METHODOLOGY FOR THE COST EVALUATION OF RADIOACTIVE WASTE MANAGEMENT ROUTES

S. Kowa , F. Stenersen
Kraftanlagen AG Heidelberg,
Im Breitspiel 7, D-6900
Heidelberg, Germany

T. Shamsi, , G.M. Thiels
TASK Ricerca & Sviluppo S.r.t.,
Via Verbano 2, I-2102 Ispra, Italy

ABSTRACT

One of the significant aspects of radioactive waste management is cost. To determine plant costs for radioactive waste management routes, a method was developed by the Joint Venture Kraftanlagen Heidelberg (FRG) and Task R & S (Italy) to perform a realistic, economic cost assessment of different waste management schemes.

This assessment procedure was first developed for System Studies concerning the Management and Storage of radioactive waste in the frame of the 2nd R & D program of the Commission of the European Communities (CEC) and is presently being applied in the 3rd R & D program to assess the costs of different management schemes for LWR Waste and Zircaloy hulls.

DETERMINATION OF COSTS

To be able to compare different waste treatment methods it is necessary to use an uniform basis for the evaluation of plant costs. The developed method is generally based on:

- Determination of various cost elements entering into the capital and operating cost calculation.
- Actualization of the costs and their conversion into annual costs per unit volume of treated waste.
- Scaling of costs with changing plant capacity.

Definition Of Cost Elements

For a management option both the capital and operating costs are evaluated taking into account the cost elements illustrated in Fig. 1. The owner's cost has been omitted from the cost assessment, since land purchase values and regulations concerning taxes, licensing and insurance completely depend on the location of the proposed plant.

Cost Determination Procedure

Chemical block diagrams, detailed process description and engineered flowsheets are essential requirements to perform an economic assessment. The capital cost is derived by evaluating the requirements for the Major Equipment and Civil Works. These direct cost values are then factored to generate the other direct and indirect costs. More specifically, the following procedure is applied:

- The material cost of the Major Equipment, based on the fabricated component prices, is used as "Base Value". Where specific design information is limited, costs are calculated utilizing engineering judgement and recent nuclear experience.
- The other direct cost elements, except the Civil Works, are expressed as a percentage of the "Base Value" (Table I). Due to the possible divergent complexity of the processes, different percentages might have to be applied.
- The cost for the Civil Works is obtained by applying a unit volume cost to the estimated volume of the facility.
- The cost of each element is further divided into material and labor costs as shown in Table III. The given values are based on experience, but might be changed due to the complexity of the process.
- The indirect capital cost, consisting of the Architectural & Engineering Services, is fixed to 25 % of the total direct capital cost.(An average value, based on many years of experience of constructing nuclear facilities.) (1) Alternatively, this fraction can be calculated using the following formula (2), which considers the size of the plant as reflected by the total direct capital cost (Fig. 2):

$$a = 1.36 - (0.0687 \cdot \ln D) \qquad \text{(Eq. 1)}$$

and

$$I = a \cdot D \qquad \text{(Eq. 2)}$$

where:

a = indirect capital cost factor

D = total direct capital cost

I = indirect capital cost

For the operating cost the criteria given in Table II are used to calculate the annual cost of the different elements.

