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COST ACCOUNTING SYSTEM FOR FUSION STUDIES

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ABSTRACT

A Cost Accounting System that is applicable to all magnetic fusion reactor design studies has been developed. This system provides (1) definitions of the elements of cost and methods for the combination of these elements to form a cost estimate, (2) a Code of Accounts that uses a functional arrangement for identification of the plant components, and (3) definitions and methods to analyze actual cost data so that the data can be directly reported into this Cost Accounting System.

The purpose of the Cost Accounting System is to provide the structure for the development of a fusion cost data base and for the development of validated cost estimating procedures. This system has been developed through use at the Fusion Engineering Design Center (FEDC) and has been applied to different confinement concepts (tokamaks and tandem mirrors) and to different types of projects (experimental devices and commercial power plants). The use of this Cost Accounting System by all magnetic fusion projects will promote the development of a common cost data base, allow the direct comparison of cost estimates, and ultimately establish the cost credibility of the program.

1. INTRODUCTION

The potential of fusion will be realized by the demonstration that fusion provides an energy source that is economically competitive with other sources. This demonstration of economic viability requires the development of a consistent cost data base and validated cost estimating procedures for fusion projects.

The accumulation of a cost data base derived from fusion project experience was begun at the Fusion Engineering Design Center (FEDC) in October 1983. A major part of this effort has been the explicit definition of the elements of project and component costs, which is essential to the evaluation of cost data for consistency. The intent of these definitions is to record the cost data obtained from fusion projects in such a way that the data are directly useful in estimating the costs of future projects. The emphasis has been on direct cost and, in particular, on the purchase price of the plant components (or estimated equivalent if the components are not commercially available).

The accurate estimation of project costs requires considerable information in addition to the component purchase price. The costs incurred by component development, engineering, management, and construction are substantial and will depend on the contracting arrangements and institutions involved, as well as on the technical nature of the project. Because of the many possible ways to organize a project, these project-specific costs are not reported in a uniform manner by all institutions. The different reporting systems complicate the development of a common data base because it is sometimes necessary to evaluate

project costs in great detail to extract costs that are comparable between projects. The cost accounting system described in this report provides uniform definitions and procedures to estimate the total costs of future projects. The method is based largely on commercial power industry practice but is sufficiently general to be used for next-generation experimental devices.

To validate the system, a successful cost accounting system must provide procedures to evaluate actual project costs relative to estimated costs. The fusion program can establish cost credibility by developing the ability to satisfy program goals within cost projections. The cost accounting system proposed in this document is intended to be explicit, yet general enough that it can provide a framework for cost validation.

Section 2 provides explicit definitions of the major elements of the base constructed cost, which are direct costs, indirect costs, and contingency. The procedures used at the FEDC to assemble cost estimates for projects are next described and recommended. Finally, the methods to be used to combine the cost elements to form the base constructed cost of a facility are described. Section 2 is expected to be used as a guide for assembling cost estimates.

Section 3 describes the Fusion Plant Code of Accounts, a detailed breakdown of the elements of direct and indirect costs. This code is to be followed for estimating costs and for reporting costs from projects. Depending on the project, some of the elements of the code may not be required, and some of the detailed breakdowns may not be needed. The mandatory level of the code is arranged functionally, with detailed descriptions of the function, so that the code is expected to be adaptable to any magnetic fusion device. The Appendix provides examples of more detailed breakdowns of the code that were developed for specific projects.

The methods used at the FEDC to collect, refine, and catalogue cost data are described in Sect. 4. The actual numerical values of these

data are not included in this procedural document. Each project should develop its own Cost Data Base File, based on information acquired from the FEDC files and other sources as appropriate for the project. Section 4 is intended primarily for guidance in the reporting of actual cost data to the data files. The intent of the procedures for data refinement is to ensure that data are reported in the correct code of accounts category and in the correct element as defined by this cost accounting system. The amount of refinement required will depend on the degree of difference between the accounting system at the data source and this accounting system.

The levelized-revenue-requirements method for calculating the cost of electricity is described in Sect. 5. This method is to be used for the economic analysis of commercial fusion plant conceptual designs. Tables of typical financial parameters are provided. Each project should select a set of financial parameters and apply them consistently to evaluate commercial plant options.

2. COST ESTIMATING METHODOLOGY

2.1 ELEMENTS OF COST

The value of fusion as a potential source of electrical power will be determined by the projected total capital cost of the plant and by the projected cost of the product or the cost of electricity (COE). The COE is determined by the total plant capital cost, the operating and fuel costs, the plant availability and lifetime, and the economic parameters that control the plant financing. The total plant capital cost depends on the economic conditions during the plant construction (interest and escalation during construction), as well as on the base constructed cost of the plant. The methods for calculating the COE are described in Sect. 5 for typical power industry financial conditions. The remainder of this document is concerned only with the estimation of

base constructed cost without financial or schedule considerations (sometimes called "overnight construction cost"). The base constructed cost is directly useful in the relative evaluation of fusion devices. The elements of base constructed cost are direct cost, indirect cost, and contingency.

2.1.1 Direct Cost

Direct costs are the costs of the equipment, engineering, and labor that are specifically identified with a permanent component of the plant. Equipment costs include the purchase price of commercially available materials and equipment delivered to the site and the "build-to-print" costs incurred by the project and its subcontractors. The "build-to-print" cost is defined so that it represents what would be the purchase price of the component if it were commercially available. This includes the materials, fabrication labor, tooling, packaging and shipping, as well as the recurring manufacturing support engineering (such as management, manufacturing engineering, design liaison, quality assurance and inspection, and vendor acceptance testing).

The engineering element of direct cost is defined to account for the first-of-a-kind, nonrecurring engineering costs. This account applies only to components that are not commercially available. If the equipment cost is defined as "build-to-print" as above, then the associated engineering cost is the cost of generating those prints. This includes the design phase management, design and analysis, the development of specifications, manufacturing and verification test plans, and tool design.

Labor costs refer to the cost of craft labor used for assembly and acceptance testing of the permanent plant. This account is generally reported as labor hours, as well as dollars.

2.1.2 Indirect Cost

Indirect costs are those that are not identified with specific permanent plant facilities, equipment, or systems but are incurred by the project as a whole. Indirect costs include those that cannot be identified with a direct account, those that are judged to be best controlled as an indirect account, and those that do not warrant the detailed accounting required for distribution to direct accounts.

The elements of indirect cost are defined in the Fusion Plant Code of Accounts Dictionary, Sect. 3.3. The four major elements are consistent with power industry practice, while the subelements are selected to correspond to the indirect cost elements most commonly used by experimental projects.

2.1.3 Contingency

Contingency is a cost allowance included in an estimate to reflect the fact that uncertainties exist in the project definition, unit pricing, and execution. The allowance represents costs that are expected to occur, and it will be expended as the project is completed. The magnitude of the contingency allowance is, therefore, inversely related to the degree of project completion.

