS only), the DOE would still incur GCEP-related outlays of $1.4 billion associated with current commitments to procure and build centrifuge machines.

The AVLIS Subroutine

The AVLIS program enterprise costs--for research and development, capital, feed, and operating and maintenance--depend on the number and capacity of the AVLIS plants brought on-line. Under Options I, II, and III, total AVLIS capacity is designed to enable the three gaseous diffusion plants to be phased out by the late 1990s.

The DOE deployment schedule for one AVLIS plant assumes an annual production rate of nine million SWUs, with production of 0.9 million SWUs beginning in 1994, 6.3 million SWUs in 1995, and the full nine million SWUs from 1996 on. In the CBO analysis, the number of plants built and the total annual AVLIS capacity for each option using that process is given below:

- Under Option I (eight-building GCEP and AVLIS), two AVLIS plants would be built with a combined annual capacity of 15.3 million SWUs;

- Under Option II (two-building GCEP and AVLIS), three AVLIS plants would be built with a combined annual capacity of 25 million SWUs;

- Under Option III (AVLIS only), three AVLIS plants would be operated with a total annual capacity of 27 million SWUs.

The deployment schedule for each AVLIS plant is based on the DOE schedule detailed above and displayed in Chapter IV, Table 7.

The AVLIS algorithm projects capital expenditures based on the DOE undiscounted cost estimate of $947 million for a nine million SWU capacity plant. 6/ The CBO analysis assumes that the maximum plant capacity would be nine million SWUs a year but that smaller plants could be built. Such smaller plants' capital construction costs are calculated without a decreasing-return-to-scale factor. 7/ The total discounted capital costs for the two-plant AVLIS program (Option I) would be $1.12 billion; under Options II and III, the capital costs for three AVLIS plants would be $1.76 billion and $1.93 billion, respectively. The discounted research and development costs to support AVLIS would be $0.63 billion. The discounted operating and maintenance costs for the AVLIS complex are roughly $8 per SWU over the 1983-2025 period, including the cost of converting natural uranium feed into a solid form, a requirement unique to the AVLIS process.

Combined Technology Costs for Each Option

To compute the enterprise costs and outlays for each option, the production and cost figures from the relevant technologies are combined and

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6. The research and development, capital, and operating and maintenance cost schedules for the AVLIS technology are projected on the basis of information prepared for DOE at the Lawrence Livermore Laboratory, where the AVLIS developmental work is being done. The AVLIS capital and operating costs and production figures are reported in the DOE operating plan (January 1983). The research and development cost data were obtained directly from the DOE Office of Uranium Enrichment and Assessment.

7. The major portion of the capital costs for an AVLIS plant represents the machinery expenditures directly related to SWU capacity; thus the DOE advised against using a decreasing-return-to-scale factor when projecting capital costs for a plant with an annual capacity of less than nine million SWUs.

discounted using a real annual rate of 4.0 percent. Tables A-1 through A-5 show the annual SWU production schedules, total enterprise costs, and outlay trends for the base plan and the four options under the initial medium SWU demand schedule. Enterprise costs and federal outlays are shown in 1983 dollars. Appendix B discusses the model results based on alternate sets of assumptions, including projected SWU demand.

In all tables, outlays represent annual government expenditures, which exclude feed costs, discounted at a real rate of 4.0 percent. These outlays do not take into account the offsetting government revenue from the enrichment services customers, which must recover the full cost to the federal government of running the enrichment program, over a ten-year period.

TABLE A-1. BASE/DOE PLAN--ANNUAL SWU PRODUCTION, ENTERPRISE COSTS, AND FEDERAL OUTLAYS, 1983-2025

Year	Annual SWU Production (In millions of SWUs) Gaseous Diffusion	GCEP	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	9.8	0.0	9.8	2,971	1,926
1984	12.1	0.0	12.1	3,602	2,202
1985	16.7	0.0	16.7	4,660	2,447
1986	18.2	0.0	18.2	4,831	2,394
1987	19.2	0.0	19.2	4,908	2,361
1988	19.2	0.4	19.6	4,828	2,292
1989	19.2	1.1	20.3	4,809	2,238
1990	19.2	3.1	22.3	4,866	2,078
1991	19.2	5.2	24.4	4,888	1,859
1992	17.9	7.3	25.2	4,749	1,710
1993	13.3	9.6	22.9	4,495	1,752
1994	13.3	11.7	25.0	4,089	1,052
1995	13.3	13.0	26.3	4,048	896
1996	13.3	13.1	26.4	3,913	864
1997	13.3	13.2	26.5	3,774	834
1998	13.3	13.2	26.5	3,633	805
1999	13.3	13.2	26.5	3,497	777
2000	13.3	13.2	26.5	3,918	749
2001	13.3	13.2	26.5	3,771	723
2002	13.3	13.2	26.5	3,629	698
2003	13.3	13.2	26.5	3,493	673
2004	13.3	13.2	26.5	3,361	650
2005	13.3	13.2	26.5	3,235	627
2006	13.3	13.2	26.5	3,113	605
2007	13.3	13.2	26.5	2,996	584
2008	13.3	13.2	26.5	2,866	563
2009	13.3	13.2	26.5	2,740	544
2010	13.3	13.2	26.5	2,622	525
2011	13.3	13.2	26.5	2,510	506
2012	13.3	13.2	26.5	2,403	489
2013	13.3	13.2	26.5	2,300	472
2014	13.3	13.2	26.5	2,202	455
2015	13.3	13.2	26.5	2,108	439
2016	13.3	13.2	26.5	2,020	424
2017	13.3	13.2	26.5	1,936	409
2018	13.3	13.2	26.5	1,856	395
2019	13.3	13.2	26.5	1,784	381
2020	13.3	13.2	26.5	1,717	368
2021	13.3	13.2	26.5	1,652	355
2022	13.3	13.2	26.5	1,590	342
2023	13.3	13.2	26.5	1,530	330
2024	13.3	13.2	26.5	1,472	319
2025	13.3	13.2	26.5	1,417	308

SOURCE: Congressional Budget Office.

