A LEVEL PLAYING FIELD—OBTAINING CONSISTENT COST ESTIMATES FOR ADVANCED REACTOR DESIGNS*

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INTRODUCTION

A level playing field in sports is necessary to avoid a situation in which a team has an unfair advantage over its competition. Similarly, rules and guidelines for developing cost estimates can be established which, in effect, provide a level playing field whereby cost estimates for advanced concepts can be presented on a consistent and equitable basis. As an example, consider the capital costs shown in Table I. Both sets of cost are for the exact same power plant; Estimate 1 is expressed in constant dollars while Estimate 2 is presented in nominal or as-spent dollars. As shown, the costs in Table I are not directly comparable. Similar problems can be introduced as a result of differing assumptions in any number of parameters including the scope of the cost estimate, inflation/escalation and interest rates, contingency costs, and site location.

TABLE I

EXAMPLE CAPITAL COST DATA, MILLIONS $

	Cost Account	Estimate 1	Estimate 2
20.	Land and land rights	5	5
21.	Structures and improvements	299	299
22.	Reactor plant equipment	713	713
23.	Turbine plant equipment	242	242
24.	Electric plant equipment	98	98
25.	Miscellaneous plant equipment	75	75
26.	Main cond. heat reject system	45	45
	Total direct costs	1477	1477
91.	Construction services	211	211
92.	Home office engr. and service	274	274
93.	Field office supervision	137	137
94.	Owner's costs	192	192
	Total indirect costs	815	815
	BASE CONSTRUCTION COST	2292	2292
	CONTINGENCY	469	469
	TOTAL OVERNIGHT COST	2761	2761
	ESCALATION	0	1089
	INTEREST DURING CONSTRUCTION	1034	2965
	TOTAL CAPITAL COST	3795	6815

Of course, the motivation for having consistent cost estimates is to permit comparison among various concepts. The emphasis in this particular endeavor has been in promoting the comparability of advanced reactor cost estimates among themselves and to existing power plant types. To continue with the analogy, the idea is to lay out the playing field and the rules of the contest such that each team participates in the match on an equal basis with the final score being solely determined by the inherent strengths and abilities of the teams. A description of the playing field and some of the more important rules will now be provided.

GROUND RULES AND GUIDELINES

In order to obtain consistent cost estimates, the scope of the estimate must first be defined. For the advanced reactor designs, the scope includes the plant capital cost, the operating and maintenance (O&M) cost, the fuel cycle cost, and the cost of decommissioning. As capital, O&M, and fuel cycle costs are the predominant contributors toward total plant cost, a cost reporting structure has been established for these elements. Each element is subdivided as is necessary to provide a common reporting format for all power plant concepts.

For detailed capital costs, the reporting format selected is the DOE Energy Economic Data Base (EEDB) account structure. This code of accounts has been used by DOE and its predecessor agencies for about 18 years to estimate the capital cost of existing and future power plant types. DOE currently maintains within the EEDB a set of detailed reference capital costs for light water reactor and coal-fired power plants

(1). These reference costs will be discussed further later in the paper. For now, an example of a portion of the EEDB account structure is provided in Table II.

Just as the scope of the cost estimate and the reporting formats mentioned above tend to define the playing field, to draw again on the analogy, the rules and required assumptions influence the conduct of the event. One of the more important rules is how the costs will be expressed. As shown in Table I, costs can be expressed in constant or nominal dollars and in different year's value. For the advanced reactor designs, all costs, irrespective of when they actually take place, are to be expressed in dollars having a constant purchasing power equivalent to the current year's dollars. Because the expenditures are all expressed in dollars of a common purchasing power, it is called a constant dollar estimate. Although the choice of reporting costs in constant or nominal dollar terms is rather arbitrary, the constant dollar estimate does have the advantage of expressing costs in magnitudes that are more familiar on a relative basis. As a quick example, a loaf of bread that costs $1.00 today will, assuming a 5 percent inflation rate, cost $3.07 in the year 2010. It is somewhat easier to comprehend $1 rather than $3 for loaf of bread. A similar situation exists for the constant and nominal dollar estimates in Table I.

