LLRW DISPOSAL: ECONOMIES OF SCALE AND HALF-LIFE SEGREGATION

Clark W. Bullard* and Hans T. Weger**
University of Illinois
Department of Mechanical and Industrial Engineering

ABSTRACT

This report examines the underlying cost structure of an advanced LLRW disposal technology designed for the State of Illinois: concrete canisters placed in an above-ground, earth-mounded concrete vault. It explores opportunities for reducing the overall cost of disposal by segregating the relatively short-lived Class A waste from long-lived Class B&C wastes, and quantifies the cost advantage as a function of the discount rate. The site consolidation issue is also addressed by examining the relative magnitudes of the fixed and variable costs. The difference between having three and ten disposal sites to handle the U. S. waste stream is estimated to average $150 million annually.

INTRODUCTION

Of six disposal sites for commercial low level radioactive waste (LLRW) that were operating in 1970, only three remain open now in the United States. The intervening years have been marked by controversy, and by complaints of inequity from the three states hosting the facilities that receive all the nation's waste. The Low-Level Waste Policy Act of 1980 and its 1985 amendments made each state responsible for the waste it generates, and encouraged the formation of Interstate Compacts to develop regional disposal facilities.

As the LLWPA's 1993 deadline nears, it appears that as many as fifteen disposal facilities may be developed (1). While the number of potential sites have proliferated, the magnitude of the waste stream has decreased by nearly 50% from its 1983 high of 76,000 m^3 (2.7 million cu. ft.). In 1988, the total waste stream received at the three currently operating disposal sites in U.S. was 40,000 m^3 (1.4 million cu. ft.) per year (2). The latest concern is that there may be too many disposal sites to handle the nation's volume of LLRW in an economically efficient manner. It is illustrated by Chem Nuclear's decision not to bid on the construction and operation of a disposal facility for the Central States Compact, citing its belief that the projected waste stream was too small to be economically viable (3).

These substantial reductions in the waste stream are resulting from implementation of a variety of volume-reduction technologies _ supercompaction, incineration, decontamination _ that were generally uneconomic until the LLRWPA's surcharges and other factors increased the cost of disposal by $700/$m^3$ ($20/cu. ft.) or more. Advanced disposal technologies offering greater and safer confinement than traditional shallow land burial were estimated by to cost about $1800-2700/$m^3$ ($50-75/cu. ft.), compared to about $1200/$m^3$ ($35/cu. ft.) for shallow land burial (4). More recent estimates for engineered facilities are considerably higher, as a result of more stringent safety standards and long-term care and remedial action funds being required by host states (5).

This report examines the underlying cost structure of an advanced LLRW disposal technology, and quantifies the potential economic benefits of having a smaller number of disposal facilities. It also explores opportunities for reducing the overall cost of disposal by segregating the relatively short-lived Class A waste from long-lived Class B&C wastes.

Both of these issues require detailed analysis of the technology's fixed and variable cost structure, which have been documented in an earlier report (6). That analysis showed half-life-related costs to be a significant fraction of the total, and suggested that some savings could result from waste segregation. Various schemes have been proposed: to place Class B and C wastes in a separate vault but on the same site as Class A waste (5), or to place B/C waste on a separate site as is being considered by the Northeast Compact Commission (7).

A draft report being prepared by the Electric Power Research Institute reportedly will show that if the existing compacts were to be consolidated into four supercompacts, cost savings of up to $2.8 billion in operational and capital costs could be achieved (8).

Such conclusions are extremely sensitive to the fraction of total disposal costs that are fixed; that is, independent of the volume of the waste stream. In addition, they depend strongly on the discount rate used to levelize costs over the facility lifetime, and on the size of the long-term care and liability fund. The following analysis begins by summarizing the fixed and variable cost structure of an advanced disposal technology, and disaggregates those costs to quantify poten-

* Department of Mechanical and Industrial Engineering, University of Illinois at Urbana Champaign. Chairman, Central Midwest Interstate Compact Commission for Low-Level Radioactive Waste Management.

** Department of Nuclear Engineering, University of Illinois at Urbana Champaign.

tial cost savings achievable by segregating wastes according to half-life. Finally, the economy of scale issue is addressed.