TABLE A-2. OPTION I--ANNUAL SWU PRODUCTION, ENTERPRISE COSTS, AND FEDERAL OUTLAYS, 1983-2025

Year	Annual SWU Production (In millions of SWUs)				Discounted Enterprise Costs	Discounted Federal Outlays
	Gaseous Diffusion	GCEP	AVLIS	Total	(In millions of 1983 dollars)	
1983	11.2	0.0	0.0	11.2	3,349	2,056
1984	12.4	0.0	0.0	12.4	3,752	2,294
1985	17.5	0.0	0.0	17.5	4,922	2,591
1986	16.5	0.0	0.0	16.5	4,587	2,423
1987	18.9	0.0	0.0	18.9	4,967	2,452
1988	17.8	0.4	0.0	18.2	4,641	2,299
1989	19.2	1.1	0.0	20.3	4,888	2,305
1990	20.6	3.1	0.0	23.7	5,186	2,259
1991	19.6	5.2	0.0	24.8	5,020	2,059
1992	16.8	7.3	0.0	24.1	5,069	2,318
1993	12.3	9.6	0.0	22.0	3,852	1,396
1994	10.6	11.7	0.9	23.2	3,777	1,120
1995	6.2	13.0	7.2	26.4	4,219	1,202
1996	0.0	13.1	13.8	26.9	3,924	827
1997	0.0	13.2	13.2	26.4	3,308	310
1998	0.0	13.2	15.3	28.5	3,412	324
1999	0.0	13.2	14.4	27.6	3,186	301
2000	0.0	13.2	12.0	25.2	3,345	262
2001	0.0	13.2	13.7	26.9	3,417	271
2002	0.0	13.2	14.2	27.4	3,342	266
2003	0.0	13.2	13.3	26.5	3,115	246
2004	0.0	13.2	13.3	26.5	2,995	237
2005	0.0	13.2	13.3	26.5	2,880	228
2006	0.0	13.2	13.3	26.5	2,769	219
2007	0.0	13.2	13.3	26.5	2,663	211
2008	0.0	13.2	13.3	26.5	2,543	202
2009	0.0	13.2	13.3	26.5	2,427	195
2010	0.0	13.2	13.3	26.5	2,319	187
2011	0.0	13.2	13.3	26.5	2,216	180
2012	0.0	13.2	13.3	26.5	2,118	173
2013	0.0	13.2	13.3	26.5	2,024	166
2014	0.0	13.2	13.3	26.5	1,934	160
2015	0.0	13.2	13.3	26.5	1,848	154
2016	0.0	13.2	13.3	26.5	1,764	148
2017	0.0	13.2	13.3	26.5	1,684	142
2018	0.0	13.2	13.3	26.5	1,607	137
2019	0.0	13.2	13.3	26.5	1,537	131
2020	0.0	13.2	13.3	26.5	1,473	126
2021	0.0	13.2	13.3	26.5	1,414	122
2022	0.0	13.2	13.3	26.5	1,360	117
2023	0.0	13.2	13.3	26.5	1,308	112
2024	0.0	13.2	13.3	26.5	1,257	108
2025	0.0	13.2	13.3	26.5	1,209	104

SOURCE: Congressional Budget Office.

TABLE A-3. OPTION II--ANNUAL SWU PRODUCTION, ENTERPRISE COSTS, AND FEDERAL OUTLAYS, 1983-2025

Year	Annual SWU Production (In millions of SWUs)				Discounted Enterprise Costs	Discounted Federal Outlays
	Gaseous Diffusion	GCEP	AVLIS	Total	(In millions of 1983 dollars)	
1983	11.2	0.0	0.0	11.2	3,347	2,054
1984	12.4	0.0	0.0	12.4	3,747	2,271
1985	17.5	0.0	0.0	17.5	4,931	2,544
1986	16.5	0.0	0.0	16.5	4,575	2,256
1987	18.9	0.0	0.0	18.9	4,920	2,189
1988	17.8	0.4	0.0	18.2	4,577	1,937
1989	19.2	1.1	0.0	20.3	4,781	1,857
1990	21.4	2.3	0.0	23.7	5,091	1,833
1991	22.3	2.4	0.0	24.7	5,069	1,881
1992	21.5	2.6	0.0	24.1	4,739	1,842
1993	19.2	2.8	0.0	22.0	4,163	1,675
1994	19.4	2.9	0.9	23.2	4,182	1,671
1995	15.5	3.1	7.2	25.8	4,547	1,828
1996	7.2	3.3	16.2	26.7	4,137	1,295
1997	0.0	3.3	24.3	27.6	3,813	863
1998	0.0	3.3	25.0	28.3	3,354	378
1999	0.0	3.3	24.0	27.3	3,120	351
2000	0.0	3.3	22.0	25.3	3,324	315
2001	0.0	3.3	23.7	27.0	3,397	322
2002	0.0	3.3	24.0	27.3	3,300	312
2003	0.0	3.3	23.2	26.5	3,086	292
2004	0.0	3.3	23.2	26.5	2,967	281
2005	0.0	3.3	23.2	26.5	3,853	270
2006	0.0	3.3	23.2	26.5	2,743	260
2007	0.0	3.3	23.2	26.5	2,638	250
2008	0.0	3.3	23.2	26.5	2,519	240
2009	0.0	3.3	23.2	26.5	2,405	231
2010	0.0	3.3	23.2	26.5	2,298	222
2011	0.0	3.3	23.2	26.5	2,200	214
2012	0.0	3.3	23.2	26.5	2,109	205
2013	0.0	3.3	23.2	26.5	2,024	197
2014	0.0	3.3	23.2	26.5	1,945	190
2015	0.0	3.3	23.2	26.5	1,868	183
2016	0.0	3.3	23.2	26.5	1,792	176
2017	0.0	3.3	23.2	26.5	1,717	169
2018	0.0	3.3	23.2	26.5	1,644	162
2019	0.0	3.3	23.2	26.5	1,572	156
2020	0.0	3.3	23.2	26.5	1,503	150
2021	0.0	3.3	23.2	26.5	1,440	144
2022	0.0	3.3	23.2	26.5	1,383	139
2023	0.0	3.3	23.2	26.5	1,330	133
2024	0.0	3.3	23.2	26.5	1,279	128
2025	0.0	3.3	23.2	26.5	1,230	123

SOURCE: Congressional Budget Office.

TABLE A-4. OPTION III--ANNUAL SWU PRODUCTION, ENTERPRISE COSTS, AND FEDERAL OUTLAYS, 1983-2025

Year	Annual SWU Production (In millions of SWUs) Gaseous Diffusion	AVLIS	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	11.2	0.0	11.2	3,820	1,965
1984	12.4	0.0	12.4	3,955	1,975
1985	17.5	0.0	17.5	4,980	2,189
1986	16.5	0.0	16.5	4,515	1,953
1987	18.9	0.0	18.9	4,657	1,810
1988	18.2	0.0	18.2	4,319	1,686
1989	20.3	0.0	20.3	4,561	1,724
1990	23.7	0.0	23.7	5,007	1,879
1991	24.8	0.0	24.8	5,102	2,038
1992	24.1	0.0	24.1	4,765	2,002
1993	22.0	0.0	22.0	4,145	1,793
1994	22.3	0.9	23.2	4,209	1,836
1995	18.6	7.2	25.8	4,192	1,607
1996	10.5	16.2	26.7	4,161	1,448
1997	2.8	24.3	27.1	3,712	941
1998	1.2	27.0	28.2	3,278	408
1999	0.0	27.0	27.0	3,350	691
2000	0.0	26.5	26.5	3,364	299
2001	0.0	26.5	26.5	3,235	288
2002	0.0	26.5	26.5	3,110	277
2003	0.0	26.5	26.5	2,991	266
2004	0.0	26.5	26.5	2,876	256
2005	0.0	26.5	26.5	2,765	246
2006	0.0	26.5	26.5	2,659	237
2007	0.0	26.5	26.5	2,556	227
2008	0.0	26.5	26.5	2,455	219
2009	0.0	26.5	26.5	2,357	210
2010	0.0	26.5	26.5	2,265	202
2011	0.0	26.5	26.5	2,177	194
2012	0.0	26.5	26.5	2,092	187
2013	0.0	26.5	26.5	2,011	180
2014	0.0	26.5	26.5	1,934	173
2015	0.0	26.5	26.5	1,857	166
2016	0.0	26.5	26.5	1,782	160
2017	0.0	26.5	26.5	1,707	154
2018	0.0	26.5	26.5	1,633	148
2019	0.0	26.5	26.5	1,561	142
2020	0.0	26.5	26.5	1,492	137
2021	0.0	26.5	26.5	1,429	131
2022	0.0	26.5	26.5	1,371	126
2023	0.0	26.5	26.5	1,318	121
2024	0.0	26.5	26.5	1,267	117
2025	0.0	26.5	26.5	1,218	112

SOURCE: Congressional Budget Office.

