ESTIMATION OF INITIAL COSTS OF DOE MIXED LOW-LEVEL WASTE MANAGEMENT OPTIONS

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ABSTRACT

In support of the Mixed Low-Level Waste Management Program, which is an U.S. Department of Energy Headquarters initiative, a methodology has been developed to estimate order-of-magnitude costs for many alternative options for cradle-to-grave management of DOE's mixed low-level wastes. The methodology is modular in structure and addresses cost growth considerations. This paper describes the cost module for each stage of mixed low-level waste management and summarizes how the individual cost modules can be integrated and applied in the future to estimate costs for alternative TSD options for the DOE MLLW Management Program.

INTRODUCTION

The U.S. Department of Energy Headquarters (DOE-HQ) has established the Mixed Low-Level Waste (MLLW) Management Program with the objective of developing and implementing a DOE system-wide integrated strategy for treatment, storage, and disposal (TSD) options for MLLW management. A TSD option is defined as any combination of methods used during each stage of MLLW management from waste generation to disposal (i.e., "cradle to grave"), including waste retrieval, characterization, storage, transportation, and treatment. In support of the MLLW Management Program, a Systems Analysis Methodology is being developed for evaluation of the effectiveness and feasibility of implementing alternative TSD options for MLLW management.

One component of the Systems Analysis involves the development of a methodology for estimation of initial costs for MLLW TSD options. Initial costs are defined as rough approximations based upon simple calculations and minimal engineering. These are also called conceptual or order-of-magnitude estimates, and are expected to be within ±40 percent of actual costs for known technologies. This paper summarizes the development of the methodology, presents the modular structure of the cost estimation methodology including descriptions of each cost module, addresses cost growth considerations, and summarizes how the individual cost modules can be integrated and applied in the future to estimate costs for alternative TSD options for the DOE MLLW Management Program.

DEVELOPMENT OF THE COST ESTIMATION METHODOLOGY

During the development of the methodology, many software packages were identified that are currently available for estimation of order-of-magnitude costs of waste management (1). These were reviewed to determine their applicability towards MLLW management. The review indicated that the majority of these packages addressed cost estimation of environmental remediation activities while others addressed only hazardous waste management. Although these packages contain individual modules that may be modified to estimate the cost of some of the activities related to MLLW management, none of these are directly applicable to the MLLW Systems Analysis.

Concurrently with the review of software packages, a literature survey was performed to identify sources of cost data for each stage of MLLW management. The survey revealed many sources of cost data for different MLLW management activities such as treatment, storage, and disposal, both within the DOE and in the commercial sector (2-9). The data from these sources were reviewed and it was determined that the data from two of these reports could be readily applied to the MLLW Systems Analysis (2,3). While Smith et al.(2) address the cost of MLLW treatment only, Feizollahi and Shropshire (3) present cost estimates for many stages of MLLW management. Where applicable, the estimates presented in (3) also distinguish between the costs for MLLW and alpha-contaminated MLLW, and between MLLW and low level waste (LLW). The data are presented in terms of unit costs (1992 dollars per cubic foot) based on a 20-year life cycle (80,640 hours of operation). The development of data in (3) has been based on cost estimates for bench scale testing, demonstration, design and engineering, NEPA-permitting, full scale facility construction, operation and maintenance, and facility decontamination and decommissioning activities. For each MLLW management activity, unit cost data are presented for facilities of three different capacities ranging from 200 pounds per hour to 2,000 pounds per hour.

With the exception of the treatment and waste characterization cost modules, the cost estimation methodology presented here uses the unit cost data presented in (3), either directly or by modification. For treatment and waste characterization modules, the methodology primarily relies on information from one or more of the other data sources (2, 4-9). In case of unavailability of published data for a given activity, information has been obtained directly from waste management personnel at various DOE and commercial sites as well as through vendor quotes.

The cost estimation methodology is composed of seven modules representing the following major operations associated with the management of MLLW:

- Characterization
- Handling
- Treatment
- Storage
- Certification and shipping
- Transportation

- Disposal

The methodology has been formulated to estimate the total cost of any given TSD option under the assumption that there are no existing facilities. Once the total cost of a TSD option is estimated, the Systems Analysis will identify appropriate existing facilities at each site that could be used, and the total estimated cost for the given TSD option will be reduced accordingly. The remainder of this paper describes each of the above mentioned cost modules and their capabilities, incorporation of cost growth considerations in the cost estimation methodology, and future application of the methodology.

