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COMPUTERIZED COST ESTIMATION SPREADSHEET AND COST DATA BASE FOR FUSION DEVICES*

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ABSTRACT

An important facet of developing engineering design concepts is the ability to promptly and accurately project the total constructed cost of a given device concept, since these cost projections are important factors for future decisions on project scope. In order to provide a credible and consistent means for projecting the total constructed cost of a given device or reactor concept, an automated approach to performing and cataloging cost estimates has been developed at the Fusion Engineering Design Center (FEDC), wherein the cost estimate record is stored in the LOTUS 1-2-3† spreadsheet on an IBM† personal computer. The cost estimation spreadsheet is based on the cost coefficient/cost algorithm approach to cost estimating and incorporates a detailed generic code of cost accounts for both tokamak and tandem mirror devices. Component design parameters (weight, surface area, etc.) and cost factors are input, and direct and indirect costs are calculated. The cost data base file derived from actual cost experience within the fusion community and refined to be compatible with the spreadsheet costing approach is a catalog of cost coefficients, algorithms, and component costs arranged into data modules corresponding to specific components and/or subsystems. Each data module contains engineering, equipment, and installation labor cost data for different configurations and types of the specific component or subsystem. This paper describes the assumptions, definitions, methodology, and architecture incorporated in the development of the cost estimation spreadsheet and cost data base, along with the type of input required and the output format.

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†Reference within this paper to any specific commercial product, process, or service by trademark, trade name, manufacturer or otherwise, does not necessarily constitute or imply its endorsement, recommendation by the U.S. government or any agency thereof.

INTRODUCTION

The role of the FEDC is to develop preconceptual engineering design concepts for the next generation of tokamak, tandem mirror, and alternative confinement concept power reactors and experimental devices. An important facet of this design activity is the effort related to projecting the cost of the given facility. Past experience has demonstrated that "bottoms-up" cost estimates of leading-edge-of-technology devices at the preconceptual design level are consistently inaccurate. This traditional estimating method involves summing the cost of subsystem components, beginning with the smallest details and combining these into larger and larger assemblies until the entire subsystem is complete. The "bottoms-up" method is an excellent cost-estimating method where the design has matured to a final level of detail and the components are standard, off-the-shelf items whose costs are accurately known. The absence of a mature design at the preconceptual level makes total "bottoms-up" cost estimating very difficult, at best, due to the inherent lack of design definition and detail.

An automated method for performing, cataloging, and recording cost estimates that is compatible with the preconceptual level of design definition and detail has been developed at FEDC. This method combines a computerized cost estimation spreadsheet that incorporates a detailed generic code of accounts, standard cost element definitions, and the parametric cost-estimating approach with a cost data base file derived from actual cost experience. This paper provides a description of the computerized cost estimation spreadsheet and the FEDC cost data base file.

FEDC COST ESTIMATE PROCEDURE

The overall approach to assembling a project cost estimate at FEDC consists of parallel project design and cost data base activities. Near the end of the preconceptual design activity, when the quantities of materials and equipment can be estimated, cognizant engineers submit standardized design data sheets and other supporting material for their assigned components/subsystems to the FEDC cost engineer. These design data sheets include the component/subsystem design description and a listing of the pertinent design parameters. This assembly of component/subsystem design data sheets and cost data obtained from a cost data base file forms the basis for the input to the computerized cost estimation spreadsheet, where the cost estimate is performed and cataloged.

WORKSHEET DESCRIPTION

The FEDC computerized cost estimation worksheet calculates the total constructed cost of a fusion power reactor or experimental device. The worksheet does not include financial (interest during construction) or schedule (escalation during construction) considerations. This section addresses the cost element definitions and code of accounts employed in the cost estimation worksheet, the methodology used in the spreadsheet for calculating the total constructed cost, the code structure, and the output that can be obtained from the spreadsheet.

Cost Element Definitions

As stated, the constructed cost of a facility is defined as the total expense of constructing a facility and placing the facility into operation. The elements of constructed costs - direct costs, indirect costs, and contingency - are all calculated in the cost estimation spreadsheet.

Direct costs are those costs that are identified with a specific permanent component, system, or facility of the plant. The elements of direct cost are engineering cost, equipment cost, and installation labor cost.

Indirect costs are those that are not identified with specific permanent plant facilities, equipment, or systems but that are incurred by the project as a whole. Elements of indirect costs are Construction Services and Equipment Cost (temporary facilities and construction equipment), Home Office Engineering and Services Cost (management, systems engineering, QA), Field Office Engineering and Services Cost (construction management, inspection, preoperational testing), and Owner's Cost (project administration, spares, and inventories).

Contingency is a cost allowance included in an estimate to reflect the fact that uncertainties exist in project definition, unit pricing, and execution. These cost element definitions are incorporated into the spreadsheet.

Code of Accounts

The FEDC computerized cost estimation spreadsheet incorporates a standard code of accounts, developed at FEDC, as the basis for reporting the estimated component/subsystem costs. The top-level accounts of the FEDC code of accounts are shown in Fig. 1.

Account number	Account title
2	DIRECT COST
20	Land and Land Rights
21	Structures and Site Facilities
22	Reactor Plant Equipment
221	Reactor Systems
222	Magnet Systems
223	Power Injection Systems
224	Vacuum Systems
225	Power Conditioning Systems
226	Heat Transport Systems
227	Fuel Handling Systems
228	Instrumentation and Control
229	Maintenance Equipment
23	Turbine Plant Equipment
24	Electric Plant Equipment
25	Miscellaneous Plant Equipment
26	Heat Rejection Systems
9	INDIRECT COST
91	Construction Services and Equipment
92	Home Office Engineering and Services
93	Field Office Engineering and Services
94	Owner's Cost

Fig. 1. FEDC code of accounts.

The FEDC code of accounts represents a systematic arrangement of the generic elements that generally comprise fusion projects. This code of accounts is developed to a mandatory account level (fourth-level maximum) that is applicable to all magnetically confined fusion concepts (tokamaks, tandem mirrors, etc.) and device types (experimental, power reactor). Additional accounts unique to a specific reactor or experimental device are further used to break down reported estimated costs below the mandatory level.

The FEDC code of accounts structure is based on the present standard fusion accounts[1] and power industry practice,[2] with some revisions being made to facilitate their application to both power reactors and experimental devices. The first-level accounts (Fig. 1) parallel those currently used by the power industry, thus facilitating comparison of fusion power reactor costs to other sources of electricity. Account 22, Reactor Plant Equipment, incorporates a generic, functional breakdown for the specific fusion systems within the power industry code. This account structure provides a natural reporting system that is closely related to the typical fusion project work breakdown structure and that is compatible with different fusion device concepts. The subaccounts of indirect cost, Account 9, correspond to normal power plant construction practice, where the utility (Owner) contracts with an engineering and construction company to design the plant (Home Office), manage the construction project (Field Office), and provide construction materials (Construction Services). These elements of indirect cost are not commonly used on near-term experimental devices where it is likely that a laboratory will act as project manager and owner and that the field office will be at a laboratory. Elements of indirect cost commonly incurred on experimental projects are included as subelements of the four major indirect accounts to ensure compatibility with experimental devices.

As stated, additional accounts unique to a specific device concept are used to further break down estimated costs below the mandatory level. Detailed, generic codes of accounts have been developed below the mandatory level for tokamak and tandem mirror devices, and each is incorporated into separate computerized cost estimation spreadsheets.

Spreadsheet Methodology

The FEDC computerized cost estimation spreadsheet utilizes LOTUS 1-2-3 software[3] on an IBM personal computer. LOTUS 1-2-3 is an advanced electronic worksheet with graphics and complete information management capacity. The worksheet is similar to a financial ledger sheet - ruled into rows and columns. The worksheet can accommodate 256 columns and 2,048 rows of information. Each of the spaces (cells) in the worksheet can store a piece of information: a number, letters, words, or equations to calculate a value. Thus, this format is ideally suited to converting the cost estimating procedures normally performed manually on cost estimate forms to the automated cost-estimating approach described herein.

The flow diagram shown in Fig. 2 illustrates the overall methodology employed in the FEDC computerized cost estimation spreadsheet for calculating the total constructed cost of a fusion plant. The spreadsheet format is illustrated in Fig. 3. Input parameters and descriptive information are introduced to the spreadsheet in the appropriate columns from the component design data sheets supplied by the cognizant engineers and from the cost data base file. The cost data base file and its use will be described later in this paper. The following design inputs can be introduced for each applicable component/subsystem in the code of accounts:

Column	Input
G	Brief component description
H	Component/subsystem quantity
L	Learning curve percent for Nth-of-a-kind device (if different than 100)
O,S,W,AA	Unit quantities corresponding to unit cost factors (cols. M,Q,U,Y) input
P,T,X,AB	Units corresponding to cols. O,S,W,AA
AC	Nth-of-a-kind device (if different than 1)

The cost inputs which can be introduced into the spreadsheet for each component/subsystem are as follows:

Column	Input
J	Engineering percent (of equipment cost)
K	Labor percent (of equipment cost)
M,Q,U,Y	Unit cost factors, component costs, or cost coefficients
N,R,V,Z	Units corresponding to cols. M,Q,U,Y
AD	References cost factor basis

These cost inputs are extracted from the FEDC cost data base file. The cost factors chosen are based on the cost of a similar component/subsystem and depend on the component/subsystem configuration and type specified on the design data sheet.

After the inputs are introduced, the calculation procedure is initiated for the specific account. The unit equipment cost (col. I) is calculated in millions of dollars according to the default equation

$$I(N) = M(N)*O(N)+Q(N)*S(N)+U(N)*W(N)+Y(N)*AA(N)/10^{6}$$

where the first letter symbol refers to the column designation and (N) refers to the Nth row. As is evident, a four-term cost equation can be accommodated in the spreadsheet. This standard default equation can be overridden for a given account and an empirical costing equation (algorithm) input to the spreadsheet, where cols. M,Q,U, and Y become the coefficients of the costing equation, and cols. O,S, W, and AA become the variables. The total equipment cost is calculated in millions of dollars using the default equation

$$D(N) = I(N)*H(N)*AC(N)\hat{}(((LogL(N)-2)/Log\ 2))/(((LogL(N)-2)/Log\ 2)+1$$

where the logarithmic terms represent the effect of the learning curve if an N-th-of-a-kind cost is desired.

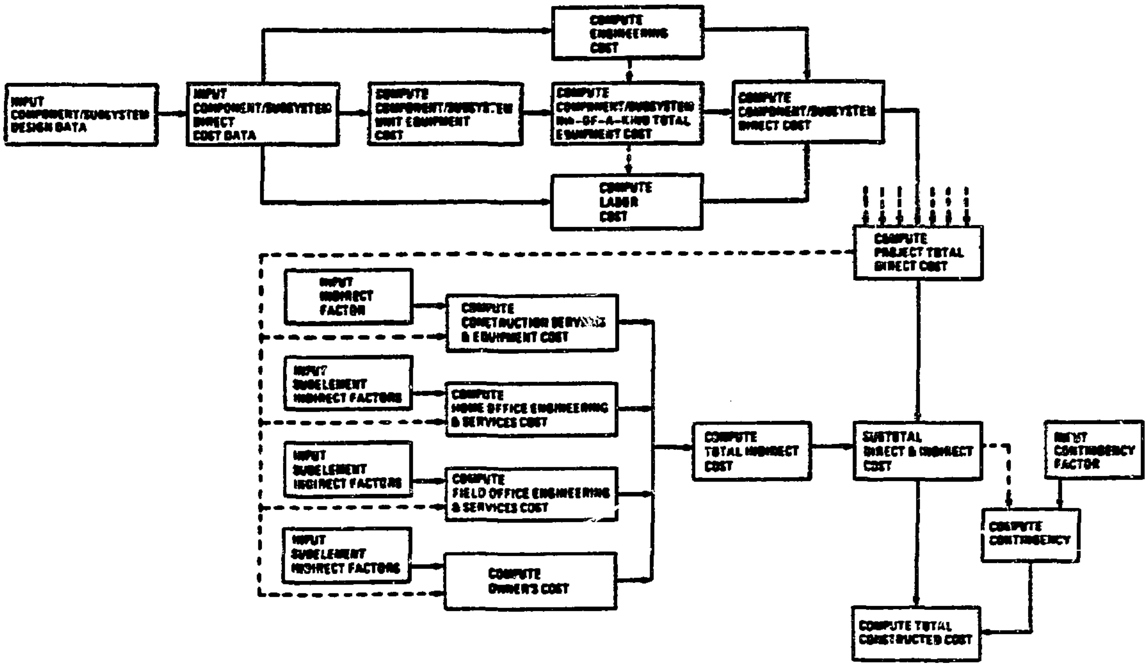

Fig. 2. Cost estimation spreadsheet methodology.

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	A	B	C	D	E	F	G	H	I	J	K	L	M	O	AA	AB	AC	AD
	ACCOUNT NUMBER	ACCOUNT TITLE	ENGRG. COST	EQPT. COST	LABOR COST	TOTAL COST	COMPONENT TYPE	COMP QTY.	UN. EQ. COST	ENGRG. %	LABOR %	L.C. %	UCFI	UCFI UNITS	UCF4 UN. QTY.	QTY. UNIT	NTH OF KIND	CABS
1	221.	REACTOR SYSTEM	0.00	0.00	0.00	0.00			0.00			100						
2	221.1	FIRST WALL ASSY	0.00	0.00	0.00	0.00			0.00			100						
3	221.1.1	PLASMA CHAMBER	0.00	0.00	0.00	0.00			0.00			100						
4	221.1.1.1	FIRST WALL STRUCTURE	0.00	0.00	0.00	0.00			0.00			100						
5	221.1.1.2	FIRST WALL SUPPORTS	0.00	0.00	0.00	0.00			0.00			100						
6	221.1.2	WALL MODIFIERS	0.00	0.00	0.00	0.00			0.00			100						
7	221.1.3	FIRST WALL INSTR.	0.00	0.00	0.00	0.00			0.00			100						
8	221.2	BLANKET ASSY	0.00	0.00	0.00	0.00			0.00			100						
9	221.2.1	BLANKET STRUCTURE	0.00	0.00	0.00	0.00			0.00			100						
10	221.2.2	BREEDER	0.00	0.00	0.00	0.00			0.00			100						
11	221.2.3	REFLECTOR	0.00	0.00	0.00	0.00			0.00			100						
12	221.2.4	MULTIPLIER	0.00	0.00	0.00	0.00			0.00			100						
13	221.3	SHIELDING	0.00	0.00	0.00	0.00			0.00			100						

Fig. 3. Cost estimation spreadsheet format.

The engineering and labor costs for the component/subsystem are calculated as a function of percent of equipment cost by the respective equations,

C(N) = J(N)*D(N) and E(N) = K(N)*D(N)

The component/subsystem direct cost is then calculated by the equation

F(N) = C(N)+D(N)+E(N)

This process is repeated for each appropriate account, and the total direct cost of the plant is calculated by summing the col. F totals of accounts 20 through 26. Equations for subtotals are included in the appropriate locations in the spreadsheet.

Inputs for calculation of project indirect cost subelements are introduced into the appropriate location of col. J of the spreadsheet as a percentage of total direct cost. These indirect cost subelements are calculated in col. F according to the equation

F(N) = J(N)*F(4)

where cell F(4) represents the total direct cost. Equations for indirect cost subtotals are included in the appropriate locations in the spreadsheet. The total project indirect cost is calculated by summing the col. F totals for accounts 91 through 94. The subtotal of total direct cost and total indirect cost is then calculated in col. F.

The input for calculation of contingency is entered into col. J of the worksheet in the appropriate location as a percentage of the subtotaled direct and indirect cost. Contingency is calculated in col. F according to the relationship

F(N) = J(N)*(Direct+Indirect Cost)

The total constructed cost of the plant is obtained by summing the col. F totals for direct cost, indirect cost, and contingency.

Spreadsheet Structure

The size requirement of the computerized cost estimation spreadsheet and the size limitations of LOTUS 1-2-3 dictate that the worksheet information be stored in a series of modules or files. The file names, along with the file account contents, are shown below.

File Designation	File Contents	
TDC	Acct. 20	Land and Land Rights
	Acct. 21	Structures & Site Facilities
	Acct. 9	Indirect Cost
RPE	Acct. 221	Reactor Systems
MAG	Acct. 222	Magnet Systems
PIVS	Acct. 223	Power Injection Sys.
	Acct. 224	Vacuum Systems
PCHT	Acct. 225	Power Conditioning Sys.
	Acct. 226	Heat Transport Sys.
FTIC	Acct. 227	Fuel Handling Systems
	Acct. 228	Instrument. & Control
	Acct. 229	Maintenance Equip.
	Acct. 23	Turbine Plant Equip.
	Acct. 24	Electric Plant Equip.
	Acct. 25	Misc. Plant Equip.
	Acct. 26	Heat Rejection Sys.

The total worksheet is compiled in one file by evaluating the worksheet equations in each file and storing only the resultant values. In order to accommodate this compilation, each of the above files has a related file containing only the values of the equations and only cols. A through F of the worksheet. The use of these files is transparent to the user.

In order to minimize the time required to execute spreadsheet commands, some of the more frequently used commands have been programmed using a LOTUS 1-2-3 feature called "macro," a stored sequence of keystrokes. These commands are executed by depressing the "Alt" key and then depressing the respective key for a particular command. The macro is programmed into the spreadsheet, and the disposition is the following:

Key	Functions
S	Updates present file & saves, writes summary file, pulls in next file
P	Prints the entire spreadsheet (cols. A through AD) by files
C	Combines all summary files into cols. A through F of spreadsheet. Applies only to TDC file
T	Prints cols. A through F of entire spreadsheet. Used after "C" command has been executed. Applies only to TDC file.

Detailed information regarding the use of LOTUS 1-2-3 can be found in ref. 3.

Master spreadsheets have been developed presently for both tokamak and tandem mirror devices and stored on separate floppy discs. These spreadsheets differ only in the detailed generic codes of accounts incorporated in the two spreadsheets. Both were developed from the mandatory level FEDC code of accounts, which was described in a prior section.

Output

Two types of printed output are available from the FEDC computerized cost estimation spreadsheet:

(1) A printout, by file, of all the information contained in the entire worksheet

(2) A printout of the calculated costs (cols. A through F) for the entire worksheet

COST DATA BASE FILE

The FEDC cost data base is derived mainly from actual cost experience and is refined to be mode compatible with the cost-element definitions and costing approach described in this paper.

The cost data base file is a catalog of cost coefficients, cost algorithms, and "component takeoff costs" formatted onto separate cost data sheets corresponding to specific component/subsystems. Each cost data sheet contains equipment, engineering, and labor cost data, in addition to pertinent design parameters, for different configurations and types of the specific component/subsystem. The cost data base file is arranged to correspond to the FEDC code of accounts. Both direct and indirect cost data are cataloged in the cost data base file.

The cost data input to the spreadsheet for estimating the specific component/subsystem cost is obtained from the cost data base file and is chosen based on the cost of a component/subsystem of similar configuration and type. The scope of the cost data included in the cost data base file is such that three techniques can be used to estimate the equipment cost of a specific component/subsystem. These costing techniques are unit costing, cost algorithms, and "component takeoff" costing. Where a solid historical cost data base is available for costing a specific component/subsystem, the unit costing method can be used whereby the equipment cost is based on cost per unit (weight, surface area, volume, power, flow, etc.) of similar equipment. Where a good cost data base does not exist, the cost algorithm method can be used. Cost algorithms are empirical costing equations, developed from experience on similar hardware, where the equipment cost is scaled as a function of component/subsystem design parameters. Where the subsystem is composed of standard items whose costs are accurately known, a "component takeoff" method can be used whereby the subsystem cost is based on the unit cost and quantity of the components which comprise the subsystem. Engineering and labor costs are compiled as a percentage of equipment cost on the cost data sheets.

Indirect cost data is compiled in the cost data base file as a percentage of total direct cost.

CONCLUSIONS

Computerized cost estimation worksheets and an associated cost data base file have been developed at FEDC in order to provide a credible and consistent means of calculating the constructed cost of tokamak and tandem mirror power reactors and experimental devices. The cost estimation worksheet utilizes LOTUS 1-2-3 software on an IBM personal computer and incorporates a detailed generic code of accounts, which adds conformity to the formation of the cost estimate, and cost element definitions, which allow cost data obtained from fusion projects to be recorded in such a way that the data are directly useful in estimating the cost of future fusion projects.

REFERENCES

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