cost elements that are central to this risk, and Chapter III analyzes how the correct generating fee changes with variations in these cost elements. Finally, Chapter IV assesses four ways of dealing with this uncertainty: assigning it to current electricity consumers, future consumers, the government, or those private investors willing to assume the risk.

CHAPTER II. THE SIZE AND SCOPE OF THE WASTE DISPOSAL PROGRAM

Various legislative proposals and Administration plans have prompted different definitions of a radioactive waste disposal program. In order to provide a standard basis for the analysis in Chapter III, this chapter defines the proposed Department of Energy (DOE) radioactive waste program, discusses possible additions to that program, and provides cost estimates for individual program elements.

ELEMENTS OF THE NUCLEAR WASTE DISPOSAL PROGRAM

Program Definition

According to the DOE program schedule and estimates of the demand for repository services, the repository program would span 44 years--from the research and development activity now underway to the decommissioning of the second repository in 2025.[1] According to this schedule, construction for the first geological repository would commence in 1987, and the facility would be available for waste loading in 1994.[2] Construction for the second repository would begin in 1992, and it would begin receiving spent fuel in 1999. DOE projects that both would be filled and decommissioned by 2025. These dates, however, are uncertain, and scheduling might be delayed for a variety of reasons. A suitable site might prove difficult to locate, both for technical reasons and because of local opposition to the facility. In addition, as will be seen in Chapter III, nuclear generating capacity growth might be sufficiently low so that the construction of a second repository could be delayed.

---

1. According to current requirements of the Nuclear Regulatory Commission, the repository would remain open for 50 years, or until 2052 under the current DOE schedule for opening the repository in 2002.

2. The schedule was in effect during the writing of this analysis. The current DOE schedule would open the first repository in 1997 and the second in 2002. Delaying the opening of both repositories, however, does not have a significant effect on the outcome of this analysis if construction costs rise no more than the rate of inflation. The stretchout in construction costs would lower the optimal fee by about 5.5 percent.

98-881 O - 82 - 4

The several activities of the DOE radioactive waste disposal program fall into two groups: "common cost" elements and "repository-specific" elements. Common cost elements are those whose costs are common to all potential repository sites, that is, they do not depend on the actual geologic medium in which the repository is built. These include research and development, site evaluation and selection, and construction of a small-scale test facility. Repository-specific elements are those whose costs depend on the nature of the repository medium. These include the construction of the repository, its operation and maintenance, payments to state and local governments that house the repository, and its final decommissioning, that is, sealing the repository once it is full.

Possible Additions to the Program

Some proposals have added other elements to the definition of a waste disposal program. The first of these is a facility for storing spent fuel on an interim basis, usually termed an away-from-reactor storage facility, or AFR. An AFR might be necessary as an interim storage facility to accommodate spent fuel for those power reactors which have exhausted their on-site storage capabilities. Current DOE estimates indicate that 29 nuclear units will require additional storage capacity between 1986 and 1990. This breaks down into seven units in 1986, six in 1987, five in 1988, ten in 1989, and one unit in 1990. If utilities are limited in their ability to increase on-site storage capacities, some may run out of storage space by 1985. On the other hand, if transshipment is allowed, along with other on-site storage enhancement methods, storage exhaustion could be delayed until 1988 or 1989. In any event, it is unlikely that a repository will be operating before 1994, and hence an AFR could become necessary. It is by no means clear, however, that the federal government would have to provide interim storage services. Indeed, the construction and financing of an AFR facility is entirely separate from the construction and financing of the final geologic repository in all current legislative proposals. Following this practice, this analysis does not investigate the implications of including an AFR in the waste disposal program.

A second potential addition to the federal program could be a Monitored Retrievable Storage (MRS) facility. A MRS might be required as an interim measure (perhaps for 100 years) in the event of significant delays in the repository program. It could also allow the uranium and plutonium fuels contained in the spent fuel assemblies to be recovered and put to use should that become economic. This latter point is cited by both proponents and critics of the MRS. Proponents, concerned with the long-run availability of energy, point out the value of preserving the fuel use option. Critics cite the availability of the fuel as a long-term temptation for misuse or theft of the nuclear materials for illegal weapons production.

The MRS facility considered in this analysis would be a small one, with a 2,800 metric ton capacity. The facility is assumed to be filled, while the first repository is under construction, and then unloaded when the repository is ready in 1994. Thus it would function as a warehouse and backup storage facility in case the repository program was delayed.