WASTE CHARACTERIZATION COST MODULE

Waste characterization is an inherent part of any TSD option for the management of MLLW. The use of the term waste characterization in the cost estimation methodology is limited to the use of one or more of the following activities; process knowledge, detailed sampling and analysis for hazardous constituents, and headspace gas analysis. Nondestructive assay (NDA), and nondestructive examination (NDE) are included in a separate cost module on waste receiving, inspection, and certification.

For newly generated MLLW, characterization may consist primarily of process knowledge, whereas detailed sampling and analysis may be necessary for stored waste. Given the early stage of the MLLW Management Program, the waste acceptance criteria for treatment, storage, or disposal have not been defined yet. Due to the lack of any defined waste characterization requirements, the cost estimation methodology makes use of simplifying assumptions in calculating waste characterization costs for each TSD option. Once the accuracy of current process knowledge is verified and the waste acceptance criteria are defined in the future, these assumptions will be modified appropriately.

The cost module for waste characterization includes two components. These components are the capital costs for waste characterization facilities and the operating costs for waste characterization activities. The cost estimation methodology for each of these components is described below.

Waste Characterization Facility Costs

This module primarily includes capital costs for a waste characterization facility as a percentage of the total cost of a TSD facility, and initial costs for the establishment of a waste characterization program at each facility. Data obtained from the Idaho National Engineering Laboratory show that the capital cost for a waste characterization facility is estimated to be between 5 to 10 percent of the capital cost of the associated TSD facility. Based on this information, the module assumes that an average multiplier of 7.5 percent will be appropriate for estimating facility costs. For options where treatment and disposal facilities are collocated at a site, the module assumes a multiplier of 5 percent to account for economies of scale.

Waste Characterization Operating Costs

Waste characterization operating costs refer to the costs of detailed sampling and analysis activities required at each stage of a given TSD option. As mentioned before, the extent of sampling and analysis requirements for a TSD option can be correctly estimated only after the waste acceptance criteria are defined and the accuracy of existing process knowledge is established. Since neither of these activities have been completed, this module makes simplifying assumptions for estimating "order-of-magnitude" costs for sampling and analysis activities. The assumptions are based on "anticipated minimum" and "anticipated maximum" sampling percentages and could be used to establish a range of characterization costs for each option. The assumptions are as follows:

- For treatment alternatives that do not qualify as a "specified technology" as defined in (11), 1 to 5 percent of the drums will undergo Toxicity Characteristic Leaching Procedure (TCLP) analysis after treatment and prior to disposal
- For treatment alternatives that qualify as a "specified technology", TCLP analysis will not be required after treatment and prior to disposal
- For newly generated waste, process knowledge will be sufficient to estimate hazardous characteristics and therefore TCLP analysis will not be required prior to treatment
- For retrievably stored waste, TCLP analysis will be required prior to treatment and transportation for 10 to 20 percent of the drums to determine hazardous characteristics.

Based on these assumptions and data on MLLW inventory projections, each alternative TSD option will be reviewed to estimate the number of drums and the total number of samples that will require analysis before and after each stage of MLLW management. Once the number of samples have been estimated, unit costs for TCLP sampling and analysis from private laboratories will be used to estimate the anticipated range of costs for each option.

WASTE HANDLING COST MODULE

The term "waste handling" is used in the cost estimation methodology to refer to the opening, dumping, and sorting of containers prior to waste treatment. The 20-year life cycle unit costs facilities handling both MLLW and alpha-MLLW were obtained from Feizollahi and Shropshire (3). The report provides unit cost data for waste handling facilities with different throughputs that range from 6 to 357 cubic feet per hour (ft^3/hr) based on an average waste density of 35 pounds per cubic foot (lbs/ft^3). The unit cost data developed were based on the assumption that the containers of waste entering the facility were already characterized.

The waste handling cost module assumes that after entering the facility, the containers of MLLW are opened manually while the containers of alpha-MLLW are opened by remote means. All dumping and sorting operations are performed remotely in a controlled environment with multiple barriers. After the container lids are removed, the waste is dumped into a sorting station for removal of bulk metals, noncombustibles, semicombustibles, combustibles, special wastes, and gas cylinders. The sorted materials are placed into transfer bins and sent to the treatment facilities. Based on the estimated waste handling capacity requirements for a given TSD option for a 20-year work-off period, the required throughputs will be multiplied by the unit costs to estimate waste handling costs for a given option. It should be noted that the use of the waste handling cost module is limited to treatment, and as explained later, to the handling of retrievably stored waste before transportation. The costs for routine waste handling, which is an essential activity at every stage of MLLW management, are included in the unit costs for the other modules.