A large percentage of the estimated costs of fusion reactor systems is accounted for by equipment for which there is no (or limited) fabrication experience. The contingency for the uncertainty in unit prices for such equipment is separately accounted for as a design allowance. The design allowance should be separately estimated for each element of the code of accounts that estimates the purchase price of new equipment, and it should reflect the uncertainty in the manufacture of the equipment to meet the design performance at the estimated cost.

The contingency allowance that applies to the overall project, excluding uncertainties in new equipment, is the project contingency.

This is further divided into uncertainties in the design, or systems contingency, and uncertainties in the construction, or construction contingency. The systems contingency allows for increases in the required quantities that will occur as the design becomes more detailed and for actual prices and wage rates as procurement and construction at the actual site proceed. The construction contingency allows for such events as unplanned accelerations to maintain the project schedule or decreased labor effectiveness, which can be caused by unforeseen project developments, such as labor strikes, weather delays, or poor soil conditions.

To reflect uncertainties in design detail, the systems contingency should be estimated separately for each major section of the project, while the construction contingency applies to the overall project (direct and indirect costs). The total of both, or the project contingency, should be specifically identified in the cost estimate because the magnitude of the total as a percentage of the project cost is a meaningful measure of the project uncertainties and implied risk. The design allowance should be listed and compiled separately as an element of direct cost.

2.2 COST ESTIMATING PROCEDURE

A procedure for performing and cataloging cost estimates at the preconceptual design level has been developed in order to provide a credible and consistent means for projecting the base constructed cost of experimental devices and power reactors. This procedure is based mainly on the parametric cost estimating method, which consists of estimating on a cost-per-unit (weight, volume, area, power, etc.) basis and incorporates a generic code of accounts for cataloging and a cost data base based on actual cost experience.

The overall approach to assembling a project cost estimate is outlined in the flowchart in Fig. 1. The approach consists of parallel

Fig. 1. Fusion plant cost estimating approach.

project design and cost data base activities. At the onset of a project, a detailed code of accounts (work breakdown structure), compatible with the particular project, is developed below the mandatory level of the Fusion Plant Code of Accounts described in detail in Sect. 3. This mandatory level of accounts adds conformity to the formation of a cost estimate. The Fusion Plant Code of Accounts is applicable to all magnetically confined fusion concepts (tokamaks, mirrors, etc.) and project types (experimental device and power reactor) and is flexible with regard to contracting arrangement. The detailed breakdown below the mandatory account level will vary, depending on the particular study application. Cognizant engineers are assigned responsibility to provide the technical input to the cost estimate for the various components and/or subsystems in the code of accounts. At or near the end of the preconceptual design activity, when the quantities of material and equipment can be estimated, the cognizant engineers submit standardized component subsystem design data sheets, along with supporting material, for their assigned elements in the code of accounts. These design data sheets include the design basis, design description, and a listing of the pertinent design parameters. This assemblage of component/subsystem design data sheets, in conjunction with the cost data base file, forms the basis for the project cost estimate. The Cost Data Base File, a catalog of cost coefficients, algorithms, and component costs arranged in a standard format, is the product of the ongoing fusion component cost data base activity, which is described in detail in Sect. 4. At the beginning of each fusion plant study, participants should agree on a Cost Data Base File to be used for the study. This will ensure that calculated plant costs are consistent among participants.

Three techniques are used to estimate the cost in the code of account direct cost elements: unit costing, cost algorithms, and "component takeoff" costing. Where a solid historical data base is available for costing a specific component/subsystem, the unit costing method is used whereby the cost is based on cost per unit (weight, volume,

area, power, etc.) of similar equipment. Where a good data base does not exist, the cost algorithm method is used. Cost algorithms are empirical costing equations, developed from experience on similar components or subsystems, where the cost is scaled as a function of component design parameters. Where the subsystem is composed of standard items of accurately known costs, a "component takeoff" method is used whereby the subsystem cost is based on the unit cost and quantity of the components that comprise the subsystem.

2.3 METHODOLOGY

This section describes a methodology for calculating the base constructed cost of a fusion power reactor or experimental device, describes the expenses that should be considered as base constructed costs, and describes the methods for estimating some of these costs. Base constructed cost is defined as the total expense of constructing a facility and placing the facility into operation, excluding time-related costs (escalation and interest during construction). Elements of base constructed cost are direct cost, indirect cost, and contingency.

The flowchart shown in Fig. 2 outlines the methodology for calculating the base constructed cost of a reactor plant or experimental device. The equipment cost of a specific component or subsystem is first calculated using the design description and parameters list submitted by the cognizant engineer and the cost data on a similar component from the cost data base file. Learning curve factors are applied at this point, if necessary, to account for learning effects. Engineering cost and labor cost for the component/subsystem are calculated using a percentage of equipment cost. To account for uncertainty in the estimate for new equipment, a design allowance is added to the subtotal of component/subsystem engineering, equipment, and labor costs. The sum of equipment cost, engineering cost, labor cost, and design allowance yields the direct cost of the component or subsystem. Engineering cost, equipment cost, and labor cost are chosen as the three

METHODOLOGY FOR CALCULATING TOTAL CONSTRUCTED COST

Fig. 2. Fusion plant cost estimating methodology.

elements of direct cost because they are the most commonly used and well-defined elements and because historical cost data are easier to obtain in this format. The direct cost of all the applicable components and subsystems in the Fusion Plant Code of Accounts is summed to form the total direct cost of the facility, which represents those costs associated with a specific, permanent component or subsystem in the plant. A separate systems contingency is then determined for each major section of the facility.

Four indirect cost elements are calculated, by subelement if necessary, using percentages of total direct cost: Construction Services and Equipment, Home Office Engineering and Services (Management, Systems Engineering, Safety and Environmental Engineering, and Quality Assurance), Field Office Engineering and Services (Construction Management, Inspection, and Preoperational Testing), and Owner's Cost (Project Administration, Inventories, and Spares). These four elements, defined in the Fusion Plant Code of Accounts Dictionary, in Sect. 3.3, are summed to form the total indirect cost of the facility, which is defined as those costs that are not identified with specific, permanent plant facilities, equipment, or systems but are incurred by the project as a whole. The total direct and indirect costs are summed, to which is added the construction and system contingency to account for project uncertainties. Total direct cost, total indirect cost, and project contingency are summed to form the base constructed cost of the facility.

3. FUSION PLANT CODE OF ACCOUNTS AND DICTIONARY

3.1 PREFACE

The Fusion Plant Code of Accounts represents a systematic arrangement of the generic elements that generally comprise fusion projects. The Fusion Plant Code of Accounts, shown in Sect. 3.2, is developed to a mandatory account level that is to be used in reporting estimated

costs. Additional accounts unique to a specific reactor or experimental device can be used to further break down reported estimated costs below the mandatory level.