Other proposals, not considered in this analysis, have envisioned a much broader concept for the MRS--namely that spent fuel remain in several 48,000 metric ton MRS facilities for up to 100 years while further research is conducted to determine optimal sites for the first two repositories. This strategy would also allow for reprocessing of the spent fuel if it eventually proved economic. The cost for this broader MRS concept would be much larger than for the limited role assumed here. One study estimates a 48,000 metric ton facility would cost $2.4 billion (in fiscal year 1981 dollars).[3]

The implications of using the MRS to postpone final disposal reach well beyond its cost. Such a strategy would introduce much larger uncertainty into the final disposal costs than would the current program, because the information gained from actual repository experience would be so long delayed. Not only would this increase the chance of error in the fee estimate, but it would also make retrospective collection impossible because the size of any error would not be known until well beyond the probable lifetime of the nuclear plants themselves.

In any event, this analysis confines itself to assessing the financial impact of a small MRS facility, with total costs of $508 million (in fiscal year 1982 dollars). Clearly, a much larger MRS facility would have a greater impact on the optimal fee across all four nuclear-power growth scenarios, which are discussed in Chapter III.

A final addition concerns transportation from reactor sites to the repository or perhaps to an AFR. This is currently assumed to be the responsibility of the individual utilities, but could be included in the formal definition of the federal repository program, if the regulatory treatment of waste transportation precluded private sector shipment of spent fuel. This could make the federal government responsible for the assumption and recoupment of these costs. Indeed, the current Senate legislation, S. 1662, includes transportation in the waste disposal program trust fund.

---

3. Department of Energy, Office of Nuclear Waste Management and Fuel Cycle Programs, The Monitored Retrievable Storage Concept (December 1981).

COSTS OF THE PROGRAM

According to the DOE, a program leading to two geological repositories, one operational in 1994 and the other in 1999, would cost about $14.8 billion (expressed in fiscal year 1982 dollars, as are all estimates given in this report unless otherwise noted). Of this total, $4.1 billion would be spent on common cost elements and $10.7 billion on repository-specific elements.

Common Cost Elements

Common costs include research and development and site evaluation. The largest of these is research and development. This is estimated to cost $2.2 billion, or over 13 percent of total program costs and about 50 percent of total common costs. The bulk of these costs is anticipated to be spent during the first ten years of the program's life, averaging over $130 million annually in constant fiscal year 1982 dollars.

The second largest common cost is the exploration and evaluation of candidate repository sites. Current proposals call for development of at least three candidates from which each repository site is to be chosen. The DOE estimates that these costs will be about $1.5 billion (or over 10 percent of total program costs and over 35 percent of total common costs). Since these costs are set by the repository schedule, most will be incurred during the first eight years of the program, averaging over $140 million per year.

The third common cost element is the test and evaluation facility. This facility may or may not be located at a potential repository site, and therefore, can be considered separately from the repository. In any event, this facility could be crucial in assessing the proper site for the actual repositories. Cost estimates for the test and evaluation facility are $300 million. These costs would be incurred during the program's early years, during which over 90 percent (or $290 million) would be spent from fiscal years 1984 to 1990.

Repository-Specific Costs

The two repositories account for $10.3 billion of the estimated program cost of $14.8 billion. The most suitable geological formations in which to build these facilities have not been decided, but candidates include salt, basalt, granite, or volcanic ash. Thus, current estimates are "generic" ones, wherein a composite cost is derived from average cost assessments of each of the various media. Consequently, considerable variation from these estimates may in fact occur as further information is gathered. DOE estimates the capital cost of each generic repository to be about $1.1 billion, yielding a total capital cost estimate of $2.2 billion. Once constructed, the repositories would incur operation and maintenance costs accounting for the remaining $8.1 billion. These costs are composed of fixed and variable elements. The fixed element represents the overhead costs of each facility and is estimated at $38 million annually (in fiscal year 1982 dollars). The variable element is dependent upon the fill rate at which nuclear waste is delivered to the repository, but ranges around $100 million per year.

Payments to state and local governments for locally incurred costs related to siting and repository construction and possible risks of accidents are estimated to total about $400 million. Much of the cost would occur relatively early in the program when repository sites are being chosen. There is considerable uncertainty about the timing and magnitude of these payments, however.

Costs of Potential Additional Elements

The cost elements discussed thus far are absolutely essential to any waste disposal program. In addition, three other cost elements could be added to the program: a MRS facility and federal assumption of responsibility for the transportation of the spent fuel. The total cost of a MRS facility is estimated at $508 million. Construction and container costs would be about $240 million, and operating and licensing costs would account for about $270 million. Transportation costs would total $4.9 billion for filling both 68,000 metric ton repositories.

CHAPTER III. FUNDING THE NUCLEAR WASTE DISPOSAL PROGRAM THROUGH A GENERATION FEE

This chapter examines a generation fee designed to finance the radioactive waste disposal program. Its underlying premise is that the users of the program--ultimately, consumers of nuclear-generated electricity--should pay its costs in direct proportion to their use. A fee to achieve this could be imposed at any of several points in the nuclear fuel cycle--at uranium fuel fabrication, at nuclear-powered electricity generation, or when spent nuclear fuel actually is delivered to the repositories. Recent legislative proposals have prescribed a fee assessed at the point of electricity generation; the analysis in this chapter, therefore, emphasizes that approach. The level of a generation fee required to pay for the waste disposal program is then examined under a variety of assumptions about program cost, program definition, and growth of nuclear capacity.

