MINNESOTA DEPARTMENT OF PUBLIC SERVICE

Volume VI

Direct Testimony and Exhibit of
Gregory Minor
MHB Technical Associates
DOE Assessments

Before the
Minnesota Public Utilities Commission

Northern States Power Company
Docket No. E002/CN-91-19

September 30, 1991

Direct Testimony and Exhibit of

Gregory Minor

Minnesota Department of Public Service

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September 30, 1991

DIRECT TESTIMONY OF

GREGORY MINOR

MINNESOTA DEPARTMENT OF PUBLIC SERVICE

* * *

BEFORE THE

MINNESOTA PUBLIC UTILITIES COMMISSION

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NORTHERN STATES POWER COMPANY

DOCKET NO. E002/CN-91-19

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SEPTEMBER 30, 1991

BEFORE THE MINNESOTA PUBLIC UTILITIES COMMISSION
IN THE MATTER OF NORTHERN STATES POWER COMPANY
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TESTIMONY OF
GREGORY C. MINOR

On Behalf Of The

MINNESOTA DEPARTMENT OF PUBLIC SERVICE

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TESTIMONY OF GREGORY C. MINOR ON BEHALF OF THE MINNESOTA DEPARTMENT OF PUBLIC SERVICE RELATED TO COST REVIEW OF SPENT FUEL DISPOSAL COSTS

INTRODUCTION AND SCOPE

Q: Please state your name and affiliation.

A: My name is Gregory C. Minor, and I am a principal consultant and Vice President of MHB Technical Associates located at 1723 Hamilton Avenue, Suite K, San Jose, California 95125.

Q: On whose behalf do you appear in presenting this testimony?

A: I appear on behalf of the Minnesota Department of Public Service. My resume is Attachment 1 hereto.

SPENT FUEL DISPOSAL COSTS

Q: Mr. Minor, what is the purpose of your testimony in this proceeding?

A: In 1978, MHB wrote a report for the Natural Resources Defense Council entitled *Spent Fuel Disposal Costs*. This report is appended as Attachment 2. MHB was requested by the Minnesota Department of Public Service to review the cost estimate for the disposal of spent nuclear fuel and to estimate the charges that might potentially be levied on the utility.

Q: Could you explain the relevance of spent fuel disposal charges to Minnesota ratepayers?

A: Yes. Spent nuclear fuel contains long-lived radio-isotopes and is highly radioactive. As such, the federal government has agreed to take responsibility for the ultimate disposal of all spent fuel generated at nuclear power plants. It is levying a charge of 1 mill (one-tenth of a cent) per kilowatt hour (kWh) for each kWh of electricity sold from a nuclear power plant. The principle behind the payments is that the beneficiaries of the government's efforts to dispose of waste should pay for the cost of disposal.

These funds are collected periodically, and placed in a Nuclear Waste Fund. The U.S. Department of Energy (DOE), which is the federal agency with responsibility for disposing of the waste, has entered into contractual agreements with utilities with ownership interest in nuclear power plants to begin to accept spent fuel in 1998. However, DOE does not have a system in place, nor is it expected that it will have one in place, by 1998. The Department of Public Service is concerned that delays in the program, as well as increases in its scope, will force DOE to raise its 1 mill per kWh rate. In addition, because of delays, many utilities, including Northern States Power (NSP), are taking extraordinary and costly steps to manage their spent fuel, including creating dry storage Independent Spent Fuel Storage Facilities (ISFSIs). These facilities would be somewhat redundant with parts of DOE's proposed system, and ratepayers may be paying for the same service twice.

Q: Would you describe the information sources used to perform your analysis?

A: Yes. I have reviewed and relied upon the following documents:

1. <u>The Nuclear Waste Fund Fee Adequacy: An Assessment</u>, November 1990, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/RW-0291P.
2. <u>Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program</u>, November 1989, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/RW0247.

3. Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Program, May 1989, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/RW-0236.
4. Preliminary Estimates of the Total System Cost for the Restructured Program: Addendum to the May 1989 Analysis of the Total System Life Cycle Costs for the Civilian Radioactive Waste Management Program, December 1990, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/RW-0295P.
5. The Mission Plan for the Office of Civilian Radioactive Waste Management (OCRWM) that was developed in response to the Nuclear Waste Policy Act of 1982.
6. The Waste Confidence Decision, prepared by the U.S. Nuclear Regulatory Commission (NRC). The Waste Confidence Decision assesses the degree of assurance that radioactive waste can be safely disposed of and estimates when such disposal or off site storage will be available.
7. Nuclear Waste: Changes Needed in DOE User-Fee Assessments to Avoid Funding Shortfall, U.S. General Accounting Office, GAO/RCED-90-65, June 1990.

Q: Please define high-level waste.

A: Radioactive waste is broadly characterized as high level waste, transuranic (TRU) waste, low level waste, and mill tailings. Included in the category of high-level waste (HLW) is the fuel that is removed from the nuclear reactors. Defense HLW includes the highly radioactive waste material that results from reprocessing of spent nuclear fuel, including the liquid waste produced directly in reprocessing. The NWPA of 1982 requires that DOE evaluate the use of disposal capacity at one or more of the civilian repositories for the disposal of defense high level waste. On the basis of the evaluation by DOE, it concluded that there are no compelling reasons for a defense-waste-only repository. Defense TRU wastes will be sent to the Waste Isolation Pilot Plant (WIPP) in New Mexico for demonstration disposal.

Q: Could you provide some background on the federal government's program for high-level waste (HLW) disposal?

A: Yes. In 1982, Congress passed the Nuclear Waste Policy Act (NWPA). The NWPA requires the DOE to site, obtain a license, construct, and operate geologic repositories for spent fuel and high level waste in a manner that will provide a reasonable assurance that the public and the environment will be adequately protected. The Act also includes the following directives:

1. Assigning responsibility for the full payment of disposal costs to those who benefit from the services and accordingly creating a special Nuclear Waste Fund to be composed of the payments made by those using the services;
2. Requiring that utilities would be charged 1 mill per kWh for electricity generated at a nuclear station;
3. Requiring the Secretary of Energy to annually review the fee, and if an adjustment is necessary, propose the adjustment to Congress;
2. Committing the government to study monitored retrievable storage (MRS) in parallel with geologic repository;
3. Providing a federally owned and operated system of interim storage facilities (no greater than 1990 MTU), and creating an Interim Storage Fund for users of such a facility.

The NWPA established a timetable for the government's acceptance of nuclear waste, provided the means for contracts with the utilities, and required DOE to develop siting criteria for a geologic repository. The Act envisioned that three sites would be characterized, one selected in the early 1990s, and a later one identified, characterized and selected following that.

In 1987, Congress passed the Nuclear Waste Policy Act Amendments (NWPAA). It selected Yucca Mountain in Nevada as the first site to be thoroughly characterized. It halted work on all other potential repository sites and required that the issue of a second repository be revisited in 20 years. The establishment of an MRS was linked to progress in developing the repository, insofar as DOE was not authorized to select an MRS site until a repository site was recommended to the President. DOE has proposed decoupling the MRS site selection from the repository siting, because the recommendation to the President for site selection of a repository is not supposed to occur until 2001. DOE is planning, however, to begin acceptance of waste at a MRS facility in the year 1998 in order to meet its legislated obligations to utilities.

In 1987, the schedule for the accepting waste at the repository was 2003. Since that time, DOE has pushed back the start date of the repository until 2010.

Q: What is an MRS?

A: DOE's MRS proposal of 1987 included a conceptual design for an MRS facility whose principal function was to serve as a centralized facility for receiving commercial spent fuel and preparing it for disposal. Its primary purpose is to receive spent fuel shipments from reactors, unload the spent fuel, transfer the intact assemblies to transportation casks or to storage casks, as necessary. The MRS will also serve as an interim dry storage facility should there be delays in the geologic repository.

Q: Please describe the major conclusions that MHB reached in its 1978 report regarding the cost of spent-fuel disposal?

A: In 1978, when we prepared our study for the NRDC, the technical features, the schedule and the costs of a repository were not well established by DOE. Using available information, MHB estimated the total costs of waste disposal as well as the costs that would be required by utilities, assuming that utilities pay the full cost of the program. For the reference case, we estimated that the program would cost slightly over $13 billion (in 1978 dollars without consideration of the time value of money), with a high case estimate of $31 billion and a low case estimate of $4 billion. Adjusting for inflation and discounting, the reference case was estimated at $40 million in 1978 present worth dollars, with the high case estimate $69 million, and a low case estimate of $21 million. For the reference case, this estimate translated to a disposal cost of approximately $650 per kilogram. Assuming that the full cost is paid by utilities, the cost would be approximately 3.4 mills per kWh. Depending on a number of variables and uncertainties, we estimated the charges could be as low as 1.2 mills per kWh, or as high as 8.0 mills per kWh. 1/

Q: How do these numbers compare with recent government studies?

A: In November 1990, DOE prepared a report entitled Nuclear Waste Fund Adequacy: An Assessment, (cited above) in which it maintains that the current fee of 1 mill per kWh is adequate to fund the civilian portion of the HLW program. However, the General Accounting Office (GAO) in its June 1990 Report to Congress (cited above) disagreed, and proposed that the fee be indexed to inflation. It also cited a study preformed by DOE's independent cost estimating staff (ICE) 2/, which concluded that there would be a shortfall in the fund of $2.4 billion, or nearly 10 percent of the cost of the civilian portion of the program.

1/ See Attachment 2, page 6-7 and 8-2. When additional uncertainties were considered, the total high-end estimate reached 20.7 mills/kWh.

2/ Independent Cost Estimates for the Total System Life Cycle Costs and Fee Adequacy of the Civilian Radioactive Waste Management Program, February, 1989

CHANGES IN ASSUMPTIONS FOR HLW DISPOSAL PROGRAM

Q: Please list the major assumptions used, and contrast them with what is now known, or can be reasonably assumed.

A: The following is a list of major assumptions or factors used by MHB to develop its estimate, compared with the assumptions made currently by DOE:

a. In 1978, MHB assumed that only spent fuel produced from U. S. commercial nuclear power reactors between the 1978 and the year 2000 3/ would be considered. DOE assumes that the program includes all spent fuel that is generated at nuclear power facilities from the initiation of the nuclear program in the U. S. through the closing of the last power facility scheduled for the year 2037. It assumes that no new plants will be built.

b. In 1978, MHB assumed that only waste generated by the civilian reactors would be disposed of in the repository. As discussed above, it is now assumed that the repository will be used by the DOE's weapons production program for the disposal of high level waste. The DOE has calculated that the defense waste share of the cost of the facility should be about 15 to 17% of total system cost over the life of the program.

c. In 1978, MHB assumed that all R&D and regulatory costs were written off against the fuel produced during the time period from 1978 - 2000. The NWPA requires a one-time assessment for all fuel generated prior to 1983, and an on-going charge for all electricity sold from a nuclear plant (i.e. 1 mill per kWh). Thus DOE assumes that all of R&D and regulatory costs are written off for all fuel generated from nuclear power plants.

3/ All fuel generated by 1995, with an allowance for five years of cool down prior to DOE accepting the waste.

d. In 1978, no credit for future reprocessing or recycling of spent fuel was assumed. DOE has not made any assumptions to the contrary. However, some advanced reactor designs (still in the early stages of design) envision reprocessing of the spent fuel.

e. In 1978, the reference scenario assumed that there would be 380 GWe capacity by the year 2000, with an annual discharge of 26 metric tons (MTU) of spent fuel per thousand MWe of installed capacity. Sensitivity analysis was performed on different amounts of nuclear capacity, the lowest being 105 GWe. The DOE reference scenario is based on "no new orders", so that the nuclear generating capacity will peak at 103 GWe in 1997 and will decline after 2006 as plants are retired. They will reach 51 GWe in 2020 and zero in 2037.

f. The MHB study assumed disposal of 60.8 thousand metric tons of uranium (MTU). DOE currently assumes 86.8 thousand MTU from civilian reactors (excluding plant life extension), and approximately 8.9 thousand MTU of defense wastes.

g. In 1978, for the reference case it was assumed that 25% of the fuel would be shipped to three "away-from-reactor" (AFR) storage facilities. Sensitivity analysis were performed on a 100% AFR requirement. DOE currently assumes that one MRS will go into operation in 1998 and will begin receiving spent fuel up to the maximum of 15,000 MTU.

h. The 1978 study assumed full decommissioning of all supporting facilities and sealing of the underground portions of the repository. DOE also makes this assumption.

i. In 1978, MHB assumed that 50% of the fuel would have to be rehandled to some degree due to changes in criteria or deficiencies in original emplacement method. The high and low cases assumed all, or conversely, no rehandling to be required. DOE does not directly address this issue in its operating cost assumptions.

j. In 1978, the reference case was estimated in 1978 dollars, assuming an inflation rate of 7% and an interest rate of 6% (or -1% real interest rate); DOE expresses total dollar costs in 1988 dollars. DOE's reference case assumes a 4% inflation rate and a 3% <u>real</u> interest rate (i.e. interest rate minus inflation rate).

k. In 1978 the reference case assumed that the utility makes a one-time payment to the government <u>at the time</u> of delivery of the fuel to the government facility. As explained previously, the NWPA requires that all spent fuel generated after April of 1983 was subject to the 1 mill per kWh charge (for each kWh of electricity sold); and that fuel generated prior to April 1983 was subject to a one time charge, which could be paid in 1983 or any time thereafter with appropriate interest being paid.

l. In 1978, we assumed that two 30,000 MTU repositories would be built and operated. Thus the costs included investigation and evaluation of two sites. The NWPAA of 1987, defers any action on a second repository for 20 years. Thus, DOE assumes only one repository in its reference case.

PROBLEMS WITH DOE ASSUMPTIONS

Q: What is your opinion of DOE's current assumptions?

A: Due to the amount of time that has been spent on the program to date and the passage of the NWPA of 1982 and the Amendments of 1987, some of DOE's assumptions are defined in more detail. However, many other assumptions are still loosely defined. Below, I note how the more recent data would likely affect the HLW disposal program and the costs of disposal.

1. DOE's current estimate is based on a system with one repository and one MRS. At this point in time, its difficult to say if this is a reasonable scenario, particularly the timing for the MRS component. In addition, it should be noted that the NWPA of 1982 calls for a single repository to receive 70,000 MTU. However, DOE's current projections call for disposal of over 90,000 MTU of spent fuel including defense

wastes. Assuming DOE is correct and all the waste can be handled in one repository, the system that it bases its cost estimate on should decrease total costs (compared to our 1978 estimate). If a second site is required, costs would increase and there may also be a second MRS required.

2. DOE spreads the costs out over all fuel generated from nuclear reactors and from defense wastes. This is reasonable to assume, and should decrease costs on a per unit basis provided the total waste volume does not exceed the limits of one repository. The timing of the assessment for costs to cover the defense wastes may change the end-of-life balance in the NWF by altering the interest earned. Similarly, the volume and form (spent fuel or reprocessed) of defense high-level waste which is ultimately stored in the repository may increase the cost of storage.

3. DOE assumes a greater volume of waste, including fuel from both civilian and defense reactors. The larger volume should decrease costs on a per unit basis unless it triggers the need for a second repository. However, DOE has not included the effect of Plant Life Extension in its volume estimates.

4. It is not clear that DOE assumes any rehandling of fuel. I believe that there will be some significant percentage of spent fuel that will have to be rehandled due to such problems as regulatory changes or geological anomalies.

5. DOE assumes a real interest rate of 3% and an inflation rate of 4%. For the long term, I do not believe that 4% inflation rate is reasonable. 4/ I believe that the U.S. historical real interest rate of 2% is perhaps more appropriate for the financial projections of the Nuclear Waste Fund. Considering the long term projections involved and the cost sensitivity to real interest rates, a 1% value may be the best value to use.

4/ See GAO/RCED-90-45, User Fee Assessments, p. 42. Wharton Econometrics forecast an annual inflation rate between 4.3 and 5.1 percent for the 25-year period from 1986-2011, and DRI forecasts the annual rate between 4.1 and 6.8 for the 25-year period from 1987 to 2012.

6. DOE bases its estimate on a pay as you "sell" arrangement, as established by law. It has the effect of providing the fund with some money early in the development stages, which can result in savings as interest is accrued. It is also an equitable assessment in that those who get the benefit of the fuel pay the cost of waste storage.

Q: Are there factors <u>not</u> described above which could affect the cost of the HLW disposal program?

A: Yes. The most relevant factors that would influence the determination of cost are as follows:

1. Reactor Plant Life Extension - If a large number of reactors have their licenses extended and are allowed to operate for an additional twenty years, it would approximately double the volume of civilian HLW. This could trigger the development of a new repository, and would increase total operating time and costs substantially. However, the costs would be spread out to the beneficiaries of license extension. Unfortunately, most of the decisions on plant life extension are not likely to be made before the end of the century.

2. Additional Orders for Nuclear Reactors - DOE and the nuclear industry are supporting major efforts to develop advanced reactors. This would have the same affect on volume, length of time for repository operation, and operational costs as described above.

3. Yucca Mountain is Found to be Unsuitable - The site characterization phase of the DOE program is scheduled to take 10 years, and is barely underway. At any point, the site could be found unsuitable. If there is this finding, DOE must gain approval

from Congress before it begins selection of another site. These delays could delay implementation of the MRS and increase costs.