DISPOSAL FACILITY COST STRUCTURE

The disposal technology analyzed here was first described by Westinghouse in its proposal to construct and operate a facility in Illinois to serve the Central Midwest Compact region (5), and by detailed design data subsequently supplied to the authors (9). It is a hybrid of the above ground vault and the above ground modular concrete canister designs, two of the four generic advanced technologies suggested by the Nuclear Regulatory Commission and analyzed by Rogers (4). The waste drums are placed first into concrete canisters, then into an above ground concrete vault which is finally covered with earth. The facility, shown in Fig. 1, was designed was for a waste stream of 5660m^3 (200,000 cu. ft.) annually, consisting of 92% Class A waste, and 8% Class B and C wastes.

The design specifications set forth by the State of Illinois required that the facility be engineered to contain the wastes for 500 years, and to allow for active monitoring for 300 years, or about ten half-lives of Cesium-137 and Strontium-90 (Illinois Department of Nuclear Safety, 1988). Illinois law requires the establishment of a long-term care and liability fund, so the facility was also designed to minimize the cost of retrieving and relocating the waste. In an earlier report, we calculated the magnitude of the surcharge required to establish a remedial action fund (RAF) large enough to cover the costs of multiple "retrieve, repackage and relocate" events during a 300-year monitoring period that would follow the facility's 50-year operating life. The number of such events would be inversely proportional to the proven lifetime of the canisters and vaults, which at the start of the monitoring period would be only 50 years. The analysis was based on the conservative assumption that the RAF surcharge would have to cover the worst case of a 50-year technology life, and that excess surcharges would be refunded throughout the monitoring period as long as the facility maintained its integrity and demonstrated that the technology's lifetime exceeded 50 years (6).

Because of the extremely long time horizon involved _ more than 350 years from start of construction to the end of the monitoring period _ great care must be exercised in selecting the discount rate for use in analyzing the economic implications of design tradeoffs that affect long-term performance, and the fee structures to pay for them. In this analysis, a real discount rate of 2% is used to levelize costs; the sensitivity of results to assumptions of 1% and 3% are also examined.

The 2% rate is consistent with other analyses covering multi-century periods, such as the U. S. Environmental Protection Agency's analysis of stratospheric ozone deple-

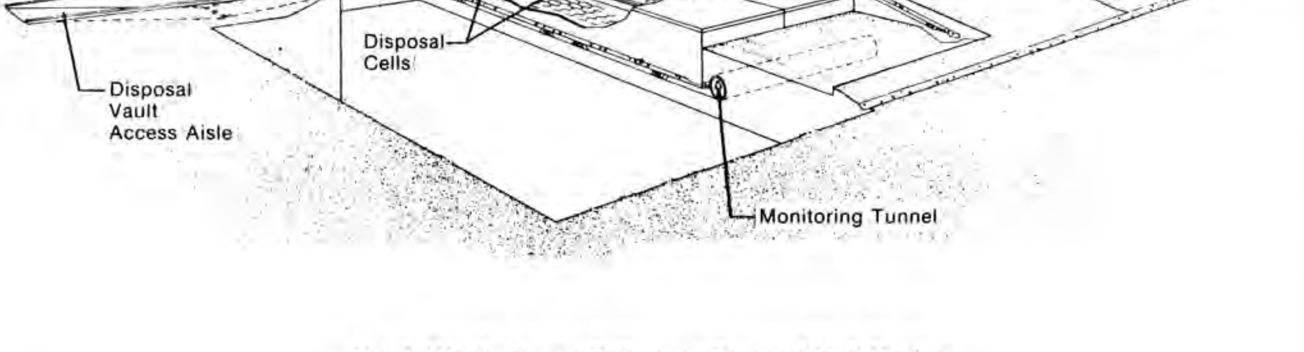

Fig. 1. Westinghouse Reference Disposal Unit Design.

tion (10). For a discount rate to be egalitarian from an intergenerational equity perspective, it must equal the rate of economic growth over the period (11). Thus, funds invested today for remedial action two hundred years in the future can be assumed to grow no faster than the average economic growth rate.* Reliable statistics on long-term economic growth do not exist; the 1929-1986 average of 2.9% was driven by a rate of population growth that is unlikely to be sustained for centuries into the future. A 2% rate for a 350-year period might also be unrealistic, as it implies a belief that real per-capita income will increase by a factor of 1023 if population remains stable, or by a factor of 500 if population doubles.

