SENSITIVITY STUDIES OF LLW PACKAGING, TRANSPORTATION, AND DISPOSAL COSTS

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ABSTRACT

Several economic factors should be considered in evaluating waste management alternatives. The total life cycle disposal costs for low-level waste and the economic tradeoffs among waste volume, transportation and disposal are examined herein. The present work utilizes the basic facility unit cost data for disposing of low-level waste in a new commercial facility as given by the Nuclear Regulatory Commission. Additional cost data for transportation, volume reduction and packaging have been included. The total facility life cycle costs are estimated to be $75 million, with preoperating costs comprising nine percent, direct operating costs equaling 74 percent and postoperating care fund costs comprising six percent of the total. The remaining 11 percent is for income taxes and return-on-investment. Expressed on a per-unit volume basis, the disposal costs are $7.60/ft^3. A major fraction of the disposal cost is independent of site capacity; therefore, when the disposal costs are expressed on a unit waste volume basis, the cost per cubic foot is significantly larger for smaller sites than for large ones. Key parameters that influence the total cost of disposal are also varied to determine the sensitivity of the cost estimate for the base case to the variations. The key parameters: the degree of volume reduction, the number of disposal sites, and the number of years of site operation. The results of these sensitivity studies is presented.

INTRODUCTION

Safety is the primary objective in the packaging, transportation and disposal of commercial low-level radioactive waste (LLW). However, economic factors play an important role in formulating a desirable waste management and disposal strategy. There are several factors that must be considered when evaluating waste management alternatives. These factors influence LLW management storage and disposal costs in different ways when considered on an industry-wide basis with new disposal facilities. For example, the escalating transportation and disposal costs for LLW are prompting a serious consideration of waste volume reduction so that impacts from these rising costs may be minimized. The total life cycle disposal costs for LLW and the economic tradeoffs among waste volume, transportation and disposal, discussed herein, are part of an Electric Power Research Institute project examining the risks and costs for site selection and operation of disposal facilities for LLW.(1)

The key design and costing parameters for a reference commercial LLW facility are first given, followed by LLW packaging and transportation cost functions. Costs for various amounts of volume reduction are included in this analysis. From these components the total waste packaging, transportation and disposal costs are formulated. Also presented are the variation of these total costs with variations in the degree of volume reduction, the associated transportation cost variations and in the disposal facility capacity.

REFERENCE DISPOSAL FACILITY COSTS

The present work utilizes the basic facility unit cost data for disposing of low-level waste in a commercial facility as presented in the NRC Draft Environmental Impact Statement (EIS)(2) prepared in support of 10CFR61.(3) Additional cost data for transportation, volume reduction and packaging have been included. The analyses differ from Reference 2 in two important aspects: All interest rates and returns on investments are expressed as real rates--that is, actual rates minus inflation. This treatment of money rates is used to calculate disposal costs in constant dollars. Also, the cost of financing capital expenditures is calculated directly rather than through the use of cost multipliers.

Activities necessary to prepare the disposal site are assumed to occur for a few years (nominally 3 years) before disposal operations begin. The operating period, during which waste is accepted and placed in the ground, is nominally 20 years. The postoperating period extends to one hundred years following operations. There is income only during the operations period. Both preoperating and postoperating activities are paid for using monies acquired during the operating period from charges for waste disposal. The fees to pay for all activities (preoperating, operating and postoperating) are assumed to be collected uniformly over the operating period.

The facility is assumed to be entirely financed by equity investment. It may be possible to raise some capital through commercial loans but the amount of collateral that could be used to help secure those loans would allow a maximum of about 30 percent of the necessary funds to be raised by borrowing using secured loans. Furthermore, an analysis of various combinations of equity financing and borrowing showed little sensitivity of disposal costs to changes in the mixture of the two ways of obtaining capital. This is due to the fact that low-level waste disposal facilities are not very capital intensive.

All calculations are based on constant 1980 dollars.

Table I. Base Case Parameters and Cost Assumptions.