4. Whether an MRS will be Needed - It is not clear that the MRS will be required, especially as the law now stands. Any delays in the program would push a decision on the MRS out to a later date, and would effectively necessitate that more and more utilities provide their own interim solutions to the waste problem; in effect shifting the MRS costs to the utilities. In my opinion, it is highly unlikely that the MRS issue will be settled in time to be operational in 1998.

5. The Effect of Delay - Delay could result from numerous factors, including the possibility that the State of Nevada may continue to withhold permits to DOE to begin site characterization, or NRC licensing taking more than the three years currently planned. However, the cost effects of delay are difficult to evaluate as such factors as interest and inflation would have a large effect on delay costs. The timing of delay is also important to consider, for if the Fund is running a surplus at the time, interest accruals could actually decrease utility assessment rates.

6. Contingency - Based on the GAO Report, DOE makes no explicit reference to application of a contingency factor, except for transportation. Most engineering cost estimates include a contingency factor to account for normal and abnormal costs. In light of the uncertainties in this program and DOE's track record of estimates, a contingency is appropriate.

7. Number of Repositories - Should it be necessary to develop two repositories, either to accommodate increased waste volume or because of legal requirements, costs would increase substantially. However, assuming that the second site is a site similar to Yucca Mountain, I would not expect the second repository to cost the same as the first because of the learning curve.

8. Increased Regulatory Requirements - Several federal and state agencies are involved in regulating the construction, licensing and operation of a repository. More stringent regulations would likely lead to increased costs.

9. Inflation and earnings Rate Assumptions - These rates are critical in the cost estimates, as one must anticipate the ultimate cost of the program, estimate the payment stream by utilities, and calculate the interest earned on the payments as well as the interest paid on debt. In DOE's reference case, changing the real interest rate from three to one percent, could lower the end-of-program fund balance from a $3 billion surplus to $8 billion deficit (assuming 4% inflation).

10. The contribution for Defense Wastes and waste generated prior to 1983 is uncertain - Although DOE has calculated the contribution of these wastes, it is not clear when they will be collected. If collections are delayed, the fund will accumulate less interest.

11. Reprocessing and Waste Separation - As discussed above, DOE has been working on various designs to develop advanced reactors. One design would depend on reprocessed spent fuel from conventional LWRs, and by separating out some constituents, reduce some of the biological risk from HLW. This could result in less expensive designs and less stringent regulatory requirements. I would also expect that the recovered fuel would have some value which could offset potential increases in the program costs. On the other hand, the reprocessed waste may require different storage techniques than spent fuel rods. However, these new designs are not likely to be implemented in this century.

Q: Would you please briefly summarize the effects of all the factors that you have identified on the 1 mill kWh fee for spent fuel disposal?

A: Yes. See Table below.

FACTOR	PROBABLE EFFECT ON UTILITY ASSESSMENT RATE		
	Increase	Decrease	Uncertain
Operational Difficulties	X		
Increases in Inflation	X		
Decreases in Interest	X		
No MRS		X	
Early contribution from defense wastes		X	
Volume increases (assuming the need for 2nd repository)	X		
Life extension	X		
Additional Nuclear Plant Orders	X		
Reprocessing at Advanced Reactors		X	
Unsuitability Finding for Yucca	X		
Delay (depends on timing and inflation/interest rates)			X
Adding Contingency	X		
2nd repository	X		
Increased Regulatory Requirements	X		

SUMMARY AND CONCLUSIONS

Q: Would you please briefly summarize your conclusions concerning this issue?

A: Yes. As a result of our review, I have reached the following conclusions:

1. The 1978 MHB study for NRDC gave a wide range of values, reflecting the large uncertainty at that time. With the passage of time, data effecting many of these

uncertainties have been refined, which in turn somewhat narrows our previous range. However, there are still substantial uncertainties in the program which could influence costs.

2. Looking ahead, it is very difficult to predict with any certainty, the costs of the spent fuel disposal program over the next 50-60 years. This fact combined with the poor experience with past government-managed development projects, makes estimates beyond 10-15 years very questionable. For that reason, I am limiting my estimate to the effects likely to be seen in the next 10-15 years and suggesting that the cost of the project needs to be reassessed after the year 2000. However, looking at the impact of events in the next 10-15 years, the following range of values is my estimate of the likely costs.

It is my opinion that the 1 mill per kWh assessment is unlikely to meet the cost of the spent fuel disposal program. At best, it would represent my lower five percentile value. My best estimate is that the fees paid by utilities for spent fuel disposal are likely to increase to approximately 3 mill per kWh. This estimate is based on the average of the following:

a. A second repository could increase costs by 30%-50%. This assumes a second host state, but a similar type of facility.

b. Assuming a more conservative one to two percent difference between interest and inflation rates has the effect of lowering the fund balance so that the end-of-program balance would be negative by about 30-70% of the currently projected total systems cost.

c. Operational difficulties with the planned repository could add another 10%-20% to the cost.

d. Increased regulatory requirements could add another 10%-20% to the original cost.

e. A negative finding on Yucca Mountain is possible and would require a new selection and site characterization (assumed to be still in Nevada) which could add 20-40%.

f. For a controversial government-managed project such as this, contingencies for factors such as schedule delays, concessions and compensation to host states, public relations problems, and the poor track record of cost estimates on government projects are likely to add at least another 50% to the original cost.

g. Because the MRS and repository are unlikely to be available by 1998, there will likely be a need to compensate utilities for their cost of storing spent fuel beyond the legislated 1998 date. Alternatively, the cost for DOE to build a much larger MRS or to build ISFSI's for all utilities could add 10-20% to the project cost.

h. If there is a major shift in the form of repository to be utilized (e.g., such as sea bed disposal), all costs must be reevaluated and the increase may be extraordinary.

Q: What would be your upper five percentile estimate?

A: This value must be limited to a short range evaluation, based on the present plan, and my projections of the decisions which are likely in the next decade. Assuming the project does not alter the basic approach to storage (i.e., underground burial in stable geological formations), I would expect the upper five percentile value to be about 5-6 mills per kWh.

Q: Do you recommend that the cost of spent fuel disposal be reviewed again in the future?

A: Yes. Although the NWPA establishes that it is in the national interest to develop a geologic repository to dispose of HLW, it is possible that the geologic repository concept as it is now defined may become technically or politically unacceptable. For example, it is recognized by the DOE, in its <u>Mission Plan</u> (cited above) that there are "major areas of uncertainty" in the geologic repository concept. 5/ Consequently, DOE continued to study sub-seabed disposal, subsequent to the passage of the NWPA. In 1985, it was reported that five areas in two oceans were actively being analyzed. Theoretical calculations to model environmental interactions, as well as field tests have been performed.

Q: Have you included program changes of this magnitude in your consideration of the costs of the repository?

A: No. I started with the program parameters that were defined by DOE. I believe that should the geological repository concept be dramatically altered or dropped if another option is found more desirable, completely new cost estimates would have to be made defining the parameters of the new option. It would be mere speculation to estimate these costs.

Q: When do you recommend that the cost estimates by DOE be revisited by this Commission?

A: Because of the major uncertainties stated above, the fact that DOE is required to annually assess the adequacy of the fee, and the fact that several crucial milestones will occur on or before 2001, it would be necessary and useful to review the program at that time. In 2001, DOE is scheduled to make a finding on the suitability of the Yucca Mountain site and make a recommendation to the President. At that time, there will also be a better definition of the MRS, which as it now stands, cannot be sited until after the President has received a recommendation on the Yucca Mountain site.

In addition, the impact of plant life extension and the possible implementation of advanced reactors may be better defined over the next 10 years. For these reasons, I feel it is important that the cost and schedule projections of DOE's HLW disposal program be reviewed at the turn of the century.

5/ Mission Plan, Office of Civilian Radioactive Waste Management, p. 19.

Q: Does this conclude your testimony?

A: Yes.

EXHIBIT OF

GREGORY MINOR

MINNESOTA DEPARTMENT OF PUBLIC SERVICE

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BEFORE THE

MINNESOTA PUBLIC UTILITIES COMMISSION

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NORTHERN STATES POWER COMPANY

DOCKET NO. E002/CN-91-19

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SEPTEMBER 30, 1991

PROFESSIONAL QUALIFICATIONS OF GREGORY C. MINOR

GREGORY C. MINOR
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EXPERIENCE:

1976 to PRESENT

Vice-President - MHB Technical Associates, San Jose, California

Engineering and energy consultant to state, federal, and private organizations and individuals. Major activities include studies of safety and risk involved in energy generation, providing technical consulting to legislative, regulatory, public and private groups and expert witness in behalf of state organizations and citizens' groups. Was co-editor of a critique of the Reactor Safety Study (WASH-1400) for the Union of Concerned Scientists and co-author of a risk analysis of Swedish reactors for the Swedish Energy Commission. Served on the Peer Review Group of the NRC/TMI Special Inquiry Group (Rogovin Committee). Actively involved in the Nuclear Power Plant Standards Committee work for the Instrument Society of America (ISA).

1972 - 1976

Manager, Advanced Control and Instrumentation Engineering, General Electric Company, Nuclear Energy Division, San Jose, California

Managed a design and development group of thirty-four engineers and support personnel designing systems for use in the measurement, control and operation of nuclear reactors. Involved coordination with other reactor design organizations, the Nuclear Regulatory Commission, and customers, both overseas and domestic. Responsibilities included coordinating and managing and design and development of control systems, safety systems, and new control concepts for use on the next generation of reactors. The position included responsibility for standards applicable to control and instrumentation, as well as the design of short-term solutions to field problems. The disciplines involved included electrical and mechanical engineering, seismic design and process computer control/programming, and equipment qualification.

1970 - 1972

Manager, Reactor Control Systems Design, General Electric Company, Nuclear Energy Division, San Jose, California

Managed a group of seven engineers and two support personnel in the design and preparation of the detailed system drawings and control documents relating to safety and emergency systems for nuclear reactors. Responsibility required coordination with other design organizations and interaction with the customer's engineering personnel, as well as regulatory personnel.

1963 - 1970

Design Engineer, General Electric Company, Nuclear Energy Division, San Jose, California

Responsible for the design of specific control and instrumentation systems for nuclear reactors. Lead design responsibility for various subsystems of instrumentation used to measure neutron flux in the reactor during startup and intermediate power operation. Performed lead system design function in the design of a major system for measuring the power generated in nuclear reactors. Other responsibilities included on-site checkout and testing of a complete reactor control system at an experimental reactor in the Southwest. Received patent for Nuclear Power Monitoring System.

1960 - 1963

Advanced Engineering Program, General Electric Company; Assignments in Washington, California, and Arizona

Rotating assignments in a variety of disciplines:

- Engineer, reactor maintenance and instrument design, KE and D reactors, Hanford, Washington, circuit design and equipment maintenance coordination.

- Design engineer, Microwave Department, Palo Alto, California. Work on design of cavity couplers for Microwave Traveling Wave Tubes (TWT).

- Design engineer, Computer Department, Phoenix, Arizona. Design of core driving circuitry.

- Design engineer, Atomic Power Equipment Department, San Jose, California. Circuit design and analysis.

- Design engineer, Space Systems Department, Santa Barbara, California. Prepared control portion of satellite proposal.

- Technical Staff - Technical Military Planning Operation. (TEMPO), Santa Barbara, California. Prepare analyses of missile exchanges.

During this period, completed three-year General Electric program of extensive education in advanced engineering principles of higher mathematics, probability and analysis. Also completed courses in Kepner-Tregoe, Effective Presentation, Management Training Program, and various technical seminars.

EDUCATION

University of California at Berkeley, BSEE, 1960.

Advanced Course in Engineering - three-year curriculum, General Electric Company, 1963.

Stanford University, MSEE, 1966.

HONORS AND ASSOCIATIONS

- Tau Beta Pi Engineering Honorary Society

- Co-holder of U.S. Patent No. 3,565-760, "Nuclear Reactor Power Monitoring System," February, 1971.

- Member: American Association for the Advancement of Science.

- Member: Nuclear Power Plant Standards Committee, Instrument Society of America.

PUBLICATIONS AND TESTIMONY

1. G. C. Minor, S. E. Moore, "Control Rod Signal Multiplexing," IEEE Transactions on Nuclear Science, Vol. NS-19, February 1972.

2. G. C. Minor, W. G. Milam, "An Integrated Control Room System for a Nuclear Power Plant," NEDO-10658, presented at International Nuclear Industries Fair and Technical Meetings, October, 1972, Basle, Switzerland.

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SPENT FUEL DISPOSAL COSTS

PREPARED FOR:

NATURAL RESOURCES DEFENSE COUNCIL

BY:

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DATE: 8/31/78

"Every year of delay in the operation of a national waste repository is cause for added percentages of the public to oppose nuclear power because of concerns about waste management. But if past experience tells us anything, more delays are assured, with each one adding years to the currently estimated startup date, already shifted from 1985 to 1988-1993.

Thus, there should be no surprise at all when the next delay, or the one after that, is announced. The names may change (the individual announcing it may not be Deutch, and perhaps the agency will not be the U.S. Department of Energy), but the scene and the wording will be much the same. Before a Washington, D.C. press conference, the announcement will close essentially as follows: 'A majority of the technical experts believe that high-level nuclear wastes can be safely disposed in geologic media, but, for reasons detailed in the report released here today, the earliest date of operation for the first permanent repository is now projected to be the year 2000, with more likely dates being 2005 or 2010. Now, if there are any questions.....'"

From the Editorial
Nuclear News - June 1978

SPENT FUEL DISPOSAL COSTS

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ABSTRACT

This report documents an economic evaluation of the proposed Spent Fuel Policy announced by the Department of Energy in October of 1977. Consideration was also given to historical, technical, and economic factors to determine what the full cost of implementing the Policy might be. The economic study considered probable spent fuel disposal scenarios, institutional and technical uncertainties, and the quantity of fuel expected to be discharged between 1978 and the year 2000. Costs were estimated for all facets of the government program, including research and development, design, licensing and construction of necessary facilities, and operations and ultimate decommissioning of the facilities. Alternative scenarios were considered, and high and low case cost estimates developed. It was found that the expected costs of the program for the reference case scenario totaled slightly over $13 billion in 1978 dollars, with a high case estimate of $31 billion and a low case of $4 billion. These costs were adjusted for the time impact on escalation and discounting, and calculations performed to determine the expected cost to the federal government. When adjusted in this fashion, the reference case cost totals just under $40 billion in present worth terms. Applied to the 60.8 metric tons of fuel scheduled for discharge by 1995, this cost translates to a disposal cost of approximately $650 per kilogram.

The manner in which this disposal cost may be collected from the utilities and charged to the ratepayer was evaluated. Assuming full costs are recovered per the announced plan, the reference case costs will amount to a charge to the ratepayer of approximately 3.4 mills per KW-hour, or roughly 10% of the current average consumer cost of electricity. Depending on how this is collected, and which scenario proves accurate, the charge could be two and one-half to six times higher, or as low as 1.2 mills per KW-hour. Conclusions on the most likely outcome of the program were developed and recommendations made concerning future implementation of the program. The results indicate that the spent fuel disposal program will impact significantly on the cost of nuclear power and that the consumer will experience a noticeable rate increase.

Sensitivity of the program costs were also evaluated. The most significant factor was found to be errors in program management. Rehandling the spent fuel can drive the cost higher by a factor of three or four. Proper financial planning was also found to be critical, as is adequate funding of necessary research and development programs.

The study did not consider the potential cost of low-level or decommissioning waste resulting from nuclear power plant operation. Such costs, and health, safety, and environmental impacts are additional factors to be considered in evaluating the acceptability of the proposed Policy.

SECTION 1

INTRODUCTION & PURPOSE

1.1 INTRODUCTION:

On April 7, 1977, President Carter announced that the United States would defer indefinitely all civilian reprocessing of spent nuclear fuel. The primary purpose of this deferral was to allow time for evaluation of alternative fuel cycles and processes which could reduce the risk of nuclear weapons proliferation. This move introduced further uncertainty into the viability of commercial nuclear power in the United States by delaying indefinitely U.S. policy decisions concerning the ultimate high-level waste storage program.

In an attempt to ease the planning problem for nuclear utilities, the Department of Energy (DOE) announced a spent nuclear fuel policy on October 18, 1977. The proposed policy was identified as a program to accept and take title to used, or spent, nuclear fuel from utilities on payment of a one-time storage fee. The purpose of this new policy was described as follows in the DOE's October 18, 1977 Press Release:

> "Storage of spent nuclear fuel.....is an issue which cannot await the outcome of longer-term studies for interim resolution. Currently, utilities are faced with the prospect of storing fuel discharged from reactors for an indefinite period with no approved plan for ultimately disposing of it. This produces an increasing uncertainty in the utilities' economic calculations, making advanced planning difficult.