The RAF surcharge computed for the case of a 2% discount rate added $76/cu. ft. to the cost of disposal, and had a substantial impact on the balance between fixed and variable costs. The fixed costs shown in Fig. 2 include only that part of the financing cost attributable to the real "risk-free" discount rate of 2%. Depending on the financing scheme, the actual cost of financing the facility would include a premium to cover the risk that loans would not be repaid. In the case of government financing that risk is essentially zero; the cost of capital to government (the interest rate on long-term government bonds) has long approximated the real economic growth rate of about 2%. The cost of capital to electric utilities is about 4% real, because their protected monopoly status reduces the risk of loan defaults. Generator financing of LLRW disposal facilities, therefore, would increase fixed costs by about 30%. The cost of capital to private companies in the highly risky field of nuclear energy can range up to 20%. Figure 2 shows the corresponding financing cost, which increases fixed costs by a factor of 4.5 over the case of government financing at the "risk-free" interest rate (6).

Siting and construction of most disposal facilities are to be financed, at least partially, by generators or state governments. Even the fixed costs during the operating phase might be financed partly through debt instruments secured by fee structures that guarantee recovery of those costs. Such provisions could therefore reduce or eliminate the "operator financing" cost.

The following analysis is based on the cost structure shown in Figure 2, recognizing the fact that the operator financing cost is an upper bound. This assumption is balanced by the omission of administrative surcharges that might be levied by state regulatory agencies or interstate compact commissions, and payments demanded by the

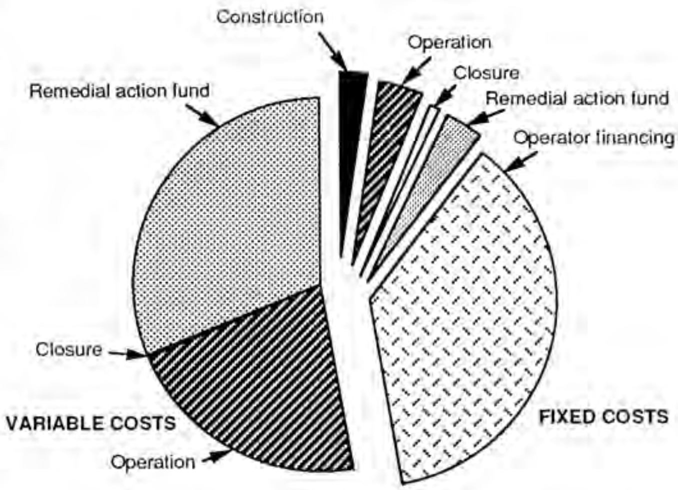

Fig. 2. Disposal Cost (Total = $7769/cu m).

local community as compensation for being the site of the LLRW facility.

HALF-LIFE-DEPENDENT COSTS

Low level radioactive waste is classified according to half-life and stability. Class A waste is segregated from Class B and C (B/C) waste based stability criteria. Regulations promulgated by the State of Illinois, which served as the basis for the Westinghouse design, require 300 years of institutional monitoring because of the presence of long-lived nuclides such as Cesium-137 in Class B/C waste (9). In this analysis, Class A waste is considered to have decayed to safe levels in 100 years.

For some categories of costs, the dependence on half-life is significant. In the following subsections, those associated with constructing vaults, monitoring, and remedial action are disaggregated. Two segregation scenarios are analyzed. In one case, waste is separated and deposited in separate vaults on a single site; in the other, the B/C waste vault is located on a separate site.

Because variable costs are directly proportional to waste volume, they are independent of whether the waste is segregated in separate vaults on a single site or at separate

* An alternative explanation would be that technological innovation reduces the costs of remedial action at a rate of 2% per annum, so that only a small amount need to be set aside now to cover an event 100 years hence. The two explanations are equivalent because technological innovation of this type is what drives economic growth.

sites. They are, however, higher for Class B/C waste than for Class A, as outlined below.

Vault Costs

Besides having a longer design life, B/C vaults are smaller and require thicker earthen caps. These and other factors make vaults for Class B/C waste more costly.

For the Illinois design, vault costs were presented separately for the Class A and B/C wastes. Vaults are constructed as they are needed throughout the facility lifetime, so they are variable costs. Dividing by the volumes of each class of waste yielded \$777 and 1271/m^3 (\$22 and \$36/cu. ft.) respectively, for a difference of \$494/m^3 (\$14/cu. ft.).