The Fusion Plant Code of Accounts is applicable to all magnetically confined fusion concepts (tokamaks, tandem mirrors, stellarators, etc.) and device types (experimental device and power reactor). This code of account structure is based on the present standard fusion accounts¹ and power industry practice,² but some revisions have been made to facilitate their application to both power reactors and experimental devices. The first-level accounts parallel those currently used by the power industry, thus facilitating comparison of fusion power reactor costs to other sources of electricity. The accounts differ from the current fusion standard accounts in three respects: First, Account 26 is used for total plant heat rejection systems rather than for special materials. (Heat rejection system elements are contained in the turbine and structures accounts in Ref. 1.) This approach was chosen because it corresponds to current power industry standards and simplifies accounting for experimental devices (if the facility does not generate electricity, then the Turbine Plant Account 23 is zero).

Second, Reactor Plant Equipment Account 22 is completely different from that of Ref. 1. The approach used in this account was to incorporate a generic, functional breakdown for the specific fusion systems within the power industry code. This account structure was chosen such that costs could be accounted for in a natural reporting system that is closely related to the typical fusion project work breakdown structure and such that the structure was compatible with different fusion device concepts.

Third, Indirect Costs, Account 9, contains four subaccounts (91-94), as opposed to three subaccounts in Ref. 1. The subaccounts of indirect cost correspond to a power plant construction project where the utility (Owner) contracts with an engineering and construction company to design the plant (Home Office), manage the construction project (Field Office),

and provide the construction materials (Construction Services). These elements of indirect cost are not commonly used on near-term experimental devices where it is likely that a laboratory will act as project manager and owner and that the field office will be at a laboratory. To ensure compatibility with experimental devices, elements of indirect cost commonly incurred on experimental projects have been included as subelements of the four major indirect accounts.

Additional accounts can be used to further break down estimated costs below the mandatory level. The level of cost account detail used in reporting estimated costs will vary, depending on the particular design study or application. In general, the level of detail of the subaccounts will parallel the level of detail of the design. The Appendix contains examples of detailed codes of accounts for tokamak and tandem mirror concepts that were developed below the mandatory level presented in Sect. 3.2.

Section 3.3 contains the Fusion Plant Code of Accounts Dictionary that provides a definition of the scope, content, interfaces, and boundaries of each code of account element at the mandatory level shown in Sect. 3.2. The elements of the code of accounts are defined in varying detail, depending on the level within the account.

3.2 FUSION PLANT CODE OF ACCOUNTS LISTING

2. Total Direct Cost

- 20. Land and Land Rights
- 21. Structures and Site Facilities
 - 211. Site Improvements and Facilities
 - 212. Reactor Building
 - 213. Turbine Building
 - 214. Reactor Maintenance Buildings
 - 215. Tritium Building

- 216. Electrical Equipment Buildings
- 217. Other Buildings and Structures
- 22. Reactor Plant Equipment
 - 221. Reactor
 - 221.1 First Wall
 - 221.1.1 Plasma Chamber
 - 221.1.2 Wall Modifiers
 - 221.2 Blanket
 - 221.2.1 Blanket Structure
 - 221.2.2 Breeder
 - 221.2.3 Reflector
 - 221.2.4 Multiplier
 - 221.3 Shield
 - 221.3.1 Bulk Shield
 - 221.3.2 Penetration Shielding
 - 221.3.3 Localized Shielding
 - 221.4 Reactor Structure
 - 221.4.1 Reactor Support Structures
 - 221.4.2 Vacuum Vessel
 - 221.4.3 Magnet Structural Supports
 - 221.4.4 Miscellaneous Support Structures
 - 221.5 Impurity Control Systems
 - 221.6 Particle Control Systems
 - 221.7 Direct Energy Conversion Systems
 - 222. Magnet System
 - 222.1 Magnet Assemblies
 - 222.2 Cryostat Assemblies
 - 223. Power Injection
 - 223.1 ECRH System
 - 223.2 ICRH System
 - 223.3 LHRH System
 - 223.4 Neutral Beam Injection

- 223.4.1 Neutral Beam
- 223.4.2 Beam Dump
- 224. Vacuum Systems
 - 224.1 Plasma Chamber System
 - 224.2 Vacuum Vessel System
 - 224.3 Secondary Vacuum Systems
- 225. Power Conditioning Systems
 - 225.1 Magnet System Power Conditioning
 - 225.2 Power Injection System Power Conditioning
 - 225.2.1 ECRH Power Supply System
 - 225.2.2 ICRH Power Supply System
 - 225.2.3 LHRH Power Supply System
 - 225.2.4 NBI Power Supply System
 - 225.3 Direct Energy Conversion Power Conditioning
 - 225.4 Energy Storage
 - 225.5 Particle Control System Power Conditioning
- 226. Heat Transport
 - 226.1 Blanket Heat Transport System
 - 226.2 Shield Heat Transport System
 - 226.3 Cryogenic Cooling System
 - 226.3.1 Helium System
 - 226.3.2 Nitrogen System
 - 226.4 Water Cooling Systems
 - 226.5 Gas Cooling Systems
- 227. Fuel Handling
 - 227.1 Fuel Injection Systems
 - 227.2 Fuel Processing and Purification
 - 227.3 Storage and Receiving
 - 227.4 Atmospheric Recovery Systems
 - 227.5 Water Recovery Systems
 - 227.6 Blanket Recovery Systems
- 228. Instrumentation and Control

- 228.1 Data Acquisition Systems
- 228.2 Man-Machine Interface Systems
- 228.3 Diagnostics
- 228.4 Central Data Processing
- 228.5 Operations Software
- 229. Maintenance Equipment
 - 229.1 Manipulator Systems
 - 229.2 Transport Systems
 - 229.3 Inspection, Viewing, and Test Systems
 - 229.4 Remote Cutting, Welding, and Machining Tool Systems
 - 229.5 Mock-up Equipment
 - 229.6 Miscellaneous Tools
 - 229.7 Decontamination Equipment
 - 229.8 Radioactive Waste Treatment and Disposal
- 23. Turbine Plant Equipment
 - 231. Turbine Generators
 - 232. Main Steam System
 - 233. Condensing Systems
 - 234. Feedwater Heating
 - 235. Other Turbine Plant Equipment
 - 236. Turbine Plant Instrumentation and Control
- 24. Electric Plant Equipment
 - 241. Switchgear
 - 242. Station Service Equipment
 - 243. Switchboards
 - 244. Protective Equipment
 - 245. Electrical Structures and Wiring Containers
 - 246. Power and Control Wiring
- 25. Miscellaneous Plant Equipment
 - 251. Transportation and Lifting Equipment
 - 252. Air and Water Service Systems
 - 253. Communications Equipment

- 254. Furnishings and Fixtures
- 255. Bulk Materials
- 26. Heat Rejection System
 - 261. Structures
 - 262. Mechanical Equipment
- 9. Indirect Cost
 - 91. Construction Services and Equipment
 - 92. Home Office Engineering and Services
 - 921. Systems Engineering
 - 922. Management
 - 923. Quality Assurance
 - 924. Safety and Environmental Engineering
 - 93. Field Office Engineering and Services
 - 931. Construction Management
 - 932. Inspection
 - 933. Preoperational Testing
 - 94. Owner's Cost
 - 941. Project Administration
 - 942. Staff Training and Plant Startup
 - 943. Inventories and Spares

2.3 FUSION PLANT CODE OF ACCOUNTS DICTIONARY

20. Land and Land Rights

Land and Land Rights includes the purchase and clearing of the land and the relocation of buildings, utilities, highways, and other services made necessary by the plant construction.