WASTE TREATMENT COST MODULE

The treatment cost module provides capabilities for estimating costs using four alternative schemes for treatment of MLLW. One of these schemes is designated as the "Reference Case" treatment scheme and is being developed by the DOE Mixed Waste Treatment Project (MWTP). The MWTP treatment scheme classifies MLLW into five different treatment lines (10). These are aqueous liquids (solutions), organic liquids (solvents and slurries), wet solids (adsorbed liquids, sludges, and resins), homogeneous dry solids (concrete, grouts, soils, and ash), and heterogeneous dry solids (equipment, combustibles, leaded gloves, glassware, filters, debris, and metal). A treatment scheme to satisfy the Land Disposal Restrictions (LDR) (11) has been outlined for each line and associated unit capital costs have been reported by the MWTP (10). For alternative TSD options that involve the MWTP treatment scheme, the treatment cost module uses these unit capital costs to estimate total capital costs for constructing facilities. The MWTP is currently developing operating costs for each treatment line and these will be added to the treatment cost module later.

In addition to the MWTP schemes, the Systems Analysis has also defined three alternative treatment schemes for each of the five lines. Examples of these treatment alternatives include nonthermal treatments such as chemical oxidation of organics instead of incineration, and solidification of ash in grout instead of vitrification. Collectively, the three alternative treatment schemes include combinations of the following technologies for treatment of the five lines:

- Chemical oxidation
- Carbon adsorption
- Coagulation/precipitation/filtration
- Ion exchange
- Air stripping
- Thermal desorption
- Decontamination
- Evaporation
- Solidification in grout
- Solidification in polymer

For the three alternative treatment schemes, the treatment cost module uses order-of-magnitude life cycle unit costs for a wide range of capacities. The unit costs that have been developed are based on cost estimates for the following activities over a 20-year life cycle:

Preconstruction, which includes project management, environmental permitting, safety analysis reports, technology development, and other studies (siting, conceptual design, etc.)

Construction, which includes building areas for different operations such as receiving and inspection, treatment equipment, certification and shipping, and support services. Also included under construction are equipment costs scaled up from various reported data (2-9), and construction management costs estimated as a percentage of total construction costs.

Engineering and design, which are estimated at approximately 26.5 percent of construction costs (2).

Start-up and operations, which include start-up, personnel training, cold testing of treatment systems, operational readiness review, facility operations, labor, materials, maintenance, and utilities.

Decontamination and decommissioning (D&D), which include closure of the treatment facility at the end of the waste work-off period and demolition of the facility upon completion of the decontamination process. D&D costs have been estimated on the basis of costs reported by Schafer and Schlueter based on the D&D of actual facilities (12).

The cost data for each of the above activities and the alternative treatment technologies have been obtained from literature (2, 4-9). These costs have been used to estimate the 20-year life cycle costs for each alternative treatment scheme for treatment capacities ranging from 200 lbs/hr to 2000 lbs/hr. Subsequently, the total life cycle costs have been divided by the assumed capacities to obtain life cycle unit costs for each alternative treatment scheme. These unit costs have been used in the treatment cost module for estimating the costs for a given volume of waste using a given alternative treatment scheme. As discussed later, the estimated effects of cost growth are added to each alternative scheme based on the status of the technology and other factors that commonly contribute to cost growth.

WASTE STORAGE COST MODULE

The cost module for storage initially considered three types of storage facilities. These were reinforced concrete building, steel frame and metal siding building, and outdoor storage module and pad. Data obtained from the literature on relative costs of the three types of facilities show that the cost increase from the least expensive storage type (steel frame and metal siding) to the most expensive (reinforced concrete building) is about 26 percent (7). These reported estimates were based only on materials and labor for construction and did not include many other fixed costs such as design and project management. It is likely that with the inclusion of additional fixed costs the cost differential between the three options will decrease. Also, based on the fact that 60 percent of the nuclear industry is currently using reinforced concrete structures for long-term storage (7), it is assumed that reinforced concrete buildings will be used for storage of DOE MLLW.

The cost module is based on combining 20-year life cycle unit cost estimates for a reinforced concrete storage facility and its front-end and back-end support facilities (3). The unit cost for a storage facility includes storage area, cleanup unit operation for potential spills, and permanent monitoring capabilities for both gamma and alpha radiation control. The storage facility receives/transfers waste from/to the storage support facility. The unit cost data for a storage support facility includes all the necessary supporting operations for storing both MLLW and alpha-MLLW. Thus the facility combines receiving and inspection with administration, laboratory functions, and shipping/unloading capabilities. The waste throughputs in the storage cost module range from 5 to 87 ft^3/hr based on an average density of 112 lbs/ft^3. Once the storage capacity requirements for an alternative TSD option are estimated from MLLW inventory data, the unit cost data will be scaled appropriately to estimate storage costs for a given capacity.