Under these various assumptions, the required generation fee to effect a self-financing program ranges between 0.5 and 0.6 mills per kilowatt hour in fiscal year 1982 dollars. The fee would increase substantially only if the waste repository program incurred significant cost overruns. But with this exception, the fee level required to finance the entire repository program would be fairly stable over a broad range of assumptions concerning nuclear capacity growth and waste program definitions.

THE NATURE OF A SELF-FINANCING RADIOACTIVE WASTE DISPOSAL PROGRAM

A radioactive waste disposal program would be self-financing if the fees assessed on the generation of waste were adequate to pay for the costs of disposing of it. The program defined in this paper is the current DOE plan to construct two geologic repositories with a combined capacity to bury 136,000 metric tons of radioactive waste. The disposal program would be self-financing, therefore, if the fees collected in conjunction with the generation of this amount of waste were equal to the ultimate costs of the entire program associated with the construction of the two repositories.

For purposes of this analysis, the basic repository program includes common costs (technological development, site evaluation and preparation, and, a separate test and evaluation facility) and site-specific costs (construction of two repositories, operation and maintenance costs for the two repositories, the costs of closing and sealing the filled repositories and payments to state and local governments). Additions to this basic program--federal transportation of the spent fuel and construction and operation of a Monitored Retrievable Storage facility (MRS)--are discussed later in this chapter.

Establishing the Generation Fee

The program would be financed through a generation fee assessed on each kilowatt hour of nuclear electricity produced in the United States, since this energy would be the source of all the radioactive waste deposited in the repositories. Defense wastes are not included in the analysis of this program; however, their inclusion would present no problem of cross-subsidies as long as the full pro-rata share of the program's costs were borne by the government.

One way to make the repository program self-financing would be to calculate the annual program costs as they are expended and to divide them by the number of kilowatt hours of electricity generated in that year. The problem with this approach is that the schedule of annual program costs and annual generation fee receipts would be very different. Annual generation fee revenues would be fairly stable, since the number of nuclear reactors in operation does not change dramatically from year to year. Rather, nuclear generating capacity probably will grow to some plateau early in the next century and remain there.

By contrast, annual repository program costs would vary significantly over time. Initially the program costs generally would be large, as significant amounts were spent to provide a strong technological base for the repositories, to test and develop sites, and to construct the repositories. Once they were constructed, the annual costs of operating and maintaining the repositories would be relatively small. When the repositories are full, the final cost of sealing the repository--usually termed decommissioning--would be incurred in the program's last year.

If a fee were assessed annually to match the stream of annual costs, it would be very large at first and much smaller later in the program's life. But a fee of this nature would charge consumers of nuclear electricity in the program's early years a far higher price for the same service (the burial of the resulting radioactive waste) than would be charged to consumers of nuclear electricity in the program's later years. This would lead to an inefficient allocation of resources since nuclear-generated electricity would cost too much in the early years and too little later on. Equally important, this distribution of charges would be widely perceived as unfair, since different electricity consumers would be charged different prices for the same benefit. A self-financing program, therefore, must find some constant level of generation fee that would be sufficient to meet the program's total cost over its complete life.