Parameter	Value
Waste	14,000 m^3/yr
Preoperating Period	3 yr
Operating Period	20 yr
Post Operating Period	
Closure	3 yr
Institutional Care	97 yr
Corporate Income Tax Rate	44 percent
Local Tax and Insurance Rate	2 percent
Real Rate of Return to Investors	5 percent
Land Cost	$2400/acre
Land Area	171 acres
Real Interest on Postoperating Sinking Fund	2 percent

Assumptions

Table I gives a list of parameters for the base case disposal facility. The facility will receive and dispose of 14,000 m^3 (493,000 ft^3) of low-level waste each year during the operating period. It is assumed that 88 percent of waste is Class A and is placed in standard shallow land burial trenches. The remaining 12 percent of the waste is Classes B, C, and D and will be disposed in improved trenches with at least 5 m of cover.

The postoperating period level of effort is the medium level described in Reference 2. All other costs are those given in Reference 2 adjusted to account for different facility capacities (total volumes of waste disposed) in the following manner:

- Preoperating period costs other than those for land purchase are assumed to vary as the cube root of the total volume to be placed in a disposal site.
- The amount of land needed is 0.4 m^2 per cubic meter of waste to be disposed, plus a 100-meter buffer zone. A square disposal area is assumed.
- Operating costs other than those for trench materials and payroll vary as the cube root of the site capacity.
- Trench material cost and payroll vary directly with the total volume of the waste to be disposed at a site, with a minimum annual payroll of $93,000 per site.
- Postoperating costs vary as the cube root of the site capacity.

The use of the above adjustments to site costs is in good agreement with previous work,[2,4] in particular the cube root scaling role is consistent with sanitary landfill cost estimating techniques.[4]

Table II. Total Facility Life Cycle Costs (millions).

Item	1980 Dollars	Percent of Total Cost
Direct Operating Costs	$55.0	73.6
Amortization and Depreciation of Pre-Operating Costs	6.7	9.0
Payments for Post-Operating Care	4.2	5.6
Return to Investors (Dividends)	4.9	6.6
Income Taxes	3.9	5.2
TOTAL	$ 74.7	100.0

Disposal Site Costs

Table II is a summary of the calculated estimates of disposal costs and expenditures for the base case. Costs are grouped into five categories. The first three of these are: direct operating costs, preoperating costs and postoperating fund payments.

The amount of amortization and depreciation of preoperating costs can not be paid as dividends during the life of the corporation without being subject to corporate income taxes. It is accumulated in equal annual increments and then paid to the investors when the corporation is liquidated at the end of the operating period. The accumulated fund is assumed to earn interest at 5 percent before income taxes. Therefore the money paid to the investors at the end of the corporate life is greater than their initial investment.

Two additional financial items must be considered before the total facility life cycle costs can be determined. The first is the investor's return on investment paid in the form of dividends. The annual dividends that are paid, at a constant rate in constant dollars over the 20-year operating period, are calculated in the following manner.

- Five percent per annum return on the initial capital, plus
- A constant annual dividend sufficient to return the deferred dividends from the preoperating period plus interest on the unpaid portion of those deferred dividends at 5 percent per annum, minus
- The constant annual payment that, if accumulated over 20 years at 5 percent annual interest rate, would yield the difference between the money accumulated from amortization and depreciation and the initial capital provided by the investors.

The total dividends paid from the fees collected for waste disposal equal $4.9 million.

The other item, corporate income taxes, is 44

percent of gross profit. This is close to the national average corporate income tax paid to state and federal governments over the last 20 years.[5] The gross profit must be large enough so that the after-tax profit equals the dividends to be paid from the fees collected. A gross profit of $8.8 million yields $3.9 million in corporate income taxes and the required $4.9 million in dividends.

The total facility life cycle costs, also listed in Table II, are equal to the sum of the direct operating costs, the amortization and depreciation of the preoperating costs, the payments to the post-operating care fund, income tax, and return on investment. Also included in the table is the percentage of total disposal costs that each category contributes.