Table I summarizes the effect of half-life segregation on variable costs.

TABLE I
Vault Costs (\$/m^3)

	No Segregation	Separate Vaults	Separate Sites
Class A	777	777	777
Class B/C	777	1271	1271
Average	777	817	817

Remedial Action Fund Surcharge

Because Class A waste would have decayed to safe levels after the first one hundred years of the institutional monitoring phase, it would not need to be retrieved, repackaged and relocated if the facility failed after the first 100 years of the 300-year period. Therefore if Class A waste were deposited separately, it would require a smaller RAF surcharge than Class B/C waste.

If the waste is not segregated by half-life, then the Class A waste would be mixed with the still-hazardous Class B and C waste. All classes would be charged equally for the remedial action fund; the implications are shown in Table II.

TABLE II
Remedial Action Fund Surcharge (\$/m^3)

	No Segregation	Separate Vaults	Separate Sites
Class A	2684	2366	2401
Class B/C	2684	2825	5544
Average	2684	2403	2652

Both segregation scenarios reduce the size of the remedial action fund surcharge by eliminating the risk that Class A waste might need to be retrieved, repackaged and relocated the waste during the last 200 years of the monitoring period. In the separate site scenario, these savings even exceed the higher fixed costs associated with relocation to separate sites. For Class the A waste, the separate site option is only slightly more costly than separate vaults. This follows from the fact that only a small fraction of the remedial action costs are independent of volume. For Class B/C waste, there is a smaller volume of waste over which to spread the site-related fixed costs, so the fixed portion of the remedial action fund increases dramatically, nearly doubling the RAF surcharge.

Monitoring

Monitoring costs are fixed costs. They depend strongly on half life, and are higher for Class B/C waste than for Class A waste.

For the case of separate vaults on a single site, each cubic foot of waste is charged equally, regardless of half-life, for the first 100 years of the institutional monitoring phase. For the last 200 years of the institutional monitoring phase, Class A waste is no longer monitored so all costs are charged to the Class B/C waste. The annual cost decreases slightly after the first 100 years because only the B/C part of the site requires continued monitoring.

For the case of separate sites, the monitoring costs per cubic foot are greater for both kinds of waste, because of the smaller volumes over which they are distributed. One site must be monitored for 100 years, the other for 300. Table III compares the levelized costs of monitoring for the three segregation options.

TABLE III
Monitoring Costs (\$/m^3)

	No Segregation	Separate Vaults	Separate Sites
Class A	151	80	363
Class B/C	151	363	28297
Average	151	80	2517

EFFECT OF DISCOUNT RATE ON HALF-LIFE SEGREGATION

All the preceding calculations were based on a discount rate of 2%, and on the assumption that the facilities' fixed costs were financed by the operator at a real interest rate of 20%. The latter assumption is retained in Fig. 3, which compares the levelized total cost for the three different segregation options at discount rates of 1%, 2% and 3%. Only at the discount rate of 1% does half-life segregation lead to significant cost savings for the separate vault option. At very high discount rates, monitoring costs and the RAF surcharge become almost negligible, but the separate vault option always yields some cost savings. For the case of separate sites, however, the levelized costs are highest due

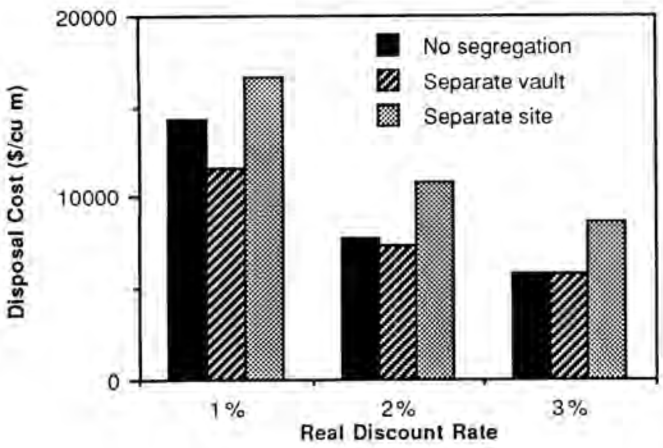

Fig. 3. Disposal Cost and Discount Rate.