> The new policy approved by the President is a logical extension, given the indefinite deferral of reprocessing, of the long-established federal responsibility for permanent disposal of high-level waste. The policy will also remove the uncertainty faced by utilities by having the federal government accept and take title to spent reactor fuel upon payment of a one-time storage fee. It is important, however, that the utiltities pay the full cost of nuclear waste storage and ultimate disposal." (Emphasis added) (See Appendix A for full text)

Subsequent to this release, the Natural Resources Defense Council (NRDC) requested in a November 4, 1977 letter to Secretary of Energy Schlesinger, that a full and open hearing be held on all aspects of this proposed policy, including the adequacy of the "one-time fee." (See Appendix B)

1.2 PURPOSE & SCOPE

This report documents a study performed by MHB Technical Associates (MHB) for the NRDC to quantify the probable full cost of such nuclear fuel storage and disposal, and to define the uncertainty band associated with the cost quantification. The study is to provide a basis for independent evaluation during future hearing processes to ensure the proposed federal charge placed on the utilities will be adequate to cover the probable technical and cost variances that may impact on the program.

In performing the study, a review was made of the U.S. commercial nuclear waste program over the past 20 years. Documentation was researched in an attempt to find a pattern in the past institutional and technical dead-ends so as to more accurately predict where the proposed program may underestimate the future effort and cost. No unusual changes to the DOE forecast of the nuclear program were incorporated. It was assumed, for example, that 380 GWe installed capacity will be in place in the United States by the year 2000, and that fuel exposure design targets are achieved.[1] However, sensitivity calculations were performed to examine the impact of reduced nuclear capacity on the unit and total costs.

The conclusions of the study are summarized in Section 8 as are the resulting recommendations. Section 2 presents the major technical and institutional uncertainties in spent fuel management. Section 3 defines the current DOE predicted spent fuel scenario and schedule and identifies potential variations to the reference plan. Section 4 presents a breakdown of the DOE scenario into discrete cost elements. Section 5 describes the cost estimate process developed during this study, gives detailed cost tables, and discusses the associated uncertainty. Section 6 assembles the detailed costs into scenario costs and projects the cost impact on electrical power generation. Section 7 examines the sensitivity of the calculations to different variables. Appendices A through G provide a ready reference to documents and material of particular interest and significance. Particular attention should be given to Appendix C which documents the detailed cost estimate of the repository and to Appendix D which explains the long-term financial methodology developed.

The primary MHB contributor in the preparation of this study was Dale Bridenbaugh, with assistance by Gregory Minor on the Away from Reactor (AFR) storage aspects, and Richard Hubbard on costs. Dr. Robert Anderson, Professor of Material Enginnering at San Jose State University performed the repository cost estimate (Appendix C), and Dick J. Van Aggelen, CPA, provided work on long-term discount and escalation methodology and calculation of impact on utility rates (Appendix D).

It should be emphasized that this study has focused on the economic implications of the proposed government policy. No attention has been given to assessing the safety implications of the policy other than to evaluate what steps might be required to provide an "adequate" level of safety. If safety issues prove to be significantly underassessed, substantive changes to the waste program, and its ultimate cost, will result.

1.3 METHODOLOGY

Numerous studies and reports are available which speculate on the magnitude of the cost of various segments of radioactive waste disposal plans. Near the end of this study period, DOE released a preliminary cost report on the expected scenario of spent fuel accumulation, storage, and permanent disposal.[2] This preliminary report has not been reviewed yet in detail, but it is unlikely that any study scenario will exactly predict the method that ultimately will be used. This is because of the great uncertainty that yet remains in the development of policy, environmental evaluation, and last but not least, the commercial choices available to the utilities in this speculative business.

The cost estimating method used for the MHB study was a combination of original cost estimating, literature search for cost comparisons, and order of magnitude estimating in the areas of high uncertainty. Following are the specific rules or guidelines that were used in the development of costs and in determining the method for analyzing these costs in the total scenario:

a. The study covers only commercial spent fuel produced by U.S. commercial nuclear power reactors between the present and the year 2000 (i.e., fuel removed from the reactor core through 1995). Fuel previously processed or stored at NFS West Valley is excluded as is U.S.-furnished fuel returned from foreign reactors. This may introduce a small conservatism into the results, but this will probably be more than compensated by reduced U.S. generation installed or poorer than planned capacity factors.

b. All R&D and regulatory costs are written off against the fuel produced during the time period described above. The benefit of R&D and knowledge gained for post-2000 cost is not quantified.

c. No credit for possible future reprocessing and receycling of spent fuel is assumed.

d. A reference scenario describing the probable storage and disposal case with the probable quantities of fuel is developed and costed.

This reference scenario assumes 380 GWe capacity by the year 2000, average fuel exposure of 25,000 megawatt-days-thermal per metric ton (MTU) and an annual discharge of 26 MTU* of spent fuel per thousand MWe installed capacity. Sensitivity calculations were performed for scenarios of 200 GWe and 105 GWe.

e. Minimal dependence on away-from-reactor (AFR) storage was assumed since it is likely that expanded at-reactors (AR) storage will result in lower costs to the utilities. Sensitivity calculations were also performed for 100% AFR requirements.

f. Full decommissioning of all facilities including backfilling and sealing of the underground portions of the final repository is assumed to be a requirement and is included in the cost estimate.

g. The reference scenario includes the assumption that 50% of the fuel during this time period must be rehandled to some degree due to changes in criteria or deficiencies in the original emplacement method. The high and low cases assume all or, conversely, no rehandling to be required.

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* An alternate term, Metric Tons of Heavy Metal (MTHM) is sometimes used in DOE reports. For purposes of this cost study, MTU and MTHM are considered synonymous.

h. The reference case costs were initially estimated in 1978 dollars, then escalated to reflect the effect of the time period in which they would be expended and then discounted to bring them back to present worth dollars.

i. For the reference case it is assumed that the utility makes a one-time payment to the government at time of delivery of the fuel to the government facility, AFR or repository.

j. The effect of prepayment by the utility in advance of delivery has been calculated as an alternate to the reference case.

k. In addition to the reference case, a high case and low case has been calculated to find possible bounding conditions for the cost of the program.

l. The resulting costs for the four different cases, i.e., the reference case paid at time of delivery, the reference case prepaid, the high case, and the low case have all been expressed in terms of fuel cycle cost in mills per kilowatt hours and in dollars per kilogram of uranium.

It should be emphasized that the results present an estimated average cost figured over the 25 to 50 year time period that may be required to accomplish the disposition of the spent fuel produced between now and the year 2000. Since the DOE has indicated the likely mode of operation will be to adjust the unit fee collected as the program progresses, it is most likely that the early fuel delivered to the government will be handled for a lower fee than the fuel delivered later in the period. This method is similar to that used in the Social Security system and could run into similar problems with escalating costs. (For example, earnings covered by Social Security benefits increase from $3600 in 1954 to $29,700 in 1981, an increase of 725% in 27 years, not even considering the percentage rate increases during that time.)

SECTION 1

REFERENCES

1. DOE/ER-004/F, UC-70, Report of Task Force for Review of Nuclear Waste Management, February 1978, page 63.

2. DOE/ET-0055, Preliminary Estimates of the Charge for Spent Fuel Storage and Disposal Services, July 1978.

SECTION 2

WASTE MANAGEMENT UNCERTAINTIES

This section describes the main areas of technical uncertainty facing the radioactive waste disposal program in general, and more specifically, the spent fuel disposal program covered by this study. The technical uncertainties are considered in the selection of cost ranges in Section 5 , but it must be emphasized that there is a substantial amount of judgment in the quantification. References to various reports and sources address the uncertainty in greater detail.

Uncertainties can be grouped into five separate categories: waste form, engineered barriers, geologic factors, monitoring, and regulatory/institutional/financial. Each of these areas is addressed in greater detail in the following sub-sections.

2.1 WASTE FORM

There has been a substantial amount of debate in the planning for high level radioactive waste disposal as to the form in which the waste material will be prepared for insertion into the final repository. Appendix F of 10 CFR Part 50 requires that high-level waste, as defined in that section, must ultimately be solidified for final disposal. Current federal reports indicate that spent fuel, in the form as discharged from the reactor, should be considered as high-level waste. This seems to be a logical step since it is for the most part in solid form, and encased by a metallic cladding. There are, however, some unanswered questions as to the acceptability of spent fuel as the waste form for disposal. The uncertainties include the following:

a. Zircaloy or other fuel cladding corrosion rate.
The basic design criteria for fuel clad have been developed for the relatively brief performance of that material in the reactor core. At least two reports [1] [2] reviewed refer to the lack of knowledge concerning long-term performance of zircaloy in the environment of water storage. Rapid deterioration may not occur in view of the rather mild environmental conditions when compared to the operating condition for which the materials are designed, but the BNWL report by Johnson[1] does recommend that corrosion rates and corrosion mechanisms need further evaluation for justification of extended fuel storage.

b. Handling of gaseous material.
Even though the majority of fission products and radioactive waste materials are contained within the fuel rods in solid form, a significant fraction does exist in the gas plenum and fuel rod gap as a gas. No specific criteria have been developed to specify whether or not such gaseous material must be removed from the rods and if it were to be removed, what further processes would be required.

EPA standards have been under formulation to address these issues in consideration for gaseous releases at spent fuel reprocessing plants. If spent fuel is to be the form of the high-level waste for permanent disposal, the question must be resolved.

c. Geometrical configuration.

Some consideration has been given in the past to the disassembly of fuel bundles and the reconfiguration of the disassembled rods into canisters or other containers for more efficient handling. Should this prove to be desirable for one or more reasons, substantive questions regarding heat transfer, that is, the method by which decay heat is removed from the more closely compacted rods, and of guarding against accidental criticality, arise. In fact, criticality control remains a nagging problem throughout the hundreds or thousands of years following geologic disposal. Disruption of the repository configuration by geological shifts or massive external forces, could presumably initiate an uncontrolled and accidental criticality. The possibility must be faced that physical modification of the waste form may be required to preclude this possibility.

2.2 ENGINEERED BARRIERS

A standard design practice of the nuclear industry is to follow the "single failure criteria."[3] Single failure criteria requires all critical systems be designed in such a way that the consequences of a single failure in any component or system will not result in loss of the capability of the safety system to perform its safety functions. As a result of these concepts, a common design practice is to use multiple systems or barriers to guard against release of radioactive materials to the environment. In an operating nuclear plant, the multiple barriers consist of fabricating the fuel material itself into ceramic form, enclosing it with a metallic cladding, containing the fuel in a pressure vessel, which in turn is enclosed in the reactor protective containment.

The multiple, or engineered barrier concept, can be utilized for a portion of the high-level waste disposal cycle. There is a difference, however, between waste disposal and operation of nuclear power plants. The multiple barrier concept at operating nuclear plants must depend ultimately upon some overt human action sometime after the single failure to restore control over the malfunctioning process. In high-level waste disposal, overt human action can be counted upon during the early years of the disposal action, but at some point it must be assumed that the human or social structure has changed so radically that the proper action cannot be assumed. It is for this reason that geologic isolation currently is the disposal method that must ultimately provide the absolute barrier between the radioactive material and the biosphere.

Waste disposal system engineered barriers are, however, required to provide multiple barrier protection against accidental release of the material during that portion of the disposal cycle prior to achieving absolute geological containment. Since the disposal of spent fuel as high-level waste is a relatively new concept, and because little research and development of proof-testing has been devoted to this concept, uncertainties do exist on the effectiveness of the engineered barriers. Following are some of the major areas of concern or uncertainty:

a. Stability of fuel material.

   Spent fuel as discharged from the reactor is assumed to be still in a stable, ceramic condition and the major portion of the fission gases are assumed to be captured within the confines of the ceramic pellet. The effectiveness of this barrier over long periods of time has not been demonstrated.

b. Fuel cladding.

   The clad of the fuel bundle itself is considered to be a second barrier to guard against release. As described in Section 2.1, the corrosion resistance of the fuel clad itself for long periods of storage has some uncertainty.

c. Encapsulation.

A significant portion of the fuel as discharged from reactors can be assumed to have clad perforations. In addition, the integrity of the clad cannot be assured for long periods of time, so it is most likely that the fuel assemblies themselves will be required to be encapsulated prior to emplacement in the geologic repository. This would probably be required for protection during the handling process alone, and, if retrievability of the material is a requirement, it would surely be required. At this point in time, however, no decision has been made as to how long retrievability must be considered and no firm design criteria have been developed for design of the encapsulation. Similar concerns have recently been expressed in a report by Dr. Greogry J. McCarthy and associates at Pennsylvania State University.[4] McCarthy's study has re-evaluated the effect of ground water on radioactive waste stored in the glass or calcine solid form. This re-evaluation finds that radioactive material leaching is of little concern if the ground water is 25°C or less and at atmospheric pressure. However, since the water is likely to be at elevated pressures and temperatures because of the radioactive decay heat, extensive leaching could occur if the water penetrates the waste containers.

d. Repository closure.

The geologic repository is assumed to be a deep, underground mining-type operation. Once all wastes have been emplaced in the repository, the drifts and shafts must be backfilled and sealed. The effectiveness of the backfilling and sealing to prevent the intrusion of surface water or the extrusion of gaseous or liquid effluents from the waste material is unproven. Geologic stability of penetrated deposits has not been demonstrated for the time periods involved with high-level waste disposal.

2.3 GEOLOGIC UNCERTAINTIES

As indicated in Section 2.2, the ultimate barrier must be considered to be the geologic isolation of the waste material from the biosphere. To quote a recent article (see Appendix H) from Science(5):

> "For more than 20 years, deep geologic disposal has been reguarded as the leading technical option for getting rid of the most dangerous and troublesome forms of nuclear wastes, with salt formations generally viewed as the most promising of the geologic media considered. Moreover, an assertion often made by government officials, scientists, and engineers associated with the waste management program, has been that the feasibility of the geologic disposal concept is not in doubt. For instance, in late 1976 a top official of the Energy Research and Development

Administration declared that fulfillment of ERDA's plans to establish six deep geologic repositories, with the first (in salt) to be available by 1985, would require only 'straightforward technology and engineering development.' It comes as a surprise, therefore, to discover now that there seems to be an emerging consensus among earth scientists familiar with waste disposal problems that the old sense of certitude was misplaced." (Emphasis added)

The uncertainty involved with the effectiveness of geologic disposal has to do with the extreme difficulty of proving the long-term effectiveness of this method. This uncertainty is further confirmed in the Science article,(4) wherein it is reported in a study performed for the Environmental Protection Agency by Raymond Siever of Harvard, and Bruno Giletti of Brown University, that:

> "We are surprised and dismayed to discover how few relevant data are available on most of the candidate rock types even thirty years after waste began to accumulate from weapons development. These rocks include granite-types, basalts and shales. Furthermore, we are only just now learning about the problem of water in salt beds, and the need for careful measurements of water in (salt) domes."

The need for additional work in this area has apparently been recognized at the federal level. As reported in the May 4, 1978 Nucleonics Week,(6) the Department of Energy and the U.S. Geological Survey have proposed a significant increase in geologic research to attempt to avoid what the U.S.G.S. has identified as "significant potential stumbling blocks." The proposed program would more than double the current level of geologic research in fiscal year 1979.

Numerous reports exist on geologic concerns facing repository development efforts, but the most recent and complete single report is the U.S.G.S. Circular 779.[7] This report identifies the following major geologic uncertainties:

a. Behavior of rock salt.

The major question involves rock salt's high solubility and the possibility that relatively small amounts of brine could cause changes in the media mechanical strength and possible movement of waste during relatively short periods of time.

b. Investigation of media other than salt.

The disadvantages of salt seem to indicate other geologic media may be preferable. As quoted from the *Science* article,[5] relatively little work has been done in evaluation of alternatives to salt storage.

c. Ground water transport system characterization.

The flow of ground water is considered to be the most likely method by which geologically disposed radioactive waste material could be transported to the biosphere. Data on water flow through fractured geologic media and on the chemistry of the radioactive materials in the water flow needs to be more thoroughly understood.

d. <u>Development of repository evaluation methods</u>.
Additional work is needed to devise methods of dating ground water and performing volumetric examination of rocks around proposed repositories.

e. <u>Effect of repository on the geologic environment</u>.
Additional research is needed to further define the short and long-term effects of repository construction and of the waste and associated heat load on the rock and the geologic environment of the repository.

f. <u>Geologic prediction</u>.
There is a great deal of uncertainty involved in the predictions of behavior for geologic-type time spans. Scientists can determine which sites have been stable in the past but they "<u>cannot guarantee future stability</u>." (Emphasis added)

2.4 <u>MONITORING</u>

Almost without exception, all recommendations on spent fuel geologic disposal concepts include a period of time during which retrievability would be assured so that repository conditions could be monitored to determine if unforeseen failure modes may be developing. Subsequent to repository closure, monitoring is also planned to forewarn of any potential release of radioactive materials to the environment. The problem with developing an effective monitoring system is twofold. First, it is not clear what condition or phenomena should be monitored, since for the most part, if a detectable condition exists, by definition it is almost too late to take preventive measures. Second, monitoring must be, in effect, passive and non-destructive in nature. This being the case, instrumentation must be permanently implaced and function essentially forever, since penetration of the repository for monitoring purposes negates the condition that is being attempted to be maintained. These two principles, therefore, lead to the following major uncertainties in developing an effective monitoring system:

a. <u>What to monitor</u>?

   Since the failure mode or transport mechanism is unknown, it is not clear what parameter or what substance must be monitored to provide advance warning of an early failure. Should the monitoring system detect gross physical movement, deterioration of the canister, transport of radioactive materials beyond certain boundaries, increasing environmental radiation levels at the repository surface, radioactive gases, temperatures or pressures, combinations of all of the above or other factors unlisted?

b. <u>Instrumentation system</u>.