It can be seen from Table II that operating period costs contribute more than 73 percent of the total cost over the disposal facility lifetime. That is, about 74 percent of the fees charged for receiving and disposing of waste will be used to defray operating costs. About 21 percent of the cost of disposal is related to preoperating costs. This fraction consists of the preoperating costs of 9 percent, and 6.6 percent to pay a dividend to the investors providing the money for the preoperating costs, as well as the 5.2 percent for income taxes on the profit used for the dividends. Postoperating costs, on the other hand, represent only about 5.6 percent of total costs, partly because monies for them are placed in a sinking fund that grows at a 2 percent real rate over the operating period and beyond in order to amass the $8.54 million expended in postoperating care.

The major contributors to the direct operations costs are the payroll, and the leasing of heavy equipment to perform the disposal operations. Together these two items account for over one-third of the total annual costs. Annual disposal costs, shown in Table III, are obtained by dividing the total cost categories by the 20-year operating period. These must be recovered from the fees charged during the operating period.

The estimated unit cost of disposal for the base case--e.g., the fee per cubic foot of waste that would be charged to cover all costs as described above--is calculated by dividing the annual cost in Table III by the annual volume of waste disposed. This comes to $\$7.60/ft^3$.

Table III. Base Case Annual Disposal Costs (thousands).

Item	1980 Dollars
Direct Operations	$2,750
Amortization of Pre-Operating Costs	335
Payments for Post-Operating Care	210
Return to Investors (Dividends)	245
Income Taxes	195
TOTAL ANNUAL COSTS	$3,735
UNIT DISPOSAL COSTS	$\$7.60/ft^3$

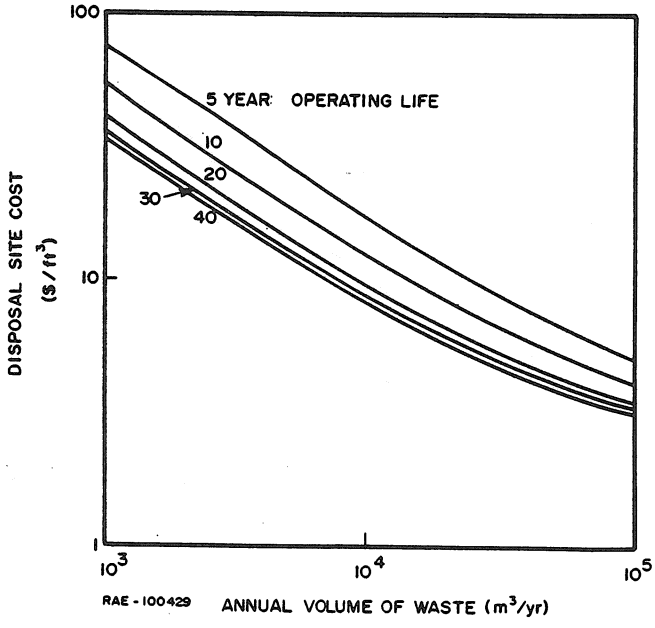


Fig. 1. Effect of Annual Waste Volume and Operating Life On Unit Disposal Site Cost.

A major fraction of the disposal cost is independent of site capacity; therefore, when the disposal costs are expressed on a unit waste volume basis, the cost per cubic foot ($\$/ft^3$) is significantly larger for smaller sites than for large ones. This is illustrated by the cost analysis shown in Fig. 1, which relates unit costs, annual disposal volume and operating lifetime.

TRANSPORTATION COSTS

A major contribution to total waste disposal costs is the cost of transporting the waste. One way to reduce this component is to reduce the distances involved by increasing the number of disposal sites. However, as the number of disposal sites increases, the volume of waste disposed at any one site decreases and the disposal cost per unit volume of waste increases. Thus, transportation costs and disposal facility costs are interrelated.

