CONF-831217--8

DE84 005287

THE ECONOMICS OF MINED GEOLOGIC REPOSITORIES

P. L. Hofmann and D. G. Dippold
Battelle Project Management Division
Battelle Memorial Institute

1.0 INTRODUCTION

During 1982, Congress considered legislation to provide for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel. The result of this legislative effort was the "Nuclear Waste Policy Act of 1982" (NWPA), PL 97-425, signed into law January 7, 1983.

An important part of the NWPA was the establishment of special funds in the U.S. Treasury for Waste Disposal and Interim Storage to be financed by user fees to pay for all costs of the program. An initial fee of 1.0 mill per kilowatt-hour was specified. The Secretary was asked to ". . . annually review the amount of the fees established . . . to evaluate whether collection of the fee will provide sufficient revenues to offset the costs. . .". In the event of a prospective fee-cost mismatch, the Secretary was asked to ". . . propose an adjustment to the fee to insure full cost recovery."

A series of studies were sponsored by DOE in 1982 to estimate program costs, to calculate the necessary fees to assure cost recovery, and to address uncertainties that could affect future program costs and consequent fee schedules.

Most of the cost estimates for the repository-waste package complex, construction, operation, and decommissioning, as well as R&D cost estimates, were prepared by the "Office of NWTS Integration" (ONI) operated by the Battelle Project Management Division (BPMD). A summary of these cost estimates was published by Waddell, et al. (1982).[1]

These cost estimates were interpreted and augmented by PNL and then translated into a fee schedule. The PNL work is documented in a report by Engle and White (1983).[2]

In the following paragraphs, a brief summary of the 1982 cost estimates is presented. Sources of key cost uncertainties are discussed and the bases for the cost recovery fee calculations are summarized.

2.0 SUMMARY OF 1982 REPOSITORY/WASTE PACKAGE COST ESTIMATES

2.1 Key Assumptions and Ground Rules

Cost estimates were to be prepared for four host rocks (domed salt, bedded salt, tuff, and granite) and two waste forms [spent fuel (SF), and reprocessing waste (CHLW)]. The repository capacity was fixed at 72000 MTU and the peak waste receipt rate was stipulated to be 3000 MTU/year. The first repository was assumed to be operational by 1998, followed by a second repository in 2002. The waste package designs were patterned after the "long-lived" package configuration developed by Westinghouse (1983)[3,4], without making any special provisions for "hole liners" or "tailored backfill". Waste packaging was assumed to be carried out at the repository and waste packages were to be emplaced in suitable, vertical boreholes. For the case of the commercial high-level waste repository, transuranic waste was to be packaged in "thin-walled" packages and emplaced in a "commingled" fashion with the CHLW packages. Even though the waste package designs made provisions for retrieval, retrieval costs, per se, were not included in the cost estimates.

2.2 Cost Estimating Procedures

In order to avoid missing or double-counting of costs, a "Cost-Matrix" was prepared. The matrix covered all systems and activities relevant to waste isolation. Two major systems were specified, "Waste Packaging" and "Repository". These major systems were subdivided, in turn, and for each subsystem category, capital, operations, and decommissioning costs were estimated. A simplified "Cost-Matrix" chart indicating the key cost elements is shown in Fig. 1. The costs for each element in the matrix were estimated by scaling and extrapolating previously available conceptual design estimates. Since the then current waste preparation and repository systems designs were generally not consistent with each other, several adjustments had to be made. The repository costs were based on the conceptual designs for salt, NWTS R1 (Stearns-Roger, 1979)[5] and NWTS R2 (Kaiser Engineers, 1978)[6], as well as cost data from the Conceptual Reference Repository Description (CRRD) (Bechtel Group, Inc., 1981)[7], the final environmental impact statement designs (U. S. Department of Energy, 1980)[8], the International Fuel Cycle Evaluation (INFCE) designs (INFCE Working Group 7, 1980)[9], and on preliminary work carried out at PNL by Clark, et al. (1982)[10]. The waste packaging facility costs were based on designs and estimates by Kaiser Engineers (1978)[11]. The NWTS Program Site Exploration and Development costs were estimated separately.

