A PARAMETRIC ANALYSIS OF A NUCLEAR WASTE REPOSITORY HANDLING AND PACKAGING FACILITY

D. G. Dippold
Battelle Project Management Division
S. Tzemos
Battelle's Columbus Laboratories
Columbus, Ohio 43201

ABSTRACT

PACCOM is a computerized, parametric model used to estimate the capital, operating, and decommissioning costs of a variety of nuclear waste repository packaging facility configurations. The model is based upon a modular waste packaging facility concept from which functional components of the overall facility have been identified and their design and costs related to various parameters such as waste type, waste throughput, and the number of operational shifts employed. The model may be used to either estimate the cost of a particular waste packaging facility configuration or to explore the cost tradeoff between plant capital and labor. That is, one may use the model to search for the particular facility size and associated staffing level leading to the lowest overall total cost.

INTRODUCTION

The Nuclear Waste Policy Act of 1982 assigns the United States Department of Energy (DOE) the responsibility for safely disposing of nuclear wastes produced in the U.S.(1). The DOE is planning to carry out their responsibility by constructing and operating underground geologic repositories in which the nuclear wastes will be permanently buried. Prior to this permanent disposal, the wastes will be received by a waste handling and packaging facility (WHPF), located at the repository, where they will be encased in metal waste packages. However, since the exact type, form, size, and annual receipts of waste are yet to be determined, it is difficult to define precisely the WHPF's design and cost.

In spite of the uncertainty surrounding the WHPF's design parameters, it is important to be able to analyze various designs and their associated costs. These analyses are important in conducting WHPF design and cost tradeoffs and in simplifying the job of overall repository system design.

This paper describes a computer model being created to estimate for a variety of waste form, waste receipt, and cost assumptions, the capital, operating, and decommissioning costs of the WHPF. The model's design is modular and parametric The following sections provide an overview of the model's more interesting logic.

THE COST MODEL: PACCOM

Underlying the parametric approach to the design and economic analysis of the WHPF is an assumption that the facility can be separated into discrete modules. Three such modules have been identified: the hot cell module, the balance of plant module, and the support services module. By adjusting the detail of these three modules, one can define a facility able to accomodate a variety of waste types, forms, and quantities. By tabulating the costs associated with the resulting three module definitions, one can estimate the total cost of such specifically defined facilities and carry out a range of economic analyses.

The PACkaging facility COst Model (PACCOM) is the result of automating the parametric approach discussed above. PACCOM calculates the capital, operating, and decommissioning costs of a variety of WHPF designs for each of four typical shift schedules, i.e., for 5, 10, 15, and 21 shifts per week. The total costs for each shift are then compared and the shift with the minimum cost is identified.

Capital Costs

The WHPF capital costs for each shift schedule L consists of the hot cell module cost (CELTOT(L)), the balance of plant module cost (BALTOT(L)), and the support facility module cost (TOTSUP(L)).

$$\mathrm{CAPTOT}(L) = \mathrm{CELTOT}(L) + \mathrm{BALTOT}(L) + \mathrm{TOTSUP}(L) \qquad (1)$$

Since the size and cost of the WHPF depend mainly on the design of the hot cell module, PACCOM first determines the annual hot cell requirements for each shift schedule by calculating the number of hot cells required to handle the waste mix for each year of the operating period.

The number and type of hot cells required to process the mix of waste received in year t, for shift schedule L is calculated as

$$\mathrm{NHCELL}(t,I,L) = \frac{\mathrm{MTU}(t,I)}{\mathrm{Capacity}\ (I,L)} \qquad (2)$$

where MTU(t,I) is the amount of waste type I received in year t,
Capacity (I,L) is the capacity of the hot cell of type I for shift schedule L, and
I represents canistered waste cells, spent fuel (SF) cells, special function cells, or combined function cells.