   Once it is decided what parameters to monitor, a decision must be made as to the design life of the monitoring system. Should it be multi-channel to minimize the possibility of loss of a critical system? Must it be functional effectively forever? Must it be emplaced so as to be reparable without disruption of the geologic containment?

c. Inspection.

What frequency of physical inspection should be scheduled? If access for physical inspection is designed into the repository, accidental release initiated by human error is not safeguarded. Additionally, if access is not engineered into the repository, future access as required to verify that the material is being contained in a safe condition would jeopardize the integrity of the geologic confinement. Nondestructive inspection methods are essential but unavailable at this time.

d. Time.

One central issue of high-level radioactive waste storage is time. How long must the waste material be safeguarded? How long must a monitoring system remain functional? If no movement has occurred within five years, can the emplacement be assumed to be safe? If not five, what about 50? 500? 5000?

2.5 REGULATORY, INSTITUTIONAL, AND FINANCIAL UNCERTAINTIES

Regulatory uncertainties facing the spent fuel disposal program today are substantial and varied. Following are listed some of the major unresolved issues that could significantly affect the scope, complexity, and eventual cost of implementing the spent fuel policy.

a. Lack of goals and standards.

No federal regulations exist on which to base the licensing of a spent fuel repository or interim storage facility. The NRC has indicated that regulations (10 CFR Part 72) are currently being written, but it is highly unlikely that they can be properly developed without benefit of established national goals for guidance of the waste disposal program. Development of Environmental Protection Agency standards faces this same uncertainty.

b. Gaseous release.

No federal regulations yet exist describing the requirements for handling of "leaker" fuel assemblies; no decision has been made as to whether or not degasification of the fuel will be required nor what disposal requirements might be issued to govern disposal of the gas thus collected.

c. Occupational exposure.

Substantial discussion has recently been heard regarding the adequacy of the occupational radiation exposure limits. It appears quite possible that exposure limits will be reduced by a factor of 10, if not immediately, at least at a time in the future that would impact significantly on spent fuel disposal. Additionally, low-level radiation effects may well dictate changes to the requirements governing releases and exposure of the general public. Such changes could materially affect the spent fuel disposal program.

d. Commercial viability.

It is not clear that the federal government will require that all utilities make an early decision to transfer their spent fuel to a federal AFR or repository for permanent disposal. Such regulations could be issued, but the current policy announcement seems to make optional the reactor owners decision to turn fuel over to the government. The decision of whether or not to consider spent fuel as high-level waste will quite likely not totally be made until a final decision is made on the U.S. breeder reactor program. Accordingly, it seems likely that utilities will make "non-decision decisions" and the federal spent fuel facility costs will be allocated to only a small percentage of the available spent fuel. If this situation develops, it is then quite likely that an indequate transport system will be built, making it impossible to handle the backlog of fuel when a decision finally is made.

e. Financial forecast factors.

The long-range trends of financial factors employed in long-range forecasts are subject to a high degree of uncertainty. All of the factors that impact upon the direction of change of interest rates or construction costs over time are difficult to identify. In addition, fluctuations due to major economic events, such as war or depression, cannot be forecast with any degree of reliability. Therefore, it is necessary to employ historical data in order to estimate the trend and general behavior of interest rates and construction costs.

The use of historical data imply that the past is in some way indicative of the future. To some degree the hypothesis is correct. Historical data indicate that interest rates tend to exhibit long-run cyclical behavior. Historical data also appear to indicate a long-run trend of increase in costs as measured in dollars. However, since the systematic collection of economic data is largely an event of this century, behavior trends over very long periods of time are based upon data that lacks reliability.

The specific historical data selected for this study were selected because they are comparable as to type with the future costs and interest rates that are being forecast and because the data are generally reliable for forecasting purposes. However, since the data are from relatively current periods, they do not exhibit all of the long-term characteristics that one would desire for a long-term forecast. See Appendix D for more details on the quantification of financial uncertainty.

3.6 QUANTIFICATION OF UNCERTAINTY

The foregoing sections on uncertainties facing the spent fuel disposal program seem to indicate that the magnitude of the technical uncertainty is extremely large. The largest total uncertainty resides in the acceptability of the geologic media for isolation of the material for geologic time periods. Determination of the unsuitability of salt and other selected geologic media at some time in the future might require mining out of material previously buried and moving it to a repository alternative of, as of now, undefined design. Performing this material shift, while complying with as yet undefined regulations and standards, could cause orders of magnitude changes to anticipated disposal costs. An attempt has been made to quantify the potential cost impact of these uncertainties in Section 5.

SECTION 2

REFERENCES

1. BNWL-2256, "Behavior of Spent Nuclear Fuel in Water Pool Storage," A.B. Johnson, September 1976.

2. Z.A. Munir, "An Assessment of the Long Term Storage of Zircaloy Fuel Rods in Water," October 15, 1977.

3. 10 CFR 50, Appendix A, See "Definitions and Explanations," plus for example, GDC 17 and GDC 21.

4. Nature, 273, 216 (1978).

5. "Nuclear Wastes: The Science of Geologic Disposal Seen as Weak," Science, Vol. 200, June 9, 1978, page 1135.

6. Nucleonics Week, Vol. 19, No. 18, May 4, 1978, page 6.

7. U.S. Geological Survey Circular 779, "Geologic Disposal of High Level Radioactive Wastes - Earth Science Perspectives," J.D. Bredehoeft, et al.

SECTION 3

WASTE DISPOSAL SCENARIO

3.1 DESCRIPTION:

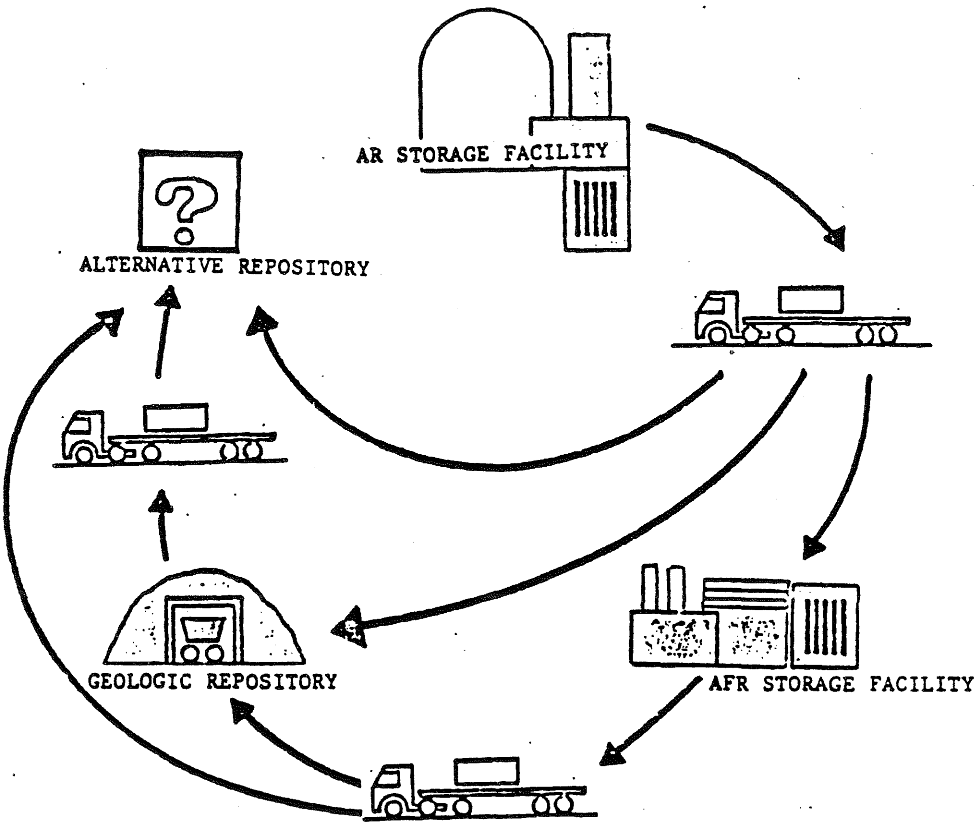
Based on the most current DOE reports on high level waste management,[1] it appears that the following scenario of spent fuel storage and disposal is the most likely or intended program. Adjustments are included for the apparent slippage occurring in the location and construction of the final repository and the schedule is also modified to include some time for contingency and recovery actions. The reference plan, for purposes of this study, is, therefore, as follows:

1. Discharge from reactor into at-reactor (AR) pool.
2. Hold in AR pool five years.
3. Ship to regional (DOE) away-from-reactor (AFR) pool(s).
4. Hold in AFR pool ten years.
5. Ship to terminal geologic repository.
6. Process/encapsulate & place in storage.
7. Monitor twenty-five years.
8. Assume conditions require rehandling some significant portion of the fuel discharged prior to 1995.
9. Cease operations & close up repository(ies).
10. Continue periodic environs monitoring indefinitely.

Figure 3-1 below shows the various spent fuel storage scenario components and movements in a pictorial way.

FIGURE 3-1

SPENT FUEL STORAGE ITERATIONS



Transport of spent fuel is accomplished by the use of heavily shielded truck or rail casks. Figure 3-2 depicts a typical rail cask. A simplified sketch of an AFR facility is found in Figure 3-3, and an artist's conception of a geologic waste repository is shown in Figure 3-4.

FIGURE 3-2 - TYPICAL RAIL CASK

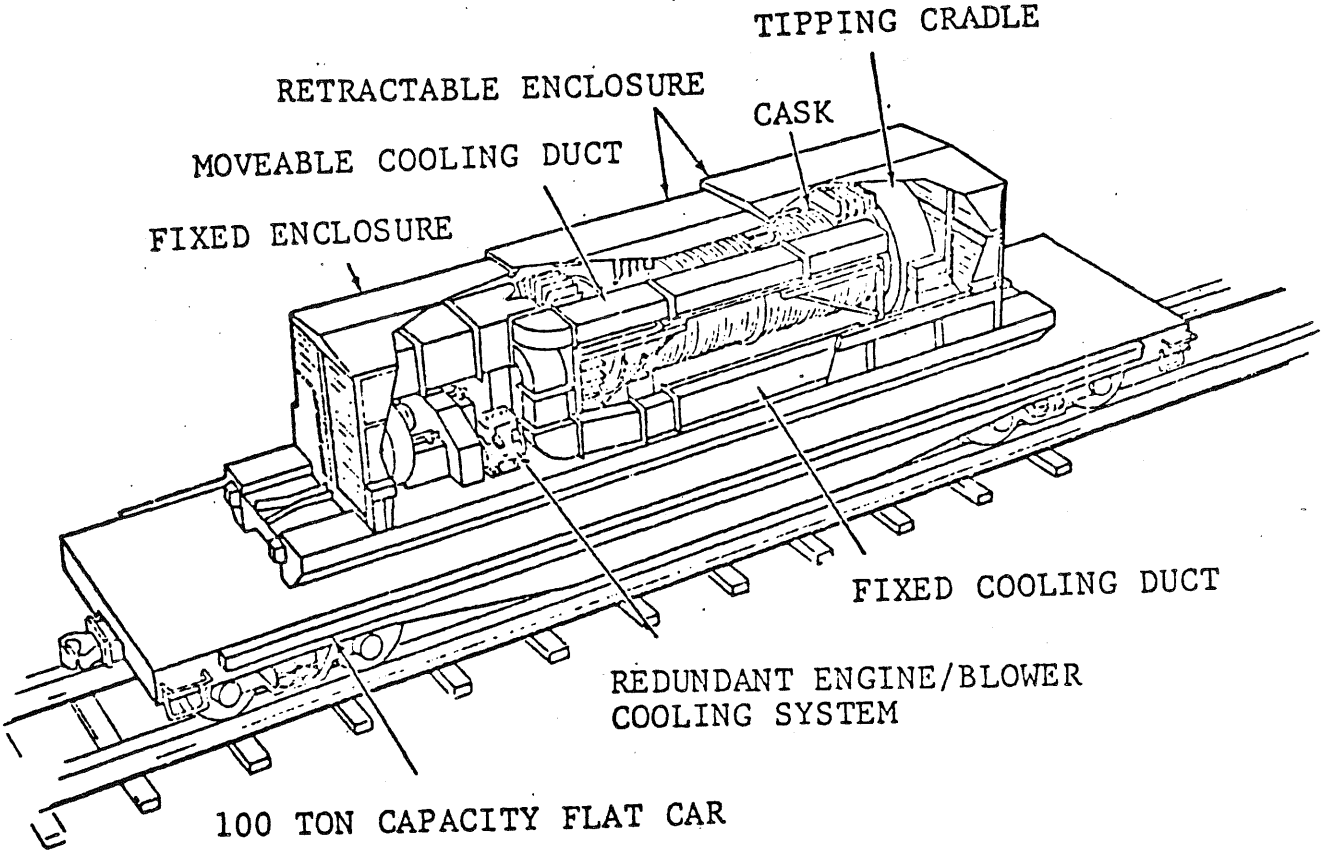


FIGURE 3-3 - SKETCH OF AN AFR FACILITY

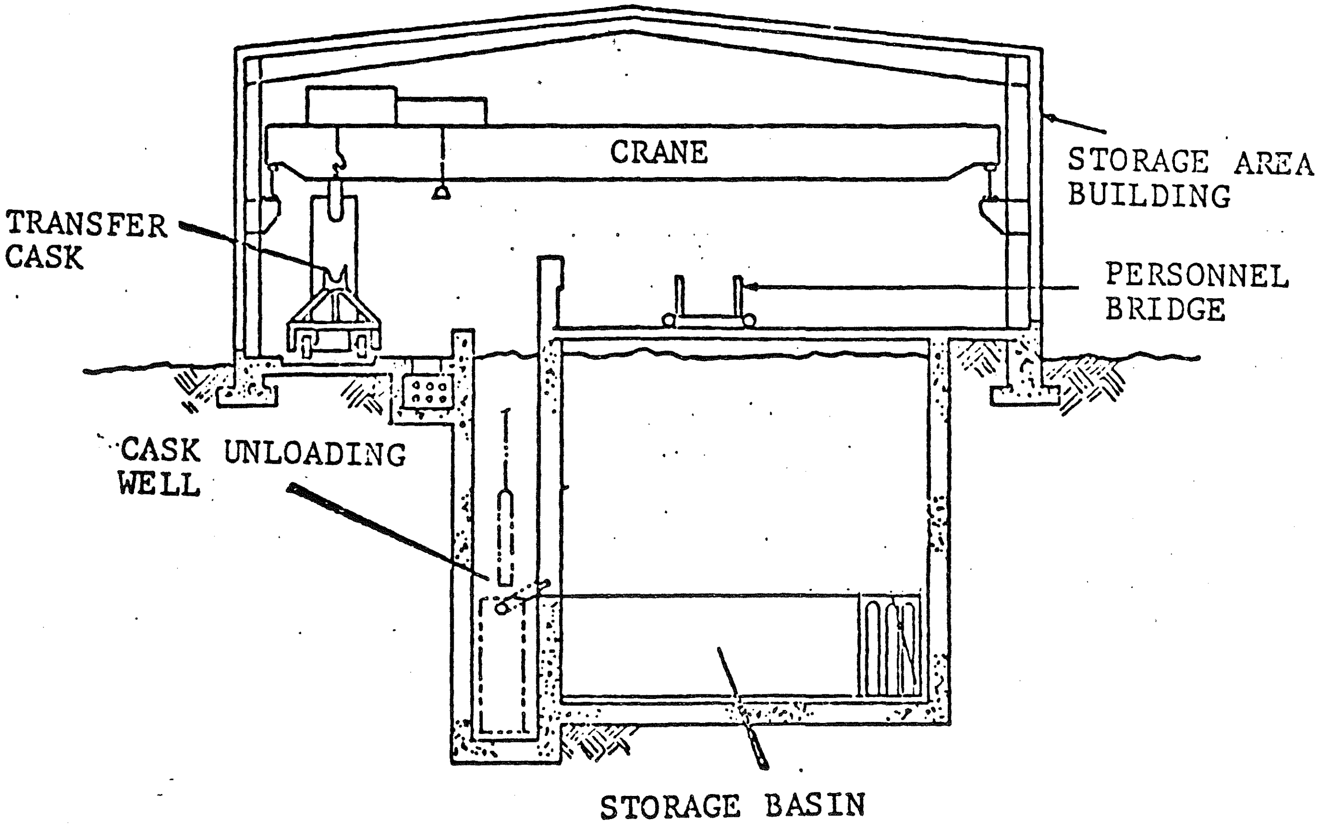


FIGURE 3-4 - GEOLOGIC WASTE REPOSITORY

(Artist's Conception)