MASTER

Activities / Systems	CAPITAL CONSTRUCTION	OPERATIONS	DECOMMISSIONING	TOTAL
WASTE PACKAGING				
WASTE PACKAGE COMPONENTS				
WASTE PACKAGE ASSEMBLY				
REPOSITORY				
SITE				
WASTE HANDLING AND EMPLACEMENT				
UNDERGROUND WORKINGS/ROCK HANDLING				
VENTILATION				
SUPPORT AND UTILITIES				
TOTAL				

Fig. 1 Key Cost Elements

The estimates do not include costs associated with waste vitrification. TRU treatment costs are similarly excluded.

2.3 Summary of Cost Estimates

As noted, the cost estimates were prepared for two types of repositories, a spent nuclear fuel and a commercial high-level waste repository. The SF package contains 2.96 MTU of close-packed fuel pins and the CHLW contains an equivalent 2.28 MTU of vitrified waste. The package inventory for the two repository types is summarized in Table 1.

Table 1 Number of Waste Packages for A 72000 MTU Repository

Type of Packages	# of Packages (Thousands)
Reprocessing Waste Repository	
HLW Glass Packages	31.6
Cladding/Remote Handled TRU Packages	66.0
Contact Handled TRU Packages	374.4
Spent Fuel Repository	
Disassembled Spent Fuel Packages	24.3
End Fittings Packages	5.0

In Table 2, the total cost estimate for both types of repositories and four host rocks are summarized. The costs are given in billions of '82 $'s. As can be seen, the costs for a 72000 MTU repository and its associated waste packages are in the neighborhood of 5 to 6 billion dollars, with about 25% to 30% of the total costs allocated to waste preparation.

Table 2 Summary-Reference Disposal Cost Estimates (Billions of '82 $'s)

Spent Fuel	Waste Preparation	Repository	Total
Domed Salt	1.6	3.7	5.2
Bedded Salt	1.6	3.8	5.4
Tuff	1.6	4.0	5.6
Granite	1.6	4.2	5.8
Reprocessing Waste			
Domed Salt	1.3	3.5	4.9
Bedded Salt	1.3	3.6	5.0
Tuff	1.3	4.0	5.4
Granite	1.3	4.1	5.5

There are many other ways in which the total costs can be categorized. Another possible cost categorization for the SF, bedded salt repository leads to the cost breakdown shown in Table 3.

NWTS program exploration and development costs were estimated for the 1982 to 1996 time span. In addition, costs incurred prior to 1982 were determined and adjusted to 82 $'s. A summary of these costs is shown in Table 4.

The costs listed in Table 4 generally cover identification and characterization of several sites and the costs associated with the development and demonstration of the technology to construct and operate repositories.

Table 3 SF, Bedded Salt Repository Cost Breakdown

	% of Total Costs
Site and Site Improvements	24
Waste Packaging and Receiving	38
Waste Shafts and Hoists	6
Ventilation and Flow Paths	11
Waste Transfer, Emplacement and Underground Workings	21
Total	100

Table 4 Exploration and Development Costs (Billions of '82 $'s)

Site Identification	.3
Site Characterization	.7
Site Approval and Construction Authorization	.2
T & E Facility	.2
Technology Development	1.5
Related Programs (Related R/D, Impact Mitigation, Fund Management)	1.2
Projected Costs, 1982 and Beyond	4.1
Adjusted Costs, Prior to 1982	.7
Total Costs	4.8

In reviewing the above cost items, one concludes that total program costs are of the order of $20 billion, i.e., two repositories and associated waste packages at ∿ $11 billion, exploration and development costs at ∿ $5 billion, and estimated transportation and other costs at ∿ $4 billion. The accommodated waste corresponds to the generation of about 30 x 10^{12} kwh. Hence, without discounting costs, a simple average cost of disposal is therefore ∿ 2/3 mills/kwh.