21. Structures and Site Facilities

Structures and Site Facilities includes Site Improvements/Facilities and Permanent Structures. Structures include the basic building structure, building services (plumbing, HVAC, fire protection, electrical

fixtures and wiring, elevators, and cranes), and containment structures (shielding).

Equipment foundations are not included in this account unless they are an integral part of the building. These foundations should ordinarily be included in equipment cost. The expected major cost buildings are itemized in the account to simplify direct comparisons. Heat rejection structures (raw water intake and discharge, pump houses, cooling tower basins, and treatment buildings) are included in Account 26.

211. Site Improvements and Facilities

Site Improvements and Facilities includes site work and electrical and mechanical site utilities. Site work includes clearing, grubbing, and grading of the site; roadways, parking, curbs, and walkways; and final finish landscaping. Electrical site utilities include underground ductwork system, primary power cable distribution, emergency power generation, and street lighting. Mechanical site utilities include site improvements for domestic water, sanitary services, storm drainage, and fire protection.

212. Reactor Building

Reactor Building includes the basic building structure, building services, and containment structures that house the fusion device and provide the radiation shielding, tritium boundary, and structural containment within the walls, roof, and floor. Transfer areas used to transfer equipment from the reactor building to the hot cell and/or warm cell are also included in this account.

213. Turbine Building

Turbine Building includes the basic building structure and building services that house the equipment necessary to generate electricity from the reactor plant heat. The turbine building

includes the turbine control area, heater bay, and diesel generator area. This account is not used for experimental devices.

214. Reactor Maintenance Buildings

Reactor Maintenance Buildings includes the basic building structures, building services, and containment structures necessary to provide working areas and radiation and tritium containment for maintenance, assembly, disassembly, and repair functions performed outside the reactor building. Specifically included in this account are the hot cell, warm cell, mock-up facility, and decontamination cell. The hot cell houses the remote maintenance assembly, disassembly, and repair functions. The warm cell houses the "hands-on" maintenance, assembly, disassembly, and repair functions. The mock-up facility houses the mock-up functions, in addition to assembly checkout and testing of remote handling equipment, fixtures, and components. The decontamination cell provides for remote decontamination of radioactively contaminated and activated components.

215. Tritium Building

Tritium Building includes the basic building structure and building services necessary to provide housing and tritium containment for tritium storage and delivery, storage vault, cleanup systems, holding tanks, waste packaging and disposal, and exhaust stack.

216. Electrical Equipment Buildings

Electrical Equipment Buildings includes the basic building structures and building services required to house the power conditioning and energy storage equipment. Included in this account are facilities such as the field coil power conversion building, rf and neutral beam power conversion building, and motor-generator building.

217. Other Buildings and Structures

Other Buildings and Structures includes those miscellaneous facilities (and services) that house systems auxiliary to, and in support of, reactor operations. Included in this account are such facilities as control room building, administration building, radioactive waste building, fabrication/assembly/maintenance building, diagnostics building, cryogenics building, and water cooling building.

22. Reactor Plant Equipment

Reactor Plant Equipment includes the fusion device and all required services. Major elements of Account 22 are the reactor system, magnet system, power injection systems, vacuum systems, power conditioning systems, heat transport systems, fuel handling systems, instrumentation and control, and maintenance equipment.

221. Reactor System

Reactor System includes the structural, mechanical, heat-removal, and nuclear components that comprise the basic reactor structural skeleton, including plasma interactive devices. Specifically included in this account are the first wall, blanket, shield, reactor structure, and energy and particle removal/control devices. Special, closed-loop service systems required for operation of the equipment are included as a part of that particular equipment.

221.1 First Wall

First Wall consists of those components immediately surrounding the plasma that absorb and remove a fraction of the incident heat loads associated with plasma operation and

disruption. If the first wall is integral with the blanket, it is included in Account 221.2.

221.1.1 Plasma Chamber

Plasma Chamber provides the mechanical structure and support and cooling for the first wall and includes the basic structural shell, first wall support structure, coolant manifolding and connections, local Instrumentation and Control, and bakeout hardware.

221.1.2 Wall Modifiers

Wall Modifiers includes those components, such as protective tile, liners, limiters, and coatings, that provide physical protection to the first wall and absorb incident heat fluxes during plasma operation and disruption. Attachment devices are also included.

221.2 Blanket System

Blanket System consists of those components that function to convert neutron energy from the fusion reaction into thermal energy while simultaneously breeding tritium.

221.2.1 Blanket Structure

Blanket Structure includes the blanket containment structure, inlet and outlet piping and joints, and internal piping.

221.2.2 Breeder

Breeder includes the special material that surrounds the fusion plasma and is contained in the blanket structure and that captures fusion neutrons produced by the fusion reaction to yield tritium.

221.2.3 Reflector

Reflector consists of the neutron moderating and reflecting structure surrounding the blanket. If the reflector is integral with the shield, it is included in Account 221.3.1.

221.2.4 Multiplier

Multiplier consists of the material that functions to multiply neutron production. The multiplier is located within the blanket or is mixed with the breeding material.

221.3 Shielding

Shielding consists of those components that provide radiation protection for personnel and sensitive components by minimizing neutron and gamma attenuation. Shielding provides for the transfer of internally generated heat by means of an active cooling system. Shielding includes the shield structure, auxiliary shielding materials, and coolant hardware.

221.3.1 Bulk Shielding

Bulk shielding consists of the radiation shielding that surrounds the plasma and is located between the first wall and magnets.

221.3.2 Penetration Shielding

Penetration Shielding consists of those shielding components that reduce radiation streaming around and through penetrations that view the plasma. Penetration shielding surrounds the ducts connecting auxiliary equipment to the plasma chamber, providing radiation protection to components adjacent to the penetrations.

221.3.3 Localized Shielding

Localized Shielding includes all shielding required to locally shield components internal and external to the reactor.

221.4 Reactor Structures

Reactor Structures includes the mechanical structures that tie together and provide support for all the major reactor components.

221.4.1 Reactor Support Structures

Reactor Support Structures consists of the mechanical structures that provide machine support from the building floor, in addition to any base structure that supports reactor components such as magnets, vacuum vessel, shielding, etc.