Creating a Repository Trust Fund

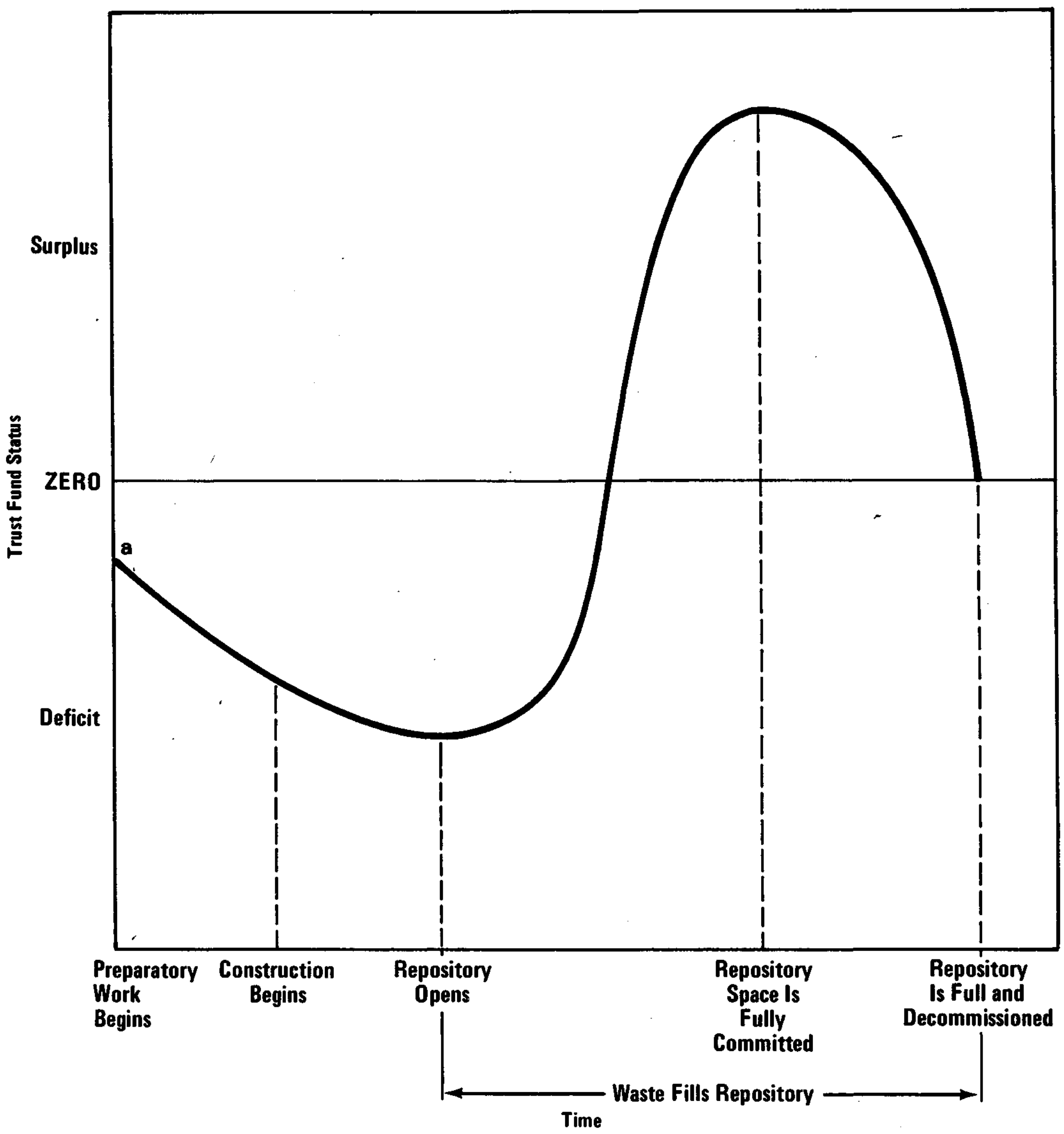
The problem of matching revenues to costs for equitable consumer charges could be resolved through use of a trust fund for the radioactive waste disposal program. The federal government would create a separate account for all of the costs associated with the two repositories, from research and testing at the beginning of the program to decommissioning at the end. The trust fund would also receive all of the revenues collected through a generation fee imposed on the production of nuclear-powered electricity. If costs exceed the revenues expressly obtained to finance the project in any one year, then the trust fund would borrow on its own account to meet its obligations. The trust fund thus would be responsible for the future interest payments that such borrowing would entail. Conversely, if the trust fund ran a surplus, it would earn interest payments on this surplus--presumably by investing in government bonds.

This analysis used an interest rate (both for borrowing and investing) equal to the rate of inflation plus 4 percent. Analysis of changes in this interest rate found they were insignificant when calculating the level of generation fee needed to make the program self-financing. The rate of inflation was assumed to be 7 percent annually through 1985, and 5 percent thereafter.

Figure 1 presents the characteristic pattern of annual costs and revenues for the two-repository program. As seen in this figure, the trust fund, however the program was defined and under all assumptions, would initially run deficits because the highest annual program costs would be incurred in the early years. Once the repository was opened and began to accept waste, annual surpluses of revenues over costs would occur because of the reduction in outlays. But despite these annual surpluses, the trust fund would require several years to revert to a surplus position. This would happen because the initial years of trust fund deficits would produce a large debt that would have to be retired along with interest costs on its accumulated borrowing. Once these debts are retired, the trust fund's surplus builds, as annual surpluses accumulate and as the trust fund's surplus earns interest. These surpluses would continue until the entire repositories' space was committed to the radioactive wastes associated with electricity production on which generation fees have been paid.

Figure 1.

Status of the Trust Fund for Two-Repository Waste Disposal Program Over the Life of the Program



[a] This analysis assumes that program costs of $187 million will be incurred in fiscal year 1982, while no revenues are collected. Assuming an 11 percent interest charge on this debt, the trust fund will begin operations with a deficit of $206 million in fiscal year 1983, the year the generation fee will start to produce revenues.

These annual surpluses would cease once the last batch of nuclear fuel committed to the repository was withdrawn from the reactor. At that point, the surplus of the trust fund, and the interest it would subsequently earn, would have to be large enough to cover all the remaining costs of the program--both the remaining operations and maintenance costs, and the costs of final decommissioning. If the fee had been set at the correct level, it would leave a surplus large enough to cover all of these final costs and perfectly expend itself. Once the last dollar of program costs has been spent, the trust fund should have a value of zero.