The transportation costs used in these analyses have been derived from Reference 6 which deals with volume reduction and transportation costs for BWR power plants. They are based on mileage-specific tariffs, the number of cubic feet of waste per truck and the return trips required to return shielding and special containers. Because of the importance of transportation costs, three different sets of cost data were considered in the analyses. The medium transportation costs are those given in Reference 6 modified by assuming that only half of the waste is from power reactors (BWR wastes require more shielding than typical low-level waste, which results in a higher transportation cost for BWR waste). The low transportation costs are two-thirds of the medium costs and high transportation costs are fifty percent greater than the medium costs. The low transportation costs would probably apply when the waste has low specific

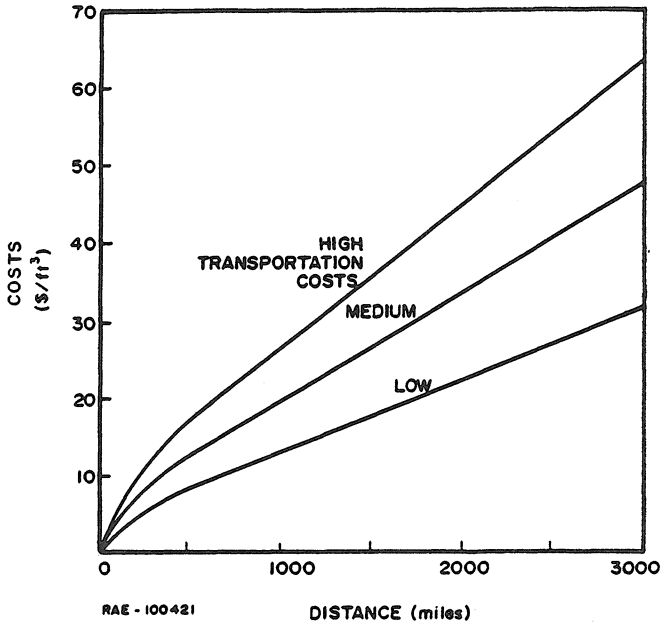


Fig. 2. Transportation Costs.

activity typical of low-level wastes from institutions. The medium transportation costs would apply when the waste is an average low-level waste mix and the high transportation costs apply when the waste is mostly from reactors or is high specific activity industrial waste. Figure 2 shows the high, medium and low transportation costs as functions of distance.

To calculate transportation costs, the area of the United States (3,600,000 square miles) is divided by the number of disposal facilities to obtain the average area served by each facility. Each disposal facility is assumed to be in the center of a circular area and the sources of waste are assumed to be uniformly distributed within that area. The average road distance from the source of the waste to the disposal facility is taken to be a factor of 2 (e.g., 1.41) times the straight line distance. The average transportation cost from all points within the area is then calculated using the rates shown in Fig. 2.

The above procedure will overestimate transportataion costs when the region serviced by a disposal facility is smaller than average or when the disposal facility is located close to the major sources of waste within the region. Likewise, if the region is larger than average or the disposal facility is not centrally located within the region, then the average transportation costs will be underestimated.

Adding the average transportation cost appropriate for the base case (six sites in the U.S., average distance of 437 miles) of $\$8.20/ft^3$ to the disposal cost, the total is $\$15.80/ft^3$ for the base case. It should be noted that the average transportation cost is not the cost for transportation over the average distance for a region.

WASTE PREPARATION

Reducing the volume of waste to be shipped does not reduce the cost of transportation proportionally. The cost benefit from having a smaller volume to transport is balanced by increased packaging costs, and the smaller volume of waste that can be carried on a given vehicle because of differences in handling and packaging. There also will be an increase in disposal costs resulting from necessary changes in handling procedures and trench design.

Table IV. Cost of Waste Preparation (Dollars Per Cubic Foot of Original Waste).

Packaging Level	Volume Reduction			
	1:1	2:1	3:1	4:1
Low	6.20	15.50	17.90	18.90
Medium	9.30	23.20	26.80	28
High	12.40	31.00	35.80	37.90

Note: The net cost of the volume reduction process for any packaging level can be calculated by subtracting the cost for 1:1 volume reduction from the appropriate figure to its right.

In the analyses three levels of waste preparation (e.g., volume reduction and packaging) are used. The cost estimates for preparation are taken from Reference 6 and are given in Table IV in dollars per cubic foot of original waste.