221.4.2 Vacuum Vessel

Vacuum Vessel consists of those components that provide the barrier between the atmosphere and the evacuated space containing the plasma and that may be located either internal or external to the bore of the magnetic field coils. Vacuum Vessel includes the vessel structure, support structure, coolant hardware, seals, insulation, bakeout apparatus, and local instrumentation.

221.4.3 Magnet Structural Support

Magnet Structural Support consists of the mechanical members specifically designed to locate and support the magnets against their experienced loading.

221.4.4 Miscellaneous Support Structures

Miscellaneous Support Structures includes the mechanical structures that provide the load path for a specific component to the support structure.

221.5 Impurity Control Systems

Impurity Control Systems consists of those plasma interactive devices that direct and collect impurities resulting from the fusion reaction. This account encompasses such components as pump limiters and divertors and includes coolant manifolding and connections, mounting structures, instrumentation, and vacuum enclosures.

221.6 Particle Control Systems

Particle Control Systems consists of those systems, such as drift pumping, that provide plasma particle control. This account includes the components required to generate, transmit, and inject power to the plasma for particle control.

221.7 Direct Energy Conversion Systems

Direct Energy Conversion Systems consists of those plasma interactive devices that collect and convert charged particle energy. Included in this account are such items as halo scrapers and collectors, along with their associated piping, instrumentation, support structure, and vacuum enclosures. Power inverters are included in Account 225.3.

222. Magnet System

Magnet System consists of the electromagnetic devices and associated hardware that provide the magnetic fields for confinement, shaping, and heating of the fusion plasma. Separate subaccounts

should be specified for each type of magnet. Electrical equipment required for magnet operation is contained in Account 225.1, and magnet cooling systems are contained in Account 226.

222.1 Magnet Assemblies

Magnet Assemblies consists of the hardware comprising the basic coil. The magnet assembly includes the conductor, insulation, joints, conductor windings, structural case, electrical power loads, coolant connections, and local instrumentation.

222.2 Cryostat Assembly

Cryostat Assembly includes those components that minimize the heat leak into cryogenically cooled superconducting coils and their support structures by minimizing gas convection and thermal radiation losses. The cryostat assembly includes the cryogenically cooled thermal shield, superinsulation, cold mass supports, and vacuum vessel structure.

223. Power Injection

Power Injection includes all rf and neutral beam systems, whether used for plasma heating, current drive, or fueling. Power supplies and electrical connections between power supply and power source for Power Injection Systems are included in Account 225.2.

223.1 ECRH System

ECRH (Electron Cyclotron Resonance Heating) System consists of the rf components required to generate, transmit, and inject high-power microwave energy in the electron cyclotron range of frequencies into the plasma and includes the power source, power distribution system, launcher, and ancillary equipment. The ECRH Power Source consists of the rf equipment from the dc power input to the rf power output and includes the

crowbar/regulator, gyrotrons, gyrotron magnets and power supplies, interconnecting cable, mounts and supports, windows, and local instrumentation and controls. The ECRH Power Distribution System consists of the components required to transmit and distribute ECRH power to the use points on the plasma containment vessel and can be either quasi-optical or waveguide transmission. Included in this account are waveguide sections, couplers, arc detectors, mode converters, mode filters, windows, switches, coupling irises, mitre bends, and local instrumentation. The ECRH launcher consists of the equipment required to efficiently deliver the ECRH power from the distribution system to the plasma and includes the launcher structure, vacuum barrier/feedthrough, cooling hardware, horns, mirrors, and local instrumentation. ECRH ancillary equipment includes any additional support equipment required for system operation.

223.2 ICRH System

ICRH (Ion Cyclotron Resonance Heating) System consists of the rf components required to generate, transmit, and inject high-power microwave energy in the ion-cyclotron frequency range into the plasma and includes the power source, power distribution system, launcher, and ancillary equipment. The ICRH power source consists of the rf equipment from the dc power input to the rf power output and includes the power amplifier, crowbar, interconnecting cable, protective gear, cooling hardware, and local instrumentation. The ICRH power distribution system consists of the components which transmit ICRH power from the power source to the use points on the plasma containment vessel. Included in this account are such components as co-axial transmission line, tuning system, breaks, power sensors, feedback control, and cooling hardware. The ICRH

launcher consists of the apparatus which delivers the rf power from the power distribution system to the plasma and includes the antenna, shield, vacuum feedthrough, sensors, and cooling hardware. ICRH ancillary equipment includes additional support equipment required for ICRH system operation.

223.3 LHRH System

LHRH (Lower Hybrid Resonance Heating) System consists of the rf components required to generate, transmit, and inject high-power microwave energy in the lower hybrid frequency range into the plasma and includes the power source, power distribution system, launcher, and ancillary equipment. The LHRH power source consists of the rf equipment from the dc power input to the rf power output and includes the klystrons, attenuators, oscillators, amplifiers, interconnecting cable, windows, and local instrumentation/control.

The LHRH power distribution system consists of the apparatus that transmits and distributes rf power to the use points on the plasma containment vessel and includes the waveguide, arc detectors, filters, circulators, windows, cooling hardware, and local instrumentation. The LHRH launcher consists of the hardware required to deliver the rf power from the distribution system to the plasma. Included in this account are the launcher structure, vacuum feedthrough, and cooling apparatus. LHRH System Ancillary Equipment includes additional support equipment required for the LHRH system.

223.4 Neutral Beam Injection System

Neutral Beam Injection (NBI) System contains the subsystems required to provide a beam of high-energy neutral particles to the plasma and includes the neutral beam and nonintegral beam dumps.

223.4.1 Neutral Beam Assembly

Neutral Beam Assembly consists of the apparatus required to generate and deliver a beam of high-energy neutral particles to the plasma. Included in this account are the source/accelerator, beamline, beam duct, and ancillary equipment. The source/accelerator consists of the equipment required to generate the ions for neutralization and includes the arc chamber, accelerator, grid, and instrumentation. The beamline consists of the components necessary to neutralize the ions and includes the vacuum chamber, neutralizer, cryopumping, ion dumps, bending magnet and power supplies, shielding, and calorimetry. The beam duct consists of the hardware required to transmit the beam to the plasma and includes the duct, bellows, valves, joints and flanges, electrical insulators, gimbals, and actuators. The ancillary equipment includes instrumentation and control and water cooling systems.

223.4.2 Beam Dump

Beam Dump consists of the hardware, nonintegral with the neutral beam, required to absorb the energy emanating from the neutral beams. Beam Dump includes vacuum enclosure, thermal collection, panels, cryopumps, and coolant hardware.

224. Vacuum Systems

Vacuum Systems contains those subsystems that provide a low-pressure environment to various reactor use points. This account includes all vacuum-related components (ducts, valves,

high-vacuum pumps, roughing/foreline pumps, regeneration systems, bakeout apparatus, and instrumentation and control).

224.1 Plasma Chamber System

Plasma Chamber System includes the vacuum equipment required to evacuate the plasma containment vessel to the base operating pressure and maintain base pressure during plasma operation.