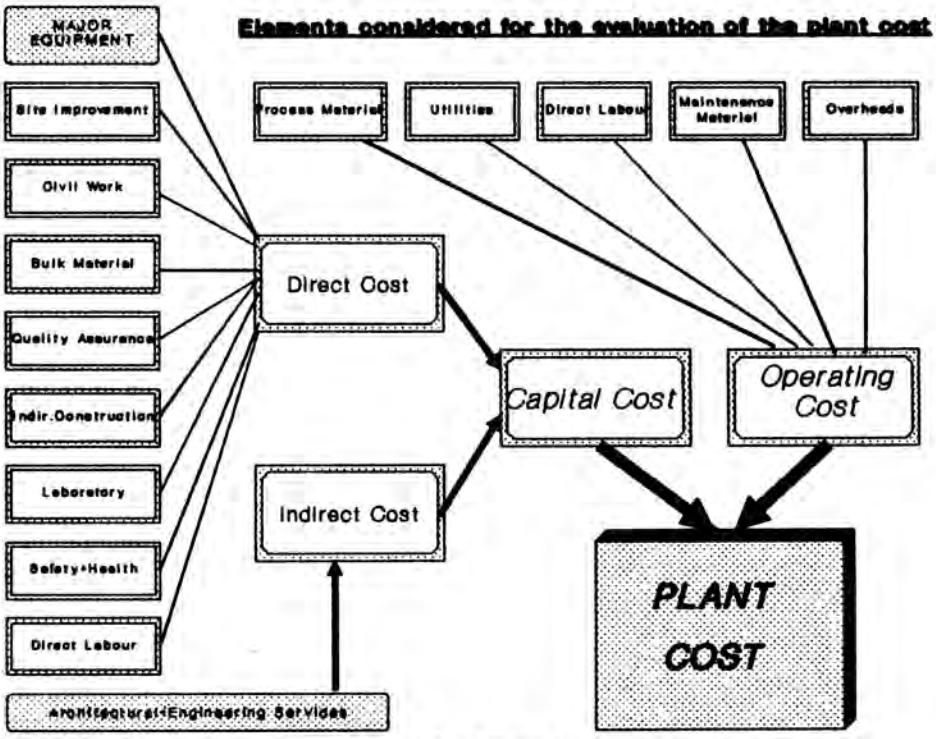

Fig. 1. Elements Considered for the Evaluation of the Plant Cost.

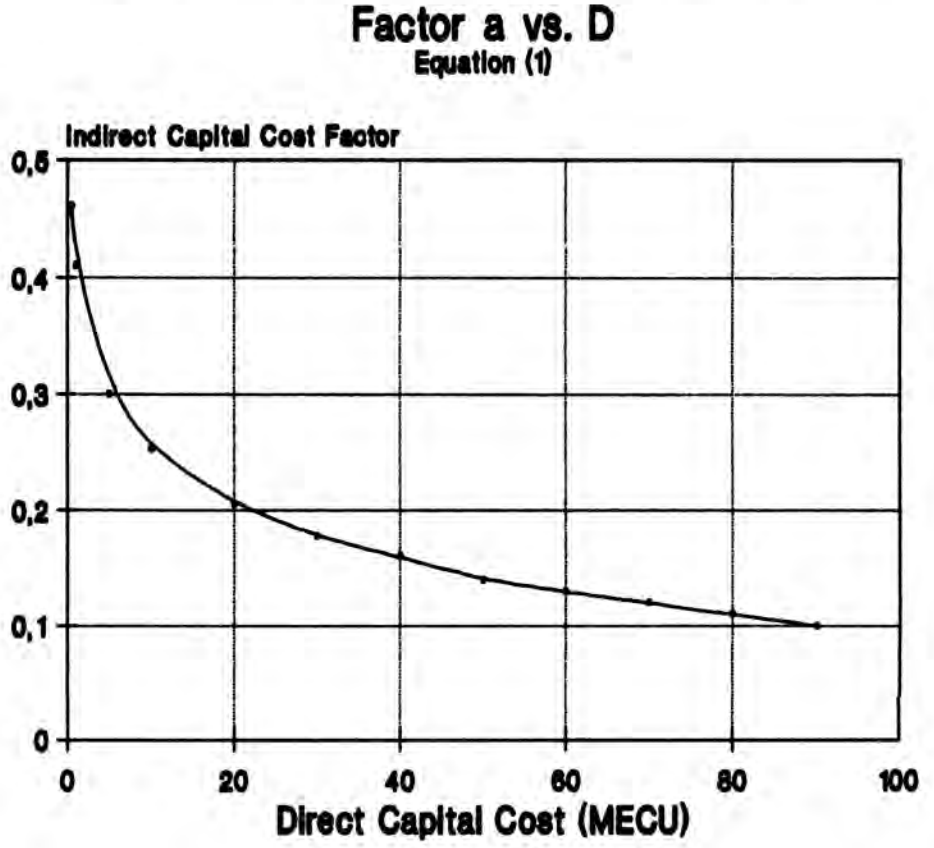

Fig. 2. Direct Capital Cost.