TABLE A-5. OPTION IV--ANNUAL SWU PRODUCTION, ENTERPRISE COSTS, AND FEDERAL OUTLAYS, 1983-2025

Year	Annual SWU Production (In millions of SWUs)			Discounted Enterprise Costs	Discounted Federal Outlays
	Gaseous Diffusion	AGC	Total	(In millions of 1983 dollars)	
1983	11.2	0.0	11.2	3,314	2,021
1984	12.4	0.0	12.4	3,675	2,221
1985	17.5	0.0	17.5	4,843	2,498
1986	16.5	0.0	16.5	4,483	2,316
1987	18.9	0.0	18.9	4,880	2,398
1988	17.8	0.4	18.2	4,596	2,287
1989	19.2	1.1	20.3	4,840	2,269
1990	20.3	3.5	23.8	5,166	2,213
1991	18.4	6.3	24.7	4,932	1,899
1992	14.4	9.6	24.0	4,879	1,993
1993	8.0	13.9	21.9	3,625	999
1994	4.3	19.0	23.3	3,786	976
1995	3.5	22.3	25.8	3,470	386
1996	3.2	23.5	26.7	3,419	327
1997	2.5	24.7	27.2	3,278	263
1998	3.1	25.8	28.9	3,345	269
1999	0.0	26.5	26.5	3,252	509
2000	0.0	26.5	26.5	3,320	130
2001	0.0	26.5	26.5	3,192	125
2002	0.0	26.5	26.5	3,070	120
2003	0.0	26.5	26.5	2,952	115
2004	0.0	26.5	26.5	2,838	111
2005	0.0	26.5	26.5	2,729	107
2006	0.0	26.5	26.5	2,624	103
2007	0.0	26.5	26.5	2,523	99
2008	0.0	26.5	26.5	2,408	95
2009	0.0	26.5	26.5	2,298	91
2010	0.0	26.5	26.5	2,194	88
2011	0.0	26.5	26.5	2,096	84
2012	0.0	26.5	26.5	2,002	81
2013	0.0	26.5	26.5	1,912	78
2014	0.0	26.5	26.5	1,827	75
2015	0.0	26.5	26.5	1,745	72
2016	0.0	26.5	26.5	1,667	69
2017	0.0	26.5	26.5	1,594	67
2018	0.0	26.5	26.5	1,526	64
2019	0.0	26.5	26.5	1,464	62
2020	0.0	26.5	26.5	1,406	59
2021	0.0	26.5	26.5	1,352	57
2022	0.0	26.5	26.5	1,299	55
2023	0.0	26.5	26.5	1,249	53
2024	0.0	26.5	26.5	1,201	51
2025	0.0	26.5	26.5	1,155	49

SOURCE: Congressional Budget Office.

APPENDIX B. SENSITIVITY ANALYSIS--DETAIL

The sensitivity analysis summarized in Chapter IV resulted from five principal changes in the underlying assumptions:

- o Project delays of the AGC and AVLIS technologies,
- o Capital cost overruns in the GCEP, AGC, and AVLIS projects,
- o Higher and lower real discount rates,
- o A higher real power esclation factor, and
- o Lower projected demand for enrichment services.

The first portion of this appendix details the rationales behind and the results of these changed assumptions (see Tables B-1 through B-12, pages 65 through 76). To supplement the sensitivity tests, the remainder of the appendix reviews the analysis with a changed assumption regarding the tails assay in the enrichment process.

In each sensitivity test, all assumptions but the one under scrutiny are held constant with those in the initial analysis. The uniform assumptions include cumulative production for all options at 1.06 billion SWUs, a real discount rate of 4 percent, a real power escalation rate of 0.5 percent, and a 4 percent real return on capital investment when calculating enterprise and SWU costs and enrichment charges. The same 1983-2025 projection period is examined in all cases. Natural uranium feed costs are treated as part of total costs, but they are not included in federal outlays and enrichment charges. All figures are expressed in 1983 dollars, treated by CBO as equal to the fiscal year 1984 dollars used in DOE's projections. In the option that calls for ultimate reliance on the AVLIS technology--Option III--a cost of $1.4 billion is assigned to the gas centrifuge process for the decommissioning of the GCEP facility already partly built.

With both the AGC and AVLIS processes still in the early stages of development, there is considerable uncertainty about their project introduction schedules. The options were examined with the following timetable changes. Under Option III, AVLIS production would come on-line in 1997 instead of 1994; the GCEP project would still be discontinued. Under Option IV, production from the initial GCEP operation would begin in 1988 with 0.4

million SWUs, but incorporation of the AGC (Set V) technology would occur in 1996 instead of in 1993. Under this schedule, the AGC project would reach its maximum annual production rate of 26.5 million SWUs in the year 2002 instead of 1999.

If either or both of the advanced technologies were not available for commercial production until three years later than current projections specify, the rankings of options reported in Chapter IV would not be affected. Option IV, relying ultimately on AGC though introducing it three years behind schedule would offer the lowest enterprise costs ($125.9 billion) over the projection period. This would hold true even if the AVLIS system could be introduced on its current schedule with the enterprise costs of Option III remaining at $128.2 billion. If the AVLIS technology were developed and brought on-line three years late, however, the costs of Option III would be $132.2 billion, $8.7 billion more than the $123.5 billion projected for Option IV in the initial analysis and $6.3 billion higher than the delayed version of Option IV. The enrichment charge for Option IV delayed AGC is also cheaper than under Option III--$29.10 per SWU compared to $31.30. (These comparisons are displayed in Table B-1).

As noted in Chapter IV, the capital cost overrun factors applied for the advanced technologies in the sensitivity analysis are as follows:

- An 8 percent cost overrun factor for the GCEP machine and building costs,

- A 100 percent cost overrun factor for the capital plant and equipment portion of AVLIS, and

- A 100 percent cost overrun factor for AGC machine and a 60 percent factor for the building costs of the GCEP/AGC complex.

The cost overrun factor of 100 percent for the capital equipment portion for both the AVLIS and AGC technologies reflects the considerable uncertainty surrounding the early developmental stage of each. Since the AGC construction phase is now under way, however, an increase of 60 percent was applied to the AGC plant costs, compared to a 100 percent cost overrun in the AVLIS plant capital costs. The 100 percent cost overrun figure applied to the AVLIS capital plant and equipment costs reflects the greater uncertainty associated with this technology. (In fact, the AVLIS process may be improved by "learning-by-doing" effects associated with new technologies; in some instances, real costs can fall below intial estimates, as experience points to improved efficiencies. This analysis, however, does not consider this possibility.)

The much lower cost overrun factor of 8 percent used for the GCEP complex reflects the later developmental stage of Sets III and IV centrifuge machines. In fact, judging from experience to date on construction of the first two buildings and support facilities, actual costs may be just at or below current projections.

The results suggest that, if the above cost overrun factors occurred in all advanced projects, Option IV would still be the least expensive choice, with enterprise costs of $130.2 billion over the projection period. If the AGC program did experience the cost overruns while the AVLIS program costs remained on schedule, Option III would become the least expensive--$128.2 billion for Option III compared to $130.2 billion for Option IV. But again, the total cost differences between the options remain rather small considering the uncertainty of the technology cost projections. (See Table B-2.)