3.0 COST UNCERTAINTIES

The cost estimates summarized in the previous sections are subject to large uncertainties. Sources of key cost uncertainties are noted in Table 5, below.

Table 5 Sources of Key Cost Uncertainties

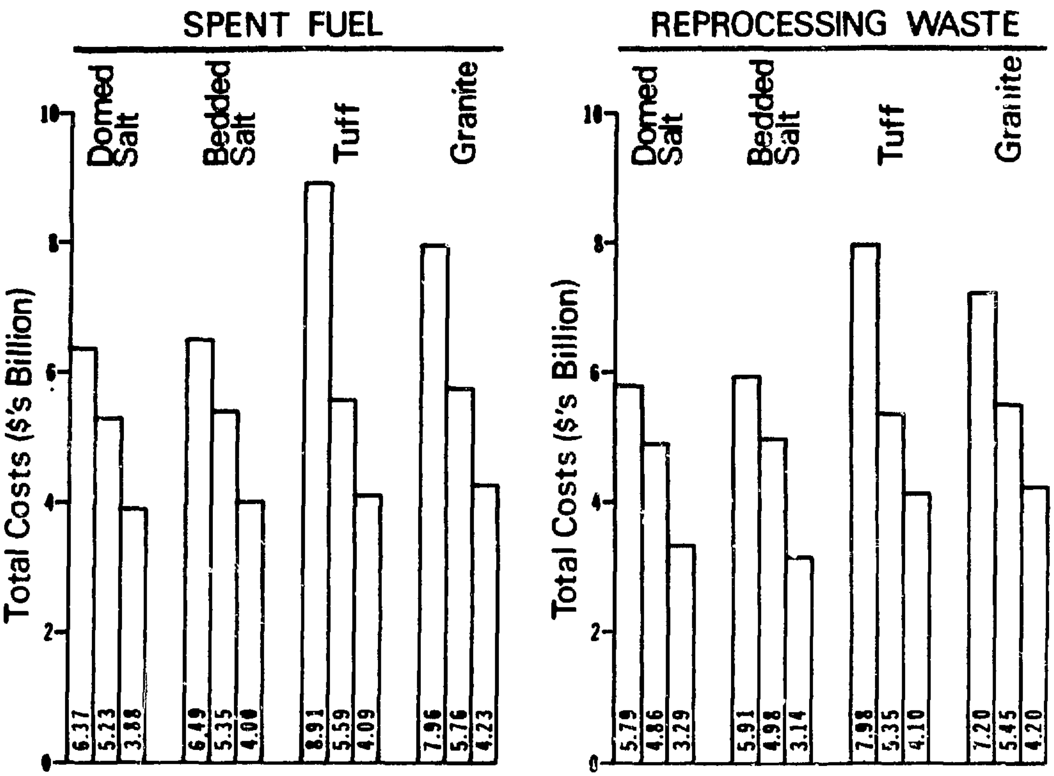
- Uncertainties in Cost Estimating; primarily uncertainties in mining costs and waste packaging costs.
- Uncertainties in Design; primarily uncertainties in package design details, use of overpacks, package emplacement densities.
- Uncertainties in Future Regulations; cost impacts resulting from variations in design limits and specifications.
- Uncertainties in Future Price Trends; i.e., real price trend uncertainties exclusive of general inflation projections.
- Uncertainties in Future Program Definitions; i.e., the accommodation of other waste forms, TRU, Defense Wastes, and other special wastes; interim waste storage and precooling strategies.

Initially, as part of the ONI work supporting the fee calculations, the first two sources of uncertainty, cost estimating and design uncertainties, were explored and a series of sensitivity calculations were performed (Waddell, et al, 1982)[1]. These calculations involved high and low waste preparation costs, variations in TRU emplacement schemes, and variations in waste package designs.