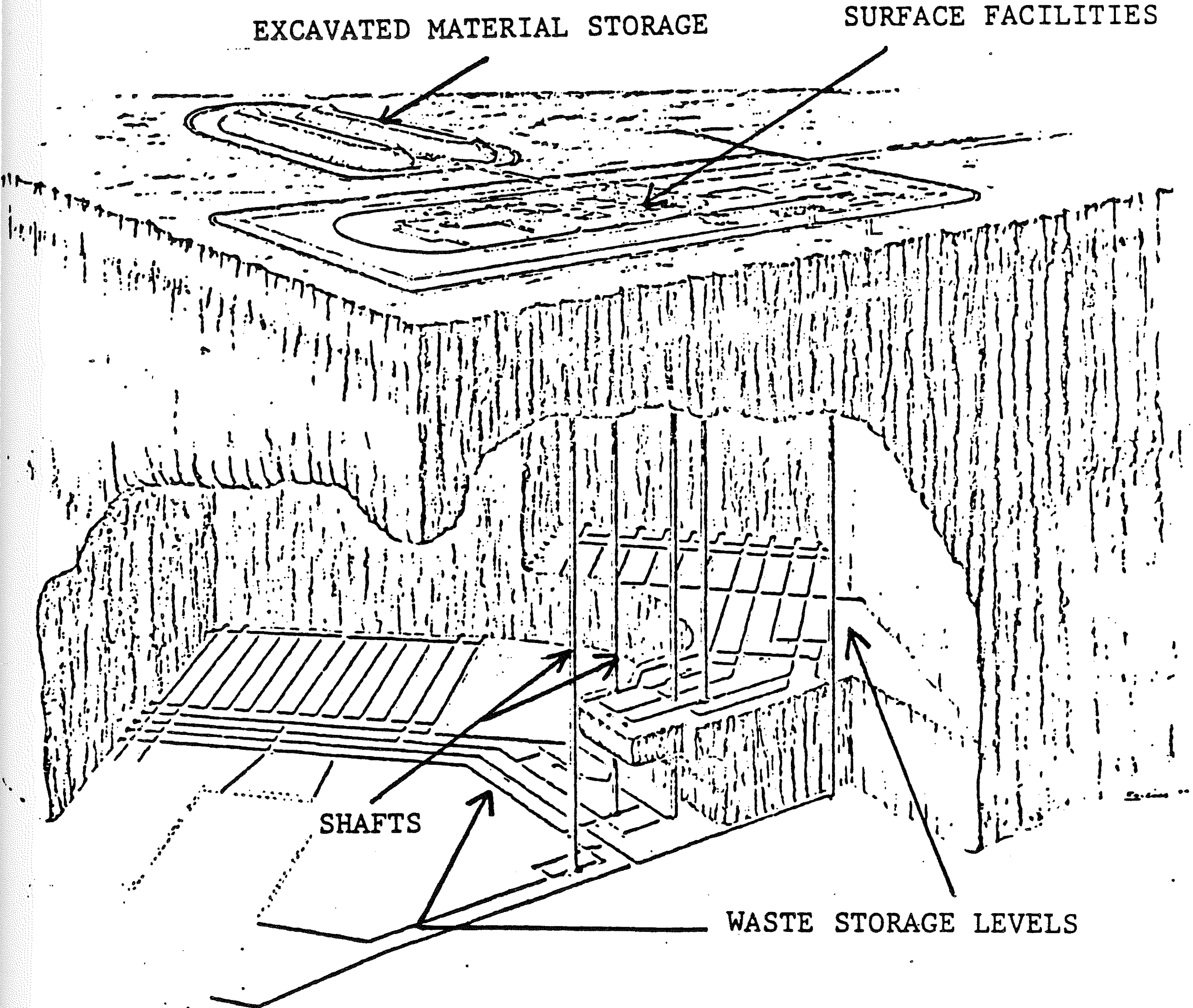
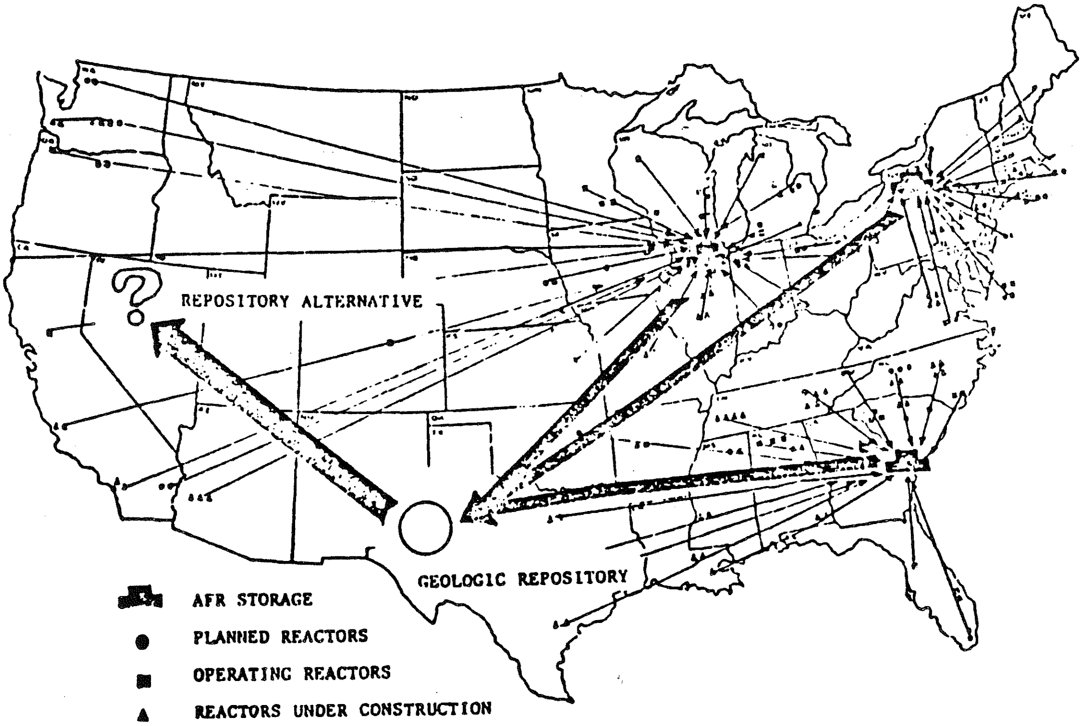


FIGURE 3-5

TRANSPORTATION ROUTES



As can be readily seen from Figure 3-5, the spent fuel disposal program potentially involves almost every one of the 48 contiguous states, due to the probability of multiple moves of each fuel bundle. Additional information on the mechanics of fuel handling is contained in Appendix F.

3.2 DOE REFERENCE/QUANTITY

The quantity of spent fuel expected to be processed is tabulated in the DOE Task Force Report.[(2)] A number of possibilities remain open as to timing, location of AFR's, number of AFR's, location of terminal repositories, etc. The following Figure 3-6, reproduced from the DOE Report, provides an upper bound of the amount of fuel that could be handled under the "Spent Fuel Offer." If reprocessing is ultimately performed, the quantity of spent fuel actually put into the repository would be less. Since a five-year cooling period is "required," the 1995 cumulative amount is theoretically the maximum that could be received by the federal government under the "Spent Fuel Plan" by the year 2000.

FIGURE 3-6

TABLE F-1 1/
Spent Fuel Discharged from Reactors
(Metric tons of heavy metal)

YEAR	U.S. Reactors Annual	U.S. Reactors Cumulated	Foreign Reactors LWR	Foreign Reactors Nat & Other	Foreign Reactors Sum	Foreign Reactors Cumulated	10% of Foreign
1975		1300	430	3600	4000	4000	400
1976	600	1900	340	1800	1200	6200	600
1977	1000	2900	500	2000	2500	8700	900
1978	1100	4000	540	2200	2700	11400	1100
1979	1300	5300	870	2300	3200	14600	1500
1980	1300	6600	1030	2400	3400	18000	1800
1981	1400	8000	1200	2500	3700	21700	2200
1982	1600	9600	1400	2500	3900	25600	2600
1983	1900	11500	1800	2600	4400	30000	3000
1984	2200	13700	2100	2700	4800	34800	3500
1985	2700	16400	2500	2800	5300	40100	4000
1986	2900	19300	3000	3000	6000	46100	4600
1987	3400	22700	3500	3100	6600	52700	5300
1988	3600	26300	4200	3300	7500	60200	6000
1989	3900	30200	4800	3500	8300	68500	6800
1990	4200	34400	5400	3600	9000	77500	7800
1991	4600	39000	5900	3800	9700	87200	8700
1992	4900	43900	6700	4100	10800	98000	9800
1993	5200	49100	7400	4300	11700	109700	11000
1994	5700	54800	8000	4600	12600	122300	12200
1995	6000	60800	8700	4800	13500	135800	13600

1/ Excludes 400 mt currently stored at Morris, Illinois and West Valley, New York

3.3 ALTERNATIVE POSSIBILITIES

Given the state-of-the-art of high-level waste management, the numerous unresolved technical issues (see Section 2) and the lack of definitive regulations governing permanent waste facilities, it is likely that substantial changes will occur to the reference DOE plan over the next 25-50 years. In estimating the adequacy of a "one-time fee," the potential costs of the following spent fuel disposal alternatives must be considered as possible requirements:

a. Perpetual monitoring.

b. Retrieve & rebury.

c. Retrieve & relocate.

d. Retrieve & reprocess.

"Reprocessing" here refers not only to the recovery of material for economic purposes, but to the physical process that might be required to stabilize or isolate the waste for safety or for biologic protection purposes. "Reprocessing" might include:

a. Re-encapsulation.

b. Vitrification or other stabilization.

c. Transmutation.

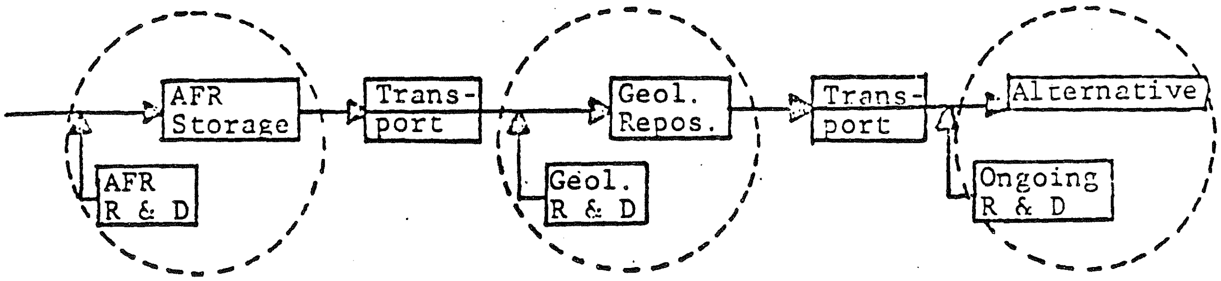
d. Other (ice cap, continental plate, space shot, etc.) disposal.

The cost uncertainty band is extremely broad for such potential requirements.

3.4 SCENARIO FLOW CHART

The simplified model shown in Figure 3-7 shows the major activities (cost centers) of the spent fuel reference plan.

FIGURE 3-7



This simplified model was used to develop a comprehensive listing of tasks necessary to develop and perform the intended function of each of the major cost centers. The tasks are described in more detail in Section 4.

SECTION ~~4~~ 3

REFERENCES

1. DOE/ER-0004/F, UC-70, "Report of Task Force for Review of Nuclear Waste Management, February 1978.

2. Ibid, page 66.

SECTION 4

SPENT FUEL SCENARIO COMPONENT DESCRIPTION

4.1 METHOD

For purposes of estimating, the range of potential costs to be incurred in spent fuel disposal, and the reference and alternative disposal scenarios were broken down into discrete cost components. This section of the report describes the task breakdown utilized, and defines the assumptions made so that costs could be quantified.

Expected costs, along with estimates of the range of cost uncertainty were developed for each major program task. In this way various permutations to the reference scenario can be assembled to permit making revisions to disposal program costs, as conditions change or requirements become more clearly identified.

4.2 COST CENTER DESCRIPTIONS

Four (4) major cost centers, AFR, Transportation, Repository, and Alternatives are included in this analysis. Detailed tasks for each are:

a. AFR Tasks:

AFR R&D
" design
" licensing
" land
" construction
" operational costs
" regulations & security
" decommissioning

b. Transportation Tasks:

Cask R&D
" design
" licensing
" storage
" fabrication
" operational costs
" regulations & security
" decommissioning

c. Repository Tasks:

Repository R&D
" design
" licensing
" land
" construction
" operational costs
" closeup & decommissioning
" regulatory/security/monitoring

d. Long-Range Alternatives Tasks:

Ongoing R&D
Long-range monitoring
Possible corrective actions:
- "perpetual" monitoring
- retrieval &
  - re-emplace
  - relocate
  - reprocess
    - re-encapsulation
    - vitrification
    - transmutation
    - recycle

These are covered in more detail in Section 5.3

4.2.1 AFR FACILITIES

The AFR facilities are assumed to be similar to those considered in the DOE Task Force Report.[1] These are, therefore, below-grade, water basins, regionally located, with a design capacity of 5000 MTU. It is assumed they will be designed to today's seismic requirements and that redundant systems are provided for standy power, cooling, and pool filtration, as well as ventilation air filtration. In addition, since the interim storage time quite likely may be substantially extended, upgraded design requirements for containment, namely resistance to tornados and tornado missiles and to sabotage, is assumed to be a requirement.

While it is recognized that DOE has stated the intent to co-locate AFRs at the expected repository site to minimize a second transportation step, this assumption does not appear to be practical because of the uncertainty that exists and will continue to exist regarding the ultimate location of the final repository.

The AFRs are to be decommissioned by total dismantlement. It is expected, however, that they will be retained in a functional condition for up to fifty years so as to be able to utilize their storage capacity should conditions change.

Figure 3-3 provides a simplified drawing of an AFR and Appendix F contains a substantial amount of additiona AFR description.

4.2.2 TRANSPORTATION SYSTEM

Transportation of spent fuel shipped from the reactor pools to the AFR is assumed to be provided by the utility in truck or rail casks. Transport from the AFR to the repository and subsequent transport, if required for a repository alternative, is also assumed to be by truck or rail cask, but provided by the federal government.

Since sub-contract services are considered to be an acceptable method for the DOE to supply the essential services, commercial costing, capital charges and profit margins are assumed.

Cask size and utilization factors are assumed to be similar to those described in the DOE Task Force Report.[2] Transportation costs are assumed to be higher than currently estimated due to increased security requirements, exclusive use shipments, and more stringent NRC I&E coverage. Additional information on costs and transportation requirements is contained in Appendix F. A simplified drawing of a rail cask is found in Figure 3-2.

4.2.3 PERMANENT REPOSITORY

It is assumed the DOE program will continue to use geologic disposal in their planning to build a repository. The location assumed is similar to the planned WIPP facility in Carlsbad, New Mexico (rock salt). The repository is assumed to operate for approximately 25 years. The repository will consisit of a total of 2000 acres (perhaps on several levels) and the mean depth of the repository is 2000 feet. The spent fuel will be cooled for a minimum of 5 years before emplacement in the repository. The fuel is encapsulated in canisters prior to emplacement. The loading of the repository is dependent on the heat load when the canisters are emplaced. Simple calculations with a range of heat loads are presented in Appendix C to show the effect on disposal cost. For the reference case, a heat load of 30 Kw per acre is assumed. The repository will be backfilled with the mined salt material and sealed using techniques that have not yet been developed.

Appropriate surface and support facilities are provided for receiving, decontamination, handling, and temporary storage of material, as well as for maintenance, laboratory, and other necessary services. See the Sandia <u>WIPP Conceptual Design Report</u>,[3] for details of the probable configurations.

Similar facilities are assumed for some of the repository alternates, but a different location and geologic media is expected with somewhat higher mining costs anticipated.

Total removal of surface facilities will be required for final decommissioning, and environmental monitoring will be required indefinitely.

4.2.4 REPOSITORY ALTERNATIVES

The following possible spent fuel disposal alternatives must be considered as possible requirements:

1. Perpetual monitoring.
2. Retrieve and rebury.

3. Retrieve and relocate.

4. Retrieve and reprocess.

In perpetual monitoring, it is assumed that a permanent work force will be required to perform the ongoing monitoring, security, and R&D.

The retrieve and rebury alternative assumes that the repository has been closed and sealed, and then is re-entered. The canisters are removed and perhaps re-encapsulated and then returned to the same repository. If migration does not occur, each canister would be located by the records of the repository. This may not be a difficult undertaking, but does incur a severe cost penalty.

The retrieve and relocate alternative is a substantial increase in effort in that the repository is re-opened and emptied and the canisters are transported to a new location. Partial treatment of the spent fuel handled by this method is assumed to be required for the reference case. Expansion of the transportation system would be required for this option, if the distances are very great.

Finally, the retrieve and reprocess alternative is the most uncertain and potentially expensive. Reprocessing here is used broadly to refer to a physical process required to stabilize or isolate the waste for safety or biologic protection purposes, as well as to the recovery of fissionable material for economic purposes.

Reprocessing possibilities include:

a. Chemical reprocessing to put the waste material into a different and presumably more stable form.

b. Transmutation through the use of an as yet undeveloped process so as to "detoxify" the waste material.

c. Separation and repackaging into a more stable form for disposal.

In all of the preceding alternatives it is assumed that subsequent reburial of some material in some form would be required, so substantial additional costs are required.