Thus, the calculation of an ideal generation fee that would cover total program costs is complicated, but unambiguous--as long as program definition and costs do not change. The fee must be set so as to build a trust fund surplus in the later years of the program sufficient to retire the program's initial debts and still leave enough of a surplus to cover the costs of the program once revenue collections cease. It must pay for interest charges when the trust fund is in deficit as well as actual program costs. It must allow for interest earned when in surplus. And in order to charge current and future consumers of nuclear-powered electricity the same price for the equal benefits they receive, the fee must have a constant real level, corrected for inflation only.

For the purposes of this analysis, a constant real fee that meets these requirements is termed an "optimal" fee. In a certain world, the level of this fee could be calculated unambiguously. In the real world, the level of the optimal fee would vary with underlying assumptions regarding program costs, the timing of program costs, and the number of nuclear reactors in operation at any time. The following section addresses these sources of sensitivity.

REVENUE SUFFICIENCY OF THE GENERATION FEE

This section provides estimates of the generation fee level required to make the radioactive waste repository program self-financing. This optimal fee, however, would change as underlying assumptions change. The three assumptions that would most significantly influence the optimal fee are:

- The Level of Nuclear Generating Capacity. If a lower rate of growth of nuclear generating capacity is assumed, then the level of the optimal fee would increase.

- The Definition of the Radioactive Waste Program. If other elements are added to the radioactive waste program, most notably the addition of a Monitored Retrievable Storage Facility or assumption of responsibility for transporting radioactive wastes from generation stations to the repository, then the level of the optimal fee would rise.

- Changes in the Cost of the Program. If the waste disposal program experiences cost overruns, as are common to first-time projects of this type, then the level of the optimal fee would increase.

Sensitivity to Nuclear Capacity Growth

The optimal fee is not highly sensitive to variations in the assumed growth of nuclear generating capacity. But in general, a lower rate of nuclear capacity growth would result in a higher value for the optimal fee. This relationship occurs for two reasons. First, with a lower rate of capacity growth, fewer reactors will be paying generation fees into the program trust fund. This would result in lower initial revenues, despite the fact that the revenue per kilowatt hour is higher; and, because revenues are lower early in the program while high early costs are fixed, the trust fund deficit would become larger. This, in turn, would lead to higher financing charges.

Second, with a lower rate of nuclear capacity growth, it would take longer to fill a repository. This would add additional years of operation and maintenance costs--which are only incurred after the repository is opened--to the program's total costs. Yet despite these effects, radically different assumptions regarding nuclear capacity growth do not lead to radically different levels of the optimal fee.

This analysis employs four different assumptions about nuclear capacity growth, as follows:

- High-Growth Case. Under the high-growth case, nuclear generating capacity grows from 109 gigawatts in 1985 to 188 gigawatts in 1995, and reaches a steady state of 250 gigawatts in the year 2004. This growth is sufficient to commit fully the first repository's space by 1998, and the second's by 2009. These fill rates are consistent with the announced schedule of the DOE program.

- Medium-Growth Case. Under the medium-growth case, nuclear generating capacity grows from 96 gigawatts in 1985 to 145 gigawatts in 1995, and reaches a steady state of 200 gigawatts in 2005. This growth is sufficient to commit fully the first repository by 2000 and the second by 2014. These fill rates are also consistent with the announced DOE program schedule.

- Low-Growth Case. Under the low-growth case, nuclear generating capacity grows from 82 gigawatts in 1985 to a steady state of 120 gigawatts in 1995. Under this case, the first repository is fully committed in 2005 and the second in 2026. This fill rate calls for modifications of the DOE program, which plans to decommission the second repository in 2024. If the second repository's space is claimed by 2026, it could not be decommissioned until 2043.

- Very Low-Growth Case. Under the very low-growth case, nuclear generating capacity grows from 70 gigawatts in 1985 to a steady state of 100 gigawatts by 1995. Under this case, space in the first repository is fully committed in 2012, and space in the second is fully committed by 2039. Again, these fill rates require extension of the DOE program timetable, so that the second repository's decommissioning would be delayed from 2024 to 2048.

These nuclear-growth scenarios are summarized in Table 1.

TABLE 1. ALTERNATIVE NUCLEAR CAPACITY GROWTH RATES (By calendar year, in gigawatts)

	1985	1990	1995	2000	2010
High Nuclear Growth	109	144	188	230	250[a]
Medium Nuclear Growth	96	128	145	175	200[b]
Low Nuclear Growth	82	115	120[c]	120	120
Very Low Nuclear Growth	70	90	100[d]	100	100

a. Steady state of 250 gigawatts reached in 2004.
b. Steady state of 200 gigawatts reached in 2005.
c. Steady state of 120 gigawatts reached in 1995.
d. Steady state of 100 gigawatts reached in 1995.