The results of this evaluation are portrayed in Fig. 2 for the four host-rocks and the two repository types under consideration. The biggest uncertainty range was calculated for the SF repository in Tuff. The range extended from ∿ $4.1 to $8.9 billion bracketing the $5.6 billion reference value.

Subsequent to the publication of ONI-3 (Waddell, et al., 1982)[1] and PNL-4513 (Engle and White, 1983)[2], work has been continued at BPMD to further explore the sources of uncertainties listed in Table 5 via a series of systems and sensitivity analyses. For example, costs were estimated over a range of waste package and repository designs, all subject to the same specific design limits (Dippold, et al., 1983)[12]. In these calculations, the entire waste disposal system, including transportation and vitrification costs - if reprocessing is included in the scenario - was analyzed for a range of designs. The resulting total cost curves have a characteristic U-shape so that the minimum system cost and its associated design can be ascertained. From these same curves it is also possible to deduce cost variations and hence cost ranges as design parameters are varied.

This system approach to cost analysis has also been applied in a variety of other cases. Near-field temperature limits, specifically the allowable peak waste centerline temperature and the near-field host rock maximum temperature, affect the waste package-repository design layout. For salt repositories accommodating glass waste, the current peak centerline temperature is specified at 500°C and the maximum salt temperature adjacent to the waste package is pegged at 250°C. If these limits were tightened, packages would have to be made smaller in diameter, leading to more packages and/or packages spaced further apart. The net result of these design changes would be increases in cost. A systems analysis of these shifts in thermal limits has indicated increases in costs ranging upwards to billions of dollars depending on the magnitude of the change in the design limits (Dippold and McSweeney, 1983)[13].



NOTE: Cost ranges have been estimated assuming that incremental costs are additive.

Fig. 2 Repository Cost Ranges

The total costs associated with waste packages of various lengths and loadings have also been explored via the systems approach (Yates and Varadarajan, 1983)[14]. It was found that relatively longer and larger (in terms of diameter) waste package designs led to a significantly lower total systems cost.

Another system analysis has indicated a potential economic incentive for TRU volume reduction. Depending upon the assumptions, this incentive can range up to as much as $1 billion in 1982 $, (Yates and Varadarajan, 1983)[15].

Waste pre-cooling ("aging") has been explored via the systems approach by (Dippold and Hofmann, 1983)[16] and (Becker and Varadarajan, 1983)[17]. The analyses have shown that delaying permanent disposal for relatively long periods of time can lead to relatively large savings. On the other hand, delaying permanent disposal for relatively short periods of time was found to be of questionable economic value.

Another important and generally unpredictable variable is future real price trends for construction and operation of facilities and for fabrication and material costs of the subcomponents of the disposal system. Such changes in specific price trends can of course occur even in periods where there is no general inflation. The only way of even crudely assessing the potential cost changes arising from this effect is by examining past price trends and making some future projections. Although results have not yet been formally reported, preliminary investigations indicate that these real price trends can have significant effects on total waste disposal costs.

Finally, future program realignments and their potential effect on disposal costs are completely unpredictable. Postulating different scenarios and assessing their potential cost impacts may be of some utility in forecasting cost variations due to such program changes.

4.0 WASTE DISPOSAL FEES

The determination of disposal fees for a variety of scenarios was carried out by PNL and is reported by Engle and White (1983)[2].

The disposal fee is based on full recovery of disposal program costs by DOE. The fee is arrived at by equating discounted costs to discounted revenues. Cost data are based on constant, uninflated 1982 $'s and a 2% real, uninflated discount rate is used in the present value calculations.