When the preparation cost of $\$9.30/ft^3$ for medium packaging and no volume reduction is added to the base case cost of $\$15.80/ft^3$ for disposal site costs and transportation costs, a total disposal cost of $\$25.10/ft^3$ for the base case is calculated.

Figure 3 shows the distribution of costs for low-level waste disposal for the base case. The disposal facility component is subdivided to show the contributions of the three phases of disposal facility life. It can be seen that the three components--transportation (33 percent), preparation (37 percent) and facility costs (30 percent))--are almost evenly divided.

TOTAL DISPOSAL COST TRADEOFFS

Costs were also determined for combined variations in packaging, transportation and disposal parameters. Figure 4 shows the combined medium waste preparation and transportation costs as a function of mileage and volume reduction. The curves are related to the volume before reduction. The transportation cost per unit volume of waste after volume reduction is the value shown on the respective curve times the volume reduction ratio. It is assumed that as the volume of the waste is reduced shielding requirements increase and the number of drums per truck decreases. Specifically, if a 4:1 volume reduction is used, the number of drums per transport is reduced by 55 percent.

Volume Reduction Payback Rates

While volume reduction reduces waste transportation and disposal costs, the cost of volume reduction must

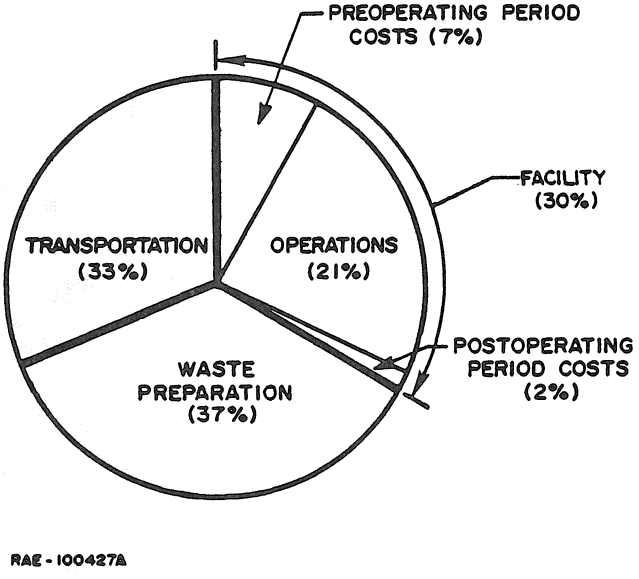


Fig. 3. Distribution of Low-Level Waste Disposal Costs.

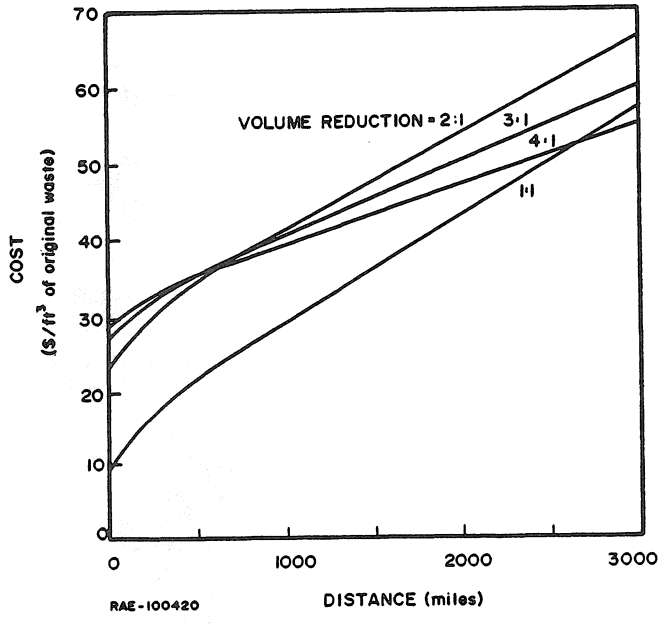


Fig. 4. Medium Waste Preparation and Transportation Costs As A Function of Mileage and Volume Reduction.

also be included in the total cost of disposal. The payback rates are the average savings in disposal site (burial) costs and transportation costs per cubic foot that result from using volume reduction. If the cost of volume reduction exceeds the payback rate, then the use of volume reduction will result in a net increase in total disposal costs.