224.2 Vacuum Vessel System

Vacuum Vessel System includes the vacuum equipment required to provide vacuum service to the vacuum vessel if a separate system is required.

224.3 Secondary Vacuum Systems

Secondary Vacuum Systems includes the vacuum equipment required to provide vacuum service to peripheral subsystems such as the magnet vacuum dewars and diagnostics.

225. Power Conditioning Systems

Power Conditioning Systems consists of the special regulation or ac/dc/ac power conversion equipment, along with the electrical connections from that equipment to the ultimate loads, required to convert or regulate normal ac line power for operation of major reactor equipment.

225.1 Magnet System Power Conditioning

Magnet System Power Conditioning consists of the electrical equipment required to convert/regulate ac line power, distribute the converted power to the magnets, and protect the magnets. Specifically included in this account are the power supplies/inverters and accessories,

power distribution bus, and coil protection systems (circuit breakers, dump resistors, varistors, interconnecting cable, and local instrumentation and control). Separate subaccounts should be specified for each separate magnet circuit.

225.2 Power Injection System Power Conditioning

Power Injection System Power Conditioning consists of the electrical apparatus required to convert and regulate normal ac line power and distribute the converted power to the Power Injection System subelements (ECRH, ICRH, LHRH, and NBI Systems). Specifically included in this account are the power supply components, power supply interconnecting cable, and power-supply to power-source cabling.

225.3 Direct Energy Conversion Power Conditioning

Direct Energy Conversion Power Conditioning consists of the electrical apparatus required to convert dc power from the collector to ac line power. Included in this account are the inverters for direct energy conversion, along with associated electrical cabling and interconnections.

225.4 Energy Storage

Energy Storage consists of the electrical apparatus and associated hardware that augment the energy supply from the electric utility and buffer it from peak power demand. Included in this account are such components as motor-generator flywheel sets and capacitor banks, along with interconnecting cabling to the ultimate load.

225.5 Particle Control System Power Conditioning

Particle Control System Power Conditioning consists of the electrical apparatus required to convert and regulate ac line power and distribute the converted power to the plasma interactive systems, such as drift pumping, that provide plasma particle control.

226. Heat Transport System

Heat Transport System consists of subsystems that remove heat from the reactor components and transport it outside the facility and includes fluid circulation equipment, refrigeration and heat transfer equipment, storage systems, treatment systems, and piping. Cooling towers are included in Account 26.

226.1 Blanket Heat Transport System

Blanket Heat Transport System consists of the components required to remove heat from the blanket and transport it to the turbine plant equipment circuit and includes pumps and motor drives, heat exchangers, tanks, and piping and valves.

226.2 Shield Heat Transport System

Shield Heat Transport System consists of the components required to remove heat from the bulk shielding and other components that contain cooling water that could become radioactive and transport it to the cooling tower circuit. This account includes pumps and motor drives, heat exchangers, tanks, treatment systems, piping and valves, and monitors for tritium and activated materials.

226.3 Cryogenic Cooling Systems

Cryogenic Cooling Systems contains the subsystems required to supply cryogenic fluids to the various reactor use points and includes refrigeration equipment, heat exchangers, storage systems, and distribution systems.

226.3.1 Helium System

Helium System consists of the cryogenic equipment required to deliver helium coolant to the required reactor use points and includes the refrigerator/liquefier, compressor, cryogenic piping and valves, ambient piping, dewars and tanks, and auxiliary (cooldown, etc.) equipment.

226.3.2 Nitrogen System

Nitrogen System consists of the cryogenic equipment required to provide nitrogen coolant to the required reactor use points and includes the reliquefier, cryogenic piping and valves, ambient piping, and storage dewars.

226.4 Water Cooling System

Water Cooling System consists of the equipment required to provide cooling water to required reactor use points, other than the blanket and shield. This account includes pumps and drives, heat exchangers, chillers, storage tanks, piping and valves, and water purification and treatment systems.

226.5 Gas Cooling System

Gas Cooling System consists of the equipment required to provide gas coolant to required reactor use points, other than the blanket and shield, and includes pumps, tanks, heat exchangers, and piping and valves.

227. Fuel Handling

Fuel Handling includes the equipment required to fuel the reactor and to process the reactor exhaust, breeding blanket tritium carrier, and other tritiated systems to separate the tritium and deuterium. This account also includes systems to receive and store tritium, to control and process building atmospheres to maintain acceptable tritium levels, and to control tritium levels in the heat transport system.

227.1 Fuel Injection Systems

Fuel Injection Systems contains the subsystems required to supply hydrogen isotopes to the reactor and includes pellet injection and gas injection systems, including all ancillary support systems, interconnecting piping and valves, and local Instrumentation and Control. The pellet injection system includes the pellet injectors, pellet tube, support structures, and isolation valves.

227.2 Fuel Processing and Purification

Fuel Processing and Purification consists of the equipment required to process and purify the reactor exhaust and includes the fuel cleanup unit, isotope separation unit, gaseous and solid tritium waste units, and a data acquisition and control system. The fuel cleanup unit removes gaseous impurities from the plasma exhaust

stream and includes mole sieve beds, catalytic reactors, freezers, electrolyzers, condensers, filters, and transfer pumps. The isotope separation unit removes protium from deuterium and tritium and includes distillation columns and accessories, equilibrators, heat exchangers, and vacuum enclosure. The gaseous tritium waste treatment system removes low levels of tritium from gas vented from the processing systems and includes tanks, recombiner, compressors, dryers, and Instrumentation and Control. The solid tritium waste treatment system packages solid waste generated in the tritium processing area and includes glovebox and compactor. The data acquisition and control system measures performance parameters and provides control of components, subsystems, and the tritium system as a whole.

227.3 Storage and Receiving Systems

Storage and Receiving Systems includes those systems required to receive and store tritium. It includes receiving gloveboxes, uranium storage beds, glovebox detritiation unit, and the tritium analysis and accountability system. The receiving glovebox receives tritium for initial startup, replenishes that lost due to decay, and packages clean tritium for shipment; it includes the glovebox, uranium beds, and transfer pumps. The uranium storage beds store tritium and also deuterium which has been fueled once to the reactor and includes the uranium beds, gloveboxes, and piping. The glovebox detritiation unit detritiates all glovebox effluents prior to discharge and includes compressors, catalytic oxidizers, dryers, and Instrumentation and Control. The tritium analysis and accountability system insures proper purity of components

and provides an account of on-site tritium. The system includes instruments such as liquid scintillation monitors, mass spectrometers, tritium-modified mass spectrometers, and gas chromatograph.

227.4 Atmospheric Recovery Systems

Atmospheric Recovery Systems contains the subsystems required to monitor the levels of, and remove, tritium and other radioactive gases from the atmospheres of radioactive-gas-containing buildings and includes the recovery systems and tritium monitors. The atmospheric recovery systems consist of compressors, catalytic oxidizers, driers, storage tanks, and Instrumentation and Control. Separate subaccounts should be specified for each separate system. Tritium monitors provide quantitative and emergency tritium levels in the tritium-containing buildings.