4.3 TASK DESCRIPTIONS

The intended and stated policy of the federal government is that "the utilities pay the full cost of nuclear waste storage and ultimate disposal." To assure completeness of considered cost elements, each of the major cost centers identified in Section 4.2 was examined for planned or probable effort to be expended in the following tasks:

1. Research & Development
2. Engineering
3. Licensing and Environmental Review
4. Land
5. Construction

6. Operating & Maintenance

7. Regulation/Security

8. Decommissioning & Disposal

The estimated costs for each of these cost center tasks was accumulated into the eighteen consolidated program tasks identified on the Reference Schedule. (See Figure 4-5.) Tables 4-1 through 4-4 describe the scope considered for the four major cost center tasks and cross-reference them with the reference schedule program tasks.

TABLE 4-1
AFR COST CENTER - TASK SCOPE

TASK	SCOPE	REF.SCHED. ITEM	COMMENTS
R & D	EPA/NRC/DOE Programs	I-2	Work prior to 1978 not considered*
Engineering	Facility Design and Construc- Supervision Quality Assurance	II-3	
Licensing/ Environmental Review	Fees & Permits DOE/NRC/EPA Participation	II-2	Assume extended hearings & state intervention.
Land	Land + Site Exploration Loss of Resources, etc.	II-3	Assume 3 proposed sites required to get one finally approved.
Construction	Facilities Labor Material NRC - I&E	II-3	
O & M	Insurance Personnel Engineering Support Material Supplies	II-4	
Regulation/ Security	NRC - I&E DOT EPA Local Agencies Site Personnel	II-4	
Decom/Disposal	Return site to unrestricted use Transport and disposal costs.	II-14	

* R&Dcosts would be substantially greater if costs incurred prior to 1978 were included. Examples are costs such as for the salt bed Lyons, Kansas facility and all reprocessing R&D expenditures.

TABLE 4-2

TRANSPORTATION COST CENTER - TASK SCOPE

TASK	SCOPE	REF.SCHED. ITEM	COMMENTS
R & D	Basic work already completed	NA	Work prior to 1978 not considered.
Engineering	As required for new casks and cask qualification.	*	
Licensing/ Environmental Review	Each cask to be certified.	*	
Land	Down time storage at AFR & repository or power plant locations.	NA	
Construction	Cost of casks and vehicles.	*	
O & M	Commercial pricing of transport service.	*	
Regulation/ Security	Exclusive use shipments Transport Guard NRC I & E	*	Armed force required. Frequent inspection.
Decom/Disposal	Assume ten year life due to heavy use. Burial charge.	*	

* All costs included in II-6 and II-11.

TABLE 4-3

REPOSITORY COST CENTER - TASK SCOPE

TASK	SCOPE	REF.SCHED. ITEM	COMMENTS
R & D	NRC/DOE/EPA/USGS and contractor programs	I-2	Work before 1978 not considered
Engineering	Site selection facility design instrumentation selection	II-5	Assume no false starts or changes in plans occur
Licensing/ Environmental Review	DOE/NRC/EPA Participation - Fees & Permits	II-2	Criteria have not yet been established
Land	Acquisition costs & surveillance costs	II-5	Based on 2000 acre repository-multiple site selection sites required
Construction	Mining cost Instrumentation Surface facilities AFR at repository Backfilling costs	II-5	
O & M	Personnel Equipment & materials Power Insurance	II-7 II-8	Operating costs assumed to be constant over the life of the repository
Regulation/ Security	Federal and local agencies	II-7	Regulations have not been established
Decom/Disposal	Total removal of surface facilities	II-14	

TABLE 4-4

REPOSITORY ALTERNATIVES

COST CENTER - TASK SCOPE

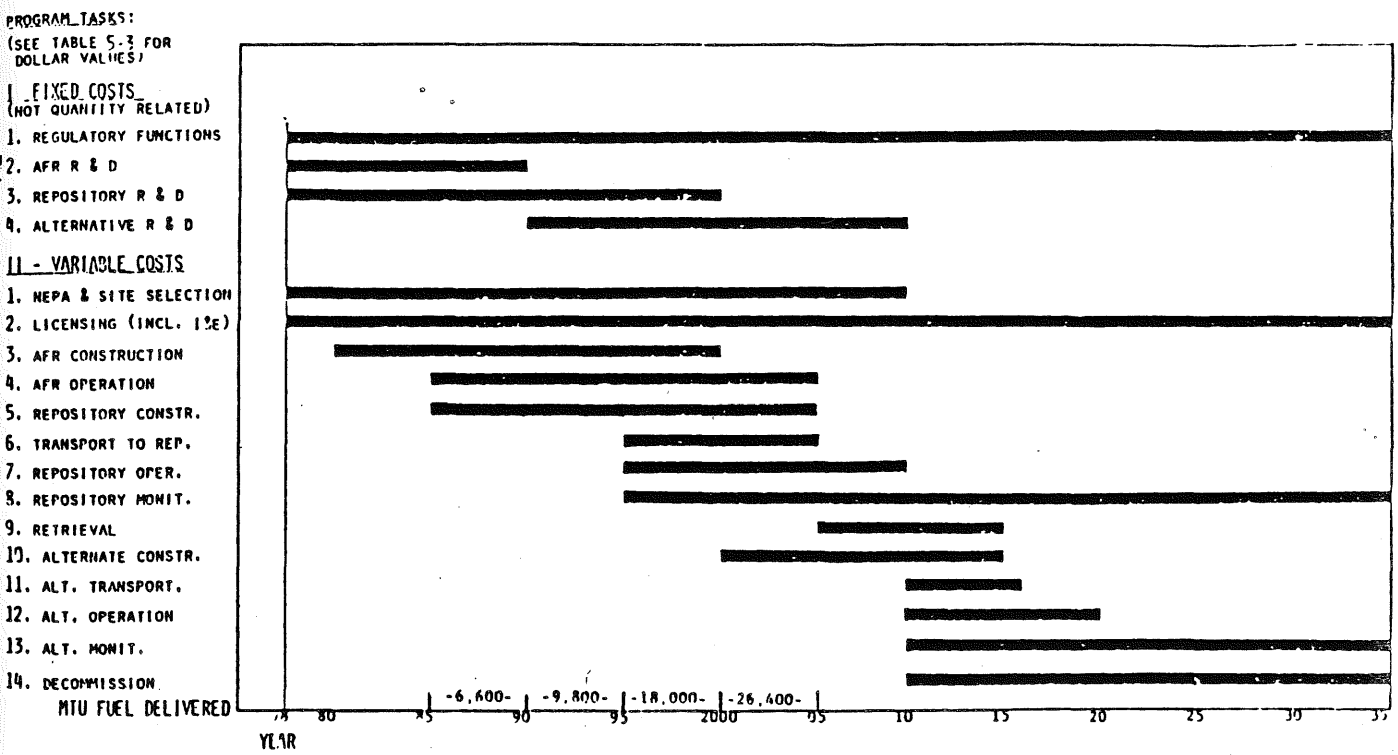
TASK	SCOPE	REF.SCHED. ITEM	COMMENTS
R & D	DOE/NRC/Contractors programs	I-4	Alternatives will be adopted only by inputs from R&D
Engineering	Operational procedures	II-10	---
Licensing/ Environmental Review	NRC/DOE/EPA review	II-2	Difficult to assess
Land	Surveillance costs preparation costs	II-10	Some alternatives do not effect land use
Construction	Retrieval procedures special facilities special monitoring	II-10	The particular alternative will affect construction cost greatly
O & M	Personnel Equipment & materials Power	II-12 II-13	---
Regulation/ Security	Federal & local agencies	II-12	Regulations not established
Decom/Disposal	Total removal of surface facilities	II-14	Employment of one of the alternatives is a form of modified decom/disposal

A spent fuel disposal plan reference schedule was then developed, based on the scenario model, the program tasks, and the schedule information contained in DOE documents and announcements. Figure 4-5 shows the eighteen program tasks and the timing of the reference schedule. These items and their costs are described and presented in Section 5.

FIGURE 4-5

SPENT FUEL DISPOSAL PLAN

REFERENCE SCHEDULE



SECTION 5

REFERENCES

1. DOE/ER-004/F, UC-70 "Report of Task Force for Review of Nuclear Waste Management," February 1978.

2. Ibid., page 76.

3. SAND 77-0274, "WIPP Conceptual Design Report," Sandia Laboratories for ERDA, June 1977.

SECTION 5

COST ANALYSIS OF PROGRAM ELEMENTS

5.1 BASIS OF COST ESTIMATES

In order to acheive maximum flexibility in the comparison of spent fuel disposal scenarios, all cost center task costs are expressed in terms of 1978 dollars. This then permits the development of various alternative spent fuel disposal management programs, with different assumptions for schedule slippage, to be analyzed for total impact on electrical generation costs.

Different methods were used for the estimating of detailed costs for the different parts of the disposal program. The method, or combinations of methods, selected was dependent on the degree of knowledge and actual experience available for the work to be performed. R&D costs, for example, were extracted from available documents with multipliers applied as judged appropriate for the "state of the art" expressed in the most current technical reports. For other tasks such as transportation, some fairly firm costs have been developed from other documents or testimony. Where conflicting costs are found, median approximations are made. Uncertainty bands, (high/low case multipliers) are expressed for all significant costs. A listing of task scope and costs is contained in Table 5-3. A description of the logic used in arriving at the costs follows the table.

5.2 UNCERTAINTY FACTORS

It should be emphasized that any cost estimate is subject to error of prediction, and the greater the degree of uncertainty of the final configuration, the less the confidence to be placed on the estimate. For most cost estimates, one way to predict estimate accuracy is to evaluate the cost of the estimating effort as compared to the cost of the ultimate product. A leading reference book on cost estimating, Cost Engineering Analysis,[1] by Park, provides the following guidance on the ability to estimate cost accurately for heavy construction projects:

TABLE 5-1

COST ESTIMATING ACCURACY

Type of Estimate	% of Project Cost	Accuracy of Estimate
Detailed	4.0	± 5%
Semi-detailed	1.5	± 10%
Order of magnitude	0.07	± 50%

If applied to this program, a cost estimate at this stage of a ten billion dollar effort could only be expected to achieve a ± 50% accuracy. It would take a massive expenditure, akin to two WASH-1400 studies, to approach Park's requirements for a ± 50% estimate.

These accuracy relationships assume that the scenario is known and that estimate errors are introduced through omissions or under/over estimates of detailed tasks. In the case of a highly speculative program such as radioactive waste disposal, additional factors to compensate for not knowing what technological or regulatory changes may be required must be considered.

In this study, this has been provided by assuming that some alternate(s) will be required, and that some portion of the spent fuel will have to be handled twice. This is called the reference case and costs are estimated for it accordingly, corrected for time of expenditure. Uncertainty is covered by calculating the costs associated with a high and a low case expressed as multipliers of the reference case tasks.

There is no scientific way to precisely calculate the high and low case factors as we are dealing with a number of independent variables. It is possible, however, to evaluate the segments of the spent fuel disposal program, and qualitatively select factors that are most likely to be controlling.

5.3 PROGRAM COST DEFINITIONS

Table 5-3 (on page 5-4) lists the eighteen program tasks from Figure 4-5, their scope, cost and rate of expenditure, the reference costs and the high and low case multipliers.

TABLE 5-3

SPENT FUEL DISPOSAL PLAN

TASK COST DEFINITION & HIGH/LOW CASE MULTIPLIERS

TASK:	INCLUDES:	COST (ALL $ IN MILLIONS-1978) Reference Case	TOTAL $ Ref. Costs	UNCERTAINTY FACTOR: MULTIPLIERS High Case	Low Case
I FIXED COST					
1. Regulatory	NRC/DOE/EPA/DOT	2.0/yr Increasing uniformly to 6.0/yr in 2005-then constant to 2035	286	3	1
2. AFR R & D	DOE & Contractor Mat'ls & LT. Eval.	2.0/yr - Constant for 20 yrs	40	4	½
3. Repository R & D	DOE, USGS, NRC & Contr. Geolog., Eng. Bar, Hyd. Inv.	30.0/yr for 22 yrs	660	2	1
4. Alternative R & D	DOE/NRC/EPA & Contr. Advance Methods Dev.	30.0/yr for 20 yrs	600	2	0***
II VARIABLE COSTS					
1. NEPA/Site	DOE/NRC/Etc. Reviews + Alt.Site Investig. + Loss of Mineral Resource	10% Item II-3, 10% Facility Portion II-5 & II-10 plus loss of resource of $200. Distribute 25% thru 1990, 75% thru 2010.	646	2*	1*
2. Licensing	DOE/NRC/Public Eval. & Hearings	10% Item II-3, 10% Facility Portion of II-5 & II-10. Distribute same as II-1	446	2*	1*
3. AFR Const.	3-5000 MTU AFR's Design Procure, Install	750.0 Distribute Evenly 1980 - 2000	750	4	1/3
4. AFR Oper.	Operate 3 - AFR's 1985 - 2005	10.0/yr 1985-89, 20.0/yr 90-94, 30.0/yr 95-04	450	4	1/3
5. Repos.Const.	2-30,000 MTU Repos. Design & Const.	157.5/yr 1985 - 2005, includes 2470 Facility, 680 canisters.	3150	2	1/3
6. Transport.	Trans 15,000 MTU AFR to Repository	450.0 Distribute Uniformly 1995 - 2005 ($30/KgU)	450	4	1/3
7. Repos.Oper.	Operate 2 - Repos. 1995 - 2010	50.0/yr 1995 - 2010	750	2	1/3
8. Repost. Monit.	Technique to be developed	10.0/yr 1995 - 2035	390	4	½
9. Retrieval	Assume all of 1st Repos. to be Recovered	For one Item II-5 Repos. use 100% of underground & 50% all other costs. Distribute uniformly 2005 - 2015	1566	2*	0***
10. Alt. Const.	New Repos. Technique for 50% Fuel	50% Item II-5 Total, Distribute uniformly 2005-2014	1575	2*	0***
11. Alt. Transp.	Trans. 30,000 MTU	900.0 Distribute Uniformly 2010 - 2016 ($30/KgU)	900	2	0***
12. Alt. Oper.	Reprocess/Bury 30,000 MTU	37.5/yr 2010 - 2019 (50% II-7 Total)	375	2	0***
13. Alt. Monit.	Technique to be developed	5.0/yr 2010 - 2035	125	2	0***
14. Decom.	3-AFRs, 2-Repos.,1 Alt. Repos.	10% II-3, 25% II-5 & II-10 Surface Facilities & Equip. Distribute uniformly 2010 - 2035	145	2*	½*
		TOTALS**	13,304	31,054	4,176

* These multipliers are applied to Reference Case totals only; new percentage totals are not calculated for the High and Low cases.
** Unadjusted for escalation/discount factors
*** A low case multiplier of zero means that task is not performed.

5.4 REFERENCE CASE - PROGRAM TASK COST DETAILS

Following is a task-by-task description, giving the details of the scope and cost of the reference case, the method by which the cost was estimated or its basis, and the rationale for selection of the high/low case multipliers. Costs listed under Part I are fixed costs (relatively insensitive to volume) and Part II costs vary with facility size and volume.

I-1 Regulatory

This task includes the costs of all regulatory functions of federal agencies. Included are fuel inventory auditing, shipment monitoring, generic standards and research, and Inspection & Enforcement functions. The amount of $2.0 million per year starting in 1978, and increasing uniformly to $6.0 million per year in 2005, then constant to 2035 is arrived at by taking 5% of estimated agency budget and assuming a growth by a factor of three in the next 27 years. It is equivalent to approximately a forty person staff now, or an average of ten each for the four major agencies.

High/low case multipliers of three and one were selected. It is assumed that more strict regulations in the waste monitoring area could cause this amount of growth, but that in no case would a lesser amount be spent.

I-2 AFR R&D

Current reports [2][3] indicate little long-term corrosion work has been done to verify that spent fuel can be safely stored for long periods of time. It has been assumed a modest materials research program will be initiated and followed for the life of the AFR portion of the program (2.0 million per year for 20 years). If unusual results develop, or if the program is extended, it could increase by a factor of four. On the low side, it might be cut in half, but is not likely to be eliminated.

I-3 Repository R&D

As discussed on page C-16 of Appendix C, the DOE R&D effort chargeable to permanent repository technology currently is estimated at over $3.0 billion for the next twenty plus years. Approximately 40% of this is assigned to commercial waste, and about one-half of that portion will be directed at high-level waste disposal, specifically for geologic, hydrologic, and engineered barrier investigations. This translates to about $30.0 million per year at least through the verification of satisfactory operation (about 22 years) of the geologic facility. This is equivalent to the full-time effort of 500 professionals (or 250, plus laboratory and field research facilities) in the various agencies and contractors. It is assumed this effort could easily double but would not likely be reduced, so high/low case multipliers of two and one are assigned.

I-4 Alternatives R&D

Additional R&D effort is assumed to be required to develop salt-bed repository alternatives. This work covers alternative geologic investigation and space, sea-level, arctic, and continental plate techniques, as well as transmutation or other exotic methods. Size of this effort is estimated to be similar to the repository R&D with the same high case multiplier. The low case assumes no R&D effort on alternatives (zero multiplier).

II-1 NEPA/Site Evaluations

Various site-related costs are included under this item, primarily all costs related to site selection and exploration, evaluation of alternate sites, NEPA required review, etc. A minimum of five facilities are contemplated with a maximum of fifteen or more. If three alternates are required for each facility, evaluation of 45 sites would be necessary.