In current dollars, changes in assumptions about nuclear capacity growth would result in sizable differences in both project costs and financing costs (the interest earned and paid out by the trust fund). But when these costs are corrected for inflation, the differences prove to be small. Project costs, financing costs, and the level of the optimal fee for each of the four nuclear capacity growth assumptions are presented in Table 2. When expressed in current dollars, total project costs under the

TABLE 2. OPTIMAL FEES AND TOTAL PROGRAM COSTS, UNDER FOUR NUCLEAR CAPACITY GROWTH RATES

	High Growth	Medium Growth	Low Growth	Very Low Growth
Optimal Fee (In mills per kilowatt hour; in fiscal year 1982 dollars)	.483	.517	.549	.570
Total Program Costs (In billions of current dollars)	47.8	47.8	86.2	98.5
Total Program Costs (In billions of fiscal year 1982 dollars)	14.8	14.8	15.9	15.9
Total Financing Costs (In billions of current dollars)	-15.6	-8.4	-27.4	2.9
Total Financing Costs (In billions of fiscal year 1982 dollars)	-1.2	-0.3	-0.2	1.7

very low-growth case would be double those of the high-growth case. But this difference occurs because of the length of time needed to fill the repositories under the very low case; it takes an additional 24 years to fill and decommission the repositories under this case than it does under the high-capacity case. Thus, the costs incurred in the additional 24 years would be subject to an additional 24 years of inflation. When corrected for inflation, this difference narrows, with low-growth program costs only marginally higher than high-growth costs ($15.9 billion for the two lowest-growth cases versus $14.8 billion for the two highest-growth cases). This slight difference occurs because waste is delivered at a lower rate under the low- and very low-growth cases. Since the repository must remain open longer to be filled, it would incur additional years of operation and maintenance costs.

Similarly, the total financing costs, when expressed in current dollars, would vary widely with different assumptions about nuclear capacity growth rates. In current dollars, no direct relationship exists between financing costs and the growth rates of nuclear capacity, because of the timing of annual deficits and surpluses in the trust fund. For example, current dollar financing costs would be greater for the low nuclear-growth case than for either the medium or very low cases. They would be higher than under the medium case because the trust fund would build its surplus later, and, therefore, earn inflated dollars. They would be higher than under the very low case because the very low case would build a deeper deficit early in the program. Thus, many different factors would affect the net earnings or payments realized by the trust fund, if expressed in current dollars.

When corrected for inflation, these differences shrink dramatically and a clear relationship emerges. Under the high-growth case, the trust fund would earn more in interest when it is in surplus than it would pay out when it is in deficit. Thus, it would earn a net $1.2 billion in interest charges, and this $1.2 billion would become available to defray total program costs. These inflation-corrected net earnings would shrink to $0.3 billion under the medium-growth case and to $0.2 billion under the low-growth case. Under the very low-growth case, net interest payments would occur at a real level of $1.7 billion; these interest costs must be added to actual program costs and like the program costs, must be recouped through the generation fee. Interest costs would be lower (in fact, earnings increase) as capacity growth increases in general, because the greater revenue base provided by high, early nuclear capacity would lead to smaller initial deficits. These smaller initial deficits would then lead to smaller interest payments, and allow the trust fund to achieve a surplus position more rapidly.

Thus, when both program and financing costs are corrected for inflation, the differences among the four nuclear-growth cases shrink dramatically. The optimal fee under the high-growth case would be .483 mills per kilowatt hour in fiscal year 1982 dollars; and, like all other fees described here, it would need to be corrected continually for inflation in actual practice. Under the medium-growth case, the optimal fee would rise to .517 mills per kilowatt hour. Under the low- and very low-growth cases, the fee would increase to .549 mills and .570 mills, respectively. While these fee levels may differ by up to 20 percent, all of them are about equal to 1 percent of the (inflation-corrected) cost of nuclear-generated electricity over the life of the program. These differences are not large when viewed from the perspective of total electricity costs. The actual payments made by electricity consumers would be less than 1 percent of the cost of nuclear-powered electricity, since most electricity consumers receive electricity from a variety of sources. Thus, the waste disposal program should not result in appreciable increased changes to electricity consumers.

Sensitivity to Program Definition

Defining the disposal program to include elements not contained in the one proposed by DOE and analyzed here also could lead to variance in the optimal fee. Specifically, the inclusion of waste transportation costs or the addition of a small Monitored Retrievable Storage (MRS) system, costing about $500 million, would increase the optimal generation fees somewhat. Adding an MRS facility would raise the optimal generation fee under each nuclear-growth scenario by approximately 5 percent. Inclusion of waste transportation costs would add about 20 percent to these optimal fee levels. But all of these fee levels would still represent only 1 percent of the cost of nuclear-powered electricity.