For purposes of specifying costs, upper bound values were used by PNL. Thus, in each case, "high" waste preparation costs, "high" mining costs, and "high" transportation costs were postulated. The total upper bound costs for two repositories and associated waste packages, transportation, and research and development were estimated to be ∿ $28 billion. This compares with the ∿ $20 billion "reference" costs mentioned previously. The fee that would generate the required revenue to cover these costs was calculated to be .85 mills/kwh. The initially mandated 1 mill/kwh fee thus appears to provide sufficient revenues to meet program costs for the range of conditions considered. However, since potential cost uncertainties are large and basically unpredictable, the fee may have to be adjusted in the future. The law provides for such adjustments.

REFERENCES

1. Waddell, J. D., D. G. Dippold, and T. I. McSweeney, 1982. Projected Costs for Mined Geologic Repositories for Disposal of Commercial Nuclear Wastes. ONI-3, Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

2. Engel, R. L. and M. K. White, 1982. Fiscal Implications of a 1-Mill/kWh Waste Management Fee. PNL-4513, Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Washington.

3. Westinghouse Electric Corporation, 1983. Engineered Waste Package Conceptual Design: Defense High-Level Waste (Form 1), Commercial High-Level Waste (Form 1), and Spent Fuel (Form 2) Disposal in Salt. ONWI-438, prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

4. Westinghouse Electric Corporation, 1983. Conceptual Waste Package Designs for Disposal of Nuclear Waste in Tuff. ONWI-439, prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

5. Stearns-Roger Engineering Company, 1979. National Waste Terminal Storage Repository for Storing Reprocessing Wastes in a Dome Salt Formation, Denver, Colorado.

6. Kaiser Engineers, 1978. Conceptual Design Report for a National Waste Terminal Storage Repository in a Bedded Salt Formation for Spent Unreprocessed Fuel, KE Report No. 78-57-RE, Oakland, California.

7. Bechtel Group, Inc., 1981. NWTS Conceptual Reference Repository Description (CRRD), Vols. I-V, ONWI-258, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

8. U.S. Department of Energy, 1980. Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste, DOE/EIS-0046F, Washington, D.C.

9. INFCE Working Group 7, 1980. Waste Management and Disposal, Report of the International Nuclear Fuel Cycle Evaluation (INFCE) Working Group 7, International Atomic Energy Agency, Vienna, Austria.

10. Clark, L. L. and B. M. Cole, 1982. An Analysis of the Cost of Mined Geologic Repositories in Alternative Media, PNL-3949, Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Washington.

11. Kaiser Engineers and Rockwell Hanford Operations, 1978. Spent Fuel Receiving and Packaging Facility Conceptual Design Report, RHO-CD-506, Richland, Washington.

12. Dippold, D. G., B. E. Urbschat, and Spyridon Tzemos, 1983. WADCOM: A Waste Disposal Cost Model. ONI-6, Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

13. Dippold, D. G. and T. I. McSweeney, 1983. Costs of Accommodating Large Changes in Repository Thermal Design Limits, presented at American Nuclear Society 1983 Winter Meeting, Battelle Memorial Institute, Columbus, Ohio.

14. Yates, K. R. and R. V. Varadarajan, 1983. The Impact of Commercial High-Level Waste Package Length on Disposal System Costs, presented at American Nuclear Society 1983 Winter Meeting, Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

15. Yates, K. R. and R. V. Varadarajan, 1983. TRU Waste Impact on Disposal Costs: Incentives for Volume Reduction, presented at American Nuclear Society 1983 Winter Meeting, Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

16. Dippold, D. G. and P. L. Hofmann, 1983. Nuclear Waste Disposal Economics: Modelling the Incentives for Waste Aging, published in the Proceedings of the IASTED International Symposium: ASM '83-APPLIED SIMULATION AND MODELLING. Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

17. Becker, Martin and R. V. Varadarajan, 1983. A Semianalytical Formulation of the Waste Aging Problem, presented at American Nuclear Society 1983 Winter Meeting, Battelle Project Management Division, Battelle Memorial Institute, Columbus, Ohio.

DISCLAIMER