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

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

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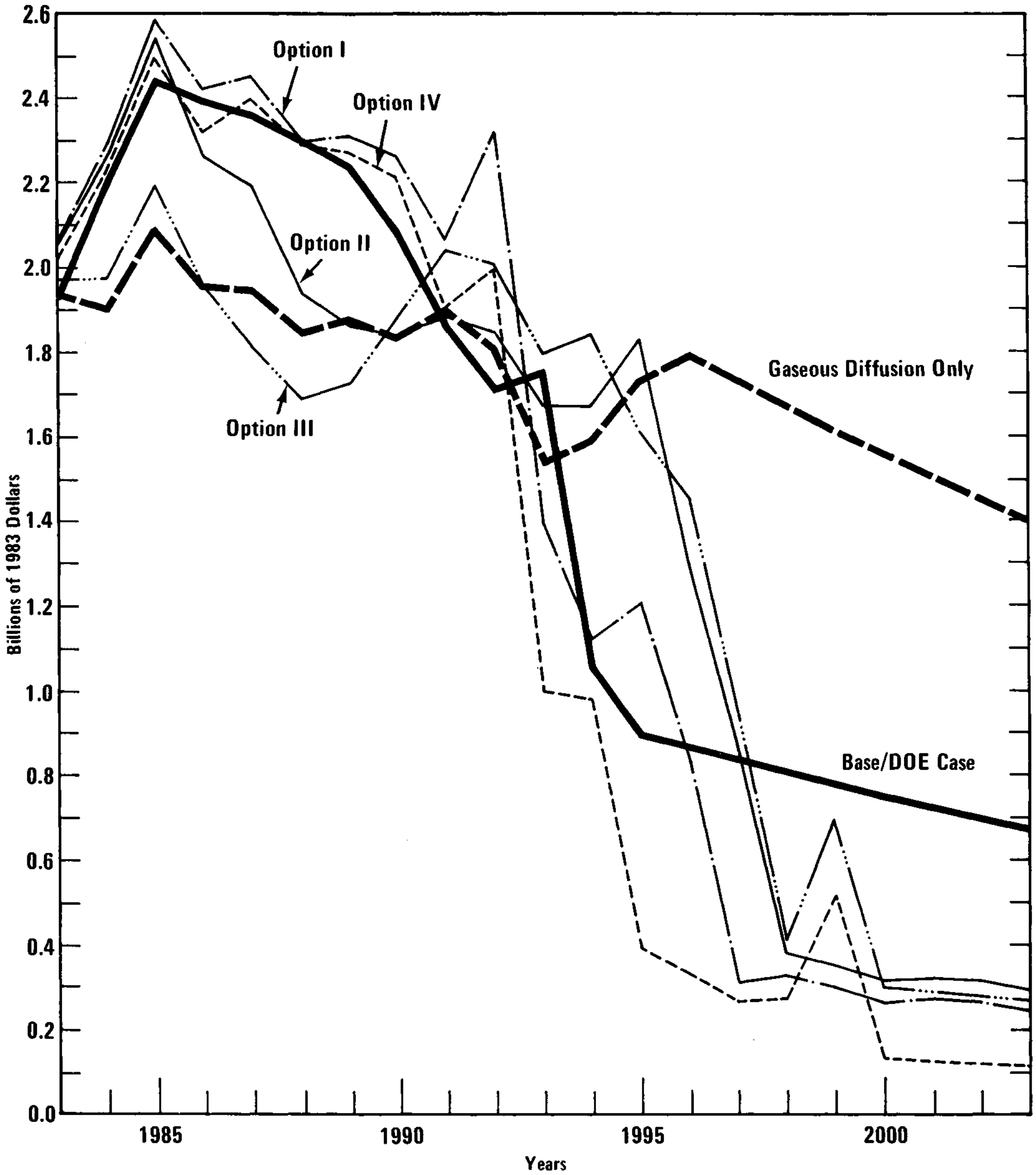
12. An analysis was also done comparing the costs two programs, using AGC and/or AVLIS technologies, under a lower tails assay assumption past 1999. Detailed examination of the tails assay issue and its implications for projected enrichment costs is given in Appendix B.

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:

- An 8 percent cost overrun factor was applied to the centrifuge machine and building costs for the current GCEP project;[16]

- A 100 percent cost overrun factor was applied to the capital plant and equipment portion of AVLIS; and

- 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.