The results of these additions are summarized in Tables 3 and 4. Table 3 presents optimal fee levels when transportation costs are included. As discussed in Chapter II, the inclusion of transportation costs would increase total program costs by about $4.9 billion. Financing costs, however, would fall if transportation costs were added (or, conversely, financing earnings rise), because transportation costs are incurred in the later part of the program's life. Thus, when the optimal fee is increased to cover transportation costs, a smaller deficit would occur in the early part of the program. This would allow the trust fund surplus to build more rapidly, and lower the total interest payments to be paid on the trust fund's initial deficit.

TABLE 3. OPTIMAL FEES AND TOTAL PROGRAM COSTS WITH TRANSPORTATION COSTS INCLUDED, UNDER FOUR NUCLEAR CAPACITY GROWTH RATES

	High Growth	Medium Growth	Low Growth	Very Low Growth
Optimal Fee (In mills per kilowatt hour; in fiscal year 1982 dollars)	.592	.633	.664	.669
Total Program Costs (In billions of current dollars)	68.4	68.4	113.1	141.9
Total Program Costs (In billions of fiscal year 1982 dollars)	19.7	19.7	20.8	20.8
Total Financing Costs (In billions of current dollars)	-28.9	-20.1	-42.1	-23.0
Total Financing Costs (In billions of fiscal year 1982 dollars)	-3.0	-1.8	-1.8	0.0

TABLE 4. OPTIMAL FEES AND TOTAL PROGRAM COSTS WITH A SMALL MONITORED RETRIEVABLE STORAGE FACILITY INCLUDED, UNDER FOUR NUCLEAR CAPACITY GROWTH RATES

	High Growth	Medium Growth	Low Growth	Very Low Growth
Optimal Fee (In mills per kilowatt hour; in fiscal year 1982 dollars)	.506	.541	.577	.600
Total Program Costs (In billions of current dollars)	48.6	48.6	86.9	99.2
Total Program Costs (In billions of fiscal year 1982 dollars)	15.3	15.3	16.4	16.4
Total Financing Costs (In billions of current dollars)	-14.8	-7.3	-25.2	7.5
Total Financing Costs (In billions of fiscal year 1982 dollars)	-1.0	0.0	0.0	2.1

When these changes for including transportation in program costs are taken into account, the optimal fees for each nuclear-growth scenario can be recalculated. For the high, medium, low, and very low nuclear-growth cases, the resulting levels of optimal fees increase to .592, .633, .664, and .669 mills per kilowatt hour, respectively (again, in fiscal year 1982 dollars). These fees would be 20 percent higher than those needed to finance the program without transportation costs.

Table 4 presents fee estimates for a program with a Monitored Retrievable Storage system. As discussed in Chapter II, the inclusion of a MRS in the waste disposal program would raise total real program costs slightly by $0.5 billion under all nuclear-growth cases. Unlike the inclusion of transportation costs, however, the addition of a MRS would increase total financing costs (or, conversely, lower financing earnings). This would happen because the MRS costs would occur during the early stages of the program's life, thus increasing the initial trust fund deficit, with associated higher interest payments, and deferring the trust fund's transition to surplus. The optimal generation fee under the four nuclear-growth cases--high, medium, low, and very low--would rise to .506, .541, .577, and .600 mills per kilowatt hour, respectively. This would represent an increase of 4 to 5 percent over fee levels calculated without the MRS facility.

Sensitivity to Cost Overruns

Cost uncertainty provides the dominant financial risk for the radioactive waste disposal program. The level of optimal fee is significantly more sensitive to cost overruns than to changes in nuclear capacity growth or in program definition. This extreme sensitivity occurs because the cost estimates, which are made during the early stage of this new and untested program, can escalate rapidly as the program development proves to be much more expensive than the original estimates. Indeed, historical analyses suggest that the actual costs of technology-intensive pioneer plants usually exceed early estimates by a large amount.

Several individual estimates appear important as potential sources of error in the current cost estimates. First, the current estimates of repository costs are generic ones, representing the weighted average of the three most attractive geological formations for repository placement. The actual site-specific costs would almost certainly be different. Second, the regulatory requirements, which the disposal program must meet, are not yet firm. Unexpected changes in them could significantly affect costs and site availability. Third, the actual level of payments to state and local governments might diverge widely from the currently anticipated $440 million (in fiscal year 1980 dollars). Finally, technological difficulties not yet anticipated could significantly alter the costs and accomplishments of the program. None of these possible misestimates mean that cost overruns would necessarily happen. They simply call attention to historical experience, which is replete with unexpected cost increases that comprise a significant financial risk.

In two recent studies, the Rand and Mitre Corporations have analyzed relevant experiences regarding cost overruns.[1] The Rand study utilized data on 44 commercial-scale process plants that involved some type of new plant design. Three overrun factors--inaccurate inflation projections, unanticipated regulatory changes, and other unforeseeable events were found to account for only 26 percent of the total cost misestimation in the sample.