TABLE I

Cost Determination of the Capital Cost

Material cost of Major Equipment	=Base Value (BV)
Labour cost of Major Equipment	=.....% of BV
Site Improvement	=.....% of BV
Bulk Material	
Piping	=.....% of BV
Instrumentation	=.....% of BV
Quality assurance	=.....% of BV
Indirect construction	=.....% of BV
Laboratory	=.....% of BV
Safety and Health Physics	=.....% of BV
Civil works	=.....X* m-3
DIRECT CAPITAL COST (D)	= Σ
INDIRECT CAPITAL COST (I)	=.....% of D or = a*D

TABLE II

Criteria Applied for the Calculation of the Elements of the Operating Costs

ELEMENT	CRITERIA VALID FOR YEAR .....
Process Material	Unit price*Annual Quantity (...X*a-1)
Utilities	Unit price*Annual Quantity (...X*a-1)
Maintenance Material	...%*a-1 of the material cost of Major Equipment + Bulk Material
Direct Labour	.....X * h-1 * Manhours/a
Overheads	.....X * h-1 * Manhours/a

TABLE III

Percentages Used to Calculate the Material and Labor Costs of Each Direct Cost Element

COST ELEMENT	% of Total Cost of Element	
	Material Cost	Labour Cost
Site Improvement	30	70
Civil works	40	60
Bulk Material (Piping+ Inst.)	50	50
Quality assurance	30	70
Indirect construction	20	80
Laboratory	90	10
Safety+Health Physics	90	10
TOTAL MATERIAL COST	Σ + Base Value	
TOTAL DIRECT LABOUR		+ 20 % of Base Value for installation of Major Equipment

X = monetary unit

Transport Cost

The capital cost for the transport reflects the acquisition of the casks at the start-up of the plant, whereas the annual operating cost consists of the freight cost by either road or rail, custom duties and insurance. A transport journey is defined as the transport of the casks to the disposal site and their return to the waste treatment plant.

ACTUALIZATION OF COSTS

To perform a cost projection for a plant, other parameters, such as the plant life, interest and inflation rates, must be considered in addition to the capital and operating costs. From an economic point of view, the plant consists of an investment for plant construction and operation; the costs for the latter are distributed over the life time of the plant. In this context, many methods have been developed to evaluate the investment cost. (3 - 6)

Actualization Procedure

The procedure elaborated for the actualization of the capital and operating costs is based on the "Present Worth" method. In this method compound interest factors are used to compound or discount all cash flows to their equivalent value at time zero, using a minimum acceptable rate of return as the interest rate. Time zero may be chosen arbitrarily, but the start of operation is usually taken.

A problem associated with this method is the determination of the appropriate interest rate. However, this is not a fault of the method itself. Considering a range of reasonable values is often sufficient in a cost-benefit analysis.

The choice of any method largely depends on available information and type of project to be evaluated. At present, preference has been given to the present worth method, because it is the most generally used procedure for cost-benefit analysis. Moreover, it is suitable for projects, which do not have positive returns, a situation in which the application of the other methods is uncertain.

The following assumptions have been made for the actualization:

- The date of actualization is the start-up of the plant.
- The duration of plant construction depends on the degree of complexity of the management route.
- Annual rate of interest $i = X\% \cdot x^{-1}$ X,Y = present values
- Annual rate of inflation $e = Y\% \cdot a^{-1}$
- For the capital cost, working capital is borrowed at the middle of the duration period of each cost element and paid back at the end of the construction period. For this purpose a bar chart is used for the actualization of the capital cost. An example of such a bar chart is shown in Fig. 3.