WASTE CERTIFICATION AND SHIPPING COST MODULE

The *certification* and shipping cost module can be used for estimating the costs of assay/certification and eventual truck loading. The module uses unit cost data for different throughput as reported in (3). Major equipment costs that are included in the unit cost estimation are alpha and gamma assay units for NDA, real-time radiography (RTR) units for NDE, and a 20-ton bridge crane for loading. The unit cost data are based on a treated waste density of 112 lbs/ft^3. However, based on analysis of the assumptions listed in (3), this module can also be used to estimate the costs of unloading untreated waste from a transport vehicle and performing assay and RTR examinations before treatment. Therefore for NDA and NDE prior to treatment, the module adjusts the unit cost data in (3) to reflect the different density of the untreated waste. Accordingly, this module is also used to estimate the costs of receiving and inspecting untreated waste, as well as for the certification and shipping of both untreated and treated waste.

WASTE TRANSPORTATION COST MODULE

The alternative transportation options being evaluated by the Systems Analysis include transportation of treated or untreated MLLW by both road and rail and also in Type A or Type B packages. For each alternative option where TSD facilities are not collocated, waste transportation will be required to move untreated waste to an offsite treatment facility, or treated waste to a disposal facility. In addition, if a no-migration variance petition is used as an alternative to treatment, the waste transportation would also include the shipment of untreated waste to a disposal facility. The major variables for the transportation cost module are the following:

- Volume and density of treated and untreated MLLW to be shipped from each site
- Distance between point of origin and destination by road and/or rail
- Weight of the payload.

The transportation of untreated MLLW that has been retrievably stored at the sites may require some form of pretreatment or repackaging before shipment because of potential deterioration of some of the containers. Since no specific data are available on the extent of repackaging required at each site, the transportation cost module assumes that if transported, 100 percent of the retrievably stored MLLW will require opening, sorting, and repackaging. However, the module also assumes that these repackaged drums will not require further characterization at the treatment facility. The waste handling module discussed earlier will be used to estimate these repackaging costs.

The costs for shipment of low-level waste (LLW) are quoted by carriers in two different ways; the costs are either based on the rate per mile for a full truckload or the rate per unit volume of waste to be transported. The transportation cost module uses the former approach, which is to estimate costs based on the maximum permissible weight of a full truckload. The U.S. Department of Transportation (DOT) regulations dictate that a truck cannot exceed 80,000 pounds gross weight. Since the average truck weighs 30,000 to 35,000 pounds, total payloads (i.e., waste and containers combined) are limited to roughly 44,000 pounds or less. In addition, a maximum of 96 55-gallon drums can be included per shipment (13). Assuming that an average drum is packed to 80 percent of its full capacity, the density of each waste form is used to estimate the weight of an average drum. Based on the estimated weight of an average drum, the module then calculates the total payload assuming a total of 96 drums per shipment. If the total payload exceeds 44,000 pounds, the number of drums per shipment is reduced accordingly.

The module assumes the use of a dedicated load (i.e, for exclusive use by the DOE). The rates per mile for dedicated loads of LLW have been obtained from registered carriers (13). It is assumed that the costs of shipping LLW would not differ significantly from the transportation of MLLW. The cost per mile for transportation of MLLW in Type B packages (which is an alternate option being evaluated) has been assumed to be similar to the cost of using the Transuranic Package Transporter-II (TRUPACT-II), which is currently planned to be used for transportation of transuranic waste to the Waste Isolation Pilot Plant (WIPP). A matrix has been prepared for inter-facility distances by road for the DOE MLLW system. A similar matrix of distances for rail transportation will be prepared at a later stage. The unit costs for rail transportation are being obtained from freight carriers for both dedicated and nondedicated trains.

WASTE DISPOSAL COST MODULE

The disposal cost module has capabilities to estimate costs for the following types of disposal facilities:

- RCRA landfill
- Non-RCRA landfill (for delisted MLLW)
- Above-ground vault
- Below ground vault
- Intermediate depth disposal.

The disposal cost module is based on modification of the unit cost data for disposal presented in (3), where unit costs are presented for shallow land disposal, engineered disposal, and intermediate depth disposal. The module supplements the data presented for shallow land disposal by the addition of the cost of a double liner, a leachate collection system, and estimated RCRA-permitting costs in order to estimate unit costs for a RCRA-landfill. For above- and below-ground vaults, the unit cost data presented in (3) for engineered disposal are readily applicable to MLLW disposal except for minor modifications as explained below.