---

1. Merrow, Phillips, and Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants (The Rand Corporation, September 1981); and The Mitre Corporation, Analysis of Nuclear Waste Disposal and Strategies for Facilities Deployment (April 1980).

The greater bulk of unanticipated capital cost growth was attributed to a lack of information at early stages of engineering. Many cost elements, Rand concluded, cannot be estimated during the early period of a project because of an inadequate information base. Thus, normal engineering-based estimation techniques cannot anticipate this source of cost overruns. Specifically, the study examined the ratio of estimated to actual costs for cost estimates made at the five stages of the development cycle of a new project--research and development, project definition, engineering, construction, and start-up. Cost estimates were made throughout this development cycle. The Rand study concluded that the ratio of estimated to actual costs rose from .49 during the research and development phase to .93 in the start-up phase. Thus, cost estimates improved as projects developed.

The nuclear waste disposal program is now between the research and development stage and the project definition stage. At the research and development stage, conceptual cost estimates are provided while basic theoretical knowledge of the new process is gathered. This applies to the nuclear waste disposal program, since basic research and development is currently underway to assess the appropriate medium in which to locate the repositories. On the other hand, parts of the program appear to have advanced into the next stage of project definition, in which the scope of the program is defined. In the Rand study, the average ratio of estimated to actual costs at this definition stage was .62 in contrast to the .49 ratio for the research and development stage. Thus, probable capital costs are 67 percent greater than estimated at this stage. This number was used in this analysis to approximate the cost overruns that might be experienced in actual repository construction. Such overruns would increase the cost of constructing the two repositories from $2.27 billion to $3.79 billion. (If the estimates from the research and development stage were employed, cost overruns would average 104 percent, increasing construction costs from $2.27 billion to $4.63 billion.)

Since the Rand study considered only capital cost overruns, this report needed to examine other sources of cost overruns in the program. The Mitre study was appropriate for this task. Mitre estimated possible cost overruns at each stage of the waste disposal program by examining the number of sites requiring investigation at each stage to ensure the selection and operation of at least one repository site. Its estimates were based on a survey of engineers, who were asked to respond to hypothetical circumstances regarding the disposal program. A cost estimate was considered an upper bound if that level of cost resulted in a 99 percent probability of locating a site. It was assumed that most of the information required to determine an appropriate site was obtained from more advanced surface testing, on-site testing, or construction, rather than from more preliminary site screening. Thus, these upper bounds may be slightly understated.

The Mitre study determined the number of sites that would have to be considered to obtain a 99 percent probability of finding an acceptable candidate. It concluded that, under the worst case, 34 to 35 sites would have to be considered at the site-screening stage, compared to two to three sites under the best circumstances. This means that worst-case site exploration and evaluation costs would be 11.25 to 17 times the best-case estimated cost. This number of required sites would decrease to 12 or 13 during the next stage of on-site testing, contrasted to one site under the best case. This translates into test and evaluation costs 12 times in excess of estimated costs under a worst-case scenario. Upon entering the next stage of actual construction, Mitre estimated that five sites would require at least some construction work to identify one satisfactory site. Actual construction costs, therefore, would be up to five times as much as anticipated costs if the worst case prevailed. During the operation phase, two facilities would have to be actually operating before one is finally considered appropriate. Thus, operation costs could be twice those estimated.

From the worst case examined in the Mitre study and from the results of the Rand study, a plausible worst-case cost overrun can be fashioned. Site exploration and evaluation costs were increased 11.25-fold, from $1.5 billion to $16.9 billion, following Mitre. Test and evaluation costs increased 12-fold (again, following Mitre) from $300 million to $3.6 billion. The research and development costs, along with payments to state and local governments, might also be subject to overruns. Since neither report considered these, however, they were held at $2.2 billion. As discussed above, the repository costs were increased 67 percent to $3.8 billion, paralleling the Rand results (but a much lower figure than the Mitre study's five-fold increase). Estimated repository operating costs were increased 50 percent, from $8.0 billion to $12.1 billion, as the two-fold increase of the Mitre study was considered excessive. Compared to the DOE base-case costs of $14.8 billion, these worst-case costs together would total $38.5 billion. This constitutes a 160 percent cost overrun. For simplicity, total costs in each year were multiplied by this figure rather than disaggregating the increases by the individual cost elements described above.

Once again, it should be stressed that cost overruns of this magnitude are not a certainty. But the history of comparable projects (as studied by Rand) and a survey of engineering opinions (as conducted by Mitre) indicate that this level of cost overrun cannot be ruled out.

To assess the impact of cost overruns on the optimal fee and trust fund schedule, program costs were increased across the board--first by 40 percent (a rule-of-thumb often used for overrun sensitivity) and second by 160 percent, a figure that represents the credible upper bound. These