The equations used for the actualization procedure are briefly described.

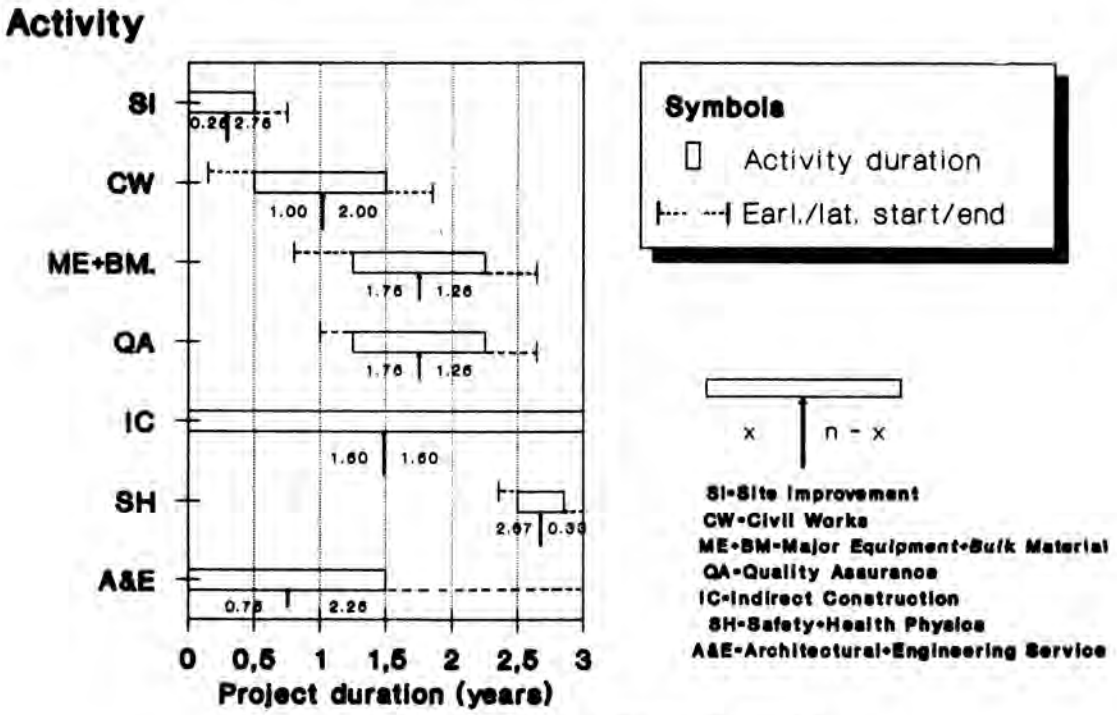

Fig. 3. Bar Chart Used for Actualization (Example).

CAPITAL COST

Direct Capital Cost

Except for the direct labor, the nominal total cost of each element with reference to the year 19.. is calculated as follows:

Civil works:

P_j = (cost per unit volume) • (volume of building) (Eq. 3)

Other cost elements:

$P_j = f_j \cdot B$ (Eq. 4)

All cost elements are then actualized to the start-up date of the plant using expression (5):

$C_j = P_j \cdot (1 + e)^x \cdot (1 + i)^{(n-x)}$ (Eq. 5)

Each actualized cost element is further divided into material and labor costs using expressions (6) and (7):

$M_j = C_j \cdot m_j$ (Eq. 6)

$L_j = C_j - M_j$ (Eq. 7)

Finally, the actualized direct capital cost is given by:

$$D_a = \sum_{j=1}^{k} M_j + \sum_{j=1}^{k} L_j \quad \text{(Eq. 8)}$$

or

$D_a = M_a - L_a$ (Eq. 9)