227.5 Water Recovery System

Water Recovery System consists of the hardware required to extract tritium from the tritiated water coolant and includes components such as a feedwater cleanup system, catalytic exchanger column, electrolysis units, dryer, and hydride storage.

227.6 Blanket Recovery System

Blanket Recovery System consists of the equipment necessary to extract tritium and corrosion products from the breeding blanket tritium carrier.

228. Instrumentation and Control

Instrumentation and Control consists of the centralized processing, monitoring, controlling, and diagnostic systems for the reactor plant equipment and includes data acquisition systems, man-machine interfaces, diagnostics, central data processing, and operations software. A distributed supervisory control and data acquisition system that has a monitor and control function complementing local control capabilities in each system is assumed. Local instrumentation and control is included within the specific subsystem.

228.1 Data Acquisition System

Data Acquisition System consists of the hardware necessary to interface subsystems, sensors, and diagnostics to the central processors and to provide necessary electrical isolation between the equipment and computer system. This account includes data channels, crates, controllers, and signal conditioning.

228.2 Man-Machine Interface Systems

Man-Machine Interface Systems contains the operations, diagnostic, and programmers' consoles required to operate the reactor from the main control room and remote control rooms and includes components such as microcomputers, controllers, crates, cathode ray tubes' control panel displays, cabinets, and hard-copy units.

228.3 Diagnostics

Diagnostics contains the diagnostic and measurement apparatus required to provide information concerning the plasma's behavior and includes both diagnostics for real-time control and plasma diagnostics.

228.4 Central Data Processing

Central Data Processing consists of all central data processing devices, storage devices, network devices and support systems and includes operations computers, diagnostics computers, programming computers, archiving computers, and data acquisition computers.

228.5 Operations Software

Operations Software consists of all activities required to provide the software capability for data acquisition, general console displays, diagnostics analysis data reduction, and supervisory control and includes establishing the functional requirements of the software system and managing the development of the software.

229. Maintenance Equipment

Maintenance Equipment includes all general purpose and special purpose equipment required to perform maintenance operations remotely on activated reactor components/subsystems, in addition to equipment for decontamination, radioactive waste treatment, and storage for the entire plant. General purpose maintenance equipment is included in Account 25.

229.1 Manipulator Systems

Manipulator Systems includes all floor-mounted, bridge-mounted, and through-the-wall manipulator systems with associated controls.

229.2 Transport Systems

Transport Systems includes cranes, transporters, handling fixtures, and transfer locks with associated

controls. General purpose transport systems, such as cranes and tracks, are included in Account 251.

229.3 Inspection, Viewing, and Test Systems

Inspection, Viewing, and Test Systems consists of the apparatus required for in-vessel and external vessel remote inspection, viewing, and testing.

229.4 Remote Cutting, Welding, and Machine Tool Systems

Remote Cutting, Welding, and Machine Tool Systems consists of all remotely controlled tools for the connecting, welding, and cutting of reactor components, such as pipes, vacuum joints, vacuum vessel, etc.

229.5 Mock-up Equipment

Mock-up Equipment includes both partial device/hot cell mockup hardware and remote maintenance equipment, such as manipulators, transporters, and cranes.

229.6 Miscellaneous Tools

Miscellaneous Tools includes such miscellaneous items as hand tools, shield plugs, manipulator end effectors, cradles, slings, and machine tools for the hot cell.

229.7 Decontamination Equipment

Decontamination Equipment consists of the equipment required to remove surface contaminants (tritium and particulate matter) from reactor components and includes water, steam, and chemical cleaning systems.

229.8 Radioactive Waste Treatment and Disposal

Radioactive Waste Treatment and Disposal consists of the facilities and equipment required for handling, packaging, and storage of activated items. Provisions for packaging, compaction, cutting, and design of shipping containers are included.

23. Turbine Plant Equipment

Turbine Plant Equipment consists of the equipment required to generate electricity from the energy supplied by the reactor plant heat transport systems. This account is not used if the plant does not generate electricity.

231. Turbine Generators

Turbine Generators includes that equipment necessary to transform the thermal energy contained in the main steam system into electrical energy. This account includes the turbine(s), generator, and all auxiliary support systems normally supplied with the units. These support systems can include turbine inlet, stop, and throttle valves; intermediate stop and throttle valves; crossover piping between high-, intermediate-, and low-pressure turbines; gland steam system; lubricating oil system; generator hydrogen seal oil system; stator winding cooling system; generator CO₂ purge system; and generator exciter system.

232. Main Steam System

Main Steam System includes the piping, valves, fittings, and supports necessary to convey steam from the steam generator outlet(s) to the turbine inlet valve(s). It can also include similar reheat and superheat piping, etc., and/or moisture separator equipment.

233. Condensate System

Condensate System includes all piping, valves, fittings, components, and supports from the turbine exhaust flange to the steam generator-feedwater pump suction. Its function is to condense the turbine exhaust and convey the condensate to the feedwater pump(s) suction connections. In addition to piping, valves, fittings, and supports, this system can include the main condenser, condensate pump(s), low-pressure feedwater heaters, deaerator, and heater drain pump system.

234. Feedwater Heating System

Feedwater Heating System consists of the equipment required to raise the pressure and temperature of the steam generator feedwater to the steam generator inlet conditions. It includes all piping, fittings, valves, equipment, and supports from the steam generator-feedwater pump(s) suction connection(s) to the feedwater inlet(s) of the steam generator(s). This may include feedwater pumps (and auxiliary turbines and condensers where appropriate), high-pressure feedwater heaters, steam generator flow control valves, and heater drain system.

235. Other Turbine Plant Equipment

Other Turbine Plant Equipment includes all other process systems and components necessary to support the turbine generator indirectly and that are not included in the previous accounts. This may include extraction steam system, auxiliary steam and boiler system, condenser makeup system, condenser air-removal system, condensate polishing system, and turbine plant sampling system.

236. Turbine Plant Instrumentation and Control

Turbine Plant Instrumentation and Control consists of monitoring, controlling, and data acquisition systems for the turbine plant equipment.

24. Electric Plant Equipment

Electric Plant Equipment distributes the generator power to the utility system and to the plant loads. In the absence of power generation, the electric plant distributes power from the utility system to the plant loads and includes stabilizers, station service equipment, switchboards, protective equipment, electrical structure and wiring containers, and power and control wiring.

The connection interfaces and high-voltage transformers required between the electric plant and utility depend on the specific design. The connection to major equipment occurs at equipment that operates off a normal ac power line (such as 13.8 kV, 4.16 kV, and 480 V). Special regulation or dc conversion equipment and the connections from the equipment to ultimate loads are included in Account 225, Power Conditioning.

