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UNIT DECONTAMINATION AND DISMANTLEMENT (D&D) COSTS[1]

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ABSTRACT

A series of relationships have been developed for estimating unit decontamination and dismantlement (D&D) costs for a number of building types which may be applied in the absence of other data to obtain rough order-of-magnitude (ROM) cost estimates for D&D activities. The relationships were developed using unit D&D costs for a number of building structure types at the Department of Energy Fernald site. These unit costs take into account the level of radioactive contamination as well as the building size.

INTRODUCTION

The U.S. Department of Energy (DOE) complex contains a large number of surplus structures with similar construction and former mission. One recent study estimated that 2,590 contaminated structures would ultimately require stabilization and maintenance (DOE 1995). Of this total, approximately 2,173 were identified as "radiologically contaminated" buildings requiring future D&D activities, at a total cost of approximately $45 billion. Nationally, D&D activities will also be performed on non-DOE structures, including structures addressed by DOE's Formerly Utilized Site Remedial Action Program. Interest has developed concerning the applicability of unit D&D costs developed for various non-reactor facility types to generate rough order-of-magnitude (ROM) D&D estimates.

Decontamination and dismantlement is the partial or total un-construction of a structure formerly used to possess or process hazardous and/or radioactive materials. The final form of the structure after D&D will vary depending upon the extent of the D&D activity to be carried out, which may range from decontamination of "hot spots" with no dismantling of the structure to complete decontamination and dismantlement of all above- and below-grade portions of a structure.

There is a wide variation in the methods applied to determine the cost of D&D, ranging from the use of a "bottoms-up" approach that relies upon detailed structure-specific information (such as the material inventory for the structure, level and type of contamination, type of construction, structure size, etc.) to develop detailed cost estimates, to estimation of D&D costs as a constant percentage of the original capital cost of the structure. The technique used for preparing D&D cost estimates will vary with the project's degree of definition; availability of data bases containing dimensional information about a given building (i.e., height, width, length, number of floors, etc.), material inventory (i.e., amount of concrete, structural steel, piping, conduit, process equipment, etc.) and information about the type, level, and extent of contamination; and the level of detail required in the cost estimate.

One method that has been applied successfully in the past for preparing cost estimates is the parametric technique. Parametric estimating relies on statistical analysis of historical cost data to find correlations between cost drivers and design or performance parameters. The statistical analysis produces unit costs which can be used to determine D&D costs on a building-by-building basis. Unit costs are especially useful for groups of structures with similar characteristics, where the total project cost may be more important than the cost for an individual structure and where the required effort is also the largest. Unit cost relationships are developed in this analysis by examining the D&D costs of structures at one large DOE facility that is in the early stages of remediation.

The facility considered is the Fernald Environmental Management Project (FEMP), located near Cincinnati, Ohio. The FEMP was used by DOE and its predecessor agencies to produce high-purity uranium metal from 1952 until 1989. The former production area of the FEMP contains over 200 structures, including about 100 buildings. Most of the structures at the FEMP date from the 1950's and many of them and portions of nearby soil and groundwater are radiologically contaminated as a result of the production activities at the facility. It is currently planned that all the structures at the FEMP will be removed during remediation. Remediation is being carried out in accordance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended. Decontamination and dismantlement of structures in the production area is being managed using an interim remedial action being carried out for Operable Unit 3 (OU3), which addresses improvements located in the 136-acre former production area. Environmental media are addressed by a different operable unit.

Most of the structures associated with OU3 are buildings. The remaining structures include tanks, utilities, storage pads, roads, railroads, ponds and basins. Because of differences in construction type and past use, dismantlement methods will vary. The various OU3 structures can be segregated into six categories that are generally representative of the buildings at the facility, namely:

- Structural steel frame structure with transite siding and roofing (type A structure)
- Concrete block structure with built-up or composite roofing (type B structure)
- Pre-engineered structures with metal siding and roofing (type C structure)
- Wood frame structure with wood siding and metal roofing (type D structure)
- Tension support structures with fabric skin (type E structure)
- Open steel-frame structures (type F structure)

METHODOLOGY

Detailed cost estimates were developed for the 240-plus FEMP OU3 structures using the approach proposed for the D&D of the three DOE gaseous diffusion plants (DOE 1991). The material inventories for each FEMP OU3 structure were used as the basis for developing a "bottoms-up" D&D estimate. The material inventories for each structure were given in terms of 51 material components, where "steel piping 2-inch or less in diameter" is an example material component. The cost of decontaminating and removing each material component (such as concrete and structural steel) was evaluated using the historic database established by EBASCO Environmental Services Incorporated (DOE 1991), supplemented by the *Environmental Cost Handling Options and Solutions (ECHOS) Unit Cost Book* (1995) and industry standards (Richardson 1993, Waier 1994). As an example, the EBASCO database indicates that scabbling concrete flooring may require four full-time general laborers, one-half of a foreman's time, one-tenth of a general foreman's time, one-tenth of a compressor with an operator, and three-tenths of a fork lift with an operator. It was assumed in this analysis that standard dismantlement techniques would generally be used for structure demolition.