Indirect capital cost

The nominal value of the indirect capital cost is expressed as a percentage of the nominal direct capital cost in 19.. and then actualized using expression (10):

$I_a = (a \cdot D) \cdot (1 + e)^x \cdot (1 + i)^{(n-x)}$ (Eq. 10)

Annual Operating Cost

Since the yearly operating cost is required at the start-up date of the plant, the nominal values of the cost elements in 19.. are actualized using expressing (11):

$C_j = P_j \cdot (1 + e)^n$ (Eq. 11)

Thus, the actualized annual operating cost is given by:

$$O_a = \sum_{j=1}^{f} C_j \quad \text{(Eq. 12)}$$

Transport Cost

It has been assumed that the transport casks will be acquired on the start-up date of the plant. Therefore, both the capital and annual operating costs are actualized using equation (11).

Annual Cost per Unit Volume

To convert the actualized capital and annual operating costs into an annual cost per unit volume of waste treated, the "Annual Cost" method is applied.

The following data form the basis for the conversion:

- Total duration of plant operation = L (a)
- All costs are actualized to the start-up date of the plant.

The following assumptions have been made:

- An investment is required for the operating cost, since no returns are foreseen.
- The money to cover the total operating cost will be invested at the start-up date of the plant. Therefore, both interest and inflation rates have to be taken into account.
- Annual rate of interest = X % • a^{-1} X,Y = present values
  Annual rate of inflation = Y % • a^{-1}

Conversion Of Annual Operating Cost Into Total Operating Cost

Since the operating cost is a constant annual expenditure, equation (13) is applied to obtain the total operating cost actualized to the start-up date of the plant:

$$O = O_a \left[\frac{1+e}{i-e}\right] \cdot [1 - \left[\frac{1+e}{1+i}\right]^L] \quad \text{(Eq. 13)}$$

for i unequal e and L > O

Actualized Total Plant Cost

The total cost of the plant is the summation of the actualized total capital cost and the actualized total operating cost:

$T = C + O$ or $T = (D_a + I_a) + O$ (Eq. 14)

Conversion of Total Cost Into Annual Cost Per Unit Volume

Using equation (15), the actualized total cost is transformed into a constant annual expenditure t, throughout the life span of the plant.

$$t = T \cdot \frac{i}{1-(1+i)^{-L}} \quad \text{(Eq. 15)}$$

Finally, the constant annual expenditure is divided by the yearly amount of waste treated, thus yielding the constant annual cost per unit volume:

$$t_w = \frac{t}{W} \qquad \text{(Eq. 16)}$$

Conversion Of Transport Cost Into Annual Cost Per Unit Volume

Equations (13) to (16) are also applied to convert the actualized capital and annual operating costs associated with the transport into a constant annual transport cost per unit volume of waste treated.

SCALING OF COSTS

A general procedure has been established for the scaling of costs with changing plant capacity. It is based on the standard formulas available in the literature. The present approach takes into account the different behavior of the various cost elements, thereby reducing the associated error.

General Equation

It has been shown (6 - 8) that the following expression satisfactorily described the correlation between cost and plant capacity:

$$C_n = C_o * \left[\frac{R_n}{R_o}\right]^m \qquad \text{(Eq. 17)}$$

Experience in the chemical industry has demonstrated that a value of 0.6 for m generally results in a good correlation between cost and plant capacity, presuming an identical process. This relationship between cost and plant capacity is shown in Fig. 4.

PLANT COST

Direct Capital Cost

Using equation (17) and a scaling factor of 0.6, the "Base Value" for the new plant capacity is calculated. All other cost elements, except the Civil Works, are expressed as a percentage of this new "Base Value".

To obtain the cost of the Civil Works, the volume of the new building is calculated as follows:

$$V_n = \left[V_s * \frac{R_n}{R_o}\right] + \left[V_p * \left[\frac{R_n}{R_o}\right]^m\right] \qquad \text{(Eq. 18)}$$

with m = 0.2 for $R_n > R_o$

m = 0.05 for $R_n < R_o$

Finally, the cost elements of the direct capital cost are actualized as described in §3.1.