The actual number of hot cells required is the maximum number of cells, by type, over all years of operation for shift schedule L.

$$\mathrm{NCELL}(I,L) = \text{maximum of } \mathrm{NHCELL}(t,I,L) \text{ over all } t \text{ for shift schedule } L \qquad (3)$$

The total hot cell capital costs (CELTOT) for shift schedule L are then calculated as

$$\mathrm{CELTOT}(L) = \mathrm{PROCOS}(L) + \mathrm{OGCOST}(L) + \mathrm{CRANE}(\mathrm{NUMBAY}) + \mathrm{TRFCOS}(L) \tag{4}$$

The costs of process equipment and structures for the SF cells (PROCOS(L)) for each shift schedule L are calculated as

$$\mathrm{PROCOS}(L) = f_1\,(\mathrm{NCELL}(I,L),\ \mathrm{STCOST}(I),\ \mathrm{EQPCOS}(I)) \tag{5}$$

where NCELL(I,L) is the number of cells of type I for shift schedule L,
STCOST(I) is the structure cost for cell type I,
EQPCOS(I) is the process equipment cost for cell type I.

The operating gallery costs (OGCOST(L)) for shift schedule L include both structure and equipment costs. They are calculated as

$$\mathrm{OGCOST}(L) = f_2(\mathrm{NCELL}(I,L),\ \mathrm{GALCOS}(I)) \tag{6}$$

where GALCOS(I) is the cost of the operating galleries for cell type I.

The crane cost component (CRANE) includes the cost of the crane maintenance bay and the crane(s) costs themselves; these costs are assumed to be fixed.

The cost of the casks used to transfer the packaged waste to the repository shaft area, for each shift schedule L, is

$$\mathrm{TRFCOS}(L) = \mathrm{MTFCAS}(L) * \mathrm{TRANFC} \tag{7}$$

where TRANFC is the cost for each transfer cask, and
MTFCAS(L) is the maximum number of casks required annually for shift schedule L.

The number of casks required annually (MTFCAS) for shift schedule L is approximated from the maximum daily number of waste packages emplaced in the repository over all years of operation.

The balance of plant costs include the cost of facilities for transportation cask receiving; transportation cask preparation and shipping; contact TRU (CHTRU) handling, if required; and the hot cell support services.

The balance of plant costs (BALTOT(L)) for shift schedule L are calculated as

$$\mathrm{BALTOT}(L) = f_3\,(\mathrm{NRCASK},\ \mathrm{TOTCELL}(L),\ \mathrm{CHTRU}) \tag{8}$$

where NRCASK is the number of transportation casks that arrive daily,
TOTCELL is the total number of hot cells, and
CHTRU is the cost of the contact handed TRU facility.

The support facilities include areas, buildings, and equipment that are used for administration, personnel services, maintenance and utility services, training, warehousing, and security services. The total capital costs for these facilities (TOTSUP(L)), by shift schedule L, are

$$\mathrm{TOTTSUP}(L) = \mathrm{ADMCAP}(L) + \mathrm{PERCAP}(L) + \mathrm{MNTCAP}(L) + \mathrm{WARCAP} + \mathrm{TRAINC} + \mathrm{SECOS} \tag{9}$$

The administration facilities costs (ADMCAP(L)) are calculated as

$$\mathrm{ADMCAP}(L) = \mathrm{FC} + \mathrm{VC} * \mathrm{INSMAN}(L) \tag{10}$$

where FC and VC are fixed and variable cost coefficients, and
INSMAN(L) is the indirect support personnel for shift schedule L.

The personnel facilities costs (PERCAP(L)) are calculated as

$$\mathrm{PERCAP}(L) = \mathrm{FC} + \mathrm{VC} * \mathrm{DIRMAN}(L) \tag{11}$$

where FC and VC are fixed and variable cost coefficients, and
DIRMAN(L) is the direct labor required for shift schedule L.

The cost of facilities for maintenance and utilities (MNTCAP(L)) is calculated as

$$\mathrm{MNTCAP}(L) = f_4(\mathrm{TCAREA}(L),\ \mathrm{TOTMAN}(L)) \tag{12}$$

where TCAREA(L) is the total hot cell area for shift schedule L, and
TOTMAN(L) is the total direct and indirect staff required for shift schedule L.

The warehouse facilities costs (WARCAP) are calculated as

$$\mathrm{WARCAP} = f_5(\mathrm{TMXMTU}) \tag{13}$$

where TMXMTU is the maximum annual MTU throughput.