Alternative Discount Rates

The choice of a discount rate can significantly affect decisions about the appropriate timing of expensive capital projects. Thus the sensitivity of the enrichment option costs to different discount rate assumptions was measured. The analysis in Chapter IV discounted the projected enterprise costs and federal outlays using a real annual discount rate of 4 percent (see Chapter IV, Table 7). This appendix displays both the results of a 6 percent real discount rate and a zero percent rate. The results show that, although absolute costs would be different under higher and lower discount rate assumptions, the effect on the comparisons of the options would be insignificant. Compared to the initial analysis, the higher discount rate results in lower total costs across all options, but the relative rankings do not change. Option IV is again the least expensive over the 1983-2025 period, with projected enterprise costs of $92.9 billion and a lifetime enrichment charge of $22.60 per SWU. Option III is the next cheapest choice, with total enterprise costs of $96.4 billion and an eventual enrichment charge of $25.90 per SWU. (See Table B-3.)

With no discounting of future costs, all options appear to require much higher outlays compared to the initial analysis (see Table B-4). For instance, the least expensive choice, again Option IV, would result in a lifetime enrichment charge of $41.10 per SWU using undiscounted costs, compared to $26.70 per SWU using a real discount rate of 4 percent. Option III is still the second cheapest, with total enterprise costs of $268.6 billion and an overall enrichment charge of $51.60 per SWU.

A Higher Inflation Rate for Electricity

The rate at which electricity prices rise will affect the costs of enrichment operations--especially in the short term, when the existing energy-intensive gaseous diffusion plants would still be heavily used. The initial analysis assumed that power costs would escalate at a real annual rate of 0.5 percent; this appendix shows the results of applying an annual 2 percent escalation factor for power costs instead (see Table B-5). As in the other sensitivity analyses, Option IV (AGC) remains the cheapest, costing $124.5 billion and with an eventual enrichment charge of $27.70 per SWU. However, the total costs of the AVLIS programs either with or without the eight-building GCEP--that is Options I and III--are now roughly equal, with total enterprise costs of about $130 billion. Since the inclusion of GCEP in Option I allows for less gaseous diffusion production, and thus lower power costs, the AVLIS-alone program, Option III, loses the advantage it had in the initial analysis.

Lower Projected Demand

The initial analysis reported in Chapter IV is based on DOE's 1983 projections of SWU demand, which assume that the United States would provide enrichment services for 220 gigawatts of nuclear power worldwide by the year 2000. Of this total, 133 gigawatts would represent domestic nuclear generating capacity and 87 gigawatts would be foreign capacity. These DOE medium-case gigawatt totals have been consistently revised downward from previous annual operating plans, reflecting lower estimates of worldwide and domestic nuclear capacity growth and diminishing success in obtaining new foreign contracts for U.S. enrichment services. The CBO has therefore performed this sensitivity analysis reflecting lower demand: one in which full capacity is built but operated at lower levels, and one in which capacity itself is scaled down.

Scaled-Down Use of Full Capacity. In modeling this analysis, CBO assumed that enrichment facilities would be built to provide the full annual complement of 26.5 million SWUs throughout the projection period; capital costs would therefore remain as in the initial analysis. After 1995, however, SWU demand would slow, leveling off after the year 2005 at an annual rate of 19.6 million SWUs. This represents a total capacity use factor of approximately 75 percent.

Again, the cost trends among the options remain the same: Option IV would provide the lowest enterprise ($102.5 billion) and enrichment ($32.10 per SWU) costs. Likewise, Option III would be the second least expensive program, with enterprise costs of $106.0 billion and enrichment costs of $36.20. (See Table B-6.)

To model the effects of the decreased use of the fully constructed enrichment buildings, the following adjustments were made regarding the options:

- o The Base/DOE Plan would use the GCEP complex fully, but it would require less production from the gaseous diffusion plants through 2025.

- o The programs that include both GCEP and AVLIS (Options I and II) would continue to use GCEP fully but would cut back on AVLIS SWU production levels. The construction of the GCEP and AVLIS plants would have been fully completed by 1995, and it would be cheapest to operate GCEP fully and cut back on AVLIS use (operating costs are $21 per SWU for the GCEP complex, compared to $22 per SWU for AVLIS.)

- o Options III and IV would cut back on production from the AVLIS and GCEP/AGC plants uniformly.

Scaled-Down Capacity. In this sensitivity test, capacity is assumed to be built to service 147 gigawatts of installed generating capacity by the year 2000, rather than 220 gigawatts under the medium-demand initial scenario. Of these, 114 gigawatts would be domestic generating capacity and 33 gigawatts would be foreign capacity. (There are currently 59.7 gigawatts of domestic capacity in operation, and 54.3 gigawatts would be added by the year 2000, all to be serviced by the DOE's enrichment program.) Corresponding to the 147 gigawatts of nuclear capacity, the analysis assumes a steady civilian enrichment demand of 18 million SWUs a year after the year 2000 (plus 1.55 million SWUs of military demand).

Since less capacity is built and fewer SWUs produced over the analysis period, all options are less costly compared to the initial analysis. The option trends are the same, however. Option IV would be least expensive, costing $93.4 billion for the total enterprise costs and $31.80 per SWU for enrichment charges, followed closely by Option III, costing $95.8 billion for the enterprise costs and $34.60 per SWU for enrichment charges. (See Table B-7.)

Under these same low-growth demand assumptions, any foreign nuclear plants now categorized as planned but not yet authorized by their governments would be either cancelled or serviced by other enrichment suppliers. Through 1992, DOE would retain all foreign non-firm enrichment contracts except for eight adjustable fixed commitment contracts with Japan (reflecting current over-contracting on Japan's part) and two Taiwanese contracts that are cancelled after 1988 and serviced thereafter by Eurodif. After 1992, all of DOE's enrichment contracts for European nuclear capacity are assumed lost except for those for three German, one Yugoslavian, and four Swedish units.

Tables B-8 through B-12 display the annual production and cost figures for each option under projected low SWU demand. Total enterprise costs, expressed in 1983 dollars, represent annual expenditures, which exclude feed costs, and are discounted at a real rate of 4.0 percent. Outlays represent annual government expenditures, which exclude feed costs, discounted at a real rate of 4.0 percent. These outlays do not take into account the offsetting government revenue from sales, which must recover the full cost to the federal government of running the enrichment program over a ten-year period. In modeling the five option costs under this low-demand schedule, the following adjustments were made regarding the production capacities and schedules described in Chapter IV.

- The Base/DOE Plan would continue to use two gaseous diffusion plants along with the eight-building GCEP, but the one gaseous diffusion plant would be decommissioned in 1992, rather than in 1993 as in the initial analysis.

- Under Option I only one AVLIS plant would be built, rather than two, with an annual capacity of 6.4 million SWUs; in addition, the three gaseous diffusion plants would be shut down by 1995 instead of 1996.

- Option II would use the two-facility GCEP building with an annual production rate of 3.3 billion SWUs; only two rather than three AVLIS plants would be required, with an annual capacity of 9 and 7.3 million SWUs each. The three diffusion plants would still be decommissioned by the year 1996.

- Option III would initially use three AVLIS plants along with the gaseous diffusion technology, phasing out the latter process entirely by 1997. Two of the three AVLIS plants would each provide 9 million SWUs a year, and the third would have an annual production rate of 2 million SWUs.

- Option IV would use only a six-building GCEP/AGC complex rather than the original eight-building project. An annual production rate of 19.6 million SWUs would be reached by 2001, and production from the gaseous diffusion plants would stop after 1996.