Indirect Capital Cost

The indirect capital cost, expressed as a fraction of the direct capital cost, varies inversely with the size of the plant (2). This fraction can be calculated using equation (1) and the direct capital cost of the re-scaled facility. The relationship between this fraction and plant capacity is illustrated in Fig. 2. The actualized value of the indirect cost is obtained as detailed under §3.1.

Annual Operating Cost

The cost elements of the annual operating cost are calculated using equation (17) and the following scaling factors (see Fig. 4):

- m = 1.0 for Process Materials;
- m = 0.6 the "Base Value" for Utilities, Direct Labor and Maintenance Materials;
- m = 0.0 for Overheads.

The cost associated with the various elements of the operating cost are actualized by applying equation (11).

Transport Cost

Both the capital and annual operating costs associated with the transport of the treated waste from the reference plant are multiplied with the capacity factor (R_n/R_o) to obtain their values for the new plant capacity. They are then actualized using equation (11).

Annual Cost per Unit Volume

The annual cost per unit volume for the new plant capacity and the associated waste transport is calculated following the procedure given under §3.5.

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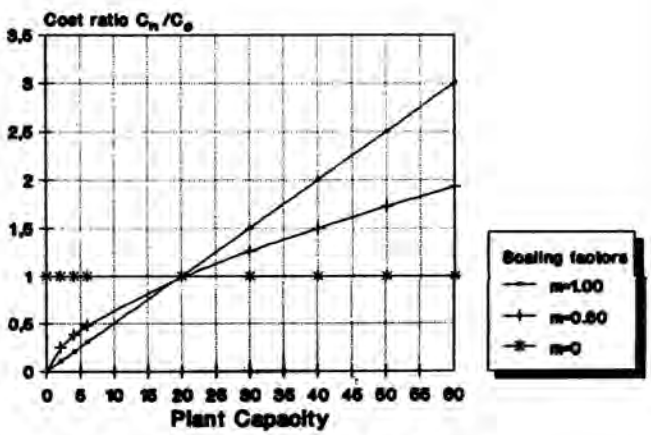

Fig. 4. Cost vs. Plant Capacity.

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NOMENCLATURE

a = Indirect capital cost factor

B = Base Value

C = Actualized total capital cost = $D_a + I_a$

C_j = Actualized total cost of j^{th} cost element

C_n = Cost of new facility

C_o = Cost of reference facility

D = Total direct capital cost

D_a = Actualized total direct capital cost

e = Annual rate of inflation

f = Total number of operating cost elements

f_j = Fraction of "Base Value" for j^{th} cost element

I = Indirect capital cost

I_a = Actualized indirect capital cost

i = Annual rate of interest

k = Total number of direct capital cost elements

L = Duration of plant operation (a)

L_a = Actualized total labor cost

L_j = Actualized labor cost of j^{th} cost element

M_a = Actualized total material cost

M_j = Actualized material cost of j^{th} cost element

m = Scaling factor

m_j = Material fraction of the total actualized cost of j^{th} cost element

n = Total duration of plant construction (a)

O = Actualized total operating cost

O_a = Actualized annual operaint cost

P_j = Nominal total cost of j^{th} cost element

p = Life of the project (a)

R_n = Capacity of new facility

R_o = Capacity of reference facility

T = Actualized total cost

t = Constant annual expenditure

t_w = Constant annual cost per unit volume

V_n = Total volume of buildings of new facility (m^3)

V_s = Volume of treated waste storage building of reference facility (m^3)

V_p = Volume of process building of reference facility (m^3)

W = Annual volume of waste treated ($m^3 . a^{-1}$)

x = Time duration between the start of plant construction and the middle of the activity for the j^{th} cost element (a)