Also related to the constant/nominal dollar selection is the choice of a summary figure of merit. As it is desirable to have a summary figure of merit that reflects all the costs of a concept, the total generation cost including capital, O&M, fuel, and decommissioning costs is a suitable choice. Of course, O&M and fuel cycle costs may differ

TABLE II

EXAMPLE EEDB CAPITAL COST ACCOUNT STRUCTURE

Account No.	Description
220A	Nuclear steam supply (NSSS)
220B	NSSS options
221	Reactor equipment
222	Main heat transfer transport system
223	Safeguards system
224	Radwaste processing
225	Fuel handling and storage
226	Other reactor plant equipment
227	Reactor instrumentation and control
228	Reactor plant miscellaneous items
22	Reactor plant equipment
231	Turbine generator
233	Condensing systems
234	Feed heating system
235	Other turbine plant equipment
236	Instrumentation and control
237	Turbine plant miscellaneous items
23	Turbine plant equipment

from year to year, even on a constant dollar basis, so it is necessary to derive a levelized value that is equivalent to the actual, varying annual costs over the life of the plant. This levelized total generation cost is developed by taking the present worth of all the expenditures during the assumed plant life and dividing that amount by the present worth of all the energy generated during that period.

Expressed mathematically,

$$\overline{LC} = \frac{\sum_{i=1}^{n} \frac{C_i}{(1+d)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+d)^i}} \qquad (1)$$

where: $\overline{LC}$ = levelized cost

C_i = cost in period i

E_i = energy generated in period i

d = present worth discount rate

n = economic plant life.

The presentation of Equation 1 introduces the need to define a host of parameters that affect the cost estimate. To obtain consistent cost estimates, the present worth discount rate and the economic life of the plant must be defined. Similarly, parameters such as escalation, inflation, cost of money, tax rates, and depreciation schedules need to be specified. Much of the data that have been used for these parameters comes from the DOE Nuclear Energy Cost Data Base [NECDB] (2). As a result of the Tax Reform Act of 1986, some of the parameters have been revised. Table III provides the previous and revised values for some of the parameters that must be specified.

TABLE III

COST ESTIMATE PARAMETERS

Parameter	Previous Value	Revised Value
Federal income tax rate, %/year	46	34
State income tax rate, %/year	4	4
Combined tax rate, %/year	48.16	36.64
Tax depreciation duration for nuclear plants, years	10	15
Economic plant life, years	30	30
Average cost of money, %/year	11.35	11.35
Effective (tax-adjusted) cost of money, %/year	9.0	9.57
Inflation rate, %/year	5	5
Real (inflation-adjusted) cost of money, %/year	3.81	4.35
Real discount rate, %/year	3.81	4.35

Other factors must also be delineated in order to have all the estimates reflecting the same conditions. An assumed plant site must be described with such information as the site geology, seismology, meteorology, hydrology, access to utilities, and local craft labor rates. Assumed market prices for certain fuel cycle items or services purchased or procured off the power plant site also need to be declared for consistent cost estimating. Examples of these and their current assumed cost are:

- Uranium ore--$35.00/pound
- Uranium conversion--$8.20/kg U
- Enrichment--$110/kg SWU
- Waste disposal--1 mill/kwh

Finally, as part of the reporting/estimating requirements, the desired type and degree of data supporting the cost estimate should be specified to the cost estimating teams. This can include labor and bulk commodity requirements, additional research and development needs, construction cash flow projections, O&M staffing requirements, and fuel cycle timing assumptions.

APPLICATION OF THE RULES

As a means of testing the application of the rules and guidelines as well as developing reference costs for current technologies, several different sized coal and pressurized water reactor (PWR) plant cost estimates have been prepared. The PWR plant costs are representative of best cost experience for recently completed stations. A summary of the results will now be presented.

Capital cost was estimated using the DOE EEDB and the CONCEPT computer code (1,3). The total plant capital cost for each plant is given in Table IV. An example of the summary level capital cost reporting is shown in Table V for a coal and PWR plant. Non-fuel O&M costs were estimated using the OMCOST computer code and are summarized in Table VI (4). A more detailed O&M summary for two plants is shown in Table VII. Coal fuel costs were based on an assumed delivered price of $1.75/million Btu in 1987 and a real escalation of 1%/year. Nuclear fuel costs were based on an extended burn-up fuel and were calculated using the REFCO computer code (5). Decommissioning cost for the PWR plants was based on the DOE NECDB assumption of $143 million for an 1100 MWe plant. Using Equation 1, a constant dollar levelized cost was calculated for each component of the total generating cost. These costs are summarized in Table VIII.