The training facility costs (TRAINC) are

$$\mathrm{TRAINC} = \mathrm{BLDGCOST} + \mathrm{EQPTOT} \tag{14}$$

where BLDGCOST is the training building cost, and
EQPTOT are the equipment costs.

The cost for the security facilities (SECOS) is assumed to be fixed.

The estimates of capital costs are distributed over an assumed time period as follows.

$$\mathrm{CAP}(t,L) = \mathrm{CAPTOT}(L) * \mathrm{DSTCAP}(t) \tag{15}$$

where CAP(t, L) is the capital expenditure incurred in year t for shift schedule L, and
DSTCAP(t) is an assumed distribution factor.

Operating Costs

The operating costs of the packaging facility consist of labor costs, material and supply costs, and utilities and miscellaneous costs.

The annual operating costs (OPCOS(L)) for shift schedule L are

$$\mathrm{OPCOS}(L) = \mathrm{MANCOS}(L) + \mathrm{SUPPLY}(L) + \mathrm{ENERGY}(L) \tag{16}$$

where MANCOS(L), SUPPLY(L), and ENERGY(L), are defined below.

The labor costs (MANCOS(L)) for shift schedule L are given by

$$\mathrm{MANCOS}(L) = (\mathrm{DIRMAN}(L) * \mathrm{WAGDIR}(L) + \mathrm{INSMAN}(L) * \mathrm{WAGINS}(L)) * (1 + \mathrm{BURFAC}) \tag{17}$$

where DIRMAN(L) is the direct labor personnel employed in shift schedule L,
INSMAN(L) is the indirect support personnel employed in shift schedule L,
WAGDIR(L) is the direct labor wage rate for shift schedule L (\$/person-year),
WAGINS(L) is the indirect support labor and management wage rate for shift schedule L (\$/person-year), and
BURFAC is the labor burden factor (decimal percent.)

Direct labor personnel (DIRMAN(L)) is further defined as

$$\text{DIRMAN(L)} = f_6\ (\text{NCELL(I,L), DIRLAB(I,L)}) \tag{18}$$

where NCELL(I,L) is the number of hot cells of type I for shift schedule L, and
DIRLAB(I,L) is the direct labor required for hot cell type I and shift schedule L.

Indirect labor (INSMAN(L)) for shift schedule L is

$$\text{INSMAN(L)} = f_7(\text{NCELL(I,L), INSLAB(I,L)}) \tag{19}$$

where INSLAB(I,L) is the indirect labor required for hot cells of type I and shift schedule L.

The material and supply costs (SUPPLY(L)) include stationary and drafting supplies, hand tools, welding rods, grease, oil, paint and painting supplies, laboratory and plant chemicals and supplies, work clothing and laundry supplies, health physics small tools and supplies, and other miscellaneous expenses.

The material and supplies costs are proportional to the number of people employed for each of the L shift schedules.

$$\text{SUPPLY(L)} = \text{DIRMAN(L)} * \text{DIRSUP} + \text{INSMAN(L)} * \text{INSSUP} \tag{20}$$

where DIRSUP is the average cost per year of material and supplies for each person in the direct labor category (\$/person-year), and
INSSUP is the same as DIRSUP but for the indirect labor category (\$/person-year).

The annual energy costs include electricity, space heating, motive power for the rail car handling system, and forklifts and equipment. The energy costs are combined with the miscellaneous costs and are represented by ENERGY(L) as

$$\text{ENERGY(L)} = f_8\ (\text{Shift Schedule, TOTCEL(L)}) \tag{21}$$

where Shift Schedule is the number of 8-hour shifts per week, and
TOTCEL(L) is the total number of hot cells utilized for shift schedule L.

Decommissioning

The packaging facility decommissioning costs (DCMCOS(t,L)) are assumed to be a fixed percentage of the total capital costs (CAPTOT(L)). The decommissioning costs for shift schedule L and year t are

$$\text{DCMCOS(t,L)} = \text{CAPTOT(L)} * \text{DECOM} * \text{DSTDCM(t)} \tag{22}$$

where DECOM is the decommissioning percentage factor, and
DSTDCM(t) is an assumed distribution factor.