Cost of this task is estimated at 10% of the installed facility costs of the AFR's and repositories. An additional $200 million is assigned for "rent" on loss of use of resources tied up in the repository as described in Appendix C, page C-10.

Uncertainty multipliers of two and one have been selected for the high/low cases. This is based on a likely possibility of a substantial increase but little possiblity of a decrease.

II-2 Licensing

This task covers all government costs in conducting the licensing review of the proposed facilities. This would include safety and economic evaluations, conduct of public hearings, coordination with state and local agencies, etc. It has been estimated at 10% of the facility cost for the AFR's and repositories. This task, which takes place between 1978 and 2010, averages about $14 million per year and would require just over 200 persons. For purposes of this study, it is distributed 25% through 1990 and 75% 1991-2010.

Uncertainty multipliers selected are two and one, the same as for II-1 for the same reasons.

II-3 AFR Construction

This cost is that required for site procurement and development, and for design and construction of three 5000 MTU facilities. Costs are estimated at $250 million each, for a total of $750 million, distributed evenly during the 1980-2000 period.

Costs were arrived at by use of a \$50 million 1976 cost for a 1000 MTU facility reported in ORNL-TM-5703[4] escalated and extrapolated using the formula:

$$\text{Cost Multiplier}_{5000/1978} = (1.07)^2 \times \left(\frac{5000}{1000}\right)^{.8}$$

An additional 25% was added to "harden" the facility and provide improved security.

An additional cost crosscheck was obtained by verbal communication with DOE. They confirmed a \$240 million, 5000 MTU AFR cost reported in the June 26, 1978 issue of Nucleonics Week.

High/low case multipliers of four and one-third were selected. These cover the range of facilities required to store all fuel to be discharged by 1995 (60,800 MTU) to only one 5000 MTU AFR.

II-4 AFR Operation

This task covers the annual cost to operate the AFR's costed in II-3. A cost of \$10 million per facility per year is assumed. This is based on a \$40 million annual operating cost taken from the SURF 40,000 MTU water basin storage study[5] escalated and extrapolated per the formula.

$$\text{Cost}_{5000/1978} = \$40 \times (1.07) \div \left(\frac{40,000}{5,000}\right)^{.8}$$

An additional 25% is added for improved security costs.

A comparative annual operating cost of $6 million is reported by a preliminary DOE study. High/low case multipliers of four and one-third are used for the same reasons as given in II-3.

II-5 Repository Construction

It is assumed that two, 2000-acre salt bed repositories will be required to dispose of the 60,800 MTU scheduled for discharge. This is based on a heat load limit of 30 Kw per acre. Costs are developed from Appendix C, pages C-4 & 5. They consist of a per facility cost of:

Mining:	$ 994	(millions)
Repository Equipment:	27	
Surface Facility:	54	
Subtotal:	1075	
Plus 15% Engineering & Project Management:	160	
FACILITY TOTAL:	$1235	

Two are required for a total of $2470. All fuel is encapsulated before emplacement. Encapsulation (canister) costs are obtained from the SURF study[6] which reports 1977 costs at $10.47/KgU. Escalated to 1978 and applied to 60,800 MTU, this cost becomes $680 million. Total repository cost, therefore, is $3150 million, or $157.5 million per year during the 1985-2005 period.

High/low case multipliers are two (to account for substantial cost underestimate) and one-third (for overestimate, or the possibility of higher heat load per acre).

II-6 Transportation

This task covers required government transport of 15,000 MTU fuel from the AFR to the repository(s). A unit cost of $30 per KgU is used for a total of $450 million, assumed uniformly distributed between 1995 and 2005. The $30/KgU cost is obtained by using the high end of the (1976) range reported in the American Physical Society Study.[7] This seems to be a reasonable value in view of the probable cross-continent shipment and increased security requirements.

High/low case multipliers of four and one-third are specified for the same reasons as given for Task II-3.

II-7 Repository Operation

A salt bed repository operating cost estimate is detailed in Appendix C, page C-6 as $28.5 million per year. Since the scenario assumes two, 2000-acre repositories at one location, this cost can be extrapolated per the formula:

$$\text{Operating Cost}_{\text{2 facilities}} \doteq 28.5 \left(\frac{2}{1}\right)^{.8} = \$50 \text{ m/yr}$$

The dual facility is assumed to operate from 1995 to 2010 for a total cost of $750 million.

High/low case multipliers of two and one-third are assigned, consistent with the logic given for Task II-5.

II-8 Repository Monitoring

An as yet undeveloped monitoring technique is assumed to be used in monitoring satisfactory performance of the two repositories. See page 2-10 for details on this. Cost is estimated at $10 million per year during the period of 1995 to 2035 for a total of $390 million. This task will be closely associated with Task I-3.

High/low multipliers of four and one-half are used in view of the large uncertainty of this effort.

II-9 Retrieval

The reference scenario assumes that 50% of the fuel emplaced in the salt bed repository (the first repository) will have to be retrieved and relocated. Costs are detailed in Appendix C, page C-14. They consist of 100% of the underground and 50% of all other costs for one-half of Task II-5. This makes a total of $1566 million distributed uniformly between 2005 and 2015.

High/low case multipliers of two and zero are assigned. This covers the possiblity of retrieving all 60,8000 MTU, or none of it.

II-10 Alternate Repository Construction

The reference scenario includes design and construction of an alternate (granite, shale, etc.) repository. Cost is assumed to be 50% of Item II-5, or $1575 million. (This is non-conservative since granite mining costs would be about 50% higher than salt costs.) This cost is distributed uniformly between 2000 and 2014.

High/low multipliers of two and zero are used, consistent with II-9.

II-11 Alternate Transportation

It is assumed that 30,000 MTU of fuel will be transported from the salt repository to the alternate repository. Cost is estimated at $30/KgU for a total of $900 million, distributed uniformly between 2010 and 2016.

The same multipliers of two and zero are used.

II-12 Alternate Repository Operation

The reference case assumes the operating cost of the alternate repository will be one-half of Item II-7, or $375 million. This cost is incurred between 2010 and 2019.

The same multipliers of two and zero are used.

II-13 Alternate Repository Monitoring

It is assumed that a substantial repository monitoring effort will be required for the alternate. This is estimated at $5 million per year (one-half of II-8) from 2010 to 2035, for a total of $125 million.

Multipliers are two and zero.

II-14 Decommissioning

It is assumed that all surface facilities of the three AFR's, two salt-bed repositories, and one alternate repository will be totally removed and the sites restored to original condition. Cost of this is estimated at 10% of Item II-3, and 25% of the cost of the surface facilities and equipment for Items II-5 and II-10. This cost of $145 million is distributed uniformly between 2010 and 2035.

The high case factor is two and the low case multiplier is one-half.

5.5 OTHER UNSPECIFIED COSTS

It is likely that some additional spent fuel disposal costs have been omitted due to oversight or lack of quantification. This section addresses several possible additional costs.

One potential cost not included in any of the three cases is the cost of accidental intrusion. This situation is described in Appendix C, page C-12. It is a low probability event, but one that must be considered in making cost/benefit decisions. The cost of recovering from such an event could range from approximately $100 million to in excess of $1000 million (one billion).

The worst case repository alternative, the need to retrieve and reprocess, has not been included in the quantified high case. An approximation of such a case is described in Appendix C, page C-15. It would add approximately $9.5 billion (unescalated) to the high case scenario costs. Another low probability event is the case of perpetual care. This case was costed as a possible alternative for decommissioning. A cost of $10 million per year was carried out for 150 years. Using the cost time-adjustment methodology described in Section 6.1, an added cost of $150 billion is incurred. This case was not included as it is assumed that a better solution could be found.

These potentially disastrous economic impacts should be considered when policy and R&D funding decisions are being made. The incentives are high. They should also be considered when evaluating the adequacy of the one-time disposal charge. All of the cases quantified could easily be low by a factor of two or more due to such possible added costs.

SECTION 5

REFERENCES

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2. BNWL-2256. Behavior of Spent Nuclear Fuel in Water Pool Storage. September 1977, pages 76 & 77, by A.B. Johnson, Jr., for ERDA.

3. An Assessment of the Long-term Storage of Zircaloy Fuel Rods in Water, Final Report, pages 7 and 8. Z.A. Munir, UC-Davis.

4. ORNL-TM-5703, March 1977, page 68.

5. RHO-LD-2 Informal Report. Spent Unreprocessed Fuel Facility Engineering Studies, February 1978, page 106. Rockwell International

6. Ibid. Page 110

7. Reviews of Modern Physics, Volume 50, No. 1, Part II, January 1978, page S64.

SECTION 6

SCENARIO COSTS & RESULTS

This section describes the methodology used to calculate the impact of time and costs of the spent fuel program on the ratepayer and presents the results of the calculations.

6.1 METHODOLOGY

Section 3 described the waste disposal reference scenario and also described possible variations to that scenario. Section 5 presented estimated costs and schedules for each of the major program tasks along with estimated (error) multipliers for them. The time line of the reference scenario is described in Section 4, Figure 4-5.

Using these elements (as summarized in Table 5-3), adjustments for the time value of each cost element were made. Table 6-1 summarizes the adjusted values for the reference case and the high and low cases.

Three elements were employed in the time value adjustment of cost based upon current 1978 dollars. An inflation/cost increase factor was applied to take into account the probable increase in cost over time. A discount factor was employed to allow for the earning value of deposits made (the one time charge) for costs to be incurred in the future. An allowance was made to compensate the U.S. Government for the use of borrowed funds during the period between the first government expenditure and the time when the government has received the total of all disposal charge payments. No allowance was made for a return on the government investment in the disposal facilities. See Appendix D for further details on the development of these cost factors and for supporting data for the financial methodology.

The inflation/cost increase factor was applied, at a 7% compound rate, over the period 1978 to 2034. The time periods in which costs are anticipated to be incurred were derived from Table 5-3. The present value, at January 1, 1978, was computed using 4% present value tables applicable to the period. The period 1985 to 2034 covers the period from the first, anticipated, payment of the one time charge to the end of the period employed in this model.

The government interest compensation factor was applied over the period 1978 to 2005. This period covers the period from the first, anticipated, payment of costs by the government until the time that all costs have been recovered by the government.

The time periods stated above applied to all cases except for the high band of error case. In that case, the ending period 2035 was used for the inflation factor and the discount factor.

Since specific periods were not designed for the receipt of payments of the one time charge, the interaction between the discount factor and the government interest compensation factor have the computational effect of averaging the receipts over the period 1985 to 2004. The total amount included for government interest compensation over the period, therefore, is the average net interest on funds expended over the period.

The total time adjusted costs under the reference case, and the two alternative cases, is the sum of the individual time adjusted cost elements over the relevant periods. This total cost will be employed in the computation of the consumer cost.

The consumer cost, under the three study cases, was computed by three methods. The first method is that the total disposal cost* will be recovered by an equal charge to ratepayers for each kilowatt hour of energy provided by all of the fuel placed in the repository. The charge can theoretically be computed with the following formula:

CONSUMER COST:

$$\left[\boxed{\frac{\text{DISPOSAL COST - \$}}{\text{MTU x 1000}}} \div \frac{\text{KW-hrs}}{\text{KgU}}\right] \times \boxed{\frac{\text{1000 Mills}}{\$}} = \boxed{\frac{\text{Mills}}{\text{KW-hr}}}$$

The second method is to assume that the total disposal cost will be recovered by an equal charge to ratepayers for each kilowatt hour of energy remaining available in the fuel that

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* This is not totally correct. In-plant handling and storage costs for the first five years storage plus charges for shipping the fuel from the plant to the first government facility are not included. It has been assumed these charges would be directly paid by the utility. These costs have not been included in this analysis since the purpose of this study is to calculate the charge for the service performed by the government.

remains to be placed in the repository. In order to estimate the remaining energy, it was assumed that no energy would be available from spent fuel on hand prior to the repository becoming operational and that the remaining fuel retained only 50% of its original, available energy content. Since 13,7000 MT of spent fuel will be on hand in 1985 when the first fuel may be deposited, and the remaining fuel retains only 50% of its usable energy, the above formula is substituted with:

$$\left[\boxed{\frac{\text{DISPOSAL COST - \$}}{(\text{MTU} - 13{,}700) \times 1{,}000}} \div 1/2 \quad \left[\frac{\text{KW-Hrs}}{\text{KgU}}\right] \right]$$

This method of calculating costs assumes that only a finite amount of fuel ("batch" costing) is being considered. That is the assumption made for this study, in order to permit the distribution of costs to be made to the beneficiaries. It may be a conservative approach, but the point is well made, as can be seen in the results listed in Table 6-2.

In both methods a number representing unit power generation (KW - HR/KgU) must be developed. The DOE Task Force Report[1] provides a basis for this number. Using their 25,000 MWDT/MTU expected exposure, and a thermal efficiency of 0.32, we find:

$$\frac{25{,}000 \text{ MWDT}}{\text{MTU}} \times \frac{24\text{hr}}{\text{Day}} \times \frac{1000\text{Kw}}{\text{MW}} \times 0.32 \times \frac{\text{MTU}}{1000\text{KgU}} = 192{,}000 \ \frac{\text{Kw Hrs}}{\text{KgU}}$$

This is the number used for this study. It could range from 15,000 MWDT to 35,000 MWDT/MTU (115,200 to 268,800 Kw-Hrs/KgU), depending on the performance of the fuel in the reactor. The number used will directly affect the resulting unit cost to the ratepayer by changing the total amount of spent fuel to be handled, the number of facilities to be built, etc. A lower exposure will increase the mills/Kw-Hr cost.

The third and simpler method to express the program cost is to put it in terms of dollars per Kg uranium disposed. This is the term used in the DOE Task Force Report (2) where $150-250/Kg was given as likely charge for the Spent Fuel Policy. This is calculated by:

$$\frac{\text{DISPOSAL COST}}{(\text{MTU x 1000})} = \$/\text{KgU}$$

Conversely to the mills/KwHr cost, reduction of fuel exposure will decrease the $/KgU cost by spreading R&D and overhead over a broader base. It will, however, directly increase the total program waste disposal cost.

6.2 RESULTS

The following tables summarize the results of the study:

TABLE 6-1

SPENT FUEL DISPOSAL PLAN

TIME ADJUSTED COSTS

(Millions of Dollars)

		Reference Case	High Case	Low Case
I.	FIXED COSTS			
	1. Regulatory	$ 968	$ 2,904	$ 968
	2. AFR R&D	164	656	82
	3. Repository R&D	2,622	5,244	2,622
	4. Alternative R&D	1,505	3,010	-0-
II.	VARIABLE COSTS			
	1. NEPA/Site	2,023	4,046	2,023
	2. Licensing	1,615	3,230	1,615
	3. AFR Construction	2,941	11,764	980
	4. AFR Operation	1,307	5,228	436
	5. Repository Construction	10,092	20,184	3,364
	6. Transportation	1,173	4,692	391
	7. Repository Operation	1,893	3,786	631
	8. Repository Monitoring	1,295	5,180	648
	9. Retrieval	3,639	7,278	-0-
	10. Alternative Construction	3,748	7,496	-0-
	11. Alternative Transport.	2,537	5,074	-0-
	12 Alternative Operation	1,010	2,020	-0-
	13. Alternative Monitoring	469	938	-0-
	14. Decommissioning	530	1,060	265
		$39,531	$93,790	$14,025

TABLE 6-2

SPENT FUEL DISPOSAL PLAN

ESTIMATE OF CONSUMER COSTS

METHOD/CASE	DISPOSAL COST-MILLIONS (FROM TABLE 6-1)	CONSUMER OR UTILITY COST
METHOD 1 (60,800 MTU)		
High	93,790	8.0 Mills/Kw-hr
Reference	39,531	3.4 " "
Low	14,025	1.2 " "
METHOD 2 (47,100 MTU)		
High	93,790	20.7 Mills/Kw-hr
Reference	39,531	8.7 " "
Low	14,025	3.1 " "
METHOD 3 (60,800 MTU)		
High	93,790	1542 $/KgU
Reference	39,531	650 "
Low	14,025	231 "

(All unit costs calculated at 192,000 $\frac{\text{Kw-hrs}}{\text{KgU}}$)

An additional calculation can be made that is not meaningful except for possible comparison to DOE released figures. If the cost estimate totals for the three cases are taken before adjusting for escalation/discount factors, the following results are obtained:

TABLE 6-3

COST OF SPENT FUEL DISPOSAL
USING ESTIMATE COSTS NOT
ADJUSTED FOR TIME
(FROM TABLE 5-3)

	ESTIMATE \$-1978 UNCORRECTED MILLIONS	BASED ON 60,800 MTU \$/KgU
High	31,054	511
Reference	13,304	219
Low	4,176	69

These figures may or may not be comparable to the \$150-250/KgU values previously released by the DOE, as no information is available as to how they had treated escalation on early estimates.

Conclusions and recommendations drawn from evaluation of the results of the analysis follow in Section 8.

SECTION 6

REFERENCES

1. DOE/ER-004/F, UC-70, Report of Task Force for Review of Nuclear Waste Management. February 1978, page 105.

2. Ibid., page 70.

SECTION 7

SENSITIVITY ANALYSIS

Section 6 presents the results of the cost analysis for the assumed reference scenario and its high and low scenario cases. Substantial uncertainty exists in this analysis, including the effects of delays or changes of schedules, possible different technical requirements for disposal, reduction of the quantity of fuel to be handled, and uncertainty in predicting financial factors that will be applied. In order to more accurately assess the potential impact of these uncertainties on the final cost of disposal, a series of calculations were performed to determine the range of sensitivity of different variations of the program. The following sections describe the more significant and likely program changes and their respective results.