TABLE B-1. DISCOUNTED COSTS OF OPTIONS ASSUMING THREE-YEAR PROJECT DELAYS FOR AVLIS AND AGC

	Base/DOE Plan	Initial Analysis Option III	Initial Analysis Option IV	With Delays Option III	With Delays Option IV
		Discounted Enterprise Costs in Billions of 1983 Dollars			
Gaseous Diffusion	90.9	58.5	44.8	71.9	52.0
Gas Centrifuge	45.6	1.4	78.7	1.4	73.9
AVLIS	None	68.3	None	58.9	None
Full-Period Total	**136.8**	**128.2**	**123.5**	**132.2**	**125.9**
1983-2003 Total	87.4	85.4	82.3	89.3	84.7
		Discounted Federal Outlays in Billions of 1983 Dollars			
1983-1990	17.9	15.2	18.2	15.1	18.2
1991-2000	11.3	13.1	7.8	16.7	9.8
2001-2025	12.2	4.7	2.0	5.0	2.5
Full-Period Total	**41.4**	**33.0**	**28.0**	**36.8**	**30.5**
		Costs per SWU in 1983 Dollars			
Full-Period Total Fuel Cost	129.4	121.3	116.8	125.0	119.2
Full-Period Enrichment Charge	39.4	31.3	26.7	34.9	29.1

SOURCE: Congressional Budget Office.

NOTE: Both the AVLIS and AGC technologies are assumed to come on-line three years later than the current schedules projected in the initial analysis.

TABLE B-2. DISCOUNTED COSTS OF OPTIONS ASSUMING PROJECT COST OVERRUNS

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	90.9	46.6	53.7	58.5	44.8
Gas Centrifuge	46.6	46.6	15.4	1.4	85.4
AVLIS	None	40.1	67.4	75.5	None
Full-Period Total	137.5	133.3	136.5	135.4	130.2
1983-2003 Total	87.9	87.6	89.3	88.5	86.9
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	18.3	19.3	17.4	15.5	21.3
1991-2000	11.5	12.1	15.1	16.2	9.7
2001-2025	12.3	6.5	8.7	8.6	3.6
Full-Period Total	42.1	37.9	41.2	40.3	34.6
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	130.1	126.0	129.1	128.2	123.2
Full-Period Enrichment Charge	40.0	36.0	39.0	38.1	33.1

SOURCE: Congressional Budget Office.

NOTE: A 100 percent cost overrun factor was assumed for the capital plant and equipment portion of AVLIS. A 100 percent overrun factor was applied to AGC machine costs. A 60 percent factor applied to the building costs of the GCEP/AGC facility. An 8 percent overrun factor was assumed for the plant and machine costs for the GCEP complex.

TABLE B-3. DISCOUNTED COSTS OF OPTIONS ASSUMING A 6 PERCENT REAL DISCOUNT RATE

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	70.1	42.1	47.9	51.8	40.5
Gas Centrifuge	31.3	31.3	10.8	1.4	52.4
AVLIS	None	23.2	38.6	43.2	None
Full-Period Total	**101.4**	**96.6**	**97.3**	**96.4**	**92.9**
1983-2003 Total	73.2	71.8	72.5	72.0	69.4
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	16.8	17.5	15.9	14.3	17.0
1991-2000	9.1	8.3	9.9	10.6	6.4
2001-2025	7.2	2.6	3.0	2.8	1.2
Full-Period Total	**33.1**	**28.4**	**28.8**	**27.7**	**24.6**
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	95.9	91.3	92.0	91.2	87.9
Full-Period Enrichment Charge	30.6	26.0	26.7	25.9	22.6

SOURCE: Congressional Budget Office.

TABLE B-4. COSTS OF OPTIONS ASSUMING A ZERO PERCENT REAL DISCOUNT RATE

	Base/DOE Plan	Option I	Option II	Option III	Option IV
			Discounted Enterprise Costs in Billions of 1983 Dollars		
Gaseous Diffusion	182.3	58.3	69.4	76.8	56.0
Gas Centrifuge	112.8	112.8	34.1	1.4	201.6
AVLIS	None	98.7	168.5	190.4	None
Full-Period Total	**295.1**	**269.8**	**272.0**	**268.6**	**257.6**
1983-2003 Total	130.9	126.2	127.8	126.3	121.4
			Discounted Federal Outlays in Billions of 1983 Dollars		
1983-1990	20.7	21.5	19.4	17.4	21.0
1991-2000	17.9	15.4	18.9	20.4	11.7
2001-2025	38.2	13.5	16.0	14.6	6.3
Full-Period Total	**76.8**	**50.4**	**54.3**	**52.4**	**39.0**
			Costs per SWU in 1983 Dollars		
Full-Period Total Fuel Cost	279.2	255.2	257.2	254.2	243.7
Full-Period Enrichment Charge	76.6	52.6	54.6	51.6	41.1

SOURCE: Congressional Budget Office.

TABLE B-5. DISCOUNTED COSTS OF OPTIONS ASSUMING A REAL POWER INFLATION RATE OF 2.0 PERCENT

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	97.5	47.7	55.3	60.3	45.8
Gas Centrifuge	45.9	45.9	15.1	1.4	78.7
AVLIS	None	36.2	60.8	68.3	None
Full-Period Total	143.4	129.8	131.2	130.0	124.5
1983-2003 Total	89.8	86.4	87.7	87.2	83.3
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	18.5	19.3	17.6	15.8	18.8
1991-2000	12.7	10.6	13.1	14.3	8.2
2001-2025	16.8	4.4	5.1	4.7	2.0
Full-Period Total	48.0	34.3	35.8	34.8	29.0
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	135.7	122.7	124.1	123.1	117.8
Full-Period Enrichment Charge	45.6	32.7	34.0	33.0	27.7

SOURCE: Congressional Budget Office.

TABLE B-6. DISCOUNTED COSTS OF OPTIONS ASSUMING FULL CAPACITY USED AT 75 PERCENT

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	68.4	46.4	53.5	57.6	43.8
Gas Centrifuge	41.3	41.3	13.9	1.4	58.7
AVLIS	None	18.8	40.1	47.0	None
Full-Period Total	109.7	106.5	107.5	106.0	102.5
1983-2003 Total	80.4	79.2	80.2	79.3	76.6
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	17.9	18.7	16.9	15.2	18.2
1991-2000	10.6	9.8	11.9	12.6	7.5
2001-2025	6.3	3.1	4.0	3.5	1.9
Full-Period Total	34.8	31.6	32.8	31.3	27.6
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	126.4	122.8	124.0	122.2	118.1
Full-Period Enrichment Charge	40.4	36.8	38.1	36.2	32.1

SOURCE: Congressional Budget Office.

NOTE: Cumulative SWU production for each option is 865 millions SWUs.