Figure 5 shows the savings in disposal and transportation costs from volume reduction for three different volume reduction ratios using medium transportation costs as a function of the transportation distance. This savings is based on the original volume of waste into the reduction process. It is the net savings in transportation and disposal site costs as the result of volume reduction. As seen in the figure this savings is less than $\$10/ft^3$. Comparison of Fig. 5 and Table IV shows that the volume reduction payback is never greater than the cost of volume reduction. Typically, the volume reduction payback is only a small fraction of the cost of volume reduction. The payback is highest for long transportation distances. It may rise slightly with decreasing distances for distances less than about 300 miles because the unit disposal site costs for the many small facilities needed at those small distances increase faster than unit transportation costs decrease.

Total Disposal Cost Sensitivities To Waste Volumes And Volume Reduction

Key parameters that influence the total cost of disposal were varied to determine the sensitivity of the cost estimate for the base case to the variations. The key parameters are: the degree of volume reduction, the number (thus the size) of disposal sites, and the number of years of site operation.

Sensitivity To Volume Reduction

Bar A in Fig. 6 shows the sensitivity of unit disposal costs to volume reduction. The disposal cost shown in the figure is the cost per unit volume of

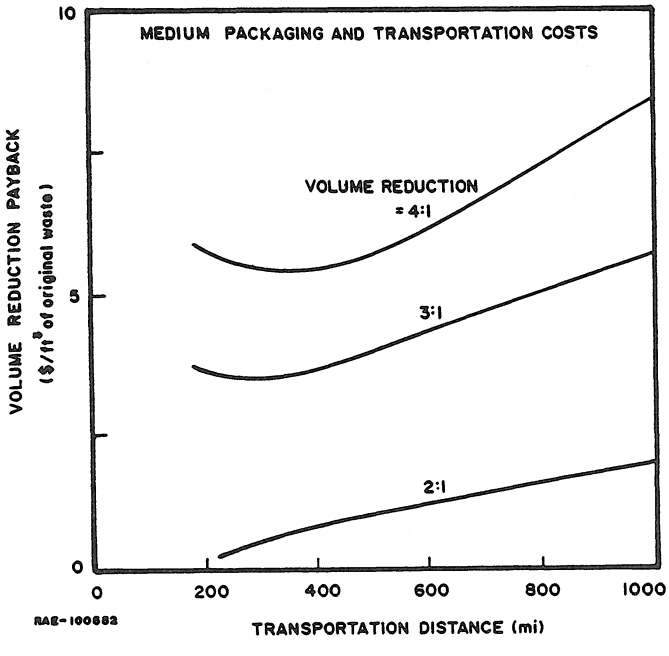
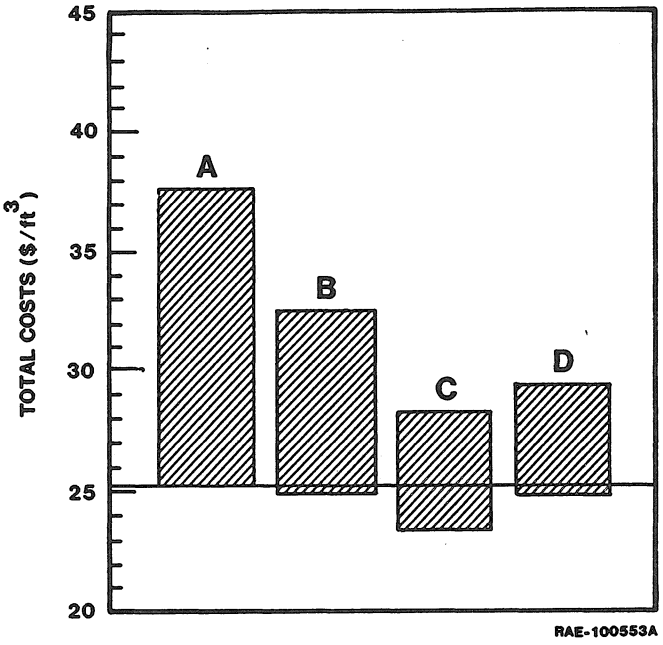