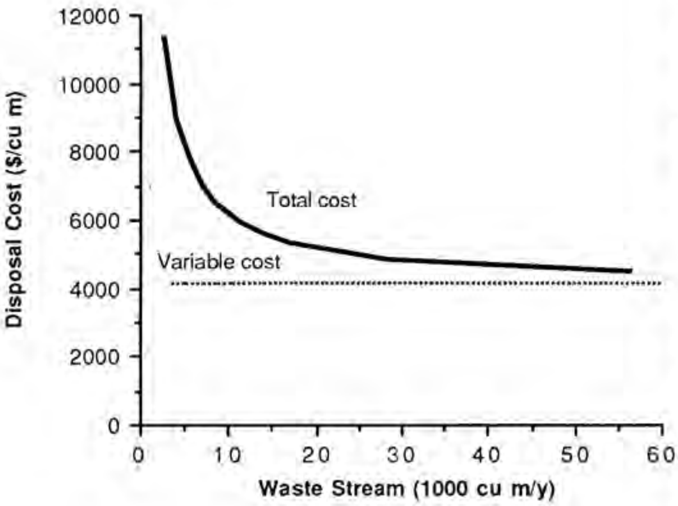

Fig. 4. Disposal Economies of Scale.

to the smaller volumes of waste to over which to distribute site-related fixed costs.

ECONOMIES OF SCALE

The preceding analysis assumed a waste stream of 5660m^3 (200,000 cu. ft.) per year for 50 years. Figure 4 shows how the total levelized cost of disposal depends on the magnitude of the anticipated waste stream. Only the no segregation option is shown. The variable cost component is constant because it is directly dependent on waste volume. For waste streams exceeding 14,000 m^3 (500,000 cu. ft.) per year, the unit cost of disposal decreases only slightly below \$5500/m^3 (\$157/cu. ft.). For facilities accepting less than about 5500 m^3 (200,000 cu. ft.), the unit cost increases rapidly above \$7700/m^3 (\$219/cu. ft). For very small facilities, the prototype design may no longer be optimal; other design concepts involving onsite storage and a disposal facility staffed to accept waste only during a few weeks each year may be more appropriate.

Table V shows how the cost of LLRW disposal would vary as a function of the number of sites, assuming that the national waste volume remains approximately constant at the current level of about 1.5 million cubic feet annually. Including transportation costs would tend to favor a larger number of sites, but their effect is negligible by comparison. Transport costs range from \$44/m3 (\$1.26/cu. ft.) per 100 miles travelled for dry active waste, to \$100/m3 (\$2.84/cu. ft.) for waste in casks (12). Even in the extreme case of a single national disposal site, with an average transport distance of about 700 miles, transportation costs would therefore add only \$300-\$700/m3 (\$9-\$20/cu. ft.) to the figures in the middle column of Table IV.

TABLE IV
Total Cost of LLRW Disposal

Number of Sites	Levelized Cost (\$/m^3)	Total Cost to Nation (Millions of \$/yr)
1	4454	197
3	5549	236
5	6522	277
10	8956	380
15	11371	484

The approximately \$3500/m^3 (\$100/cu. ft.) cost differential between three sites and ten provides a substantial incentive for generators to call for interregional cooperation and compact consolidation. However at the national level, \$150 million annual savings corresponds to only 60 cents per person, which could be interpreted as society's willingness to pay for the privilege of excluding waste generated outside the compact region.

SUMMARY

At a single disposal site, the cost savings attributable to segregating waste according to half-life and placing it in separate vaults occur mainly in the distant future. The cost difference is less than \$350/m^3 (\$10/cu. ft.) at a real discount of 2%, but rises rapidly to more than \$2500/m^3 (\$70/cu. ft.) for a discount rate of 1%.

Segregating waste for disposal at separate sites was shown more costly than either of the single-site options, because the diseconomies of scale of the B/C site outweigh the savings. The cost penalty of about \$2500/m^3 (\$70/cu. ft.) is relatively insensitive to discount rate, and could theoretically be eliminated if a single region were willing to take a substantial fraction of the nation's B/C waste.

The site consolidation issue was addressed by examining the relative magnitudes of the fixed and variable costs. It was found that for LLRW disposal facilities handling waste streams exceeding about 14,000m^3 (500,000 cu. ft.) per year, the levelized cost is affected only negligibly by increases in waste volume. The savings obtainable through compact consolidation, while substantial for generators, may appear negligible to the average citizen.

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