TABLE B-7. DISCOUNTED COST OF OPTIONS ASSUMING CAPACITY SCALED DOWN TO MEET LOW DEMAND

	Base/DOE Plan	Option I	Option II	Option III	Option IV
	Discounted Enterprise Costs in Billions of 1983 Dollars				
Gaseous Diffusion	57.7	40.7	46.7	50.2	39.8
Gas Centrifuge	41.3	41.3	13.9	1.4	53.6
AVLIS	None	15.0	37.2	44.2	None
Full-Period Total	**99.0**	**97.0**	**97.8**	**95.8**	**93.4**
1983-2003 Total	70.0	70.1	70.8	69.5	68.0
	Discounted Federal Outlays in Billions of 1983 Dollars				
1983-1990	17.4	18.1	16.3	14.5	17.5
1991-2000	7.7	7.7	9.5	9.9	6.0
2001-2025	5.9	3.1	3.9	3.5	1.9
Full-Period Total	**31.0**	**28.9**	**29.7**	**27.9**	**25.4**
	Costs per SWU in 1983 Dollars				
Full-Period Total Fuel Cost	122.7	120.1	121.0	118.7	115.8
Full-Period Enrichment Charge	38.6	36.1	36.9	34.6	31.8

SOURCE: Congressional Budget Office.

NOTE: Cumulative SWU production for each option is 807 millions SWUs.

TABLE B-8. THE BASE/DOE PLAN ASSUMING LOW SWU DEMAND

Year	Annual SWU Production (In millions of SWUs): Gaseous Diffusion	GCEP	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	11.5	0.0	11.5	3,388	2,045
1984	13.3	0.0	13.3	3,896	2,300
1985	15.9	0.0	15.9	4,486	2,400
1986	13.8	0.0	13.8	3,851	2,111
1987	17.5	0.0	17.5	4,550	2,256
1988	17.3	0.4	17.6	4,450	2,196
1989	17.0	1.1	18.1	4,400	2,135
1990	17.4	3.1	20.5	4,533	1,991
1991	16.3	5.2	21.5	4,383	1,724
1992	13.2	7.3	20.5	4,310	1,847
1993	8.7	9.6	18.3	3,178	987
1994	7.0	11.7	18.7	3,397	1,083
1995	5.9	13.0	18.9	2,731	391
1996	5.5	13.1	18.6	2,583	361
1997	5.3	13.2	18.5	2,467	341
1998	5.4	13.2	18.6	2,381	329
1999	4.9	13.2	18.1	2,236	306
2000	5.4	13.2	18.6	2,207	307
2001	6.4	13.2	19.6	2,265	353
2002	6.4	13.2	19.6	2,180	340
2003	6.4	13.2	19.6	2,097	328
2004	6.4	13.2	19.6	2,018	316
2005	6.4	13.2	19.6	1,942	305
2006	6.4	13.2	19.6	1,869	294
2007	6.4	13.2	19.6	1,798	283
2008	6.4	13.2	19.6	1,713	273
2009	6.4	13.2	19.6	1,630	263
2010	6.4	13.2	19.6	1,554	254
2011	6.4	13.2	19.6	1,481	245
2012	6.4	13.2	19.6	1,413	236
2013	6.4	13.2	19.6	1,347	228
2014	6.4	13.2	19.6	1,284	219
2015	6.4	13.2	19.6	1,225	212
2016	6.4	13.2	19.6	1,170	204
2017	6.4	13.2	19.6	1,117	197
2018	6.4	13.2	19.6	1,068	190
2019	6.4	13.2	19.6	1,025	183
2020	6.4	13.2	19.6	986	176
2021	6.4	13.2	19.6	949	170
2022	6.4	13.2	19.6	913	164
2023	6.4	13.2	19.6	878	158
2024	6.4	13.2	19.6	845	152
2025	6.4	13.2	19.6	813	147

SOURCE: Congressional Budget Office.

TABLE B-9. OPTION I ASSUMING LOW SWU DEMAND

Year	Annual SWU Production (In millions of SWUs) Gaseous Diffusion	GCEP	AVLIS	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	11.5	0.0	0.0	11.5	3,423	2,080
1984	13.3	0.0	0.0	13.3	3,971	2,375
1985	15.9	0.0	0.0	15.9	4,586	2,500
1986	13.8	0.0	0.0	13.8	3,970	2,229
1987	17.5	0.0	0.0	17.5	4,656	2,362
1988	17.3	0.4	0.0	17.6	4,523	2,268
1989	17.0	1.1	0.0	18.1	4,461	2,197
1990	17.4	3.1	0.0	20.5	4,569	2,064
1991	16.3	5.2	0.0	21.5	4,413	1,811
1992	13.2	7.3	0.0	20.5	1,791	1,939
1993	8.7	9.6	0.0	18.3	1,019	1,078
1994	6.3	11.7	0.9	18.9	1,225	1,124
1995	0.0	13.0	6.0	19.0	3,063	754
1996	0.0	13.1	5.6	18.7	2,493	222
1997	0.0	13.2	5.2	18.4	2,361	209
1998	0.0	13.2	5.6	18.8	2,314	206
1999	0.0	13.2	4.9	18.1	2,151	189
2000	0.0	13.2	4.9	18.1	2,068	182
2001	0.0	13.2	6.4	19.6	2,131	191
2002	0.0	13.2	6.4	19.6	2,050	184
2003	0.0	13.2	6.4	19.6	1,971	177
2004	0.0	13.2	6.4	19.6	1,895	170
2005	0.0	13.2	6.4	19.6	1,822	163
2006	0.0	13.2	6.4	19.6	1,752	157
2007	0.0	13.2	6.4	19.6	1,684	151
2008	0.0	13.2	6.4	19.6	1,602	145
2009	0.0	13.2	6.4	19.6	1,523	140
2010	0.0	13.2	6.4	19.6	1,449	134
2011	0.0	13.2	6.4	19.6	1,379	129
2012	0.0	13.2	6.4	19.6	1,314	124
2013	0.0	13.2	6.4	19.6	1,251	119
2014	0.0	13.2	6.4	19.6	1,191	115
2015	0.0	13.2	6.4	19.6	1,133	110
2016	0.0	13.2	6.4	19.6	1,079	106
2017	0.0	13.2	6.4	19.6	1,027	102
2018	0.0	13.2	6.4	19.6	978	98
2019	0.0	13.2	6.4	19.6	936	94
2020	0.0	13.2	6.4	19.6	898	91
2021	0.0	13.2	6.4	19.6	863	87
2022	0.0	13.2	6.4	19.6	830	84
2023	0.0	13.2	6.4	19.6	798	81
2024	0.0	13.2	6.4	19.6	767	77
2025	0.0	13.2	6.4	19.6	738	75

SOURCE: Congressional Budget Office.