Fig. 5. Volume Reduction Payback



BAR	PARAMETER	RANGE
A	VOLUME REDUCTION	1:1 to 4:1
B	NO. OF DISPOSAL SITES	1 to 25
C	CONSTANT TOTAL VOLUME, VARYING YEARS OF OPERATION	5 to 40
D	CONSTANT ANNUAL VOLUME, VARYING YEARS OF OPERATION	40 to 5

Fig. 6. Disposal Cost Sensitivity To Variations In Key Parameters.

original waste. The lower end of the bar is the $25.10/ft^3 base case cost when there is no volume reduction beyond the current practice assumed (Spectrum 1 in Ref. 2). The highest unit disposal cost, $38.70/ft^3, occurs when a 4:1 volume reduction ratio is assumed.

Several factors contribute to the increase in costs resulting from volume reduction:

- Certain disposal site costs, such as site selection, licensing, etc, remain essentially fixed and others do not scale directly with the volume of waste to be buried. Therefore, unit costs rise as the volume to be disposed decreases.
- Volume reduction increases the radionuclide concentrations in the waste, requiring improved, and more expensive, handling and disposal site practices. With a 4:1 volume reduction, 38 percent of the waste disposed is Class B, C, and D.
- Transportation costs do not decrease in proportion to the volume of the waste being shipped.

Sensitivity To The Number of Disposal Sites

The number of disposal sites available to receive equal volumes of the annual amount of low-level waste generated in the U.S. influences the total amount of waste disposed at each site in the 20-year period and the average transportation distance. Therefore it has an impact on unit disposal site and transportation costs. Bar B in Fig. 6 shows the sensitivity of disposal costs to the number of sites. Unit costs range from a low of $24.90/ft^3 for 4 sites in the U.S. to $32.50/ft^3 for 25 sites. Costs for one, two and three sites were also analyzed, but the minimum unit cost results from using four sites.

Sensitivity To The Number of Years of Facility Operation

Bar C in Fig. 6 shows the range of unit costs resulting from varying the number of years of site operation, holding total volume of waste disposed at each site constant. The unit costs vary from $23.30/ft^3 for a site that remains in operation only 5 years to $28.10/ft^3 for one that operates for 40 years. The costs are lower for the shorter operating period because rapid payback of capital costs reduces the effective cost of raising the month to develop the disposal facility and the operating cost is lower due to the high rate of waste receipt.

Bar D in Fig. 6 shows the range of unit costs resulting from varying the length of facility operations without changing the annual volume of waste being handled. Unit costs range from $24.80/ft^3 for 40 years of operation to $29.40/ft^3 for 5 years. The unit costs go down with increased operating life because the total volume of waste handled increases under the assumption of constant annual volume, allowing amortization of the preoperating and postoperating period costs over a larger volume of wastes. However, the unit costs are not very sensitive to the total volume of waste because the dominant disposal cost component is the annual operating costs, and it is constant for this analysis. The change that is observed occurs entirely in the disposal site costs, which increase by about 60 percent when the operating life is reduced from 20 years to 5 years.

On the other hand, it can be seen that doubling the facility lifetime--from 20 years (base case) to 40 years--only reduces the unit costs by about 30 cents per cubic foot.

CONCLUSIONS

Waste preparation, transportation and disposal costs for LLW are interrelated. The cost parameters and tradeoff analyses of the present investigation give the following observations:

- Minimal disposal costs occur for about four well-spaced disposal facilities.
- For the base case, the unit total disposal costs of $25.13/ft^3 are comprised of nearly equal packaging, transportation and disposal components.
- Volume reduction reduces the transportation and disposal costs by less than $10/ft^3 of original waste; thus, the cost of volume reduction operations should not exceed this amount in order to provide a total cost savings.

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