The cost data for the engineered disposal facilities developed in (3) includes packaging of drums into concrete canisters, sealing with grout, and placing them in *concrete disposal* cells that are backfilled and further sealed with a concrete cover. The cover is assumed to be capped with engineered layers of sand, impervious clay, high density polyethylene liner, and vegetative material. Decontamination and decommissioning of the facility includes allowance for a two-stage maintenance period. Short-term maintenance includes closure and post-closure periods, whereas long-term maintenance includes active and passive institutional care. Since the engineered vault concepts being evaluated by the Systems Analysis do not include overpacking in concrete canisters, the costs presented in (3) have been reduced accordingly in the module. The disposal cost module assumes that the order-of-magnitude unit costs of below-ground engineered disposal facilities would not differ significantly from above-ground facilities because of their structural similarity. Unit costs for disposal front end support facilities are added to the unit costs of both shallow land burial and engineered disposal to estimate total costs of disposal.

The disposal cost module for intermediate depth disposal is based on the assumption that the projected costs of WIPP are accurate enough to provide an order-of-magnitude cost estimate for an intermediate depth MLLW disposal facility. The construction and estimated operating costs for WIPP have been used to estimate the unit cost of intermediate depth disposal in salt beds. The module also includes provisions of estimating costs for intermediate depth disposal in other geologic media such as granite, basalt, tuff, and shale. Estimated costs of repository construction in different geologic media were obtained from a DOE report (14). The disposal cost module uses the relative ratio of construction costs in different media in conjunction with WIPP unit cost data to estimate the unit costs of intermediate depth disposal in different media. For each particular combination of treatment and disposal alternatives, the volume of the waste requiring disposal is determined from the overall volume reduction factors for the selected treatment scheme. The required volume is multiplied by the unit disposal cost to estimate the total disposal cost for each alternative TSD option.

COST GROWTH CONSIDERATIONS

Cost growth refers to the almost universal tendency for underestimating capital costs for first-of-a-kind technologies, resulting in unforeseen increases in overall project cost. In 1992, the General Accounting Office (GAO) reported that the Defense Waste Processing Facility which is currently under construction at the DOE Savannah River Site, has incurred large amounts of cost growth and schedule slippage from original project estimates for both treatment and disposal units (15). Although the data presented by the GAO cannot be readily extrapolated to estimate cost growth for MLLW TSD options, it serves as an indicator of the almost inevitable nature of cost increases that can be expected for innovative projects. Since many of the MLLW treatment technologies have not yet been tested on a commercial scale level, and since no mixed waste disposal facility currently exists in the DOE system, it is likely that MLLW TSD options may incur cost growth. Therefore, the effect of cost growth is included in the cost estimation methodology for both treatment and disposal technologies.

The methodology being used to estimate cost growth is based on three major studies related to cost growth and schedule slippage observed in large projects (16-18). Collectively, these studies examined the reasons for cost growth observed in a variety of large projects involving 16 process plants, 12 petroleum refining complexes, 7 minerals extraction projects, 6 civil construction projects, and 6 nuclear power plants. Based on statistical analysis of the cost growth data obtained for these 47 projects, a predictive algorithm is postulated in one of the studies to account for cost growth (16). The variables in the algorithm are the extent of technological innovation, regulatory constraints, type of project ownership (government or private), and the extent of additional infrastructure required for project implementation. The measures for each of these variables are listed in the study (16). The MLLW cost estimation methodology estimates cost growth effects of each treatment and disposal option by multiplying the projected capital costs by the cost growth factor estimated by the predictive algorithm.

INTEGRATION OF COST MODULES AND FUTURE APPLICATION

Based on the projected characteristics of the DOE MLLW inventory (e.g., current inventory, generation rates, waste form properties, etc.), the quantity of each type of MLLW requiring treatment, storage, transportation, or disposal at each DOE site will be estimated by assuming a 20-year inventory work-off period. The life cycle unit costs in the individual cost modules will then be used to estimate order-of-magnitude costs for each MLLW management activity for an option. After estimating the total cost of each activity for an option and supplementing these estimates with the effects of cost growth, the results from individual modules will be added to estimate the total cost for a given TSD option. Finally, a multiattribute decision making method will be used to combine the total cost of each option with other components of the Systems Analysis such as effectiveness, health and safety risks, and regulatory acceptance to establish the relative overall rating of each alternative TSD option. The results will provide recommendations regarding the preferred TSD options for DOE. The Systems Analysis is expected to be completed by the end of 1993 with a final report published by DOE in early 1994.

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