The total estimated D&D cost is composed of direct and indirect cost components. Direct costs are those incurred as an essential part of the D&D process, such as concrete removal, surface decontamination, or concrete floor scabbling; indirect costs reflect overhead expenditures such as insurance, rent, administration, construction management, project contingency, etc. The unit costs presented in this study exclude the indirect cost component because indirect costs may vary from organization to organization. Costs associated with transportation and disposal of the wastes resulting from the D&D activities are also excluded.

The direct costs of D&D in this analysis were assumed to include the cost of labor and materials required for gross surface contamination of materials in structures and for dismantlement of structures. They also include the cost of any required D&D equipment (such as a concrete scabbler, high-pressure water jet system for surface decontamination, etc.). Loss of labor productivity due to the presence of hazardous and/or radioactive materials was included. A productivity cost factor was applied to adjust the cost estimate for the level of worker protection defined by NIOSH (1985). It was assumed that Level C protective equipment will be required for demolition of structures identified as containing significant levels of radioactive contamination; demolition of other structures will require Level D protection. It should be noted that the estimated costs are very sensitive to the assumed working conditions.

The development of the detailed cost estimate for each structure relied on the concept of unit factors for the direct cost. The cost of each repetitive event such as cutting and packaging pipe, demolishing concrete, and water washing with vacuum collection for decontamination, is individually estimated. The costs include labor, equipment, job materials, permanent materials, and subcontract services. The unit factors are expressed in terms of cost per cubic foot demolished or cost per square foot of internal building area, etc. The detailed inventory of each structure (including equipment and structural materials) was then used in conjunction with the factors to develop the direct costs. Calculation of activity-dependent cost factors considered operating time, required crew size, consumables usage, and support services.

Average D&D costs per square foot of floor area were determined for each structure. Total costs include the following: piping, equipment, concrete, and structural steel removal costs; decontamination (washing) costs; packaging costs; and manpower staffing costs. Using equipment and consumables costs and inventory data, unit direct cost factors for structure "I" were calculated using the following formula:

$$[\text{Unit D\&D Direct Cost } (\$/\text{ft}^2)]_I = [\text{D\&D Direct Cost } (\$)]_I \ / \ [\text{Total Floor Area } (\text{ft}^2)]_I \qquad (1)$$

The various structures were segregated by structure type, number of floors, and level of contamination. Data for statistical analysis were available for the cases shown in Table I.

PLACE TABLE I HERE

Unit cost factors have been historically developed as an average of the costs seen over the range of interest (e.g., Kisieleski et al. 1994). However, the results for the six case studies in Table I exhibit a wide range of unit costs for each structure type. It does not appear that a constant unit cost factor is applicable over the range of floor sizes included in the analysis. For example, the unit D&D direct cost for a clean, single-level category F (i.e., open steel-frame) structure decreases by an order-of-magnitude, from approximately $\$18/\text{ft}^2$ at a floor size of 200 ft^2 to $\$0.1/\text{ft}^2$ at 32,000 ft^2.

Unit D&D costs are better estimated using a power-law relationship such as is commonly applied to estimate the capital costs of building construction as a function of building size:

$$[\text{Unit D\&D Direct Cost } (\$/\text{ft}^2)] = A \ [\text{Floor Area } (\text{ft}^2)]^Y \quad (2)$$

where A and Y are constants. Taking the logarithm of both sides of the above equation results in:

$$\log_{10} [\text{Unit D\&D Direct Cost}] = \log_{10} (A) + Y \log_{10} [\text{Floor Area}] \quad (3)$$

If a power-law relationship exists between the unit D&D costs and floor area, then on a log-log plot, the relationship of the unit D&D costs and floor area should be a straight line. Figure I, which presents the unit D&D costs for a contaminated, single-level category A (structural steel frame with transite siding and roofing) structure, confirms this relationship.

PLACE FIGURE I HERE

RESULTS

A simple regression analysis using the least-squares method was used to fit a regression line through the data points. The least-squares method minimizes the sum of squared deviations between the "observed" and predicted values for unit D&D costs. The results of the regression analysis, including the range of floor areas for which the regressions were developed, are provided in Table II.

PLACE TABLE II HERE

Table II also shows the power-law relationship for costs developed using the results of the regression. The negative exponent indicates that smaller buildings cost more to D&D on a per- building-size basis than do larger buildings. Cost savings for larger structures is referred to as "economies of scale" and is commonly observed (as an example, it is not possible to build two 1,000 ft^2 houses for the same cost as one 2,000 ft^2 house of comparable quality). Unit costs also vary with building type, with higher costs seen for structures with more robust construction (e.g., concrete block with built-up roofing). The nearly linear reciprocal relationship seen for clean, category F structures may be attributable to the relative ease of dismantling basically steel structures without prior decontamination.