CONCLUSION

The remaining step in this process of setting the stage for obtaining consistent cost estimates is to document the ground rules and guidelines so that they may be used by the designers as a reference during cost estimate preparation. This has been done in a report prepared by Oak Ridge National Laboratory which provides additional detail on the rules and example calculations (6). These guidelines have now been used in the preparation of recent cost estimates by the advanced liquid metal reactor (LMR) designers. A review of these estimates has shown that the guidelines are effective in producing consistent cost estimates, or in other words, a level playing field.

TABLE IV

TOTAL PLANT CAPITAL COST DATA, MILLIONS 1987$

Plant type	Total capital cost
400-MW(e) single-unit coal	730
400-MW(e) first of two units coal	733
400-MW(e) second of two units coal	556
600-MW(e) single-unit coal	913
600-MW(e) first of two units coal	917
600-MW(e) second of two units coal	696
800-MW(e) single-unit coal	1071
800-MW(e) PWR	1733
1200-MW(e) PWR	2123

TABLE V

SUMMARY CAPITAL COST ESTIMATES, MILLIONS 1987$

EEDB Account No.	EEDB Account description	800 MWe PWR plant	800 MWe coal plant
20	Land and land rights	5	5
21	Structures and improvements	340	213
22	Reactor/boiler plant equipment	383	306
23	Turbine plant equipment	273	228
24	Electric plant equipment	120	79
25	Miscellaneous plant equipment	64	43
26	Main conditioning heat reject system	59	49
Total direct costs		1244	923
91	Construction services	301	164
92	Home office engineering and service	368	201
93	Field office engineering and service	407	102
94	Owner's costs	232	139
Total indirect costs		1309	606
BASE CONSTRUCTION COST		2553	1529
	— [$/kW(e)]	2128	1274
CONTINGENCY		499	299
TOTAL OVERNIGHT COST		3052	1828
	— [$/kW(e)]	2543	1523
ESCALATION		0	0
INTEREST DURING CONSTRUCTION		699	295
TOTAL CAPITAL COST		3751	2123
	— [$/kW(e)]	3126	1769

TABLE VI

POWER PLANT O&M COST DATA, MILLIONS 1987$

Plant type	Annual O&M cost
400-MW(e) single-unit coal	22.9
600-MW(e) single-unit coal	25.0
800-MW(e) single-unit coal	27.1
800-MW(e) two-unit coal	34.6
1200-MW(e) two-unit coal	38.9
800-MW(e) PWR	47.4
1200-MW(e) PWR	47.8

TABLE VII

ANNUAL OPERATING AND MAINTENANCE COST ESTIMATES, MILLIONS 1987$

O&M Cost Description	800 MWe PWR plant	800 MWe Coal plant
Power Generation Costs		
On-site staff	19.08	15.04
Maintenance materials		
Fixed	5.93	4.84
Variable	1.61	0.83
Supplies and expenses		
Fixed	6.30	5.95
Variable	0.94	0.56
Off-site technical support	8.24	1.44
Subtotal	42.10	28.66
Administrative and General Costs		
Pensions and benefits	4.85	4.85
Nuclear regulatory fees	1.25	0.00
Liability insurance	0.50	0.00
Property insurance	4.10	4.10
Replacement power insurance	1.60	0.00
Other A&G expenses	6.32	4.59
Subtotal	18.62	13.54
Total non-fuel O&M cost	60.72	42.20

TABLE VIII

POWER PLANT LEVELIZED COST SUMMARY, 1987 MILLS/KWH

Plant	Capital	O&M	Fuel	Decommissioning	Total
400-MW(e) single-unit coal	27.90	9.33	22.19		59.42
600-MW(e) single-unit coal	23.26	6.79	21.97		52.02
800-MW(e) single-unit coal	20.47	5.52	21.74		47.73
800-MW(e) two-unit coal	24.69	7.13	22.30		54.12
1200-MW(e) two-unit coal	20.60	5.34	22.08		48.02
800-MW(e) PWR	34.24	9.66	6.96	0.42	51.28
1200-MW(e) PWR	27.97	6.49	6.96	0.42	41.84

As a result of the new tax laws and experience from the recent LMR estimates, the guidelines are currently being revised, and an updated report will be available soon.

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