TABLE B-10. OPTION II ASSUMING LOW SWU DEMAND

Year	Annual SWU Production (In millions of SWUs) Gaseous Diffusion	GCEP	AVLIS	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	11.5	0.0	0.0	11.5	3,421	2,078
1984	13.3	0.0	0.0	13.3	3,969	2,352
1985	15.9	0.0	0.0	15.9	4,582	2,453
1986	13.8	0.0	0.0	13.8	3,955	2,062
1987	17.5	0.0	0.0	17.5	4,625	2,099
1988	17.3	0.4	0.0	17.6	4,469	1,907
1989	17.0	1.1	0.0	18.1	4,362	1,749
1990	18.2	2.3	0.0	20.5	4,468	1,646
1991	19.1	2.4	0.0	21.5	4,386	1,607
1992	17.9	2.6	0.0	20.5	4,019	1,518
1993	15.5	2.8	0.0	18.3	3,903	1,786
1994	14.9	2.9	0.9	18.7	3,335	1,260
1995	8.6	3.1	7.2	18.9	2,974	936
1996	1.0	3.3	15.3	19.6	3,058	897
1997	0.0	3.3	15.1	18.4	2,723	671
1998	0.0	3.3	15.5	18.8	2,279	262
1999	0.0	3.3	14.8	18.1	2,117	243
2000	0.0	3.3	14.8	18.1	2,036	234
2001	0.0	3.3	16.3	19.6	2,100	241
2002	0.0	3.3	16.3	19.6	2,019	231
2003	0.0	3.3	16.3	19.6	1,942	223
2004	0.0	3.3	16.3	19.6	1,867	214
2005	0.0	3.3	16.3	19.6	1,795	206
2006	0.0	3.3	16.3	19.6	1,726	198
2007	0.0	3.3	16.3	19.6	1,660	190
2008	0.0	3.3	16.3	19.6	1,578	183
2009	0.0	3.3	16.3	19.6	1,501	176
2010	0.0	3.3	16.3	19.6	1,429	169
2011	0.0	3.3	16.3	19.6	1,364	163
2012	0.0	3.3	16.3	19.6	1,305	156
2013	0.0	3.3	16.3	19.6	1,251	150
2014	0.0	3.3	16.3	19.6	1,201	145
2015	0.0	3.3	16.3	19.6	1,154	139
2016	0.0	3.3	16.3	19.6	1,106	134
2017	0.0	3.3	16.3	19.6	1,058	129
2018	0.0	3.3	16.3	19.6	1,012	124
2019	0.0	3.3	16.3	19.6	967	119
2020	0.0	3.3	16.3	19.6	924	114
2021	0.0	3.3	16.3	19.6	886	110
2022	0.0	3.3	16.3	19.6	852	106
2023	0.0	3.3	16.3	19.6	819	102
2024	0.0	3.3	16.3	19.6	788	98
2025	0.0	3.3	16.3	19.6	757	94

SOURCE: Congressional Budget Office.

TABLE B-11. OPTION III ASSUMING LOW SWU DEMAND

Year	Annual SWU Production (In millions of SWUs) Gaseous Diffusion	AVLIS	Total	Discounted Enterprise Costs (In millions of 1983 dollars)	Discounted Federal Outlays (In millions of 1983 dollars)
1983	11.5	0.0	11.5	3,894	1,989
1984	13.3	0.0	13.3	4,177	2,056
1985	15.9	0.0	15.9	4,631	2,098
1986	13.8	0.0	13.8	3,895	1,759
1987	17.5	0.0	17.5	4,362	1,720
1988	17.6	0.0	17.6	4,227	1,671
1989	18.1	0.0	18.1	4,138	1,613
1990	20.5	0.0	20.5	4,328	1,636
1991	21.5	0.0	21.5	4,329	1,685
1992	20.5	0.0	20.5	3,970	1,616
1993	18.3	0.0	18.3	3,400	1,435
1994	17.8	0.9	18.7	3,344	1,420
1995	11.7	7.2	18.9	3,364	1,474
1996	3.0	16.2	19.2	2,916	931
1997	0.0	18.4	18.4	2,605	660
1998	0.0	18.8	18.8	2,166	230
1999	0.0	18.1	18.1	2,008	213
2000	0.0	18.1	18.1	1,931	204
2001	0.0	19.6	19.6	1,999	212
2002	0.0	19.6	19.6	1,922	204
2003	0.0	19.6	19.6	1,848	196
2004	0.0	19.6	19.6	1,777	189
2005	0.0	19.6	19.6	1,708	181
2006	0.0	19.6	19.6	1,643	175
2007	0.0	19.6	19.6	1,580	168
2008	0.0	19.6	19.6	1,516	161
2009	0.0	19.6	19.6	1,454	155
2010	0.0	19.6	19.6	1.307	149
2011	0.0	19.6	19.6	1,342	143
2012	0.0	19.6	19.6	1,289	138
2013	0.0	19.6	19.6	1,239	133
2014	0.0	19.6	19.6	1,191	128
2015	0.0	19.6	19.6	1,144	123
2016	0.0	19.6	19.6	1,096	118
2017	0.0	19.6	19.6	1,048	113
2018	0.0	19.6	19.6	1,001	109
2019	0.0	19.6	19.6	955	912
2020	0.0	19.6	19.6	105	101
2021	0.0	19.6	19.6	873	97
2022	0.0	19.6	19.6	839	93
2023	0.0	19.6	19.6	807	90
2024	0.0	19.6	19.6	776	86
2025	0.0	19.6	19.6	746	83

SOURCE: Congressional Budget Office.

TABLE B-12. OPTION IV ASSUMING LOW SWU DEMAND

Year	Annual SWU Production (In millions of SWUs)			Discounted Enterprise Costs	Discounted Federal Outlays
	Gaseous Diffusion	AGC	Total	(In millions of 1983 dollars)	
1983	11.5	0.0	11.5	3,388	2,045
1984	13.3	0.0	13.3	3,898	2,302
1985	15.9	0.0	15.9	4,494	2,408
1986	13.8	0.0	13.8	3,863	2,122
1987	17.5	0.0	17.5	4,586	2,308
1988	17.3	0.4	17.6	4,489	2,257
1989	17.0	1.1	18.1	4,421	2,114
1990	17.0	3.5	20.5	4,532	1,965
1991	15.2	6.3	21.5	4,343	1,665
1992	10.9	9.6	20.5	4,152	1,520
1993	5.5	12.8	18.3	3,335	920
1994	4.1	14.6	18.7	2,760	390
1995	3.2	15.7	18.9	2,635	336
1996	2.3	16.9	19.1	2,532	287
1997	0.0	18.1	18.1	2,602	539
1998	0.0	19.0	19.0	2,206	130
1999	0.0	18.1	18.1	2,036	125
2000	0.0	18.1	18.1	1,958	120
2001	0.0	19.6	19.6	2,009	116
2002	0.0	19.6	19.6	1,932	111
2003	0.0	19.6	19.6	1,857	107
2004	0.0	19.6	19.6	1,786	103
2005	0.0	19.6	19.6	1,717	99
2006	0.0	19.6	19.6	1,651	95
2007	0.0	19.6	19.6	1,588	91
2008	0.0	19.6	19.6	1,509	88
2009	0.0	19.6	19.6	1,433	84
2010	0.0	19.6	19.6	1,363	81
2011	0.0	19.6	19.6	1,297	78
2012	0.0	19.6	19.6	1,234	75
2013	0.0	19.6	19.6	1,173	72
2014	0.0	19.6	19.6	1,117	69
2015	0.0	19.6	19.6	1,064	67
2016	0.0	19.6	19.6	1,015	971
2017	0.0	19.6	19.6	971	62
2018	0.0	19.6	19.6	933	59
2019	0.0	19.6	19.6	897	57
2020	0.0	19.6	19.6	862	55
2021	0.0	19.6	19.6	829	53
2022	0.0	19.6	19.6	797	51
2023	0.0	19.6	19.6	766	49
2024	0.0	19.6	19.6	736	47
2025	0.0	19.6	19.6	708	45

SOURCE: Congressional Budget Office.

ANALYSIS RESULTS ASSUMING A LOW TAILS ASSAY

An operating tails assay represents the concentration of the U-235 isotope remaining in the depleted waste stream (tails) after the uranium feedstock undergoes the enrichment process. For a given amount of enriched product, there is a trade-off between the operating tails assay and uranium feedstock requirements: a high tails assay (0.25 percent, for example) would leave a higher U-235 concentration in the depleted tails and would thus require more feed to equal the enriched uranium product produced under a low tails assay (such as 0.10 percent). On the other hand, a high tails assay would require less energy (SWUs) than a low tails assay, since the feedstock is enriched to a lesser degree. (The feed does not pass through so many enrichment stages, since more of the U-235 isotope is left in the tails.)