In Table II, the coefficient of determination, R^2, is the percentage of the total variation in the dependent variable (unit D&D cost) which is explained by the independent variable (floor area), and is a measure which indicates how well the regression line fits the data. The better the fit, the closer R^2 will be to unity. The R^2 values indicate that there is not a significant degree of scatter about the regression line.

The significance of the regressions developed was examined. Based on an F test for significance of regression for the six case studies in Table II, the regressions developed are statistically significant (95% confidence level), indicating that using the least-squares model would be generally preferable to using simply an unit D&D cost averaged over the range of floor areas studied.

The estimated D&D costs given in this paper were compared with those developed for similar structures by commercial firms with D&D experience. The estimated costs presented in this paper were found to be bounded by the commercial cost estimates.

EXAMPLE CALCULATION

To demonstrate use of the relationships presented in Table II, a sample calculation is provided. The example involves a clean, single-level category B structure with a floor area of 5,000 ft^2. The unit D&D direct cost is computed to be approximately $\$7.1/ft^2$:

$$[\text{Unit D\&D Direct Cost } (\$/ft^2)]_{\text{category B}} = 99 \times [\text{Floor Area } (ft^2)]^{-0.31} = 99 \times [5{,}000\ ft^2\ ]^{-0.31} \sim 7.1 \quad (4)$$

The direct component of the total D&D cost is therefore approximately $35,000. Assuming that the indirect component is approximately 50% of the total D&D cost results in a total D&D cost of $70,000.

CONCLUSIONS

A series of relationships have been developed that provide estimates for unit D&D costs for a number of building types. The unit cost values are intended for estimating total programmatic costs that will be within a reasonable range of the actual costs. These cost-estimating relationships may be applied in the absence of other data to obtain ROM cost estimates for D&D activities. It should be noted that the estimated unit D&D costs are very sensitive to the assumed working conditions, as Level C protective equipment was assumed for demolition of structures identified as containing significant levels of radioactive contamination.

Smaller buildings appear to cost more to D&D on a per-building-size basis than do larger buildings. This difference appears to be attributable to general economies of scale. Unit costs also vary with building type, with higher costs seen for structures with more robust construction (e.g., concrete block with built-up roofing).

More unit cost data is required to extend the range of applicability of the regressions. In addition, the estimates of the unit costs require validation against actual costs incurred at facilities other than the FEMP. Further cost data is required to develop unit costs for the structure types where insufficient data were available in this study for statistical analysis.

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TABLE I. Cases Included in the Statistical Analysis

Structure Category	Structure Description	Assumed Degree of Contamination	Number of Levels
A	Structure consists of structural steel framing on a foundation system of reinforced concrete spread footings. The ground floor is a concrete grade slab, and any upper floors are steel floor plates and/or reinforced concrete slabs. The building enclosure is transite siding and roof panels (containing asbestos fibers).	100%	Single
		100%	Multiple
B	Structure consists of reinforced concrete block load-bearing walls on a foundation system of reinforced concrete wall footings. The ground floor is a concrete grade slab, and any upper floors are reinforced concrete slabs. The roof covering is a built-up roofing system, supported on either a reinforced flat concrete slab or metal decking on steel bar joists.	100%	Single
		0%	Single
F	Structure consists of open structural steel framing on a foundation system of reinforced concrete spread footings. This type includes open steel structures such as weather covers over storage pads or frames supporting equipment and/or providing maintenance access.	100%	Single
		0%	Single

NOTE: For other structure types, insufficient data were available for statistical analysis.

TABLE II. Regression Analysis Results

Structure Category	Assumed Degree of Contamination	Number of Levels	Regression Coefficients		Applicable Range of Correlation (floor area, ft^2)		Standard Error of the Estimate	Coefficient of Determination R^2	Power-Law Relationship for Unit D&D Cost ($\$/ft^2$)
			A	Y	Lower Bound	Upper Bound			
A	100%	single	2.9	-0.34	600	27,000	0.034	0.97	$790 \times [\text{Floor Area}]^{-0.34}$
	100%	multiple	2.5	-0.23	300	130,000	0.09	0.86	$350 \times [\text{Floor Area}]^{-0.23}$
B	100%	single	2.1	-0.25	150	10,000	0.087	0.78	$140 \times [\text{Floor Area}]^{-0.25}$
	0%	single	2.0	-0.31	50	27,000	0.14	0.85	$99 \times [\text{Floor Area}]^{-0.31}$
F	100%	single	1.9	-0.31	800	12,000	0.13	0.69	$72 \times [\text{Floor Area}]^{-0.31}$
	0%	single	3.5	-0.9	200	32,000	0.41	0.80	$2900 \times [\text{Floor Area}]^{-0.9}$

Figure I: Unit D&D Direct Costs for a Contaminated, Single-level Category A Structure as a Function of Floor Area