Other Adjustments

In order to facilitate certain economic analyses, all of the previously described costs may be discounted to their present value. The present value analysis involves equations which allow one to perform two operations. First, one may incorporate real price trends into each of the previously described cost calculations. That is, the user may either keep relative prices constant over time or let them change so that real, constant dollar costs change with time. Second, the user may discount the time streams of constant dollar costs to their present value with a user-supplied discount rate.

Capital, operating, and decommissioning costs are adjusted for relative price trends as follows.

$$\text{Real Cap Cost(t,L)} = \text{CAP(t,L)} * \left[\frac{1+r_c}{1+g}\right]^I \tag{23}$$

$$\text{Real Op Cost(t,L)} = \text{OPCOS(t,L)} * \left[\frac{1+r_o}{1+g}\right]^I \tag{24}$$

$$\text{Real Decom Cost(t,L)} = \text{DCMCOS(t,L)} * \left[\frac{1+r_d}{1+g}\right]^I \tag{25}$$

where r_c is the annual rate at which capital costs change,
r_o is the annual rate at which operating costs change,
r_d is the annual rate at which decommissioning costs change,
g is the annual rate at which the GNP deflator changes, and
I is the number of years between the base year and the simulated year t.

Once the costs have been adjusted for relative price trends, they are discounted to their present value as follows:

$$\text{PV Cap Costs(L)} = \sum_t \frac{\text{Real Cap Costs(t,L)}}{(1+\text{DSCNT})^I} \tag{26}$$

$$\text{PV Op Costs(L)} = \sum_t \frac{\text{Real Op Costs(t,L)}}{(1+\text{DSCNT})^I} \tag{27}$$

$$\text{PV Decom Costs(L)} = \sum_t \frac{\text{Real Decom Costs(t,L)}}{(1+\text{DSCNT})^I} \tag{28}$$

where DSCNT is the real discount rate, and
I is the number of years between the base year and the simulated year t.

PACCOM determines the optimum shift schedule for the WHPF operations by identifying the shift schedule for which the sum of the capital, operating, and decommissioning costs is the smallest. The optimum total cost (OPTCOS) is given by

$$\text{OPTCOS} = \text{Minimum of TOTCOS(L) over all L} \tag{29}$$

where TOTCOS(L) is the sum of the discounted capital, operating, and decommissioning costs for all the years of the facility's life cycle.

MODEL USE

One repository design issue of interest is the extent to which one creates a facility in which capital is the relatively dominant factor versus one in which labor is the relatively dominant factor. In the case of the WHPF, this issue involves the number of hot cells included in the facility, the number of shifts for which those hot cells are operated, and the total number of persons employed.

Since the repository, and consequently the WHPF, will presumably operate at a predetermined production rate, choosing the optimum capital to labor mix represents a classic economic problem; namely, that of finding the mix of capital and labor that minimizes total costs subject to a fixed level of production. Using economic theory, one can deduce that this minimization is achieved when the combination of labor and capital is such that the ratio of their respective factor prices (labor and capital) is equal to the ratio of their marginal products. Factor prices are a function of wage rates, facility and equipment costs, and the discount rate used in converting future costs to their present value. Marginal products, which represent the additional output one could realize through the application of one additional unit of the respective factor, are affected by technology and by the relative amounts of labor and capital employed in the production process.

For real facilities, including the WHPF, it is difficult to analytically determine marginal products; consequently, the optimum mix of labor and capital is not readily apparent. However, the problem can be solved quite easily using PACCOM. For fixed production levels, factor prices, and technology (facility capacities), PACCOM identifies the number of shifts leading to the facility's lowest total life cycle cost. The staff and the number of hot cells associated with this least cost number of shifts represent the optimum capital to laboratory ratio.

CONCLUSION

PACCOM is currently undergoing model verification. Upon completion of this verification phase, the model will become a useful tool for analyzing alternative conceptual designs of the WHPF. In this regard, PACCOM's main strength lies in its parametric nature. This parametric nature allows one to quickly investigate the effects of many alternative assumptions on the design and cost of the WHPF. A parametric tool such as PACCOM should consequently contribute to a more efficient repository conceptual design phase.

REFERENCE

1. U. S. Congress, Nuclear Waste Policy Act of 1982, Pub. L. 97-425, 97th Congress, Jan. 7, 1983, H. R. 3809.