To produce a desired amount of enriched product, there are two options:

- o Operate under a lower tails assay, using less feed but more energy, or
- o Operate under a higher tails assay, using more feed but fewer separative work units (SWUs).

The optimal tails assay, in terms of minimizing total enterprise costs, depends on both natural uranium feed costs and enrichment processing costs that reflect the efficiencies of the different technologies.

The enrichment program recommended in DOE's January 1983 operating plan (the Base/DOE Plan) is based on an analysis that assumes an operating tails assay of 0.20 percent through 1999, and 0.25 percent thereafter. Raising the tails assay in the year 2000 reduces SWU production requirements from the energy-intensive gaseous diffusion plants; this would allow one gaseous diffusion plant to be shut down permanently, while the other two would continue to operate along with the full GCEP facility. All four option costs presented in the Chapter IV analysis were based on this same tails assay schedule, to enable consistent comparisons to be made with the Base/DOE Plan.

The more advanced technologies, however, are designed to operate more efficiently (and less expensively) than either the gaseous diffusion or the Sets III/IV gas centrifuge processes, suggesting that it would be more cost-effective from the customers' standpoint to operate these under a low tails assay. Doing so would take advantage of the increased efficiencies of the AGC and AVLIS technologies by increasing SWU production and cutting down on feedstock requirements. This section considers two enrichment programs that would use AGC and/or AVLIS, operating under a tails assay of 0.20 percent from 1983 to 1999 and 0.10 percent from 2000 to 2025. Discussion of the two options and their cost projections and comparisons follow.

Alternative Enrichment Programs Under Low Tails Assay

The two program options considered here are designed to meet the same enriched uranium fuel levels produced under the initial analysis' medium-SWU-demand projections. The low tails rate assumption from 2000 on, however, results in greater SWU but lower feed requirements in these later years, so the two options must provide greater SWU capacities than the Chapter IV options.

Option A--Eliminate GCEP, Build AVLIS. This option is similar to the AVLIS program in Option III, but it provides a maximum annual capacity of 42 million SWUs rather than 26.5 million. Five AVLIS plants would be built, with production beginning in 1994 as in Option III. The gaseous diffusion plants would provide all SWU requirements until then, and the GCEP facility would be halted at the end of fiscal year 1983. All three gaseous diffusion plants would be decommissioned by 1998.

Option B--Build AGC and AVLIS. This option would proceed with the AGC implementation schedule assumed in Option IV. The AGC facility would provide a maximum capacity of 26.5 million SWUs a year and, to provide the remaining 15.5 million SWUs a year required under the low tails assay, two AVLIS plants would be built. The first AVLIS plant would begin production in 1995, the second in 2000. The AGC facility would operate at its maximum capacity rate of 26.5 million SWUs from 1999 through 2025, and the AVLIS plants would provide another 15.5 million SWUs from 2000 on; the three gaseous diffusion plants would be phased out entirely by 1996.

Aside from the tails assay, the assumptions used to project the costs of the above programs are consistent with those in the base case analysis: a real annual discount rate of 4 percent, a real power escalation rate of 0.5 percent, and a real capital recovery rate of 4 percent applied to new capital charges (fully discounted over 25 years) when calculating enterprise and total SWU costs and enrichment charges. The results of the analysis are discussed below.

Option Cost Comparisons Under a Low Tails Assay

The projected costs of these programs are summarized in Table B-13. The analysis suggests that, of the two options, the program using both the AGC and AVLIS facilities (Option B) would be most cost effective in terms of both enterprise costs and outlays over the period 1983 to 2025. The enterprise costs of Option B would be $2.9 billion cheaper than Option A ($117.7 billion, compared to $120.6 billion), and the enrichment charge would be $2.10 per SWU lower. 1/

A more important comparison can be made between Option B and Option IV, the least-cost option presented in the initial analysis. The total enterprise costs of Option B through 2025 would be $5.8 billion less than those of Option IV--$117.7 billion compared to $123.5 billion (see Table 8 in Chapter IV). The cost per SWU and enrichment charge are also projected to be cheaper under the Option B program, although more SWUs must be purchased under the low tails assay Option B. Still, the projected lower total enterprise cost suggests that, from the customers' standpoint, which total feed cost is an important factor, the most cost-effective strategy would include both the AGC and AVLIS processes, operated under a low tails assay, once the gaseous diffusion plants are phased out of production.

On the other hand, the government outlays required under Option B would be $3.6 billion greater than the Option IV outlay requirements through 2025. These higher outlays represent the capital costs of building the additional capacity required under the low tails assay assumption. Total feed costs, which are greatly reduced under the low tails assay, are not included in outlays; thus these savings are represented only in enterprise and SWU costs, not in outlays.

This trade-off of higher outlays and lower enterprise and SWU costs between different programs is an important issue the DOE faces when determining the operating tails assay. This analysis suggests that the total costs to the customer, represented by the total enterprise costs, would be 5 percent lower over the period 1983 to 2025 under Option B, compared to

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1. A program designed to meet the low tails assay SWU requirements based on only the AGC technology was also examined. An additional 15.5 million SWU capacity would be required, an increase of almost 60 percent in the productive capacity of the currently proposed eight-building GCEP/AGC facility. The incremental capital costs associated with the larger AGC capacity would have to be under 50 percent of the current cost projections for the eight-building GCEP/AGC facility for this program to be more cost effective than Option B.

TABLE B-13. COST OF ALTERNATIVE ENRICHMENT PROGRAMS ASSUMING A TAILS ASSAY OF 0.10 PERCENT, FROM 2000-2025

	Option A	Option B
	Discounted Enterprise Costs in Billions of 1983 Dollars	
Gaseous Diffusion	58.2	43.2
Gas Centrifuge	1.4	54.4
AVLIS	61.0	20.1
Full-Period Total	120.6	117.7
1983-2003 Total	84.3	82.1
	Discounted Federal Outlays in Billions of 1983 Dollars	
1983-1990	15.2	18.9
1991-2000	14.1	8.7
2001-2025	5.5	4.0
Full-Period Total	34.8	31.6
	Costs per SWU in 1983 Dollars	
Full-Period Fuel Cost	82.7	80.6
Full-Period Enrichment Charge	24.0	21.9

SOURCE: Congressional Budget Office.

NOTE: Cumulative SWU production for each option is 1,460 million SWUs. From 1983 to 1999, all technologies operate under a tails assay of 0.2 percent, as in the initial analysis. From 2000 to 2025, all technologies would operate under a tails assay of 0.1 percent. All other assumptions are the same as those applied in Table 8.

Option IV in the initial analysis. However, looking at budgetary expenditures, the Option B program would appear less favorable than Option I, since its outlay requirements would be 13 percent higher owing to the larger capacity needs.

For any period, the optimal tails assay depends on the uranium feed costs, energy prices, and efficiencies of the technologies in use. A new model currently being developed at the Oak Ridge Laboratory to analyze the DOE uranium enrichment program using the different technologies is designed to determine the optimal tails assay for minimizing program costs. While the gaseous diffusion plants are in operation through most of the remainder of this century, the DOE will most likely continue to operate using a tails assay of 0.20 percent. After that, however, the DOE may find it cost effective to lower the operating tails assay, depending on whether and when the AGC and AVLIS technologies are brought on-line for commercial production, and on the future prices of uranium feedstock.