7.1 INCREASED AFR

The reference scenario assumes that final repository construction and operation will be nearly in accord with the proposed DOE schedules. If this is accomplished, only about 25% of the spent fuel will move into an AFR.

Because of the likelihood of significant schedule slippage, the potential cost of the program was calculated for the case in which repository operation is delayed ten years or more, making nearly 100% AFR storage capacity a requirement. Table 7-1 (page 7-5) shows the changes assumed or calculated for the eighteen program tasks compared to the reference case for such a variation.

No changes are assumed in the cost of the basic R&D programs. Major increases are incurred in Tasks II-1, 2, 3, and 4 for the review, licensing, construction, and operation of nine additional AFR facilities. Repository construction costs, Task II-5, decreases due to the time value of advance payments for the spent fuel to be disposed. Transportation, Task II-6, increases, since four times as much spent fuel will be transported from the AFR to the repository. Repository operation, Task II-7, increases slightly due to financial factors, and Task II-14 increases substantially because of the additional facilities that must be decommissioned.

Total impact on the adjusted cost of the 100% AFR case is an increase of 42% over the reference case. The resulting disposal cost (Table 7-2, page 7-6) is $925 per KgU or a consumer cost of 4.8 mills per Kw-hr.

7.2 REDUCED NUCLEAR CAPACITY

The reference scenario assumed that installed nuclear capacity in the U.S. Will total 380 GWe by 2000. The predicted total has been revised downward almost every year for the past several years, and some believe it will continue to decline due to increasing costs, improved conservation, and lack of resolution of waste and other generic issues.

Calculations were performed for the impact of two reduced capacity scenarios, 200 GWe and 105 GWe by 2000 respectively. Revised costs for the program tasks are given in Table 7-1.

The total program costs change very little for these two cases. Basic R&D costs are assumed indentical to the reference case for the 200 GWe case, and a reduction of one-third the Alternative R&D cost, Task I-4, is assumed for the 105 GWe case. All other costs remain the same with the exception of relatively minor reductions for Repository Construction, Task II-5, and Operation, Task II-7. This is due to the need for a lesser number of canisters and for a shorter period of repository operation.

The resulting adjusted costs are reduced from the reference case by approximately 1% for 200 GWe and 6% for 105 GWe. Table 7-2 presents the disposal and consumer costs for these two cases. A 200 GWe capacity results in a disposal cost of $737 per KgU and a consumer cost of 3.8 mills per Kw-hr, while a 105 GWe capacity produces $904 per KgU and 4.7 mills per Kw-hr.

7.3 FINANCIAL FACTORS

The impact of changes to the assumed financial factors of cost increase, discount rate, and interest compensation rate were found to be of highest significance in the sensitivity calculations. These factors are discussed in detail in

Appendix D, Financial and Forecast Methodology. For the reference case, 7% was used for the cost increase rate, 4% for the discount rate, and 6% for the interest compensation rate.

For the sensitivity analysis, the interest compensation rate was assumed to remain constant at 6%. Analysis of available long-term data was examined (see Appendix D, pages D-14 through 22). Cost increase rates were considered to range from a low of 5.5% to a high of 8.0% and discount rates varied between 2.6% and 5.6%. To simplify the analytical process, two cases were calculated. One case uses high escalation rate and low discount rate, the other assumes low escalation and high discount.

The appropriate rates were applied to the reference case task costs. The resulting costs are shown in the last two columns of Table 7-1. Total program costs range from a high financial case cost of $68,666 million to a low of $21,423 million. This represents an increase of 73% or a decrease of 46% respectively when compared to adjusted reference case costs.

The resulting program disposal and consumer costs are shown in Table 7-2. Disposal cost ranges from $1129 to $352 per KgU and consumer cost runs from 4.9 to 1.8 mills per Kw-hr.

TABLE 7-1

ADJUSTED COSTS FOR SENSITIVITY ANALYSIS CASES

TASK		Reference Case Time Adjusted $ in Millions	100 % AFR Case Time Adjusted $ in Millions	Low Nuclear Capacity Cases - $ in Millions 200 GWe	105 GWe	Financial Factor Variations - $ in Millions High Escal. Low Discount	Low Escal High Disc.
I-1	Regulatory	968	NC	NC	NC	2228	422
-2	AFR R&D	164	NC	NC	NC	202	133
-3	Repository R&D	2622	NC	NC	NC	3292	2110
-4	Alternative R&D	1505	NC	NC	1004	2605	870
II-1	NEPA/Site	2023	2727	NC	NC	2968	1331
-2	Licensing	1615	2429	NC	NC	3252	842
-3	AFR Construction	2941	11764	NC	NC	3720	2219
-4	AFR Operation	1307	5228	NC	NC	2057	778
-5	Repos. Const.	10092	8141	9802	8582	14663	6304
-6	Transportation	1173	4584	NC	NC	2011	614
-7	Repos. Operation	1893	2066	1701	1419	3173	924
-8	Repos. Monitoring	1295	NC	NC	NC	3319	423
-9	Retrieval	3639	NC	NC	NC	7597	1514
-10	Alternate Const.	3748	NC	NC	NC	7405	1625
-11	Alternate Transp.	2537	NC	NC	NC	4969	743
-12	Alternate Oper.	1010	NC	NC	NC	2363	324
-13	Alternate Monit.	469	NC	NC	NC	1316	114
-14	Decommissioning	530	1354	NC	NC	1526	133
	TOTAL:	39531	56250	39049	37046	68666	21423

"NC" = No change from reference case.

TABLE 7-2

SENSITIVITY ANALYSIS RESULTS

CASE	Program Cost in Millions of 1978 Present Worth $	Disposal Cost in $ per KgU	Consumer Cost in Mills per Kw-hr
Reference	39531	650	3.4
100% AFR	56250	925	4.8
200 GWe Nuclear Capacity (53,000 MTU in 1995)	39049	737	3.8
105 GWe Nuclear Capacity (41,000 MTU in 1995)	37046	904	4.7
High Financial Factors (8% Cost Increase 2.6% Discount Rate 6% Interest Compensation Rate)	68666	1129	5.9
Low Financial Factors (5.5% Cost Increase 5.6% Discount Rate 6.0% Interest Compensation Rate)	21423	352	1.8

SECTION 8

CONCLUSIONS & RECOMMENDATIONS

The primary purpose of this study was to determine, as accurately as possible, the full costs of the most likely course that the disposition of commercial spent fuel produced by 1995 might take. Literally thousands of scenarios could be considered, involving many technical and management disciplines, as well as thousands of business and governmental entities. Each such iteration could be evaluated for numerous impacts such as affect on corporate profitability, nuclear market penetration, creation of jobs, etc., etc. . The two major goals of this study, however, were to determine:

(1) What is the FULL COST of the proposed "Spent Fuel Offer"?

(2) What is the impact of that cost on the cost of electricity delivered to the user?

The following conclusions and recommendations have been developed as a result of this study effort. They have been limited primarily to issues relating to program and costs. Additional safety and environmental issues could be addressed as the spent fuel program continues.

8.1 SPECIFIC CONCLUSIONS

The study resulted in significant conclusions in the following major categories:

8.1.1 COSTS

The results of the cost analysis of the proposed spent fuel program indicated that the total cost will likely be substantially greater than has been previously estimated by DOE. We estimate that the unescalated reference case cost will exceed thirteen billion 1978 dollars. When adjusted for factors of escalation and monetary risk, this total becomes a commitment of approximately forty billion dollars for disposal of the U.S. spent fuel produced between now and the end of the century. This translates to a consumer cost of approximately 3.4 mills per kilowatt-hour. This is equal to approximately ten percent of the current average cost of electricity and should be reflected in rates for electricity generated by nuclear facilities.

The uncertainty band on these results is high. The reference case cost could be low or high by a factor of two to three or more. The largest single factor impacting the high/low cases is the need, or lack of need, to relocate or otherwise reprocess any or all of the fuel after it is emplaced in the repository. Specific numeric results are:

TABLE 8-1

RESULTS

CASE	Program Cost in Millions of 1978 Present Worth $	Disposal Cost in $ per Kg Uranium	Consumer Cost in Mills per Kw Hour
High	93790	1542	8.0
Reference	39531	650	3.4
Low	14025	231	1.2

These costs are the best estimates of the 1978 financial commitment for the proposed disposal of the spent fuel. They do not include quantification of possible environmental or biological (human health) damages.

The cost analysis results were also evaluated for sensitivity to the variation of parameters other than the need to relocate or reprocess. The factors selected for quantification were increased AFR storage requirements, reduced installed nuclear generating capacity, and variation of cost increase and discount rate factors. Results of the sensitivity analysis are:

TABLE 8-2

SENSITIVITY

CASE	Adjusted Program Cost Millions	Disposal Cost $ per Kg Uranium	Consumer Cost Mills per Kw-hr
Reference	39531	650	3.4
100% AFR	56250	925	4.8
200 GWe	39049	737	3.8
105 GWe	37046	904	4.7
High Financial	68666	1129	5.9
Low Financial	21423	352	1.8

This analysis shows that the spent fuel program cost results are least sensitive to nuclear capacity and most sensitive to variations in financial factors and cost increase.

8.1.2 UTILITY FINANCING

Evaluation of the proposed method of financing the disposal program reveals potential problems. The "voluntary" participation feature will delay commitment for capacity and cause increased costs due to cash flow demands. The difficulty of long-term forecasting of escalation and discount rates compounds these effects. Delay of commitment and payment will increase the burden to be carried by future ratepayers on behalf of today's beneficiaries. A calculation performed on the current eight year delay anticipated before start of actual fuel disposal increases the future ratepayer cost by a factor of two and one-half. These potential problems and inequities require alternative methods of financing be developed.

8.1.3 UNCERTAINTIES

Numerous uncertainty classifications have been identified:

- Past Performance: The record of performance of the last thirty years gives good reason to be concerned that successful management of the spent fuel disposal program will not be achieved. One has only to look at the handling of high level waste at Hanford and Savannah River, the salt deposit work at Lyons, Kansas, fuel reprocessing fiascoes at West Valley, Morris, and Barnwell, and the SURF, WIPP, and other well-intentioned but equally unsuccessful programs to arrive at this conclusion. The possibility exists that the difficulty of successful waste management may be so great that a high degree of containment may not be attainable, at least not to the degree of certainty that seems to be required. At best it will be extremely expensive; at worst, it could be an environmental disaster.

- Program Delays: The complexity of the problem and of the decision-making process almost guarantees that substantial program delays must be expected. For example, during the six-month period in which this study was performed, schedule slippages of three years or more have been announced by the Department of Energy in the expected operational date of the Waste Isolation Pilot Plant in New Mexico. More delays are inevitable and it may well be the next century before any high-level waste is really emplaced in a "permanent" repository.

- Technical: The technology of high-level waste disposal has in the past been described by nuclear proponents as "available or under development." It is extremely disconcerting to see recently an increasing number of unresolved concerns being expressed by the technical community. The recent issuance of the U.S.G.S. Report [1] describing extensive geologic uncertainty, the June 9th Science magazine article,[2] expanding upon these uncertainties and discussing other studies confirming them, and the ongoing debate about the apparent hamful effect of low-level radiation are examples of technical problems that must be resolved before a permanent program can be implemented. Resolution of these problems requires extensive amounts of time and money.

- Institutional: A continuing concern over-shadowing this program remains in the question of unresolved institutional responsibility. It is clear that the Department of Energy is responsible for implementation of the spent fuel program. It is not clear, however, as to the nature of the interface between that agency and the Environmental Protection Agency, the Nuclear Regulatory Commission, and last, but certainly not least, international agencies, such as the IAEA. The ongoing discussions about continuation of the breeder reactor program, and the control of weapons proliferation elevate these questions into the international politics arena wherein decisions require decades rather than years to achieve. At a more mundane level, the institutional problem of past licensing of away-from reactor fuel storage facilities without benefit of licensing regulations should not be tolerated in the future.

4 PROGRAM DIRECTION

The cost analyses indicate that major costs are incurred . it becomes necessary to correct that which has been done ıg. A mistake will be three or four times as expensive as ıg it right in the first place. Because of the magnitude of :s potentially involved in this program, and because of the ınse environmental and health damage that could occur, it is ɔlutely essential that a sound program be developed and ɥuate technical verification work be performed.

> It does not appear that such a program properly subjected to peer and public review is now available.

:ional waste management goals have not been developed, environ-ıtal standards are incomplete, and regulations for licensing ːnt fuel disposal facilities are not yet in existence.

! RECOMMENDATIONS

Recommendations developed as a result of this study are follows:

!.1 COSTS

- Establish an adequate fee, including a realistic contingency, for the fuel disposed. Include all current

R&D costs, and allocate the costs to a conservative quantity of fuel to be disposed.

- Ensure adequate funding and schedule time to complete necessary spent fuel disposal R&D efforts, so as to avoid expensive future retrieval programs.
- Charge the full estimated cost of the disposal program to the current beneficiaries of the power produced.
- Avoid government subsidy of the program through under-assessment of the cost.
- Make no new facility commitments until an approved comprehensive plan has been developed.
- Minimize or avoid the establishment of AFRs, if at all possible.

8.2.2 UTILITY FINANCING

Make utility participation in the spent fuel program mandatory and fair. Collect advance payment for utility participation and develop methods for distributing the costs to the users. A suggested method is as follows:

- Advanced purchase of nuclear fuel disposal capacity would be required of any users of the facility.
- A single one-time payment would be made in an amount computed using a method similar to that used in this report. The single amount would be computed on a project-by-project basis.

- All payments made in advance for capacity would be placed in a segregated fund separate from all other government funds and managed by a board of directors composed of government, industry and public members. All earnings on the funds would be retained for maintenance or operation of the disposal facility.
- Utilities making deposits in the facility would capitalize the amounts of the cash deposits, and the amounts of cash deposits would be included in the utility's rate base for the computation of rate of return on investment. The amount of cash deposits would be amortized over the remaining life of the nuclear fuel to which the deposit relates.
- The one-time purchase fee should be computed based upon anticipated costs of a specific facility. A method similar to that used in this report should be employed except that no interest compensation to the U.S. Government for the use of government funds will be required.

8.2.3 UNCERTAINTIES

Develop realistic programs to deal with the many potential problems now identified. Specifically:

- Thoroughly analyze causes of project content, schedule, and cost difficulties on all past waste programs. Review these analyses for applicability to the spent fuel disposal program.

- Develop realistic schedules for site reviews and construction of facilities. Avoid site selection for reasons of convenience only. Do cost/benefit analyses based also on retrieval cost impact.

- Institute necessary technical R&D programs to resolve fuel cladding corrosion questions, canister design criteria, geologic evaluation techniques, hydrology modeling, and monitoring method uncertainties. Supplement these programs with aggressive development of back-up alternatives.

- Expedite resolution of agency interface questions and the establishment of necessary standards and regulations.

8.2.4 PROGRAM DIRECTION

- Develop clear and concise overriding goals for the nuclear waste management program. They should be subjected to peer and public review, and be promulgated well in advance of any irretrievable action in the waste disposal program. This particularly applies to spent fuel handled as high level waste.
- Complete the development of environmental standards and of spent fuel and waste facility licensing regulations.
- Require full and complete adherence to NEPA requirements in the evaluation and review of <u>all</u> spent fuel storage and disposal facilities.

- Perform additional assessment and studies of long term environmental and health effects of the spent fuel disposal program to ensure that decisions are not primarily based on solution to the short term problem.
- Develop an effective program of public participation in the decision-making process.

8.3 GENERAL

During the conduct of this study it has become more and more evident that the source of error in past waste program management decisions has been the inability to effectively deal with the complexity, the vast number of subtle interactions of the different parts of the total waste disposal issue. Complexity appears in the form of unanswered questions ranging from adequacy of funding for resolution of technical problems, to governmental agency jurisdictional disputes, to how best to cooperate with foreign entities. No one person or agency has been able to answer these questions because of a lack of a framework, a standard, against which to measure the adequacy of the proposed solutions. How safe, how long, how deep, which generation pays, what is acceptable, etc., cannot be answered without an agreed upon statement of goal. Thus, the overriding conclusion of this study is that a well thought out definition of national (and perhaps international) waste management goals should be generated, reviewed with peers and public, and used to guide future direction. Thirty years of reacting to the perceived location of the fire should be enough to encourage some fire prevention. The issuance at last of a proposed set of national waste management goals,[3] albeit it draft and disclaimed, is an optimistic sign that we are really about to address the problem.

SECTION 8

REFERENCES

1. USGS 779, "Geologic Disposal of High-Level Radioactive Wastes - Earth Science Prospectives," J.D. Bredehoeft, et al., Geological Survey, Circular 779, 1978.

2. "Nuclear Wastes: The Science of Geologic Disposal Seen as Weak," Science, Volume 200, June 9, 1978, pages 1135-1137.

3. NUREG-0300, "Proposed Goals for Radioactive Waste Management," May 1978. Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission.