Fusion Reactor Design Studies - Standard Accounts for Cost Estimates

May 1978

Pacific Northwest Laboratory
Richland, Washington 99352
Operated for the
U.S. Department of Energy
by

Battelle
Memorial Institute

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$____*; Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.50
026-050	\$5.00
051-075	\$5.50
076-100	\$6.00
101-125	\$6.50
126-150	\$7.00
151-175	\$7.75
176-200	\$8.50
201-225	\$8.75
226-250	\$9.00
251-275	\$10.00
276-300	\$10.25

FUSION REACTOR DESIGN STUDIES -
STANDARD ACCOUNTS FOR COST ESTIMATES

by
Steven C. Schulte
Theodore L. Willke
John R. Young(a)

May 1978

Pacific Northwest Laboratory
Richland, Washington 99352

Operated by
Battelle Memorial Institute

(a) Formerly employed at Battelle, now employed at
Washington Public Power Supply System (WPPSS)
George Washington Way
Richland, Washington 99352

FOREWORD

"In preparation of this document, the DOE Office of Fusion Energy and the Pacific Northwest Laboratory arranged for the user community to review and agree to the content of the document. The utility of the document is based on this common satisfaction of the diverse needs and approaches of the user community.

"To maintain this utility, this document should not be revised without first obtaining the concurrence of the Office of Fusion Energy that any proposed revision will be compatible with the current needs and procedures of the magnetic fusion power development program."

ABSTRACT

The *fusion reactor design studies - standard accounts for cost estimates* provides a common format from which to assess the economic character of magnetically confined fusion reactor design concepts. The format will aid designers in the preparation of design concept costs estimates and also provide policy makers with a tool to assist in appraising which design concept may be economically promising.

The format sets forth a categorization and accounting procedure to be used when estimating fusion reactor busbar energy cost that can be easily and consistently applied. Reasons for developing the procedure, explanations of the procedure, justifications for assumptions made in the procedure, and the applicability of the procedure are described in this document. Adherence to the format when evaluating prospective fusion reactor design concepts will result in the identification of the more promising design concepts thus enabling the fusion power alternatives with better economic potential to be quickly and efficiently developed.

CONTENTS

FOREWORD	iii
ABSTRACT	iv
II. INTRODUCTION	1
PURPOSE	1
SCOPE	2
ORGANIZATION OF THE DOCUMENT	2
ACKNOWLEDGEMENTS	3
III. HOW TO USE THE DOCUMENT	4
IV. GENERAL INFORMATION REQUIREMENTS	6
GUIDELINES	6
ADDITIONAL INFORMATION REQUIREMENTS	8
V. CAPITAL COST ESTIMATION	10
DESCRIPTION OF CAPITAL COST ACCOUNTS	12
CAPITAL COSTS EXCLUDED	18
ESTIMATING CAPITAL COSTS	18
CALCULATING TOTAL CAPITAL COST	22
VI. OPERATING AND MAINTENANCE COST ESTIMATION.	23
DESCRIPTION OF OPERATING AND MAINTENANCE COST ACCOUNTS	24
OPERATING AND MAINTENANCE COSTS EXCLUDED	27
ESTIMATING OPERATING AND MAINTENANCE COSTS	27
VII. SCHEDULED COMPONENT REPLACEMENT COST ESTIMATION	28
DESCRIPTION OF SCHEDULED COMPONENT REPLACEMENT COST ACCOUNTS	28
SCHEDULED COMPONENT REPLACEMENT COSTS EXCLUDED	29
ESTIMATING SCHEDULED COMPONENT REPLACEMENT COSTS	29

VIII.	FUEL COST ESTIMATION.	30
	DESCRIPTION OF FUEL COST ACCOUNTS	31
	FUEL COSTS EXCLUDED	33
	ESTIMATING FUEL COSTS	33
IX.	TOTAL ENERGY COST DETERMINATION - FUSION REACTOR FACILITIES PRODUCING ELECTRICITY	35
	PLANT CAPACITY	36
	PLANT AVAILABILITY FACTOR	37
	FINANCING ASSUMPTIONS.	38
	FIXED CHARGE RATE	40
	COMPUTATION OF TOTAL BUSBAR ENERGY COST	42
	REFERENCES	44
APPENDIX A	Reference Construction and Operating Site	A-1
APPENDIX B	Uniform Capital Cost Accounts	B-1
APPENDIX C	Uniform Detailed Capital Cost Reporting Accounts	C-1
APPENDIX D	Uniform Operating and Maintenance Cost Accounts	D-1
APPENDIX E	Uniform Scheduled Component Replacement Cost Accounts	E-1
APPENDIX F	Uniform Fuel Cost Accounts	F-1
APPENDIX G	Indirect Cost Account Estimating Percentages - Derivations	G-1
APPENDIX H	Alternative Values for F_{IDC} and F_{EDC}	H-1
APPENDIX I	Example Calculations	I-1

LIST OF TABLES

1	Capital Cost Account Summary.	11
2	Values for F_{IDC} and F_{EDC}	21
3	Operating and Maintenance Cost Accounts	23
4	Scheduled Component Replacement Cost Account	28
5	Fuel Cost Accounts	30
A-1	Accident Meteorology for a Ground Level Release	A-6
A-2	Accident Meteorology for a Elevated Release.	A-7
F-1	Fuel Cost Accounts	F-1
H-1	Values for F_{IDC} and F_{EDC}	H-1
H-2	Values for F_{IDC} and F_{EDC}	H-2
H-3	Values for F_{IDC} and F_{EDC}	H-2
H-4	Values for F_{IDC} and F_{EDC}	H-3
H-5	Values for F_{IDC} and F_{EDC}	H-3

LIST OF FIGURES

1	Economic Evaluation Format	5
2	Example Power Plant Cumulative Expenditure Pattern	17
3	Capital Cost Estimation	22
4	Fuel Cost Estimation	34
5	Total Energy Cost Determination	36
A-1	Dispersion Factor - χ/Q - Sec/Meter ³	A-8
A-2	Dispersion Factor - χ/Q - Sec/Meter ³	A-9

G-1	Construction Facilities, Equipment and Services, Cost Account 91.	G-1
G-2	Engineering and Construction Management, Cost Account 92 . . .	G-1
G-3	Taxes, Insurance and Owner's G&A, Cost Account 93.	G-2

II. INTRODUCTION

1. The Department of Energy and its contractors are presently and will continue to be engaged in the economic evaluation of different fusion reactor concepts. Both the importance and the complexity of these evaluations necessitate that a common evaluative format be established and utilized. Adherence to such a format will result in economic comparisons of different design concepts being generated on a uniform and consistent basis.
2. The format described in this document was developed by Battelle at the Pacific Northwest Laboratory for the Department of Energy. The format establishes standard costing principles to be utilized in the economic evaluation of different magnetically confined fusion reactor concepts. Fusion reactor design technology is in its infancy, yet many approaches to reactor configuration are being introduced. As early as possible in the design process, these approaches must be evaluated on a consistent basis to determine which approaches appear economically promising.

PURPOSE

3. The purpose of the document is to define a cost categorization format and to develop evaluative procedures for the economic calculations of fusion reactor construction and operation. Such format and procedures will: 1) aid designers in the preparation of reactor design concept cost estimates, and 2) provide decision makers with a tool to assist in appraising which design concepts may be economically promising. In aiding the designer, the procedures will serve as a step-by-step costing manual from which to consistently cost design concepts. In assisting the decision maker, the procedures will ensure consistency when evaluating alterantive concepts.

SCOPE

4. The format describes accounting and estimating procedures necessary to compile estimates of the costs of magnetically confined fusion reactor power plant design concepts. The procedures are also applicable to fusion-fission (hybrid) reactor concepts and nonelectric fusion reactor applications. Descriptions of costs, procedures for estimating costs, and a procedure for totaling costs are given. Estimated busbar energy cost for electricity-producing reactor design concepts is used as the measure of economic performance. This measure is computed from the financing assumptions, capital cost, operating costs, and fuel costs. By-product benefits of the electricity generating process such as nonelectric utilization of process heat are not included in economic computations.

ORGANIZATION OF THE DOCUMENT

5. The document is organized as a step-by-step costing manual. Such a "cook book"-like approach should: 1) increase reader understanding of the evaluation procedures, 2) ensure consistency in the application of the procedures and 3) provide the user with an information source in which material can be quickly referenced. The following seven chapters are included in the manual:
 - How to use the guidelines (III)
 - General information requirements (IV)
 - Capital cost estimation (V)
 - Operating and maintenance cost estimation (VI)
 - Scheduled component replacement cost estimation (VII)
 - Fuel cost estimation (VIII)
 - Total energy cost determination - fusion reactor facilities producing electricity (IX)
6. The implementation of the procedures described in each of these chapters when evaluating design concepts will result in the useful and consistent determination of total busbar energy cost.

ACKNOWLEDGEMENTS

7. This report has been prepared by Battelle at the Pacific Northwest Laboratory (PNL) for the Office of Fusion Energy (OFE) of the U.S. Department of Energy under the guidance of Mr. Charles Head.

PNL wishes to thank Mr. Sunil Ghose and Mr. Tony Bowles of Bechtel Corporation, and Mr. Dale DeFreece and Mr. Les Waganer of McDonnell Douglas Astronautics Company - East for their generous assistance during the writing of this document. The authors also wish to thank Ms. Betsy Owzarski and Ms. Barbara Roberts for their assistance in the preparation of this document.

III. HOW TO USE THE DOCUMENT

8. The procedures contained in this document are organized to reflect a step-by-step estimation process. The estimator should proceed through the document implementing the procedures described in each chapter as they are developed. When all the procedures have been implemented, the evaluation process is complete. At this point, the measure of economic performance, busbar energy cost, will have been determined.
9. Each chapter of the document contains a description of a phase of the estimation process. Each phase is utilized in the estimation process in the order in which it is described in the document. A diagram illustrating this order is shown in Figure 1. A description of each phase (i.e., chapter) is given below.

- IV. General Information Requirements

This chapter describes the required characterization and documentation of design concepts and the general philosophy under which design concepts will be evaluated.

- V. Capital Cost Estimation

This chapter describes how fusion reactor design concept capital costs should be categorized. Included is a listing of the cost accounts to be used when reporting estimated costs, descriptions of the cost accounts, a listing of costs that should not be considered in the evaluation process, and descriptions of standard techniques for estimating indirect and time-related account costs.

- VI. Operating and Maintenance Cost Estimation

This chapter describes how design concept operating and maintenance costs should be categorized and estimated. Included is a listing of the cost accounts to be used when reporting estimated costs, descriptions of the cost accounts, and a listing of costs that should not be considered in cost estimates.

- VII. Scheduled Component Replacement Cost Estimation

This chapter describes how design concept schedule component replacement costs should be categorized. The same items described in the previous chapter for estimating operating and maintenance costs are described in this chapter for scheduled component replacement cost estimation.

- VIII. Fuel Cost Estimation

This chapter describes how design concept fuel costs should be categorized. The same items described in previous chapters are described in this chapter for fuel cost estimation.

- IX. Total Energy Cost Determination - Fusion Reactor Facilities Producing Electricity

This chapter describes the methodology that should be used to compute total busbar energy cost (mills/kWh) for electricity producing reactor design concepts. Descriptions of total energy cost components, procedures for calculating the values of the components, and a procedure for combining the components to yield a total busbar energy cost figure are given.

FIGURE 1. Economic Evaluation Format

IV. GENERAL INFORMATION REQUIREMENTS

10. The comparative economic evaluation of fusion reactor design concepts requires that design and costing assumptions utilized before and during the evaluation process be applied consistently and equally to every concept. Such consistency is mandatory if economic evaluations are expected to be of any real value.
11. Two problems that often occur during the evaluation process are lack of sufficient information and lack of uniformity in documents describing the specific design concept. As a result, economic comparisons are of questionable value or substantial additional effort is necessary to either modify the design information or provide the missing information.
12. This chapter describes the design information that should be developed during preparation of fusion reactor design studies. Documentation of such information will allow useful comparisons of design concepts. Also described are design and economic guidelines that should be used in evaluations.

GUIDELINES

13. Before a standard procedure for the economic evaluation of a specific fusion reactor design concept can be implemented, the design concept itself must be based on and conform to a set of standard design assumptions and requirements.⁽¹⁾ These reflect a basic and consistent design philosophy. Such a philosophy defines the degree of accuracy required in the evaluations, the level of technical knowledge on which the designs are based, and maturity of the industry. General design and economic guidelines that should be used in fusion reactor design studies are described in the following assumptions.
 - 1. The Technology Level Must Be Stated. Many levels of technology are utilized in the design of fusion reactor systems and supporting subsystems (waste treatment, heat exchange, etc.). These levels will range from current technology to advanced technology, where advanced technology is defined as any technology which has not been demonstrated on a commercial scale.

The technology levels used in design studies should be described to the fullest extent possible to lessen the difficulties of economically evaluating the concepts.

- 2. No Technical Normalization. Reactor design studies are not required to utilize standard technical assumptions during the design process.
- 3. Single or Multiple Reactor Unit(s) Per Power Plant. Multiple fusion reactors may be contained within a single power plant. Such integration would result in a lower cost of energy per reactor because some plant facilities would be shared among reactors. The evaluation format described in this report is applicable to both single fusion reactor and multiple fusion reactor plant concepts.
- 4. Reference Fusion Reactor Site. For design studies not tied to a specific reactor location, designs should adhere to the technical specifications and characteristics of a reference construction and operating site. These specifications and characteristics are described in Appendix A.⁽²⁾
- 5. The Industry Maturity Must Be Stated. Design study documents should state the level of industry maturity assumed in design and economic evaluations. In instances where a mature industry is assumed, estimated costs should reflect learning curve characteristics of the tenth plant built of a specific design technology. In instances where a sophistication level of something less than a mature industry is assumed, maturity assumptions should be stated.
- 6. Present Year Price Levels. The costs of all labor, material, and equipment required during facility construction and operation should be estimated using present (current) year price levels. The present year or price level year should be stated in all cost studies.

Two modes of economic analysis are described in this document. The first is a constant dollar mode which assumes the purchasing value of the dollar remains constant over time. The second is a current dollar mode (nominal dollar mode) which assumes this purchasing value changes over time. The constant dollar mode utilized in these analysis procedures defines general inflation rates and component escalation rates equal to zero. All costs, regardless of when they are expected to be incurred, will be reported in present year price level dollars. The current dollar mode utilized in these procedures is identical to the constant dollar mode except for the following: 1) cost escalation on the estimated capital costs is assumed to exist and is costed in a single escalation during construction cost account (i.e., account 95), and 2) cost escalation on estimated operating and maintenance, scheduled component replacement and fuel costs is assumed to exist and is costed within the respective parent cost account.

The current dollar analysis mode is in essence a nominal first year facility cost. Escalation cost will only be computed up to this first year.

Either mode of economic analysis can be used in design studies. When costing actual construction projects, the current dollar analysis should be utilized. When costing conceptual or paper study designs, use of both analysis modes is recommended.

- 7. Investor Owned Electric Utility. The financing computations for commercial power reactor designs are based on the premise that the fusion reactor is constructed and owned by an investor-owned (private) electric utility organization.

ADDITIONAL INFORMATION REQUIREMENTS

14. As a general rule, publication of a document describing a fusion reactor design concept will provide a satisfactory description of the reactor and its supporting systems. However, many of the design details

necessary for the economic evaluation of the concept are often not described. The following types of information should be included in design documents to assure satisfactory understanding of the general design, the material requirements, and the physical processes assumed during construction and operation of the plant.⁽¹⁾

1. Energy flow diagrams showing the flow paths and flow rates of all energy flow.
2. Process flow diagrams showing the flow paths and flow rates of all major process materials (i.e., fuel, coolants, wastes, etc.)
3. A general description of the fuel cycle.
4. Sufficient descriptive material so that all radioactive material contained in inventories, and flow paths and flow rates for this material is known or can be estimated.
5. A general description of all major supporting subsystems (i.e., waste treatment, ventilation, power generation, waste disposal, etc).
6. Descriptions of equipment that controls the release rates of pollutants.
7. Building layout.
8. Any unique siting or construction requirements.
9. A tabulation of the quantities of all significant materials and equipment, showing locations, weights, sizes, power requirements and capacity limitations.

V. CAPITAL COST ESTIMATION

15. The primary determinant of busbar unit electricity cost for fusion reactor generated electricity is the capital investment cost or capital cost. The capital cost is defined as the total expense of constructing the facility and placing the facility into operation. This chapter describes the expenses that should be considered as capital costs, develops standard methods for estimating some of these costs, and describes a methodology for calculating the total capital cost.⁽³⁻⁶⁾
16. The major capital cost accounts that should be used in reporting estimated costs are shown in Table 1. A detailed listing of these accounts is contained in Appendix B.^(1,7-9) These designated accounts should be beneficial in two respects. First, the accounts add conformity to the formation of cost estimates, making estimate comparisons easy. Second, the accounts serve as a checklist assuring that no costs are inadvertently omitted from the estimate.
17. Additional costs accounts can be used to further breakdown and report estimated costs. These additional accounts consists of a uniform or generic set of reporting categories located at the 6th breakdown level (i.e., account xx.xx.xx.xx.xx.01 - account xx.xx.xx.xx.xx.99.) of the cost account structure shown in Appendix B. The uniform set can be used with all accounts shown in the appendix. However, not all of the costs reported in the Appendix B accounts can be categorized within this generic account set. The purpose in specifying a uniform reporting set at a detailed breakdown level is to provide identical indexing of facility costs by material/equipment type (i.e., concrete, structural steel, pipe, etc.) rather than by facility system (i.e., reactor system, turbine generator system, etc.). These uniform reporting categories are shown in Appendix C.
18. The cost accounts are applicable to all magnetically confined fusion reactor design concept cost estimating. However, the level of cost account detail used in reporting costs will vary with the particular design study or application. For those applications where design is relatively established,

it would be appropriate to use detailed accounts for reporting costs. For applications where the design is highly conceptual and detailed individual component cost estimating is not feasible, it would be appropriate to use only the major accounts for reporting costs.

TABLE 1. Capital Cost Account Summary

<u>Account Number</u>	<u>Account Title</u>	<u>Cost</u>
<u>DIRECT COSTS:</u>		
Nondepreciating Assets:		
20	Land and Land Rights	
Depreciating Assets:		
21	Structures and Site Facilities	
22	Reactor Plant Equipment	
23	Turbine Plant Equipment	
24	Electric Plant Equipment	
25	Miscellaneous Plant Equipment	
26	Special Materials	
	SUB-TOTAL	
	Total Spare Parts Allowance	
	Total Contingency Allowance	
<u>INDIRECT COSTS (All Depreciating Assets):</u>		
91	Construction Facilities, Equipment, and Services	
92	Engineering and Construction Management Services	
93	Other Costs	
	SUB-TOTAL	
<u>TIME RELATED COSTS (All Depreciating Assets)</u>		
94	Interest During Construction	
95	Escalation During Construction (Current Dollar Economic Analysis Mode Only)	
	SUB-TOTAL	
	<u>TOTAL CAPITAL COST</u>	

DESCRIPTION OF CAPITAL COST ACCOUNTS

19. Capital costs comprise direct, indirect, and time related costs. Direct costs are directly associated with some phase of construction or startup on an item by item basis. Indirect costs are expenses of a general nature that result from the support activities required when accomplishing direct cost activities. Time related costs are expenses that occur because 1) facility construction and startup take place over a period of time, 2) there is an opportunity cost associated with money over this time period and 3) price levels can be expected to change over this time period.

Direct Costs

20. Direct costs associated with construction and startup activities result primarily from the purchase of material, equipment and labor.⁽²⁾ Direct capital cost account purchase costs should include the following:

- Material Purchases

- Basic purchase price (including sales taxes)
- All expenses associated with shipment to site, including crating and special shipping supports, insurance, and handling until item is stored at the site.
- All research and development (R&D) expenses incurred in the development or qualification of a component for the specific facility being costed.

- Equipment Purchases

- Basic purchase price (including sales taxes).
- All expenses associated with shipment to site, including crating and special shipping supports, insurance, and handling until item is stored at the site.
- Factory testing and expenses (i.e., customer acceptance tests).
- Cost of shop drawings and instruction in maintenance manuals.

- All research and development (R&D) expenses incurred in the development or qualification of a component for the specific facility being costed.

- Labor Purchases

- Construction, installation, and testing expenses which can be related to labor manhours, including total payroll costs (wages, taxes, and fringe benefits), travel and living allowances, supervision, and overhead profit to the labor contractor.
- Expenses associated with technical direction of construction, installation, testing, and inspection of vendor's personnel.
- Expenses for services associated with preoperational tests and inspections at the plant site, including radiography, concrete strength tests, dye penetration, etc., but excluding services performed by personnel or the owner or outside organizations or individuals providing engineering services.

21. Descriptions of direct cost accounts can be extracted from the three and four digit subaccount titles given in Appendix B. Contingency and spare parts allowance accounts are described in the following sections.

Contingency

22. This account is an allowance for unforeseen or unpredictable expenses that will be incurred during facility construction and startup. Contingency should reflect cost uncertainty resulting from potential acts of nature (i.e., excessive rain delay, etc.) and nondesign-related construction problems (i.e., labor problems, supplier delays, etc), and not from uncertainty resulting from a lack of design definition. Uncertainties in reactor technical design should be costed in design allowances (see page 18). Costs of small support systems that may be difficult to estimate are not included in the contingency allowance.

The degree of accuracy required in the estimate and the nature of the item or activity to be estimated determine the magnitude of this

contingency allowance. Some items, primarily labor costing, will require the larger contingency allowances to reflect such things as work stoppages and productivity losses. Other items, such as common building materials costing, can be more accurately estimated, requiring smaller contingency allowances.

Spare Parts Allowance

24. Spare parts allowance is the purchase cost and inventorying cost prior to facility operation of the initial inventory of spare parts required onsite. In fusion reactor design studies, the cost of any spare part whose installed cost is greater than \$10,000 should be included in this account.⁽²⁾ Spare parts costing less than \$10,000 are costed in operating and maintenance cost accounts. Fusion device parts rotated into service as part of a scheduled maintenance program are not considered spare parts.

Indirect Costs

25. Indirect costs are expenses resulting from the support activities required to accomplish direct cost activities. The following sections contain descriptions of indirect cost accounts.⁽²⁾

Construction Facilities, Equipment, and Services (Account 91)

26. The activities and components included in this account are described in Appendix B.

Engineering and Construction Management Services (Account 92)

27. Expenses for reactor engineering, plant engineering, and construction management services are included in this account. Reactor engineering costs are expenses for the design and engineering of the reactor, auxiliary systems, and fuel. These costs are quite dependent upon the degree to which the reactor design is considered to be established.
28. Plant engineering costs are the nonreactor design and engineering expenses. Such expenses are also known as balance of plant engineering costs. These expenses can be accurately estimated because construction and operation of this portion of the plant is relatively conventional.

29. Construction management costs result from home office and job site management activities required during plant construction and startup.

Taxes and Insurance (Account 931)

30. This account includes the taxes and insurance incurred during construction and startup of the facility. The account should include the following expenses:

- Property insurance
- All risk insurance
- State property taxes
- Local property taxes.

Staff Training and Plant Startup (Account 932)

31. The two activities costed in this account, staff training and facility startup, are included in a single account because of the difficulty in differentiating between the activities. Staff training is accomplished, in part, through the facility startup activities.

32. Staff training costs are expenses incurred by the future facility operating and maintenance staff when familiarizing themselves with the facility, and for assisting, reviewing, and conducting preoperational tests. Facility startup costs are expenses for facility fuel loading, fuel testing, buildup to power operation activities, and for facility performance demonstration and acceptance test.

Owners General and Administrative (Account 933)

33. Miscellaneous expenses incurred by the facility owner in constructing and starting up the facility are included in this account. The expenses are attributable to the following items:

- Owner licensing fees
- Printing of safety analysis reports
- Attendance of personnel at meetings
- Preparation of testimony
- Legal fees
- Public relations programs

- General administrative overhead
- Owner's engineering.

Time-Related Costs

34. Time-related costs are expenses that are incurred because facility design, construction, and startup occur over a period of time and not instantaneously. These expenses result from: 1) the opportunity cost associated with money, and 2) the changes that occur in the purchasing power of the dollar over time. Time related costs include interest during construction and escalation during construction. In fusion reactor design studies, escalation during construction costs should only be computed when costing in a current dollar economic analysis mode. However, interest during construction should be computed when costing in both the current dollar or constant dollar analysis mode.

Interest During Construction (Account 94)

35. Allowance for funds used during construction (AFDC) or interest during construction (IDC) is the net cost during construction of procuring the capital required to design, construct and start up the facility. This expense is comprised of the interest charges on the debt portion of the financing, the equity holder charges on the equity (common stock) portion of the financing, and any administrative charges on the financing.
36. Interest during construction cost is a function of three components: 1) the total direct and indirect capital cost of the facility, 2) the time distribution of capital expenditures (i.e., costs) and 3) the aggregate interest rate on all financing charges. The aggregate interest rate and standard financing assumptions that should be used in design studies are given in Chapter IX. The time distribution of capital expenditures during facility construction is assumed to be identical to that of a conventional LWR facility and is shown in Figure 2.⁽²⁾ The figure is shown for explanatory purposes only and its use is not required when estimating capital costs.

FIGURE 2. Example Power Plant Cumulative Expenditure Pattern

Escalation During Construction (Account 95)

37. Construction of a fusion reactor facility will take place over a period of time. During this time period, the prices of materials, equipment, and labor used in facility construction can be expected to change. In most instances, prices will increase or inflate over time (i.e., costs will escalate). The amount of these price increases is computed in cost estimates as escalation during construction (EDC).
38. Escalation during construction cost is a function of three components: 1) the total direct and indirect capital cost of the facility 2) the time distribution of capital expenditures (i.e., costs) during the construction period and 3) the aggregate cost escalation rate on all facility components purchased during construction. The aggregate

cost escalation rate that should be used in design studies is given in Chapter IX. The assumed time distribution of capital expenditures during facility construction is shown in Figure 2. The figure is shown for explanatory purposes only and its use is not required when estimating capital costs.

CAPITAL COSTS EXCLUDED

39. Costs for the following items or activities should not be included in costs estimates:

- Switchyard
- Transmission lines
- Escalation prior to construction
- Escalation during construction (excluded in constant dollar economic analysis mode only)
- Working capital
- Decommissioning
- Research and development (except the R&D performed to develop or qualify a component for the specific plant being costed. These costs should be included in capital cost estimates.)

ESTIMATING CAPITAL COSTS

40. Total capital cost is calculated as the sum of the total estimated direct, indirect and time-related costs. Standard techniques to be used in estimating capital costs are described in the following sections.

Direct Costs

41. Total direct capital cost is the sum of total direct labor, material, and equipment costs. This categorization of costs by activity is important for later calculations of indirect expenses.

42. A conservative approach should be used in estimating direct costs. Past experience has demonstrated that advocates of new technologies frequently underestimate costs because of: 1) optimism in design, and 2) failure to include sufficient "design allowances" for unforeseen difficulties. In fusion reactor design study cost estimating, direct costs should include a design allowance whenever design uncertainties exist.
43. No guidelines for estimating design allowances are given because these allowances will vary considerably. Some accounts such as Structures and Site Facilities (Account 21) will have small design allowances because construction and startup are relatively conventional. Other accounts, such as Reactor Plant Equipment (Account 22) will have greater design allowances because the level of technical maturity in fusion reactor equipment design is relatively unadvanced.
44. No attempt should be made to develop detailed designs for the numerous small support systems required in the plant. It should become apparent early in the evaluation process that order of magnitude costs for such items would be adequate. Large errors in these costs will have an insignificant effect on the total direct cost.
45. Most direct costs can be estimated using standard costs per unit of required quantity. After development of the general design for the plant, quantities of material and equipment required in the plant can be estimated. These quantities can then be multiplied by a standard cost per unit to obtain total installed costs.
46. Research and development (R&D) costs that remain to be incurred in the development of specific reactor components for the facility being costed must be included in capital cost estimates.
47. Land and land rights (Account 20) costs are nondepreciable expenses. However, in fusion reactor design studies, because land and land rights costs are relatively insignificant and because of the large amount of additional methodology required to handle the economics of nondepreciable costs, the costs should be assumed to be depreciable.

Indirect Costs

48. Indirect costs are estimated using standard indirect cost percentages. These standard percentages when multiplied by the total direct capital cost equal the estimated indirect cost.⁽¹⁰⁾
49. The percentages designated in this document have been developed from historical relationships (see Appendix G) and are based on construction and operation of a 1000 MWe power plant in a mature industry. If a particular study warrants using a different percentage when estimating indirect costs, this alternate percentage should be used and justification included.

The following equations should be used to estimate indirect costs:

$$\begin{array}{lcl} \text{Construction Facilities,} & & \\ \text{Equipment, and Services} & = & 15\% \text{ of Total Direct} \\ \text{(Account 91) Cost} & & \text{Capital Cost} \end{array} \quad (\text{Eq. 1})$$

$$\begin{array}{lcl} \text{Engineering and} & & \\ \text{Construction Management} & = & 15\% \text{ of Total Direct} \\ \text{Services (Account 92) Cost} & & \text{Capital Cost} \end{array} \quad (\text{Eq. 2})$$

$$\begin{array}{lcl} \text{Owner's (Account 93)} & & \\ \text{Cost} & = & 5\% \text{ of Total Direct} \end{array} \quad (\text{eq. 3})$$

50. The sources from which these percentages were derived are shown in Appendix G.

Time-Related Costs

51. The two time-related costs are the cost of interest during construction (Account 94) and the cost of escalation during construction (Account 95). When using a current dollar economic analysis mode, both should be computed with a reference 10%/year nominal cost of capital, and a reference 5%/year escalation rate (see Chapter IX). When using a constant dollar analysis mode, interest during construction cost should be computed with a reference 5%/year deflated (real) cost of capital and escalation during construction cost should not be computed.
52. The following equations should be used to estimate time related costs. Equations are based on the expenditure pattern shown in Figure 2.

$$\begin{array}{l} \text{Interest During} \\ \text{Construction} \\ \text{(Account 94) Cost} \end{array} = \left(\frac{\text{Total Direct Capital}}{\text{Cost} + \text{Total Indirect}} \right) \times F_{IDC} \quad (\text{Eq. 4})$$

$$\begin{array}{l} \text{Escalation During} \\ \text{Construction} \\ \text{(Account 95) Cost} \end{array} = \left(\frac{\text{Total Direct Capital}}{\text{Cost} + \text{Total Indirect}} \right) \times F_{EDC} \quad (\text{Eq. 5})$$

53. Values for F_{IDC} and F_{EDC} using the reference financing assumptions are given below in Table 2.(11) Values for F_{IDC} and F_{EDC} using other financing assumptions are given in Appendix H. The period required to design, construct and start up the facility is the period during which time related costs will be incurred. This period is known as the construction period. This period will vary for each design concept requiring that a preliminary scheduling of construction activities be included in the design study.

TABLE 2. Values for F_{IDC} and F_{EDC}

Construction Period (Yr)	Constant Dollar Economic Analysis Mode (Assumed Cost of Capital = 5%/Year) (Escalation Rate = None)		Current Dollar Economic Analysis Mode (Assumed Cost of Capital = 10%/Year) (Escalation Rate = 5%/Year)	
	F_{IDC}	F_{EDC}	F_{IDC}	F_{EDC}
4	.081	-0-	.191	.122
5	.108	-0-	.251	.155
6	.129	-0-	.316	.190
7	.152	-0-	.388	.225
8	.170	-0-	.466	.261
9	.192	-0-	.551	.229
10	.221	-0-	.644	.338

CALCULATING TOTAL CAPITAL COST

54. Total capital cost is calculated as a function of direct labor cost, direct material cost, direct equipment cost, indirect costs, financing assumptions and time related cost. The diagram shown in Figure 3 indicates how these costs are totaled to result in total capital cost. Table 1 (page 11) contains a format for computing total capital cost.

FIGURE 3. Capital Cost Estimation

VI. OPERATING AND MAINTENANCE COST ESTIMATION

55. Operating and maintenance costs consist of the routine day to day expenditures required to operate the facility. These expenses include the cost of salaries, supplies, maintenance materials, and process chemicals. The operating and maintenance cost accounts for fusion reactor design studies are shown in Table 3. These accounts are described below, along with a standard percentage to be used in estimating costs.

TABLE 3. Operating and Maintenance Cost Accounts

<u>Account Number</u>	<u>Account Title</u>	<u>Cost</u>
40	Annual Salaries of Facility Personnel	
41	Annual Miscellaneous Supplies and Equipment	
42	Annual Outside Support Services	
43	Annual General and Administrative Costs	
44	Annual Coolant Makeup	
45	Annual Process Materials	
46	Annual Fuel Handling Costs	
47	Annual Miscellaneous Costs	
	<u>Total Annual Operating and Maintenance Cost</u>	<u> </u>

56. Operating and maintenance expenses reported in operating and maintenance cost accounts (Table 3) should be considered variable expenses. Variable operating and maintenance expenses vary with facility production levels. Fixed operating and maintenance expenses are different and are not reported in operating and maintenance cost accounts (Table 3). Fixed operating and maintenance (O & M) expenses vary with the magnitude of the initial capital investment cost and not with facility production levels. Examples of fixed O & M costs are depreciation expense, interim

replacement expense and property insurance expense. Fixed O & M costs are costed in estimates using an annual fixed charge rate (see Chapter IX).

DESCRIPTION OF OPERATING AND MAINTENANCE COST ACCOUNTS

57. Operating and maintenance cost accounts are described below.

Annual Salaries of Facility Personnel (Account 40)

58. The salaries required by facility operating and maintenance personnel are costed in this account. The size of the operating crew needed in a fusion reactor facility will vary depending on the number of facilities at the site, the utilities' personnel policies, the amount of automation, etc. Consequently, a set of operating conditions and procedures must be projected in order to permit estimation of the operating crew size. The following assumptions should be used in projecting these conditions and estimating crew sizes for electricity producing fusion reactor power plants:

- Power plant design and operation requires only routine technical assistance.
- The power plant is base-loaded operating as much as possible.
- Five complete operating crews are used to provide full facility operation, an additional daycrew, and relief coverage.
- General and administrative services are provided by the utilities' central administrative organization.
- Facility operations are highly automated and computer controlled from a central control room.
- Onsite fuel handling activity costs, if such activities require less than 20% of the operating staff's work time, are included in this account.
- Offsite fuel handling costs are not included in this account. Assumptions regarding operating and maintenance conditions for nonelectricity producing fusion reactor facilities should be developed by the estimator and documented in the cost estimate.

59. Fusion reactor facilities should be costed assuming the plant operates using a typical utility staff organization. The services of four functional groups should be costed - operations, maintenance, technical and clerical. These groups should be assumed to be headed by a supervisor with full responsibility for his function. These four supervisors, in turn, would report to an assistant superintendent and plant superintendent, who would be responsible for overall plant safety and efficient operation.

Annual Miscellaneous Supplies and Equipment (Account 41)

60. This account costs miscellaneous nonprocess material items used during routine day to day operations. Such small volume items include ion-exchange chemicals, biocides for fouling protection, gases, routine maintenance materials, and waste containers.

Annual Outside Support Services (Account 42)

61. Outside support services such as radioactive waste disposal, laundry, and film badge processing are costed in this account. These services should be assumed to be provided by outside contractors. Included in this category are costs of personnel borrowed from other power plants.

Annual General and Administrative Costs (Account 43)

62. This account costs activities such as payroll administration, purchasing, and division level management. Also included in the account are costs for miscellaneous power plant administration activities such as contributions to local charities, educational programs, etc.

Annual Coolant Makeup (Account 44)

63. Expenses reported in this account should include only the cost of materials that must be added to the coolant streams to make up for losses due to leakage, transmutation, and cleanup operations. Costs for replenishing coolant inventories stored outside of process equipment should not be included nor should costs for the initial coolant inventory.

Annual Process Materials (Account 45)

64. The items costed in this account, process materials, are large quantity materials consumed during reactor operation. Examples of such items are chemicals used for water treatment. Small quantity process materials should be costed in the miscellaneous supplies and equipment account.

Annual Fuel Handling Costs (Account 46)

65. Some fusion reactor concepts require extensive onsite fuel handling activities. Costs for these activities are included in this account. These activities include the processing of irradiated fuel materials and neutron multipliers after they have been removed from the reactor. Reprocessed materials must then be disposed of or recycled back to the reactors for further irradiation. Such activities should be assumed to be accomplished onsite. Offsite processing would result in substantially higher economic costs and increased radiation exposure during transportation and handling activities. Some reactor designs may utilize fuel cycles requiring extensive onsite fuel preparation and disposal activities. These activities should also be costed in this account.
66. If onsite fuel handling activities require more than 20% of the operating staff's work time, the activities should be costed entirely in this account. If onsite fuel handling activities require less than 20% of the operating staff's work time, these activity costs should be included in other operating and maintenance cost accounts, and no cost will be included in this account. Offsite fuel handling costs should be included in fuel cost accounts.

Annual Miscellaneous Costs (Account 47)

67. Miscellaneous expenses are the numerous relatively small expenses not applicable to inclusion within other operating cost accounts. These expenses include costs for such items as office supplies, vehicle maintenance, public relations, travel, rent, and staff training.

OPERATING AND MAINTENANCE COSTS EXCLUDED

68. Costs for the following items or activities should not be considered in design studies:

- Nuclear liability insurance
- License and fees
- Working capital.

ESTIMATING OPERATING AND MAINTENANCE COSTS

69. The total estimated operating and maintenance cost is the summation of the estimated costs for the eight operating cost accounts. This total cost figure is computed as an annual expense at the same price levels as capital cost estimates.

70. Costs of the operating and maintenance cost accounts can be easily estimated using a standard estimating percentage. The percentage was derived from recent operating and maintenance cost relationships developed for conventional LWR facilities. Use of this standard percentage should add consistency to estimates and also make the estimating task simpler.

The following equation should be used in estimating costs:

$$\begin{array}{lcl} \text{Annual Operating} & & \\ \text{and Maintenance} & = & 2\% \text{ of Total Direct and} \\ \text{(Account 40-47) Cost} & & \text{Indirect Capital Cost} \end{array} \quad (\text{Eq. 6})$$

71. Table 3 (page 23) contains a format for computing total operating and maintenance cost.

VII. SCHEDULED COMPONENT REPLACEMENT COST ESTIMATION

72. Scheduled component replacement costs are the expected annual costs of routine maintenance and replacement of major (cost greater than \$10,000) reactor components such as first wall modules. Included in cost accounts are only those expenses directly associated with these activities.⁽¹²⁾ The scheduled component replacement cost accounts to be used in fusion reactor design studies are shown in Table 4. The same facility and staffing assumptions used in computing operating and maintenance costs should be used in computing scheduled component replacement costs. Cost accounts are described below.

TABLE 4. Scheduled Component Replacement Cost Account

<u>Account Number</u>	<u>Account Title</u>	<u>Cost</u>
50	Annual Reactor First Wall Component Replacement	
51	Others	
		<u>Total Scheduled Component Replacement Cost</u> _____

DESCRIPTION OF SCHEDULED COMPONENT REPLACEMENT COST ACCOUNTS

73. Scheduled component replacement cost accounts are described below.

Annual Reactor First Wall Component Material (Account 50)

74. Included in this account are the annual costs of major materials required to rebuild or replace reactor first wall components. Costs of minor materials, such as process chemicals, are included in operating and maintenance cost accounts.
75. All labor costs incurred in disassembling the reactor, moving the irradiated components to storage cells, moving rebuilt components to the reactor, and reassembling the reactor are included in this account. Labor activities associated with rebuilding reactor wall components are also costed in this account.

Others (Account 51)

76. Included in this account are the annual costs of scheduled maintenance and replacement of major reactor components other than first wall modules.

SCHEDULED COMPONENT REPLACEMENT COSTS EXCLUDED

77. Costs of initial reactor first wall replacement component material and handling should not be included in scheduled component replacement accounts. (These costs should be included in capital cost estimates.)

ESTIMATING SCHEDULED COMPONENT REPLACEMENT COSTS

78. Table 4 contains a format for computing scheduled component replacement costs. Cost estimates should be based on present (current) year price levels.

VIII. FUEL COST ESTIMATION

79. Fusion reactors will utilize different fueling scenarios than conventional reactors operating today. Fusion reactors are expected to: 1) generate part of their fuel by irradiation of lithium to create tritium, 2) recycle generated tritium back to the reactor as fuel, and 3) recover unburned fuel from spent plasma and recycle it back to the reactor.
80. The costing procedure developed for fusion reactor design studies attempts to be consistent with past costing procedures in spite of these differences in fueling scenarios. In design studies fusion reactor fuel costs are defined as the purchase costs of fuel cycle materials consumed during an operating year and the offsite processing and disposal costs for those same fuel cycle materials. All onsite expenses for handling, preparation and disposal of fuel materials are costed in operating and maintenance cost accounts and not in fuel cost accounts. Purchase costs of fuel materials should consist of fuel material costs at the time of purchase transactions and any indirect costs (i.e., interest charges) resulting from the timing of these transactions. Fuel cost accounts are listed in Table 5.

TABLE 5. Fuel Cost Accounts

<u>Account Number</u>	<u>Account Title</u>	<u>Cost</u>
02	Annual Fuel Cycle Materials Consumed	
02.01	Deuterium	
02.02	Tritium	
02.03	Tritium Breeding Material	
02.04	Neutron Multipliers	
02.05	Cladding	
02.06	Other Fuel Materials	
03	Annual Offsite Processing and Disposal	
03.01	Deuterium	
03.02	Tritium	
03.03	Tritium Breeding Material	
03.04	Neutron Multipliers	
03.05	Cladding	
03.06	Other Fuel Materials	
<u>Total Annual Fuel Cost</u>		<u> </u>

DESCRIPTION OF FUEL COST ACCOUNTS

81. Fuel cost accounts are described below.

Annual Fuel Cycle Materials Consumed (Account 02)

82. The annual cost of reactor fuels consumed during facility operation are included in this account. The cost of the initial inventory of reactor fuel materials (i.e., fuel purchased prior to plant startup) should be included in capital cost accounts. Fuel materials removed from this inventory during reactor operation should be charged as a current fuel cost, and fuel materials returned to this inventory should be shown as a credit to fuel cost. In both situations, the market price will determine the value of the material added to or subtracted from inventories. Assumptions that should be used in establishing market prices for fuel materials are described below.

Deuterium (Account 02.01)

83. Deuterium should be assumed to be purchased in the open market.

Tritium (Account 02.02)

84. Tritium should be assumed to be purchased in the open market. When a precommercial industry maturity is assumed, tritium will have a positive market value. When a mature industry is assumed, tritium should be taken as having zero market value.
85. A zero market value assumes that a surplus of tritium will be available for newly constructed reactors initially becoming operational, because previously operated reactors will have generated tritium stockpiles. The only use for tritium stockpiles will be the initial inventories of newly constructed reactors. Unless new reactors are constructed at a very fast rate, a surplus of tritium will provably exist and would certainly soon exist because high market prices for tritium would result in design and operation of fusion reactors with higher breeding ratios (greater than 1.2). For this reason, it can be expected that there will be a surplus of tritium resulting in a zero market value. Although this assumption is probably not entirely correct, use of the assumption

avoids distortion of the economics for individual reactors as a result of the sale of surplus tritium.

86. After the fusion power industry is established, the market price of tritium will probably become equivalent to the incremental cost for producing a small amount of additional tritium. However, until commercial facility designs are known, it will not be possible to estimate this incremental tritium production cost.

Tritium Breeding Materials (Account 02.03)

87. Tritium breeding materials should be assumed to be purchased in the open market. Creation of tritium results in the destruction of some breeding materials. The cost of the initial inventory of breeding material should be included in capital cost accounts. The cost of breeding material makeup resulting from destruction or loss during recycling activities should be included in fuel cost accounts if the need for makeup can be shown to result from the creation of tritium.

Neutron Multipliers (Account 02.04)

88. Neutron multipliers should be assumed to be purchased in the open market.

Cladding (Account 02.05)

89. Cladding should be assumed to be purchased in the open market.

Other Fuel Materials (Account 02.06)

90. Fuel additives should be assumed to be purchased in the open market.

Annual Offsite Processing and Disposal Costs (Account 03)

91. The annual costs of offsite processing and disposal of fuel cycle materials are included in this account. The assumptions stated in the previous sections should be used in estimating costs for these accounts.

FUEL COSTS EXCLUDED

92. Cost for the following items or activities should not be included in fuel cost accounts.
- Onsite fuel preparation (to be included in operating and maintenance cost accounts)
 - Onsite fuel storage (to be included in operating and maintenance cost accounts)
 - Onsite fuel injection (to be included in operating and maintenance cost accounts)
 - Onsite irradiated fuel processing (to be included in operating and maintenance cost accounts)
 - Pumping activities if using lithium and neutron multipliers as coolant (to be included in operating and maintenance cost accounts)
 - Cooling system maintenance if using lithium and neutron multipliers as coolant (to be included in operating and maintenance cost accounts)
 - Coolant purification if using lithium and neutron multipliers as coolant (to be included in operating and maintenance cost accounts)

ESTIMATING FUEL COSTS

93. Total fuel cost is computed as an annual total fuel cost. The cost is calculated by summing the market costs of the fuel cycle materials consumed annually and the offsite processing and disposal cost of those same materials. Costs should be based on present (current) year price levels. Total fuel costs can be determined in the manner shown in Figure 4.

FIGURE 4. Fuel Cost Estimation

IX. TOTAL ENERGY COST DETERMINATION - FUSION
REACTOR FACILITIES PRODUCING ELECTRICITY

94. This chapter describes a format for combining estimates of capital investment costs, annual operating costs, and facility performance levels into a single measure of economic performance or cost. The computational techniques described were specifically developed for investor-owned electricity producing fusion reactor facilities. When evaluating nonelectricity producing fusion reactor facilities and non-investor-owned facilities, such as government owned and directed projects, the specific computational techniques employed should be developed by the evaluation team and documented in cost estimates.
95. Total busbar energy cost or total electricity cost is defined as the unit cost of generating electrical energy. The total energy cost for fusion reactor electricity-producing facilities is computed as a function of the following components:
- Plant availability factor
 - Financing assumptions
 - Fixed charge rate
 - Capital cost
 - Annual operating and maintenance cost
 - Annual scheduled component replacement cost
 - Annual fuel cost
 - Plant capacity.
96. The diagram in Figure 5 shows the method in which these components are used to compute total energy cost. Appendix D gives an example illustrating how costs should be combined to yield a total energy cost.
97. Four components have been described previously. These components are:
- Capital cost (Chapter V)
 - Annual operating and maintenance cost (Chapter VI)
 - Annual scheduled component replacement cost (Chapter VIII)
 - Annual fuel cost (Chapter VIII)

FIGURE 5. Total Energy Cost Determination

98. The remaining four components required in computing total energy cost are described in this chapter. Guidelines are established for determining the values of these components. These components are:

- Plant capacity
- Plant availability factor
- Financing assumptions
- Fixed charge rate.

PLANT CAPACITY

99. Plant capacity is the net electric power that would be produced annually by the fusion reactor if operating continuously at the design level of power generation. The plant capacity or maximum net energy generated per year at capacity is stated in kilowatt hours production per year. Plant capacity should be calculated from the following equation:

$$\text{Plant Capacity} = (P_d) 8,760,000$$

(kWh/yr)

(Eq. 7)

Where: P_d = plant design net electrical power level (MWe)

PLANT AVAILABILITY FACTOR

100. Plant availability factor is defined as the ratio between the expected available amount of power generation and the amount of power generation that would occur if the plant operated 100% of the time at the design power level. The plant availability factor is always less than 100% because of: 1) outage time for maintenance and refueling, and 2) operation at less than design level because equipment failure reduces the power generation capability. The equation used to calculate the plant availability factor is:

$$\text{Plant Availability Factor (\%)} = \frac{(8760 - T_u - T_s)}{8760} \quad (\text{Eq. 8})$$

Where: T_u = annual unscheduled outage time (hours)
 T_s = annual scheduled outage time (hours)

Components of this equation are described in the following sections.

Unscheduled Outage Time

101. The unscheduled outage time is the estimated hours per year that the plant is not operating due to unscheduled stoppages in plant operations. All power plants are plagued by unexpected outages due to minor equipment failures, loss of transmission systems, etc. In addition, it is probable that segments of fusion reactors will occasionally have to be replaced because of failures in heat transfer walls, inner walls, diverter systems, or magnets. If such replacements are necessary, they probably could be installed rapidly because spare segments would be kept in inventories ready for installation. Failed segments would be simply moved to a storage cell, and the spare segments installed. The failed segments could be repaired during subsequent reactor operating periods.
102. An exact estimate of the amount of unscheduled outage time cannot be made because reactor designs cannot be projected with accuracy. However, based on operating experience at conventional nuclear power plants, a total unscheduled outage time of four weeks per year should be projected. This estimate is based on average operating conditions for a debugged

reactor system. This amount of four weeks should be used except in those cases where it can be demonstrated that another amount is correct.

Scheduled Outage Time

103. The scheduled outage time is the estimated hours per year that the plant is not operating due to scheduled stoppages in plant operations. The amount of scheduled outage time will depend primarily on the plant design. This allowance should include time for routine maintenance such as replacement of the reactor inner walls and periodic overhauls of major equipment such as turbine generators.
104. Scheduled outage time should be estimated by the designer. Planning of maintenance procedures should be documented in design studies.

FINANCING ASSUMPTIONS

105. The cost of all labor, material, and equipment required during facility construction and operation should be estimated using present (current) year price levels. The present year or price level year should be stated in all cost studies.
106. Two modes of economic analysis are described in this document. The first is a constant dollar mode which assumes the purchasing value of the dollar remains constant over time. The second is a current dollar mode (nominal dollar mode) which assumes this purchasing value changes over time. The constant dollar mode utilized in these analysis procedures defines general inflation rates and component escalation rates equal to zero. All costs, regardless of when they are expected to be incurred, will be reported in present year price level dollars. The current dollar mode utilized in these procedures is identical to the constant dollar mode except for the following: 1) cost escalation on the estimated capital costs is assumed to exist and is costed in a single escalation during construction cost account (i.e., Account 95), and 2) cost escalation on estimated operating and maintenance, scheduled component replacement and fuel costs is assumed to exist and is costed within the respective parent cost account.

107. The current dollar analysis mode is in essence a nominal first year facility cost. Escalation cost will only be computed up to this first year.
108. Either mode of economic analysis can be used in design studies. When costing actual construction projects, the current dollar analysis should be utilized. When costing conceptual or paper study designs, use of both analysis modes is suggested.
109. The financing assumptions used to determine the cost of capital to the owning and constructing utility are stated below.⁽¹³⁻¹⁵⁾ It is mandatory that a consistent set of financing assumptions be utilized in any evaluation procedure. Any differences can have significant impact on the relative magnitudes of busbar energy costs. The following assumptions were used as the basis for determining the utilities cost of capital.
- The operating utility is an investor- (privately-) owned organization (see Chapter IV)
 - The capital structure is 53% debt financing and 47% equity (common stock) financing
 - The nominal cost of debt financing is 8% per year
 - The nominal cost of equity financing is 14% per year
 - Cost escalation and general inflation is 5% per year
 - The power plant's operating life is 30 years
 - The power plant's salvage value is zero.
110. The nominal cost of capital to the utility and the real (deflated) cost of capital to the utility can be computed from the above assumptions. The assumed values for these costs of capital are:
- Nominal cost of capital = 10% per year
 - Real (deflated) cost of capital = 5% per year

FIXED CHARGE RATE

111. The fixed charge rate to be used in economic computations is an annual charge rate.⁽²⁾ This charge rate, when applied to the initial facility capital investment cost, yields the annual expense resulting from 1) the capital investment cost being divided equally and charged equally to all annual operating periods and 2) the annual fixed operating and maintenance expenses which are costed as a function of the capital investment cost.
112. The makeup or components of the fixed charge rate are listed below for each economic analysis mode (see Chapter IV). All capital costs are assumed to be depreciable.

	Current Dollar Economic Analysis Mode	Constant Dollar Economic Analysis Mode
<u>Component</u>	<u>Percentage (%)</u>	<u>Percentage (%)</u>
Cost of capital	10.0	5.0
Depreciation	.5	1.3
Interim replacement	.3	.3
Property insurance	.2	.2
Federal income taxes	2.0	2.0
State and local taxes	<u>2.8</u>	<u>2.8</u>
Assumed Annual fixed charge rate	15.0	10.0

113. Fixed charge rates of 15%/year and 10%/year for current dollar and constant dollar analysis modes should be used in all fusion reactor design studies, in the absence of economic information pertaining to a specific application under consideration. Components of the fixed charge rate are described below.

Cost of Capital

114. The cost of capital component of the fixed charge rate costs the annual expense resulting from having to borrow the money to construct

and start up the power plant. The cost of procuring the required capital is equivalent to the rate of return on investment allowed by regulatory agencies. The capital structure of the utility and the rate of return required for each component of the capital structure determines this cost of capital.

Depreciation

115. The depreciation component of the fixed charge rate costs the portion of the total capital investment cost that must be realized or expensed each year. This yearly charge must be costed in order that the entire capital cost be realized and costed equally over the operating life of the plant. The sinking fund method for calculating annual depreciation charges is used in this fixed charge rate.

Interim Replacements

116. Interim replacement costs are the annual expenses for replacing plant equipment having shorter service lives than the 30 year plant life. Many fusion power plant components are expected to require periodic replacement, and the interim replacement component of the fixed charge rate costs the annual allowance for the purchase of such replacements. Costs of major (greater than \$10,000) scheduled replacement components (i.e., inner wall segments, etc.) are not included as interim replacement costs.

Property Insurance

117. The property insurance component of the fixed charge rate costs the annual property insurance expense. Two types of insurance are costed for fusion power plants: property damage and third party liability.

Federal Income Taxes

118. The federal income tax component of the fixed charge rate costs annual federal tax expenses. The magnitude of this component is calculated based on the capital structure of the utility, sum-of-the-year digits (SYD) depreciation, and a 50% federal income tax rate.

State and Local Taxes

119. State and local taxes are also an annual expense of operating the facility and must be recognized in the fixed charge rate. The magnitude of these taxes will vary greatly with facility location. The tax rate component designated in this fixed charge rate should be used in the absence of specific tax rate information for a particular locality under consideration.

COMPUTATION OF TOTAL BUSBAR ENERGY COST

120. Total busbar energy cost or the unit cost of generating electricity from the fusion reactor facility should be calculated using the procedures described in this document.⁽¹⁶⁾ In fusion reactor power plant design studies the single measure of design concept economic performance is total busbar energy cost. Equations for computing this cost in both a current dollar economic analysis mode and in a constant dollar economic analysis mode are given below.

Constant Dollar Economic Analysis Mode

121. The constant dollar economic analysis mode assumes general inflation rates and escalation rates are equal to zero. The equation that should be used to determine total energy cost is as follows:

$$\text{Total Busbar Energy Cost (mills/kWh)} = \frac{C_C(\text{fcr}) + C_{\text{o\&m}} + C_{\text{scr}} + C_F}{(\text{PC}) (\text{PAF}) (10^{-3})} \quad (\text{Eq. 9})$$

Where:

- C_C = Facility capital cost (dollars)
- fcr = Annual fixed charge rate (= .10)
- $C_{\text{o\&m}}$ = Annual operating and maintenance cost (dollars)
- C_F = Annual fuel cost (dollars)
- C_{scr} = Annual scheduled component replacement cost (dollars)
- PC = Plant capacity (kWh/yr)
- PAF = Plant availability factor (=%/100)

Current Dollar Economic Analysis Mode

122. The current dollar economic analysis mode assumes general inflation and escalation exist. Costs are escalated to reflect this assumption. The total busbar energy cost figure is a nominal or actual first year busbar energy cost. For this reason, annual operating and maintenance costs, annual scheduled component replacement costs, and annual fuel costs that were estimated using preconstruction year price levels are escalated to first year of facility operation price levels. The equation that should be used to determine total busbar energy cost is as follows:

$$\text{Total Busbar Energy Cost} = \frac{C_c(\text{fcr}) + C_{o\&m}(E+1)^P + C_{scr}(E+1)^P + C_f(E+1)^P}{(\text{PC})(\text{PAF})(10^{-3})}$$

(mills/kWh)

Where:

- C_c = Facility capital cost (dollars)
- fcr = Annual fixed charge rate (= .15)
- $C_{o\&m}$ = Annual operating and maintenance cost (dollars)
- E = Annual escalation rate (= .05)
- P = Construction period (years)
- C_{scr} = Annual scheduled component replacement cost (dollars)
- C_f = Annual fuel cost (dollars)
- PC = Plant capacity (kWh/yr)
- PAF = Plant availability factor (= %/100)

123. These equations should be used in computing all design study total busbar energy costs, regardless of the availability of equations that may seem more appropriate for a particular application.

REFERENCES

1. J. R. Young, Economic Information Requirements - Fusion Reactor Design Studies. Battelle, Pacific Northwest Laboratories, Richland, Wa, 1977.
2. "Guide for Economic Evaluation of Nuclear Reactor Plant Designs," NUS-531, NUS Corporation, January 1969.
3. B. Badger, et al., UWMAK-I, A Wisconsin Toroidal Fusion Reactor Design. UWFD-68, Nuclear Engineering Department, University of Wisconsin, Volume 1, November 1973.
4. B. Badger, et al., UWMAK-II, A Conceptual D-T Fueled, Helium Cooled Tokamak Fusion Power Reactor Design, Fusion Technology Program. UWMAK-112, Nuclear Engineering Department, University of Wisconsin, May 1975.
5. B. Badger, et al., UWMAK-III, A High Performance, Non-Circular Tokamak Power Reactor Design. UWFD-150, Nuclear Engineering Department, University of Wisconsin.
6. R. Mills, A Fusion Power Plant. Princeton Plasma Physics Laboratory Report, MATT-1050, August 1974.
7. Fossil and Nuclear 1000 MW Central Station Power Plants Investment Estimates. Ebasco Services Incorporated, September 1975.
8. Uniform Systems of Accounts Prescribed - Public Utilities and Licensees. Federal Power Commission, June 18, 1975.
9. Capital Cost: Boiling Water Reactor Plant. United Engineers and Constructors, NUREG-0242, June 1977.
10. Impact of Confinement Physics on Reactor Design and Economics. McDonnell Douglas Astronautics Company - East, June 1977.
11. D. L. Phung, A Method for Estimating Escalation and Interest During Construction. Institute for Energy Analysis, Oak Ridge Associates Universities, October 1977.
12. G. L. Kulcinski and J. R. Young, The Influence of First Wall Lifetime on the Cost of Electricity in UWMAK Type Fusion Reactors. University of Wisconsin Report, UWFD-140, October 20, 1975.
13. J. W. Doane, et al., The Cost of Energy From Utility-Owned Solar Electric Systems. JPL 5040-29, June 1976.
14. R. Skamser, Coal Gasification Commercial Concepts Gas Cost Guidelines. C. F. Braun and Co., FE-1235-1, January 1976.

15. Guidelines For Cost Analysis of Energy Production - Regulated Utility Industry. Institute for Energy Analysis, Oak Ridge Associates Universities, Draft 1, July 1977.
16. L. Grant and W. Ireson, Principles of Engineering Economy. The Ronald Press Company.

APPENDIX A

REFERENCE CONSTRUCTION AND OPERATING SITE⁽²⁾

DESCRIPTION OF REFERENCE SITE

- A-1. The reference hypothetical plant site described in this Appendix has been established for use in the preparation of fusion power plant economic evaluations, design studies, cost normalizations, and other types of studies relating to the economic factors associated with fusion power generation. It is intended that the site described herein should be used as the design basis whenever empirical data for a specific location are not available. It is recognized that certain aspects of the standard site description and associated factors may have to be modified to meet specific requirements of the study, since each site will have environmental and economic factors unique to that particular site.

A.1 TOPOGRAPHY AND GENERAL SITE CHARACTERISTICS

- A-2. The site is located on the east bank of the North River at a distance of twenty-five miles south of Middletown, the nearest large city. The North River flows from north to south and is one-half mile (2600 feet) wide adjacent to the plant site. A flood plain extends from both river banks an average distance of 1/2 miles, ending with hilltops generally 150 to 250 feet above the river level. Beyond this area, the topography is gently rolling, with no major topographical features. The plant site itself extends from river level to elevations of fifty feet above river level. The reactor building, other structures and the switchyard will be located on level ground at an elevation of eighteen feet above the mean river level. This elevation is ten feet above the 100-year maximum river level, according to U.S. Army Corps of Engineers studies of the area.
- A-3. In order to optimize land area requirements for the fusion power plant site, maximum use of the river location is employed. The reactor building structure is located 400 feet from the east bank of the river.

A.2 SITE ACCESS

- A-4. Highway access is provided to the Hypothetical Site by five miles of secondary road connecting to a state highway; this road is in good condition and needs no additional improvements. Railroad access will be provided by constructing a railroad spur which intersects the B&M Railroad. The length of the required spur from the main line to the plant site is assumed to be five miles in length for all plant sizes. The North River is navigable throughout the year with a forty-foot wide channel, 12 feet deep. The distance from the shoreline to the center of the ship channel is 2000 feet. All plant shipments will be made overland except that heavy equipment (such as generator stator) may be transported by barge. The Middletown Municipal Airport is located 3 miles west of the State highway, 15 miles south of Middletown, and 10 miles north of the site.

A.3 POPULATION DENSITY AND LAND USE

- A-5. The Hypothetical Site is near a large city (Middletown, 250,000 population) but in an area of low population density. Variation in population with distance from the site boundary is:

<u>Miles</u>	<u>Cumulative Population</u>
0.5	0
1.0	310
2.0	1,370
5.0	5,020
10.0	28,600
20.0	133,000
30.0	1,010,000

The nearest residence to the plant is on the opposite bank of the North River, directly west of the reactor location, 2600 feet west of the plant boundary, and 3000 feet west of the reactor building.

A-6. There are five industrial manufacturing plants within 15 miles of the Hypothetical Site. Four are small plants employing less than 100 people each. The fifth, near the airport, employs 2500 people. Closely populated areas are found only in the centers of the small towns so the total land area used for housing is small. The remaining land, including that across the river, is used as forest or cultivated crop land, except for railroads and highways.

A.4 COST OF LAND

A-7. The cost of land and land rights, including clearing and relocating highways, bridges, rail lines, utilities, etc., is \$2500 per acre.

A.5 COOLING WATER AND PUBLIC UTILITY SERVICES

A-8. Utilities are available as follows:

- The North River provides an adequate source of raw make up and condenser cooling water for the ultimate station capacity. The average maximum temperature is 75°F and the average minimum is 39°F. The mean annual temperature is 57°F. (These temperatures are such as to enable the turbine back-pressure to be specified as 1.5 inches Hg absolute.)
- Natural gas service is available two miles from the site boundary on the same side of the river.
- Communication lines will be furnished to the project boundaries at no cost.
- Power and water for construction activities are available at the southwest corner of the site boundary.
- The distribution system in the area is a single source transmission, and is subject to occasional outages.

A.6 METEOROLOGY AND CLIMATOLOGY

1. Prevailing Wind

A-9. According to Weather Bureau records at the Middletown Airport, located ten miles north of the site on a low plateau just east of the

North River, surface winds are predominantly southwesterly 4 - 10 knots during the warm months of the year, and westerly 6 - 13 knots during the cool months. There are no large daily variations in wind speed or direction. Observations of wind velocities at altitude indicate a gradual increase in mean speed and a gradual veering of the prevailing wind direction from southwest and west near the surface to westerly and northwesterly aloft.

- A-10. Studies of the area indicated that there is a significant channeling of the winds below the surrounding hills into the north-south orientation of the North River. It is estimated that winds within the river valley blow approximately parallel to the valley orientation in excess of 50 percent of the time.

2. Atmospheric Diffusion Properties

- A-11. During the warm months of the year, according to analysis of Weather Bureau records, the atmospheric conditions near the surface are 25 percent unstable (Pasquill A, B, and C), 40 percent neutral (Pasquill D), and 35 percent stable (Pasquill E and F). Average wind speeds are approximately six miles per hour during unstable conditions, ten miles per hour during neutral conditions, and four miles per hour during stable conditions.
- A-12. During the cool months of the year, the atmospheric conditions are 15 percent unstable, 50 percent neutral, and 35 percent stable. Average wind speeds are six miles per hour during unstable conditions, twelve miles per hour during neutral conditions, and four miles per hour during stable conditions.

3. Severe Meteorological Phenomena

- A-13. A maximum instantaneous wind velocity of 100 mph has been recorded at the site. During the past 50 years, three tropical storms, all of them in the final dissipation stages, have passed within 50 miles of the site. Some heavy precipitation and winds in excess of 40 miles per hour were recorded, but no significant damage other than to crops resulted.

A-14. The area near the site experiences an average of 35 thunderstorms a year, with maximum frequency in early summer. High winds near 60 mph, heavy precipitation, and hail are recorded about once every four years.

A-15. In forty years of record, there have been twenty tornadoes reported within fifty miles of the site. Maximum tornado frequency occurs in May and June.

A-16. During the past forty years, there have been ten storms in which freezing rain has caused power line disruptions. Most of these storms have occurred in early December.

4. Potential Accidental Release Meteorology

A-17. A review of weather bureau records taken at the Middletown Municipal Airport over the past ten years indicates that the poorest atmospheric diffusion conditions occur in the autumn. The following conditions were noted:

- Nocturnal inversions occur on four of five nights.
- Stagnating high-pressure systems have occurred each year for the past ten years during the fall, causing a persistent subsidence inversion over the entire area. Average duration of these stagnating anticyclones has been five days, with the longest occurrence being nine days.
- The longest wind persistence (duration of time winds blew constantly from one 22-1/2° sector) during the period of records was for 96 hours from the south, along the river valley. During this time, stabilities were 20 percent unstable (Pasquill B and C), 30 percent neutral (Pasquill D), and 50 percent stable (Pasquill E and F). This occurred during a stagnation period, so that there was also a persistent subsidence inversion aloft at an average height of 3000 feet.

A-18. From these data, 30 day accident meteorological regimes are assumed to be as given in Tables A-1 and A-2 for a ground level release and an elevated release.

5. Dispersion Characteristics

A-19. The accident meteorology presented in Tables A-1 and A-2 provide the basic data for calculating dispersion factors (χ/Q) using equations based upon the Pasquill dispersion model^(b). (χ/Q) values for center-line, ground level locations as a function of downwind distances are given in Figures A-1 and A-2 for ground level and elevated releases, respectively. A lateral restriction at 1200 meters imposed by the river valley and a building wake factor of $C = 1/2$ has been used in the ground level release calculations.

TABLE A-1. Accident Meteorology for a Ground Level Release

<u>Time Period</u>	<u>Pasquill Stability Category</u>	<u>Stability Frequency</u>	<u>Direction Frequency</u>	<u>Wind Speed (m/sec)</u>	<u>Wind Direction type *</u>
0-2 hrs	F	1.0	1.0	1.0	Invariant
2-24 hrs	F	1.0	1.0	2.0	Invariant
1-5 days	B	0.2	1.0	2.0	Variant
	D	0.3	1.0	4.0	Variant
	F	0.5	1.0	2.0	Variant
5-30 days	B	0.15	0.5	3.0	Variant
	D	0.50	0.5	5.0	Variant
	F	0.35	0.5	2.0	Variant

* Lateral dispersion restricted to 1200 meters from center line for all time periods.

(b) Section 3-3.5 of "Meteorology and Atomic Energy", D. H. Slade, Editor, TID-24190, 1968.

TABLE A-2. Accident Meteorology for a Elevated Release

<u>Time Period</u>	<u>Pasquill Stability Category</u>	<u>Stability Frequency</u>	<u>Direction Frequency</u>	<u>Wind Speed (m/sec)</u>	<u>Wind Direction type *</u>
0-2 hrs	B*	1	1	1	Invariant
2-24 hrs	B	1	1	2	Invariant
1-5 days	B	0.33	0.75	3	Variant
	D	0.33	0.75	5	Variant
	F	0.33	0.75	2	Variant
5-30 days	B	0.15	0.5	4	Variant
	D	0.15	0.5	6	Variant
	F	0.35	0.5	3	Variant

* Inversion cap at release height.

A.7 GEOLOGY AND SEISMOLOGY

1. Soil Profiles and Load Bearing Characteristics

A-20. Soil profiles for the site show alluvial soil and rock fill to a depth of eight feet; Brassfield limestone to a depth of 30 feet; blue weathered shale and fossiliferous Richmond limestone to a depth of 50 feet; and bedrock over a depth of 50 feet. Allowable soil bearing is 6000 psf and rock bearing characteristics are 18,000 psf and 15,000 psf for Brassfield and Richmond strata, respectively. No underground cavities exist in the limestone.

2. Seismology

A-21. This is a Zone 1 site, as designated by the Uniform Building Code, based on the observation of three earthquakes of seismic intensities 4-6 on the Modified Mercall scale during the period 1870-1958, causing minor damage to towns in the surrounding area.

FIGURE A-1. Dispersion Factor - X/Q - Sec/Meter³

FIGURE A-2. Dispersion Factor - χ/Q - Sec/Meter³

A.8 SEWAGE AND RADIOACTIVE WASTE DISPOSAL

1. Sewage

All sewage must receive primary and secondary treatment prior to discharge into the North River.

2. Gaseous and Liquid Radioactive Wastes

A-23. Maximum permissible concentrations or dosages shall be as prescribed in the current revision of 10 CFR 20. The activity level of the liquid effluent shall be measured as it leaves the plant. No credit for dilution in the North River will be assumed.

3. Solid Radioactive Wastes

A-24. Storage onsite for decay will be permissible but no ultimate disposal on site will be made.

APPENDIX B

UNIFORM CAPITAL COST ACCOUNTS

CAPITAL COST ACCOUNTS

Account Number	Account Title
20	<u>LAND AND LAND RIGHTS</u>
20.01	Land and Privilege Acquisition
20.02	Relocation of Buildings, Utilities, Highways, and Other Services
21	<u>STRUCTURES AND SITE FACILITIES</u>
21.01	Site Improvements and Facilities
21.01.01	General Yard Improvements
	<i>Grading, General Excavation and/or Fill,</i>
	<i>Landscaping, Site Clearing</i>
	<i>Roads, Sidewalks and Parking Areas</i>
	<i>Retaining Walls</i>
	<i>Fences, Railings, and Gateways</i>
	<i>Sanitary Sewer System</i>
	<i>Yard Drainage and Storm Sewer System</i>
21.01.02	Waterfront Improvements
	<i>Revetments</i>
	<i>Levees</i>
	<i>Breakwaters</i>
21.01.03	Transportation Access (Off Site)
	<i>Highway Access</i>
	<i>Railway Access</i>
	<i>Waterway Access Facilities</i>
21.02	Reactor Building (Including Radwaste and Fuel Handling Areas)
21.02.01	Basic Building Structures
	<i>Earth Work Including Dewatering, Walers Steel Sheeting</i>
	<i>Substructure Up to Grade Including Concrete, Reinforcing,</i>
	<i>Forms, Embedments</i>
	<i>Superstructure</i>
	<i>Structural Steel Stack</i>
21.02.02	Building Services
	<i>Plumbing Below and Above Grade</i>
	<i>Heating, Ventilation, Air-Conditioning</i>
	<i>Fire Protection System</i>
	<i>Elevator</i>
21.02.03	Containment Structures
	<i>Primary Containment Liners at Reactor Area</i>
	<i>Secondary Liner Plant Work for Walls, Floors, Roof</i>
	<i>Penetrations (Mechanical and Electrical)</i>
21.03	Turbine Building (Including Control Room, Heater Bay, Diesel Generator Area)
21.03.01	Basic Building Structures
	<i>Earth Work</i>
	<i>Substructure, Embedments</i>
	<i>Superstructure Including Structural and Gallery</i>
	<i>Steel</i>

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
21	<u>STRUCTURES AND SITE FACILITIES (Cont'd)</u>
21.03	Turbine Building (Including Control Room, Heater Bay, Diesel Generator Area)
21.03.02	Building Services
	Plumbing
	Heating, Ventilation, Air-Conditioning
	Fire Protection System
	Elevator
21.04	Cooling System Structures
21.04.01	Intake Structures
	Earth Work
	Supply Pump House
	Protective Relief Slabs for Supply Pipe Lines
21.04.02	Discharge Structures
	Earth Work
	Protective Relief Slabs for Discharge Lines
21.04.03	Unpressurized Intake and Discharge Conduits
	Discharge Tunnel
	Discharge Canal
	De-icing Pump Pit
21.04.04	Recirculating Structures
	Earth Work
	Recirculating Pump House
	Protective Relief Slabs for Circulating Pipe Lines
21.04.05	Cooling Tower Systems
	Earth Work
21.05	Power Supply and Energy Storage Building
21.05.01	Basic Building Structures
	Earth Work
	Substructure, Embedments
	Superstructure Including Gallery Steel
21.05.02	Building Services
	Plumbing
	Heating, Ventilation, and Air-Conditioning
	Fire Protection System
	Elevator
21.06	Miscellaneous Buildings
21.06.01	Reactor Auxiliaries Building (Including Switchgear Bay)
	Basic Building Structures
	Building Services
21.06.02	Radioactive Waste Building
	Basic Building Structures
	Building Services

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
21	<u>STRUCTURES AND SITE FACILITIES (Cont'd)</u>
21.06	Miscellaneous Buildings (Cont'd)
21.06.03	Fuel Storage Building
	Basic Building Structures
	Building Services
21.06.04	Control Room Building
	Basic Building Structures
	Building Services
21.06.05	Diesel Generator Building
	Basic Building Structure
	Building Services
21.06.06	Administration Building
	Basic Building Structures
	Building Services
21.06.07	Service Building
	Basic Building Structures
	Building Services
21.06.08	Helium Storage Building
	Basic Building Structures
	Building Services
21.06.09	Miscellaneous Structures and Building Work
	Gate House (Permanent)
	Visitor Center Building
	Electrical Yard Foundations and Structures
	Heating Boiler House
	Hypochlorination Solution Tank Foundation
	Oil Separator Underground Vault
	Foundation for Tanks (Water Storage)
	Berm and Foundation for Oil Storage Tanks
	Test Borings
	Miscellaneous Yard Structures and Buildings
	Work for Permanent Plant
21.07	Ventilation Stack
21.98	Spare Parts Allowance
21.99	Contingency Allowance
22	<u>REACTOR PLANT EQUIPMENT</u>
22.01	Reactor Equipment
22.01.01	Blanket and First Wall
22.01.01.01	Breeding Material (Including Tritium Breeding)
22.01.01.02	First Wall and Structural Material
22.01.01.03	Attenuators, Reflectors and Multipliers
22.01.01.04	Wall Modifiers (Coatings, Liners, Limiters, etc.)
22.01.01.05	Others

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
22	<u>REACTOR PLANT EQUIPMENT (Con'd)</u>
22.01	Reactor Equipment (Con'd)
22.01.02	Shield
	Primary
	Secondary
22.01.03	Magnets
22.01.03.01	Principal Field Magnet
22.01.03.02	Secondary Field Magnet
22.01.04	Supplemental Heating
22.01.04.01	Beam Heating (Neutral, Ion or Electron)
22.01.04.02	RF Heating
22.01.04.03	Laser Heating
22.01.04.04	Other
22.01.05	Primary Structure and Support
22.01.05.01	Reactor Structure
22.01.05.02	Equipment Support Structure
22.01.06	Reactor Vacuum Systems (If Vacuum Components are Integral to Subsystem, Cost is Included in Subsystem)
22.01.06.01	Plasma Chamber Vacuum
22.01.06.01.01	Pumps/Compressors
22.01.06.01.02	Piping
22.01.06.02	Magnet Dewar Vacuum
22.01.06.02.01	Pumps/Compressors
22.01.06.02.02	Piping
22.01.06.03	Supplemental Heating Vacuum
22.01.06.03.01	Pumps/Compressors
22.01.06.03.02	Piping
22.01.06.04	Direct Converter Vacuum
22.01.06.04.01	Pumps/Compressors
22.01.06.04.02	Piping
22.01.06.05	Reactor Vacuum System
22.01.06.05.01	Pumps/Compressors
22.01.06.05.02	Piping
22.01.06.06	Reactor Vacuum Wall
22.01.07	Power Supply Switching & Energy Storage
22.01.07.01	Heating
22.01.07.02	Confinement
22.01.07.03	Control System
22.01.07.04	Central Energy Storage
22.01.07.05	Other
22.01.08	Impurity Control
22.01.09	Direct Energy Converter

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
22	REACTOR PLANT EQUIPMENT (Cont'd)
22.01	Reactor Equipment (Cont'd)
22.01.09.01	Vacuum Tank
22.01.09.02	Direct Converter Modules
22.01.09.03	Thermal Panels
22.01.09.04	Power Conditioning Equipment
22.02	Main Heat Transfer and Transport Systems (and/or Blanket Energy Utilization)
22.02.01	Primary Coolant System (Included Blanket, Shield, Diverter, etc.)
22.02.01.01	Pumps and Motor Drives, Modular and Nonmodular
22.02.01.02	Piping
22.02.01.03	Heat Exchanges
22.02.01.04	Tanks
22.02.01.04.01	Dump Tanks
22.02.01.04.02	Make-Up Tanks
22.02.01.04.03	Clean-Up Tanks
22.02.01.04.04	Tritium Extraction Tanks
22.02.01.04.05	Hot Storage Tanks
22.02.01.05	Clean-Up System
22.02.01.06	Thermal Insulation, Piping and Equipment
22.02.01.07	Tritium Extraction
22.02.02	Intermediate Coolant System
22.02.02.01	Pumps and Motor Drives, Modular and Nonmodular
22.02.02.02	Piping
22.02.02.03	Heat Exchangers
22.02.02.04	Tanks
22.02.02.04.01	Dump Tanks
22.02.02.04.02	Make-Up Tanks
22.02.02.04.03	Clean-Up Tanks
22.02.02.04.04	Tritium Extraction Tanks
22.02.02.04.05	Hot Storage Tanks
22.02.02.05	Clean-Up System
22.02.02.06	Thermal Insulation, Piping and Equipment
22.02.02.07	Tritium Extraction
22.03	Auxiliary Cooling System
22.03.01	Magnet Cooling
22.03.01.01	Refrigeration
22.03.01.02	Piping
22.03.01.03	Fluid Circulation Driving System
22.03.01.04	Tanks
22.03.01.04	Purification
22.03.02	Shield and Structure Cooling
22.03.02.01	Refrigeration
22.03.02.02	Piping
22.03.02.03	Fluid Circulation Driving System
22.03.02.04	Purification

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
22	<u>REACTOR PLANT EQUIPMENT (Cont'd)</u>
22.03	Auxiliary Cooling Systems (Cont'd)
22.03.03	Supplemental-Heating Cooling
22.03.03.01	Refrigeration
22.03.03.02	Piping
22.03.03.03	Fluid Circulation Driving System
22.03.03.04	Tanks
22.03.03.05	Purification
22.03.04	Power Supply Cooling
22.03.04.01	Refrigeration
22.03.04.02	Piping
22.03.04.03	Fluid Circulation Driving System
22.03.04.04	Tanks
22.03.04.05	Purification
22.03.05	Other
22.04	Radioactive Waste Treatment and Disposal
22.04.01	Liquid Waste Processing and Equipment
22.04.02	Gaseous Wastes and Off-Gas Processing System
22.04.03	Solid Wastes Processing Equipment
22.05	Fuel Handling and Storage Systems (Fuel Injection)
22.05.01	Fuel Purification Systems
22.05.02	Liquefaction
22.05.03	Fuel Preparation
22.05.04	Fuel Injection
22.05.05	Fuel Storage
22.05.06	Tritium Recovery
22.05.07	Emergency Air Detritiation
22.06	Other Reactor Plant Equipment
22.06.01	Maintenance Equipment
22.06.01.01	Blanket and Coil Maintenance Equipment
22.06.01.02	Components Rotated into Service to Allow Maintenance
22.06.01.03	Other Maintenance Equipment
22.06.02	Special Heating Systems (Startup Heating, Equipment Heating, Trace Heating, etc.)
22.06.03	Coolant Receiving, Storage and Make-Up Systems
22.06.04	Gas Systems
22.06.05	Building Vacuum Systems
22.07	Instrumentation and Control
22.07.01	Reactor I&C Equipment (Burn Control, Plasma Diagnostics, etc.)
22.07.02	Radiation Monitoring Systems
22.07.03	Isolated Indicating and Recording Gauges, etc.
22.98	Spare Parts Allowance
22.99	Contingency Allowance

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
23	<u>TURBINE PLANT EQUIPMENT</u>
23.01	Turbine-Generators
23.01.01	Turbine-Generators and Accessories
	<i>Turbines</i>
	<i>Generators</i>
	<i>Nonstandard Accessories</i>
	<i>Steam By-Pass System</i>
	<i>Live Steam Reheaters</i>
	<i>Piping, Valves and Hangers for By-Pass System</i> <i>(supplied by T/G Vendor)</i>
	<i>Thermal Insulation</i>
23.01.02	Foundations
23.01.03	Standby Exciters
23.01.04	Lubricating System
	<i>Oil Conditioning Equipment</i>
	<i>Clean and Dirty Oil Storage Tanks</i>
	<i>Turbine Oil Transfer Pumps and Motors</i>
23.01.05	Gas Systems
23.01.06	Reheaters
23.01.07	Shielding
23.01.08	Weather-Proof Housing
23.02	Main Steam (or other fluid) System
23.03	Heat Rejection Systems
23.03.01	Water Intake Common Facilities
	<i>Traveling Screens</i>
	<i>Screen Wash Pumps</i>
	<i>Chlorination Equipment</i>
23.03.02	Circulating Water Systems
	<i>Circulating Water Pumps and Motor Drives</i>
	<i>Pumps to Condensers and to the Cooling Towers</i>
23.03.03	Cooling Towers
	<i>Foundations and Basins</i>
	<i>Primary Cooling Towers</i>
	<i>Waste Heat Cooling Tower</i>
	<i>Waste Heat System Heat Exchanger</i>
23.03.04	Other Systems Which Reject Heat to the Atmosphere
23.04	Condensing Systems
23.04.01	Condensers
	<i>Condensers Complete Including Shells, Tube</i> <i>Plates, Water Boxes, Hot Wells, etc.</i>
	<i>Condenser Tubes</i>
	<i>Expansion Joints and Exhaust Stack Extensions</i>
	<i>Foundations</i>
23.04.02	Condensate System
	<i>Condensate Pumping Units Consisting of:</i> <i>Condensate Pumps and Motor Drive</i> <i>Condensate Booster Pumps and Motor Drive</i>

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
23	<u>TURBINE PLANT EQUIPMENT (Cont'd)</u>
23.04	Condensing Systems (Cont'd)
23.04.03	Gas Removal System
	<i>Vacuum Pumps and Motor Drives</i>
	<i>Air Ejector Equipment</i>
	<i>Priming Ejectors</i>
23.04.04	Turbine By-Pass Systems
23.05	Feed Heating System
23.05.01	Regenerators and Recuperators
	<i>H.P. Closed Feedwater Heaters</i>
	<i>L.P. Closed Feedwater Heaters</i>
23.05.02	Pumps
	<i>Turbine Driven Feed Pumps, Bedplates, Complete with Appurtenances</i>
	<i>Motor Driven Feed Pumps, Bedplates, Complete with Motor Drives</i>
	<i>Turbine Drives, for Feed Pumps</i>
	<i>Exhaust Ducts and Appurtenances to Main Condenser</i>
	<i>Heater Drain Pumps and Motor Drives</i>
	<i>All other Miscellaneous Pumps and Motors</i>
23.05.03	Tanks
	<i>Tanks (Condensate, Chemicals, Oil)</i>
23.06	Other Turbine Plant Equipment
23.06.01	Turbine Auxiliaries
23.06.02	Auxiliaries Cooling System
23.06.03	Make-Up Treatment System
23.06.04	Chemical Treatment and Condensate Purification Systems
	<i>Filtration Equipment, Including Sand Filters, Aerators, Retention Tanks, Pumps, etc.</i>
	<i>Demineralizing Equipment, Including Anion and Cation Units, Decarbonator, Mixed Bed Units, Pumps</i>
	<i>Regeneration Units</i>
	<i>Condensate Polishing Equipment Including Polishers, Anion and Cation Regeneration Equipment, Resin</i>
	<i>Mixing and Storage Vessels, Pumps, Tanks, Instruments, Controls</i>
	<i>Chemical Feed Equipment Including Mixing Tanks Pumps</i>
23.06.05	Central Lubrication Service System
	<i>Clean Oil Tank</i>
	<i>Dirty Oil Tank</i>
	<i>Turbine Oil Conditioning Equipment Including Pumps</i>
	<i>Turbine Oil Transfer Pumps and Motors</i>
	<i>Portable Oil Centrifuge and Filters</i>
	<i>Miscellaneous</i>

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
23	<u>TURBINE PLANT EQUIPMENT (Cont'd)</u>
23.07	Instrumentation and Control (I&C) Equipment
23.98	Spare Parts Allowance
23.99	Contingency Allowance
24	<u>ELECTRIC PLANT EQUIPMENT</u>
24.01	Switchgear
24.01.01	Generator Circuits
24.01.02	Station Service
24.02	Station Service Equipment
24.02.01	Station Service and Startup Transformers
24.02.02	Low Voltage Unit Substation and Lighting Transformers
24.02.03	Battery System
24.02.04	Diesel Engine Generators
24.02.05	Gas Turbine Generators
24.02.06	Motor Generator Sets
24.03	Switchboards (Including Heat Tracing)
24.03.01	Main Control Board for Electric System
24.03.02	Auxiliary Power and Signal Boards
24.04	Protective Equipment (General Station Grounding Systems and Cathodic Protection)
24.05	Electrical Structures and Wiring Containers
24.05.01	Concrete Cable Tunnels, Trenches and Envelopes
24.05.02	Cable Trays and Support
24.05.03	Conduit
24.05.04	Other Structures
24.06	Power and Control Wiring
24.06.01	Generator Circuits Wiring
24.06.02	Station Service Power Wiring
24.06.03	Control Wiring
24.06.04	Instrument Wiring
24.06.05	Containment Penetrations
24.07	Electrical Lighting
24.07.01	Reactor Building Lighting
24.07.02	Turbine Building Lighting
24.07.03	Reactor Auxiliaries Building Lighting
24.07.04	Radioactive Waste Building Lighting
24.07.05	Fuel Storage Building Lighting
24.07.06	Miscellaneous Structures and Building Lighting
	<i>Control Room Building</i>
	<i>Diesel Generation Building</i>
	<i>Administration Building</i>
	<i>Service Building</i>
	<i>Other Buildings</i>

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
24	<u>ELECTRIC PLANT EQUIPMENT (Cont'd)</u>
24.07	Electrical Lighting (Cont'd)
24.04.07	Yard Lighting
24.98	Spare Parts Allowance
24.99	Contingency Allowance
25	<u>MISCELLANEOUS PLANT EQUIPMENT</u>
25.01	Transportation and Lifting Equipment
25.01.01	Cranes, Hoists, Monorails and Conveyors
	<i>Turbine Room Cranes</i>
	<i>Hot Cell Cranes</i>
	<i>Miscellaneous Hoists Cranes, Jibs and Trolleys</i>
	<i>for Equipment Maintenance</i>
	<i>Inductive Coil and Storage Building Crane</i>
	<i>Other Building Cranes</i>
	<i>Reactor Hall Crane</i>
25.01.02	Railway
25.01.03	Roadway Equipment
25.01.04	Watercraft
25.01.05	Vehicle Maintenance Equipment
25.02	Air and Water Service Systems
25.02.01	Air Systems
	<i>Service Air Compressor and Motor Drives</i>
	<i>Service Air Receivers</i>
	<i>Instrument Air Compressors and Motor Drives</i>
	<i>Instrument Air Receivers</i>
	<i>Instrument Air Dryers</i>
25.02.02	Water System
25.02.03	Auxiliary Heating Boilers
25.03	Communications Equipment
25.03.01	Local Communications Systems
25.03.02	Signal Systems
25.04	Furnishing and Fixtures
25.04.01	Safety Equipment
25.04.02	Shop, Laboratory and Test Equipment
25.04.03	Office Equipment and Furnishings
25.04.04	Change Room Equipment
25.04.05	Environmental Monitoring Equipment
25.04.06	Dining Facilities
25.98	Spare Parts Allowance
25.99	Contingency Allowance
26	<u>SPECIAL MATERIALS</u>
26.01	Reactor Coolant
26.02	Intermediate Coolant

CAPITAL COST ACCOUNTS (Cont'd)

Account Number	Account Title
26	<u>SPECIAL MATERIALS (Cont'd)</u>
26.03	Turbine Cycle Working Fluids
26.04	Other Materials
26.98	Spare Parts Allowance
26.99	Contingency Allowance
91	<u>CONSTRUCTION FACILITIES, EQUIPMENT, AND SERVICES</u>
91.01	Temporary Facilities
91.01.01	Site Access and Improvements
91.01.02	Building and Structures
91.01.03	Electricity and Water (Temporary Power Lines, Pipe Lines, and Equipment for Providing Services During the Construction Period)
91.01.04	Communications Equipment
91.01.05	Aggregate Plant (Includes Equipment for Pouring or Receiving, Crushing, Classifying, and Washing Sand, Stone, and Rock Aggregates)
91.01.06	Concrete Batch Plant
91.02	Construction Equipment
91.02.01	Transportation, Lifting and Unloading Equipment
91.02.02	Welding Equipment
91.02.03	Air Compressor
91.02.04	Steam Generators
91.02.05	Chemical Cleaning Facilities
91.02.06	Scaffold, Ladders and Stairways
91.02.07	Buildings, Furnishings and Fixtures
91.02.08	Miscellaneous Items (Signs, Barricades, Rope, Tarpaulins, Plastic Sheeting, Office and Drafting Supplies, Small Tools, Welding Rod, and other Expendable Items)
91.03	Construction Services
91.03.01	Purchased Utilities
91.03.02	Security Watchmen and Guards
91.03.03	Education and Testing Programs for Labor Force
91.03.04	Materials Receiving and Storage (Pertains only to Receiving and Handling Miscellaneous Materials at the Plant Site)
91.03.05	Inspection and Testing of Construction Materials (Includes Radiography Equipment, Testing Machines, etc.)
91.03.06	Site Cleanup (Includes General Cleanup Operations During Construction and Final Job Cleanup)
91.03.07	Operation and Maintenance of Construction Facilities and Equipment
91.03.08	Insurance, Injuries and Damage (Excludes Workman Compensation Insurance, which is included in the Labor Charges associated with the Direct Costs)

CAPITAL COST ACCOUNTS (Cont'd)

<u>Account Number</u>	<u>Account Title</u>
92	<u>ENGINEERING AND CONSTRUCTION MANAGEMENT SERVICES</u>
93	<u>OTHER COSTS</u>
93.01	Taxes and Insurance
93.02	Staff Training and Plant Startup
93.03	Owner's G&A
94	<u>INTEREST DURING CONSTRUCTION</u>
95	<u>ESCALATION DURING CONSTRUCTION (Current Dollar Economic Analysis Mode Only)</u>

APPENDIX C

UNIFORM DETAILED CAPITAL COST REPORTING ACCOUNTS

DETAILED CAPITAL COST REPORTING ACCOUNTS

<u>Account Number</u>	<u>Account Title</u>
xx.xx.xx.xx.xx.01	Earthwork
xx.xx.xx.xx.xx.02	Formwork
xx.xx.xx.xx.xx.03	Reinforcing Steel
xx.xx.xx.xx.xx.04	Concrete
xx.xx.xx.xx.xx.05	Structural Steel
xx.xx.xx.xx.xx.06	Structural Liners
xx.xx.xx.xx.xx.07	Architectural Steel
xx.xx.xx.xx.xx.08	Piping (Including Valves and Control Valves)
xx.xx.xx.xx.xx.09	Insulation (Including Paint and Protective Coatings)
xx.xx.xx.xx.xx.10	Instrumentation Bulks
xx.xx.xx.xx.xx.11	Electrical Bulks
xx.xx.xx.xx.xx.12	Other

•

•

•

•

•

•

•

•

•

•

•

APPENDIX D

UNIFORM OPERATING AND MAINTENANCE COST ACCOUNTS

OPERATING AND MAINTENANCE COST ACCOUNTS

<u>Account Number</u>	<u>Account Title</u>
40	Annual Salaries of Facility Personnel
41	Annual Miscellaneous Supplies and Equipment
42	Annual Outside Support Services
43	Annual General and Administrative Costs
44	Annual Coolant Makeup
45	Annual Process Materials
46	Annual Fuel Handling Costs
47	Annual Miscellaneous Costs

✓

•

•

•

•

•

•

•

•

•

•

APPENDIX E

UNIFORM SCHEDULED COMPONENT REPLACEMENT COST ACCOUNTS

SCHEDULED COMPONENT REPLACEMENT COST ACCOUNTS

<u>Account Number</u>	<u>Account Title</u>
50	Annual Reactor First Wall Component Replacement
51	Others

APPENDIX F

UNIFORM FUEL COST ACCOUNTS

FUEL COST ACCOUNTS

<u>Account Number</u>	<u>Account Title</u>
02	Annual Fuel Cycle Materials Consumed
02.01	Deuterium
02.02	Tritium
02.03	Tritium Breeding Material
02.04	Neutron Multipliers
02.05	Cladding
02.06	Other Fuel Materials
03	Annual Offsite Processing and Disposal
03.01	Deuterium
03.02	Tritium
03.03	Tritium Breeding Material
03.04	Neutron Multipliers
03.05	Cladding
03.06	Other Fuel Materials

APPENDIX G

INDIRECT COST ACCOUNT ESTIMATING PERCENTAGES - DERIVATIONS

FIGURE G-1. Construction Facilities, Equipment and Services, Cost Account 91

Source: Impact of Design Physics on Fusion Reactor Design and Economics
McDonnell Douglas Astronautics Company - East, June 1977.

FIGURE G-2. Engineering and Construction Management, Cost Account 92

Source: Impact of Design Physics on Fusion Reactor Design and Economics,
McDonnell Douglas Astronautics Company - East, June 1977.

FIGURE G-3. Taxes, Insurance and Owner's G&A,
Cost Account 93

Source: Impact of Design Physics on Fusion Reactor Design and Economics,
McDonnell Douglas Astronautics Company - East, June 1977.

APPENDIX H

ALTERNATIVE VALUES FOR F_{IDC} AND F_{EDC}

ALTERNATIVE VALUES FOR F_{IDC} AND F_{EDC}

Alternative values for F_{IDC} and F_{EDC} given different escalation rate assumptions are shown in the following tables. These tables should be used only when it can be justified that the 5%/Year reference escalation rate is not appropriate.

TABLE H-1. Values for F_{IDC} and F_{EDC}

<u>Construction Period (Yr)</u>	Constant Dollar Economic Analysis Mode		Current Dollar Economic Analysis Mode	
	(Cost of Capital = 5%/Year) (Escalation Rate = None)		(Cost of Capital = 10%/Year) (Escalation Rate = 6%/Year)	
	<u>F_{IDC}</u>	<u>F_{EDC}</u>	<u>F_{IDC}</u>	<u>F_{EDC}</u>
4	.081	-0-	0.195	0.148
5	.108	-0-	0.257	0.189
6	.129	-0-	0.325	0.231
7	.152	-0-	0.401	0.275
8	.170	-0-	0.484	0.321
9	.192	-0-	0.575	0.368
10	.221	-0-	0.675	0.417

Note: Expenditure pattern as shown in Figure 2.

TABLE H-2. Values for F_{IDC} and F_{EDC}

Construction Period (Yr)	Constant Dollar Economic Analysis Mode		Current Dollar Economic Analysis Mode	
	(Cost of Capital = 5%/Year) (Escalation Rate = None)		(Cost of Capital = 10%/Year) (Escalation Rate = 7%/Year)	
	F_{IDC}	F_{EDC}	F_{IDC}	F_{EDC}
4	.081	-0-	0.198	0.174
5	.108	-0-	0.263	0.223
6	.129	-0-	0.335	0.273
7	.152	-0-	0.414	0.327
8	.170	-0-	0.502	0.382
9	.192	-0-	0.599	0.440
10	.221	-0-	0.707	0.501

Note: Expenditure pattern as shown in Figure 2.

TABLE H-3. Values for F_{IDC} and F_{EDC}

Construction Period (Yr)	Constant Dollar Economic Analysis Mode		Current Dollar Economic Analysis Mode	
	(Cost of Capital = 5%/Year) (Escalation Rate = None)		(Cost of Capital = 10%/Year) (Escalation Rate = 8%/Year)	
	F_{IDC}	F_{EDC}	F_{IDC}	F_{EDC}
4	.081	-0-	0.202	0.200
5	.108	-0-	0.269	0.257
6	.129	-0-	0.344	0.317
7	.152	-0-	0.428	0.380
8	.170	-0-	0.521	0.446
9	.192	-0-	0.625	0.516
10	.221	-0-	0.740	0.590

Note: Expenditure pattern as shown in Figure 2.

TABLE H-4. Values for F_{IDC} and F_{EDC}

Construction Period (Yr)	Constant Dollar Economic Analysis Mode		Current Dollar Economic Analysis Mode	
	(Cost of Capital = 5%/Year) (Escalation Rate = None)		(Cost of Capital = 10%/Year) (Escalation Rate = 9%/Year)	
	F_{IDC}	F_{EDC}	F_{IDC}	F_{EDC}
4	.081	-0-	.206	.227
5	.108	-0-	.275	.293
6	.129	-0-	.354	.362
7	.152	-0-	.442	.435
8	.170	-0-	.540	.513
9	.192	-0-	.651	.596
10	.221	-0-	.775	.683

Note: Expenditure pattern as shown in Figure 2.

TABLE H-5. Values for F_{IDC} and F_{EDC}

Construction Period (Yr)	Constant Dollar Economic Analysis Mode		Current Dollar Economic Analysis Mode	
	(Cost of Capital = 5%/Year) (Escalation Rate = None)		(Cost of Capital = 10%/Year) (Escalation Rate = 10%/Year)	
	F_{IDC}	F_{EDC}	F_{IDC}	F_{EDC}
4	.081	-0-	.210	.255
5	.108	-0-	.282	.329
6	.129	-0-	.363	.408
7	.152	-0-	.456	.493
8	.170	-0-	.561	.583
9	.192	-0-	.679	.679
10	.221	-0-	.812	.781

Note: Expenditure pattern as shown in Figure 2.

APPENDIX I

EXAMPLE CALCULATIONS

EXAMPLE CALCULATIONS

Sample economic computations for a hypothetical fusion reactor facility design study are shown below. These computations are intended to illustrate the correct application of the equations and procedures described in this document. Sample computations are given using both a current dollar analysis mode and a constant dollar analysis mode. The initial information developed in the hypothetical design study cost estimate is as follows:

- Land and Land Rights (Account 20) Cost = \$1,200,000
- Structure and Site Facilities (Account 21) Cost = \$150,000,000
(excluding Design Allowances, Contingencies and Spare Parts Allowances)
- Reactor Plant Equipment (Account 22) Cost = \$700,000,000
(excluding Design Allowances, Contingencies and Spare Parts Allowances)
- Turbine Plant Equipment (Account 23) Cost = \$160,000,000
(excluding Design Allowances, Contingencies and Spare Parts Allowances)
- Electric Plant Equipment (Account 24) Cost = \$80,000,000
(excluding Design Allowances, Contingencies and Spare Parts Allowances)
- Miscellaneous Plant Equipment (Account 25) Cost = \$20,000,000
(excluding Design Allowances, Contingencies and Spare Parts Allowances)
- Special Materials (Account 26) Cost = \$6,000,000
- Annual Reactor First Wall Scheduled Component Replacement (Account 50) Cost = \$50,000,000
- Annual Fuel (Account 02 and Account 03) Cost = \$130,000
- Plant Design Net Power Level = 2000 MWe
- Annual Unscheduled outage time = 672 hours (4 weeks)
- Annual Scheduled Outage time = 1344 hours (8 weeks)
- Construction Period = 8 years

Sample computations for a constant dollar economic analysis, and a current dollar economic analysis are described below:

CONSTANT DOLLAR ECONOMIC ANALYSIS MODE

The procedures for computing total busbar energy cost given the previously described cost information and using a constant dollar economic analysis mode are as follows:

Step 1 - Compute Total Direct Cost

Land and Land Rights Cost	=	\$1,200,000	(given)
Structure and Site Facilities Cost	=	\$150,000,000	(given)
Design Allowance (10%)	=	\$15,000,000	(hypothetical assumption)
Contingency (10%)	=	\$15,000,000	(hypothetical assumption)
Spare Parts Allowance (0.5%)	=	\$750,000	(hypothetical assumption)
Reactor Plant Equipment Cost	=	\$700,000,000	(given)
Design Allowance (20%)	=	\$140,000,000	(hypothetical assumption)
Contingency (10%)	=	\$70,000,000	(hypothetical assumption)
Spare Parts Allowance (1%)	=	\$7,000,000	(hypothetical assumption)
Turbine Plant Equipment Cost	=	\$160,000,000	(given)
Design Allowance (15%)	=	\$24,000,000	(hypothetical assumption)
Contingency (10%)	=	\$16,000,000	(hypothetical assumption)
Spare Parts Allowance (1%)	=	\$1,600,000	(hypothetical assumption)
Electric Plant Equipment Cost	=	\$80,000,000	(given)
Design Allowances (10%)	=	\$8,000,000	(hypothetical assumption)
Contingency (10%)	=	\$8,000,000	(hypothetical assumption)
Spare Parts Allowance (0.5%)	=	\$400,000	(hypothetical assumption)

Miscellaneous Plant Equipment Cost	=	\$20,000,000	(given)
Design Allowances (10%)	=	\$2,000,000	(hypothetical assumption)
Contingency (10%)	=	\$2,000,000	(hypothetical assumption)
Spare Parts Allowance (1%)	=	\$200,000	(hypothetical assumption)
Special Materials Cost	=	\$6,000,000	(given)
Design Allowances (5%)	=	\$300,000	(hypothetical assumption)
Contingency (10%)	=	\$600,000	(hypothetical assumption)
Spare Parts Allowance (5%)	=	\$300,000	(hypothetical assumption)

TOTAL DIRECT COST = \$1,428,350,000

Step 2 - Compute Total Indirect Cost

Construction Facilities, Equipment, and Services Cost	=	\$214,253,000	(Eq. 1)
Engineering and Construction Management Services Cost	=	\$214,253,000	(Eq. 2)
Owner's Cost	=	\$71,420,000	(Eq. 3)

TOTAL INDIRECT COST = \$499,930,000

Step 3 - Compute Total Time- Related Cost

Construction Period = 8 years	(given)
Cost of Capital = 5%/Year	(given)
Escalation Rate = 0	(given)
F_{IDC} = .170	(Table 2)
F_{EDC} = 0	(Table 2)

Interest During Construction Cost	= \$327,810,000	(Eq. 4)
Escalation During Construction Cost	= 0	(Eq. 5)

TOTAL TIME-RELATED COST = \$327,10,000

Step 4 - Compute Total Capital Cost

TOTAL CAPITAL COST = \$2,256,090,000 (Table 1)

Step 5 - Compute Total Operating and Maintenance Cost

TOTAL ANNUAL OPERATING
AND MAINTENANCE COST = \$38,570,000 (Eq. 6)

Step 6 - Compute Scheduled Component Replacement Cost

TOTAL ANNUAL SCHEDULED
COMPONENT REPLACEMENT
COST = \$50,000,000 (given)

Step 7 - Compute Annual Fuel Cost

TOTAL ANNUAL FUEL COST = \$130,000 (given)

Step 8 - Compute Technical Performance Parameters

Plant Design Net Power Level	= 2000 MWe	(given)
Plant Capacity	= 1.752×10^{10} kWh/Yr	(Eq. 7)
Annual Unscheduled Outage Time	= 672 hrs	(given)
Annual Scheduled Outage Time	= 1344 hrs	(given)
Plant Availability Factor	= 77%	(Eq. 8)

Step 9 - Compute Total Busbar Energy Cost

Fixed Charge Rate = 10%/Year (given)

$$\begin{array}{lcl} \text{Total Busbar} & & \\ \text{Energy} & = & (\$2,256,090,000) \cdot 10 + \$38,570,000 + 50,000,000 + \$130,000 \\ \text{Cost} & & 1.752 \times 10^{10} \times .77 \times 10^{-3} \\ \text{(mills/kWh)} & & \end{array} \quad (\text{Eq. 9})$$

$$\begin{array}{lcl} \text{Total Busbar} & & \\ \text{Energy} & = & \frac{\$314,310,000}{1.349 \times 10^7} = 23.3 \text{ mills/kWh} \\ \text{Cost} & & \end{array}$$

CURRENT DOLLAR ECONOMIC ANALYSIS MODE

The procedures for computing total busbar energy cost given the previously described cost information and using a constant dollar economic analysis mode are as follows:

Step 1 - Compute Total Direct Cost

Same as constant dollar analysis computations.

$$\text{TOTAL DIRECT COST} = \$1,428,350,000$$

Step 2 - Compute Total Indirect Cost

Same as constant dollar analysis computations.

$$\text{TOTAL INDIRECT COST} = \$499,930,000$$

Step 3 - Compute Total Time-Related Cost

Construction Period = 8 years (given)

Cost of Capital = 10%/Year (given)

Escalation Rate = 5%/Year (given)

$F_{IDC} = .466$ (Table 2)

$F_{EDC} = .261$ (Table 2)

Interest During Construction Cost = \$898,580,000 (Eq. 4)

Escalation During Construction Cost = \$503,280,000 (Eq. 5)

$$\text{TOTAL TIME-RELATED COST} = \$1,401,860,000$$

Step 4 - Compute Total Capital Cost

TOTAL CAPITAL COST = \$3,330,140,000 (Table 1)

Step 5 - Compute Total Operating and Maintenance Cost

Same as constant dollar analysis computations.

TOTAL ANNUAL OPERATING
AND MAINTENANCE COST = \$38,570,000 (Eq. 6)

Step 6 - Compute Scheduled Component Replacement Cost

Same as constant dollar analysis computations.

TOTAL ANNUAL SCHEDULED
COMPONENT REPLACEMENT
COST = \$50,000,000 (given)

Step 7 - Compute Annual Fuel Cost

Same as constant dollar analysis computations.

TOTAL ANNUAL FUEL COST = \$130,000 (given)

Step 8 - Compute Performance Parameters

Same as constant dollar analysis computations.

Plant Capacity = 1.752×10^{10} kWh/Yr (Eq. 7)

Plant Availability = 77% (Eq. 8)

Step 9 - Compute Total Energy Cost

Fixed Charge Rate = 15%/Year (given)

Escalation Rate = 5%/Year (given)

Construction Period = 8 years (given)

$$\begin{array}{l} \text{Total Busbar} \\ \text{Energy} \\ \text{Cost} \\ \text{(mills/kWh)} \end{array} = \frac{(\$3,330,140,000) (.15) + (\$38,570,000)(1.05)^8 + (\$50,000,000)(1.05)^8 + (\$130,000)(1.05)^8}{1.752 \times 10^{10} (.77)(10^{-3})} \quad (\text{Eq.10})$$

$$\begin{array}{l} \text{Total Busbar} \\ \text{Energy} \\ \text{Cost} \\ \text{(mills/kWh)} \end{array} = \frac{\$630,790,000}{1.349 \times 10^7} = 46.8 \text{ mills/kWh}$$

2

▲

~

~

~

~

~

~

~

~

~

~

DISTRIBUTION

OFFSITE

A. A. Churn
DOE Chicago Patent
Group
9800 S. Cass Avenue
Argonne, IL 60439

J. W. Beal
DOE Office of Fusion
Energy
Washington, DC 20545

C. Head
DOE Office of Fusion
Energy
Washington, DC 20545

S. O. Dean
DOE Office of Fusion
Energy
Washington, DC 20545

E. E. Kintner
DOE Office of Fusion
Energy
Washington, DC 20545

J. M. Williams
DOE Office of Fusion
Energy
Washington, DC 20545

R. Kostoff
DOE Office of Fusion
Energy
Washington, DC 20545

J. N. Grace
DOE Office of Fusion
Energy
Washington, DC 20545

J. Baublitz
DOE Office of Fusion
Energy
Washington, DC 20545

F. E. Coffman
DOE Office of Fusion
Energy
Washington, DC 20545

J. F. Decker
DOE Office of Fusion
Energy
Washington, DC 20545

K. M. Zwilsky
DOE Office of Fusion
Energy
Washington, DC 20545

Dr. Philip M. Stone
DOE Applied Plasma Physics
Program
Washington, DC 20545

OFFSITE

E. Rossi
Office of Laser
Fusion, C404
Department of Energy
Washington, DC 20545

G. W. Kuswa
DOE Office of Laser Fusion
Washington, DC 20545

T. Frank
Office of Laser
Fusion, C404
Department of Energy
Washington, DC 20545

6 E. Braunschweig
DOE Office of Laser Fusion
Washington, DC 20545

R. Blaunstein
DOE Div. of Biomedical
and Environmental Research
Washington, DC 20545

H. M. Busey
DOE Div. of Military
Application
Washington, DC 20545

M. A. Bell
DOE Div. of Safety
Standards and Compliance
Washington, DC 20545

27 DOE Technical Information
Center

M. Abdou
Argonne National Laboratory
Building 208
Argonne, IL 60439

C. Baker
Argonne National Laboratory
Building 208
Argonne, IL 60439

M. S. Kaminsky
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

V. A. Maroni
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

P. M. Persiani
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

OFFSITE

M. Petrick
Engineering and Technology
Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

W. E. Parkins, Manager
Atomics International
Component Engineering and
Technology Division
North American Rockwell
P.O. Box 309
Canoga Park, CA 91304

Mark Triplett
Battelle Columbus Laboratories
505 King Avenue
Columbus, OH 43201

A. Bowles
Bechtel Corporation
P.O. Box 3965
San Francisco, CA 94119

S. Ghose
Bechtel Corporation
P.O. Box 3965
San Francisco, CA 94119

D. Gurinsky
Brookhaven National Laboratory
DOE Brookhaven Area Office
Upton, NY 11973

H. J. Kouts
Brookhaven National Laboratory
DOE Brookhaven Area Office
Upton, NY 11973

S. Pearlstein
Brookhaven National Laboratory
DOE Brookhaven Area Office
Upton, NY 11973

J. R. Powell
Brookhaven National Laboratory
DOE Brookhaven Area Office
Upton, NY 11973

A. J. Impink, Jr.
Carnegie Mellon University
Pittsburgh, PA 15213

R. A. Gross
Plasma Research Laboratory
236 SW Mudd Bldg.
Columbia University
New York, NY 10027

W. C. Gough
Electric Power Research Inst.
3412 Hillview Ave.
Palo Alto, CA 94304

OFFSITE

D. Sonn
General Atomics
P.O. Box 81608
San Diego, CA 92138

Bob Black
Grumman Aerospace Corp.
Bethpage, Long Island, NY 11714

G. R. Hopkins
Gulf General Atomic
P.O. Box 1111
San Diego, CA 92112

Zeinab Sabri
Iowa State University
261 Sweeney Hall
Nuclear Engineering Department
Ames, IA 50010

R. Borg
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

G. Carlson
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

T. K. Fowler
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

W. Meier
Lawrence Livermore Laboratory
Mail Stop L488
P.O. Box 808
Livermore, CA 94550

R. Moir
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

A. Carl Haussmann
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

J. Hovingh
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

R. F. Post
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

C. J. Taylor
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

OFFSITE

J. Maniscalco
Lawrence Livermore
Laboratory
P.O. Box 808
Livermore, CA 94550

W. Meier
Lawrence Livermore
Laboratory
P.O. Box 808
Livermore, CA 94550

R. Werner
Oak Ridge National
Laboratory
P.O. Box 808
Livermore, CA 94550

L. L. Wood
Lawrence Livermore
Laboratory
P.O. Box 808
Livermore, CA 94550

W. Bauer
Division Supervisor
of Physical Research
Sandia Labs Livermore
Livermore, CA 94550

L. Booth
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

D. J. Dudziak
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

D. B. Henderson
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

E. L. Kemp
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

R. Krakowski
Los Alamos Scientific
Laboratory
P.O. Box 1663
Los Alamos, NM 87545

OFFSITE

J. Pendergrass
Los Alamos Scientific
Laboratory
P.O. Box 1663
Los Alamos, NM 87545

L. Stewart
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

K. Thomassen
Los Alamos Scientific
Laboratory
CTN Research
P.O. Box 1663
Los Alamos, NM 87544

O. K. Harling
Massachusetts Institute of
Technology
Cambridge, MA 02139

D. Hay
Massachusetts Institute
of Technology
Building MW16-209
167 Albany St.
Cambridge, MA 02139

Bruno Coppi
Department of Physics
Massachusetts Institute
of Technology
Cambridge, MA 02139

L. Lidsky
Dept. of Nuclear Engineering
Massachusetts Institute
of Technology
Cambridge, MA 02139

N. Rasmussen
Dept. of Nuclear Engineering
Massachusetts Institute of
Technology
Cambridge, MA 02139

David Rose
Massachusetts Institute
of Technology
Cambridge, MA 02139

R. E. Stickney
Mechanical Engineering
Massachusetts Institute
of Technology
Cambridge, MA 02139

OFFSITE

Rolf Buenoe
Max-Planck-Institut für
Plasmaphysik
8046 Garching Bei München

D. Defreece
McDonnell - Douglas
Building 106, Level 3
P.O. Box 516
St. Louis, MO 63166

L. Waganer
McDonnell - Douglas
Building 106, Level 3
P.O. Box 516
St. Louis, MO 63166

J. J. Reinmann
NASA - Lewis Research Center
2100 Bookpark Rd.
Cleveland, OH 44135

Vincent Arp
National Bureau of Standards
Cryogenics Division
Boulder, CO 80302

J. F. Clarke
Oak Ridge National
Laboratory
P.O. Box Y
Oak Ridge, TN 37830

A. P. Fraas
Oak Ridge National
Laboratory
P.O. Box Y
Oak Ridge, TN 37830

J. Rand McNally, Jr.
Oak Ridge National
Laboratory
P.O. Box Y
Oak Ridge, TN 37830

L. Reid
Oak Ridge National
Laboratory
P.O. Box Y
Oak Ridge, TN 37830

D. Steiner
Oak Ridge National
Laboratory
P.O. Box Y
Oak Ridge, TN 37830

J. Scott
Oak Ridge National
Laboratory
P.O. Box X
Oak Ridge, TN 37830

OFFSITE

J. Banford
Physics International
2700 Merced St.
San Leandro, CA 94577

R. A. Huse
Public Service Electric
and Gas Co.
80 Park Place
Newark, NJ 07101

M. Gottlieb
Princeton University, PPPL
P.O. Box 451
Princeton, NJ 08540

R. Hill
Princeton University
Plasma Physics Laboratory
Forrestal Center
Building IE
Princeton, NJ 08540

A. Kaffashan
Princeton
Plasma Physics Laboratory
Forrestal Center
Princeton, NJ 08540

R. G. Mills
Princeton University
P.O. Box 451
Princeton, NJ 08540

E. C. Tanner
Princeton University
P.O. Box 451
Princeton, NJ 08540

H. Perkins
Dept. of Chemistry
Princeton University
Princeton, NJ 06540

R. E. Gold
303 Sayre Hall
Forrestal Campus
P.O. Box 451
Princeton, NJ 06540

R. Wilson
Princeton University
Plasma Physics Laboratory
Forrestal Center
Building IE
Princeton, NJ 08540

Audrey Perino
Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87115

OFFSITE

J. Mitchiner
Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87115

M. Kristiansen
Texas Tech. University
Lubbock, TX 79409

A. F. Haught
United Aircraft Research Lab.
United Aircraft Corporation
East Hartford, CT 06108

L. Levine
U.S. Naval Research Laboratory
Washington, DC 20390

C. Z. Serpan, Jr.
U.S. Naval Research Laboratory
Washington, DC 20390

Francis Chen
University of California
Electronics Research
Laboratory
College of Engineering
Berkeley, CA 94720

A. J. Lichtenberg
University of California
Electronics Research
Laboratory
College of Engineering
Berkeley, CA 94720

Dave Okrent
U.C.L.A.
Los Angeles, CA 90024

C. D. Hendricks
University of Illinois
Nuclear Engineering
Laboratory
Urbana, IL 61801

G. H. Miley
University of Illinois
Nuclear Engineering
Laboratory

Terry Kammash
University of Michigan
Nuclear Engineering
Department
Ann Arbor, MI 48105

Dean Abrahamson
University of Minnesota
School of Public Affairs
Social Science
Building/309
Minneapolis, MN 55455

OFFSITE

W. G. Davey
University of Texas
Department of Physics
Austin, TX 78712

E. Linn Draper, Jr.
University of Texas
Department of Physics
Austin, TX 78712

W. E. Drummond
University of Texas
Department of Physics
Austin, TX 78712

Abraham Hertzberg
University of Washington
Aerospace Research
Laboratory
316 Guggenheim
Seattle, WA 98105

A. L. Babb
University of Washington
Nuclear Engineering
Department
Seattle, WA 98105

R. Conn
University of Wisconsin
Nuclear Engineering
Department
Madison, WI 53706

Igor Sviatoslavsky
University of Wisconsin
Nuclear Engineering
Department
Madison, WI 53706

C. W. Maynard
University of Wisconsin
Nuclear Engineering
Department
Madison, WI 53706

D. Lichtman
Department of physics
University of Wisconsin
Milwaukee, WI 53201

E. E. Donaldson
Washington State University
Department of Physics
Pullman, WA 99163

D. D. Mahlum
Division of Biomedical
and Environmental Research
Washington, DC 20545

OFFSITE

J. V. Vanston
Engineering Science
Building
University of Texas
Austin, TX 78712

S. Nichols
Engineering Science
Building
University of Texas
Austin, TX 78712

Leslie S. Ramsey
450 North 5th Street
Indiana, PA 15701

E. Beckner
Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87115

J. Clayton
KMS Fusion, Inc.
P.O. Box 1567
Ann Arbor, MI 48106

J. Kelly
Westinghouse Fusion Power
Systems
P.O. Box 10864
Pittsburgh, PA 15236

E. W. Sucov
Westinghouse Fusion Power
Systems
P.O. Box 10864
Pittsburgh, PA 15236

D. H. Berwald
Exxon Research and
Engineering Company
P.O. Box 8
Linden, NJ 07036

ONSITEDOE Richland Operations Office

W. A. Burns

Hanford Engineering
Development Labs

D. G. Doran
H. H. Yoshkawa

Pacific Northwest Laboratory

D. T. Aase
G. S. Allison
T. W. Ambrose
D. G. Atteridge
D. A. Baker
J. L. Bates
M. A. Bayne
E. R. Bradley

OFFSITE

J. L. Brimhall
R. L. Brodzinski
R. J. Brouns
L. R. Bunnell
L. L. Burger
S. H. Bush
N. E. Carter
T. D. Chikalla
R. G. Clark
T. L. Criswell
S. D. Dahlgren
M. T. Dana
D. E. Deonigi (10)
R. L. Dillon
D. A. Dingee
P. J. Dionne
B. H. Duane
R. L. Engel
J. W. Finnigan
J. C. Fox
J. J. Fuquay
J. E. Garnier
R. D. Gastil
B. F. Fore
J. N. Hartley
A. J. Haverfield
U. P. Jenquin
A. B. Johnson, Jr.
R. H. Jones
T. J. Kabele
W. S. Kelly
H. E. Kissinger
D. A. Kottwitz
N. Laegried
B. R. Leonard, Jr.
D. L. Lessor
H. B. Liemohn
R. C. Liikala
M. A. McKinnon
R. F. Maness
R. P. Marshall
E. S. Murphy
R. D. Nelson
D. F. Newman
R. E. Nightingale
D. E. Olesen
E. L. Owzarski
L. T. Pedersen
R. T. Perry
D. R. Pratt
L. A. Rancitelli
J. F. Remark
D. S. Renne
R. E. Rhoads
W. D. Richmond
W. F. Sandusky
L. C. Schmid
S. C. Schulte (50)
N. M. Sherer
E. P. Simonen
R. I. Smith
J. K. Soldat
C. W. Stewart
K. B. Stewart
R. W. Stewart

OFFSITE

J. A. Strand
D. L. Styris
A. M. Sutey
V. L. Teofilo
G. L. Tingey
M. T. Thomas
R. C. Thompson
L. H. Toburen
T. J. Trapp
R. Wang
R. E. Westerman
T. L. Willke
L. D. Williams
M. G. Zimmerman

1 Technical Publications
5 Technical Information
10 Economics Library