241. Switchgear

Switchgear consists of the protective switchgear for both the generator and station service circuits, in addition to the utility line, and includes circuit breakers, reactors, and disconnects.

242. Station Service Equipment

Station Service Equipment consists of the equipment required to transform, meter, and control the energy supply from the utility system and provide backup power. This account includes medium- and high-voltage substation transformers, load centers, backup power system, uninterruptible power supply system, and power factor correction equipment.

243. Switchboards

Switchboards consists of the equipment required to provide monitoring and control of the electric plant equipment and includes the control and instrument power panels for both the main electric system and auxiliary power control board.

244. Protective Equipment

Protective Equipment consists of the electrical hardware necessary to provide the station grounding system and cathodic protection and includes the ground grid, connectors, and interconnecting cable.

245. Electrical Structures and Wiring Containers

Electrical Structures and Wiring Containers consists of the raceways required to house and support the power and control wiring and includes tunnels, cable trays, supports, and conduit.

246. Power and Control Wiring

Power and Control Wiring consists of the cabling and busing necessary to distribute energy from the energy distribution bus to the reactor electrical components and includes high-voltage and medium-voltage cable and busing and low-voltage wiring.

25. Miscellaneous Plant Equipment

Miscellaneous Plant Equipment includes general services that are provided to several parts of the plant and are not associated with any particular piece of equipment, subsystem, or system. It also includes transportation and lifting equipment, air and water service systems, communications equipment, furnishings and fixtures, and bulk materials.

251. Transportation and Lifting Equipment

Transportation and Lifting Equipment consists of general transportation and lifting equipment and includes such equipment as

cranes, hoists, monorails, conveyors, railways, and roadway equipment.

252. Air and Water Service Systems

Air and Water Service Systems includes all common air systems, water systems, and heating boilers.

253. Communications Equipment

Communications Equipment includes local communication systems and signal systems.

254. Furnishings and Fixtures

Furnishings and Fixtures includes safety equipment, shop, laboratory and test equipment, office equipment and furnishings, and dining facilities.

255. Bulk Materials

Bulk Materials consists of all permanent plant materials usually purchased in bulk quantities, such as concrete, steel, small piping, and wire.

26. Heat Rejection System

Heat Rejection System consists of the structures and mechanical equipment necessary to reject heat from the plant cooling water circulation systems to the atmosphere. If a turbine cycle is used, the main circulating system is between the condensers and the cooling towers. In the absence of a steam cycle, the Heat Rejection System is connected to the shield and water cooling heat transport systems. Intermediate heat exchangers are included in the Heat Transport System (Account 226) and are a natural interface. If there is no intermediate heat exchanger, a natural manifold point in the piping system must be selected as the

interface. Special coolants are included in the system accounts that require the coolant.

261. Structures

Structures contains structures and facilities that house, or are a part of, the plant heat rejection system and includes intake and discharge structures, cooling tower basin and structures, pump houses, and water treatment buildings.

262. Mechanical Equipment

Mechanical Equipment consists of the mechanical equipment required to reject heat from the plant cooling water systems to the atmosphere. It includes pumps, piping, and valves associated with water intake and discharge; raw treatment; plant water circulation; and cooling tower circulation.

9. Indirect Costs

Indirect costs are those that are not identified with specific, permanent plant facilities, equipment, or systems but are incurred by the project as a whole. Indirect costs are not identified with a direct account and will vary depending on the type of contracting arrangement and the type of device being constructed.

91. Construction Services and Equipment

Construction Services and Equipment includes temporary construction facilities (buildings and structures, temporary roads and parking areas, and temporary utility connections), construction equipment (purchased and rented equipment, maintenance, and fuel), and taxes and insurance (craft labor payroll insurance and taxes and permits, and insurance and taxes associated with site development).

92. Home Office Engineering and Services

Home Office Engineering and Services consists of the overall project engineering, management, and services provided by the prime contractor, mainly during the design phase. Major elements of this account are project systems engineering, management, and quality assurance.

921. Project Management

Project Management consists of those activities associated with the prime contractor's overall control, monitoring, and direction of the project and includes project administration, cost/schedule control, technical coordination, and data management.

922. Project Systems Engineering

Project Systems Engineering consists of the project-wide integrated technical planning and coordination required to meet project interface procedures and includes systems integration, systems analysis, configuration control, and environmental and safety engineering.

923. Project Quality Assurance

Project Quality Assurance consists of those activities required to provide quality assurance management, quality analysis, supplier quality assurance, quality engineering, and quality planning. This account includes procedures development, review, audit, surveillance, and reporting.

924. Project Safety and Environmental Engineering

Project Safety and Environmental Engineering consists of those activities required to provide both industrial and radiation safety engineering. Industrial safety includes safety systems for personnel protection and electrical, conventional, and operational safety. Radiation safety includes environmental impact study and

statements, environmental monitoring, and on- and off-site safety analysis.

93. Field Office Engineering and Services

Field Office Engineering and Services consists of the prime-contractor-associated activities at the job site during the construction phase and includes construction management, inspection, and preoperational testing.

931. Construction Management

Construction Management consists of the prime contractor's control, monitoring, and directive function at the project site and includes construction site supervision, construction scheduling, procurement and contract administration, expediting, construction engineering, and warehousing.

932. Inspection

Inspection includes quality assurance inspection/verification activities required to verify/accept components at the project site and quality inspection efforts in support of installation activities.

933. Preoperational Testing

Preoperational Testing consists of the prime contractor's on-site activities required to plan for, conduct, direct, verify, and document the integrated testing of the reactor to demonstrate its operational status.

94. Owner's Cost

Owner's Cost consists of the overall project engineering and services cost incurred by the owner (utility or lab) and the initial inventory of spare parts.

941. Project Administration

Project Administration consists of the owner's technical, management, and administrative staff prior to operation, including overheads and general and administrative expenses. Specifically included are project management, systems engineering, quality assurance, taxes, and insurance.

942. Staff Training and Plant Startup

Staff Training and Plant Startup includes the owner's cost of selecting and training the initial operating staff and the cost of any preoperational and startup testing performed by the owner before plant turnover or before commercial operation.

943. Inventories and Spares

Inventories and Spares includes the cost of identification, acquisition, inventory, and control of the initial stock of components, repair parts, bulk material, and consumables.

4. COST DATA BASE DEVELOPMENT

4.1 INTRODUCTION

Past experience has demonstrated that "bottoms-up" cost estimates of leading-edge-of-technology devices at the preconceptual design levels are consistently inaccurate. This traditional estimating method involves summing the cost of subsystem components, beginning with the smallest details and combining these into larger and larger assemblies until the entire subsystem is complete. The "bottoms-up" method is an excellent cost-estimating method where the design has matured to a fine level of detail and the components are standard, off-the-shelf items with well-known costs. The absence of a mature design at the preconceptual level makes total "bottoms-up" cost estimating very difficult at best because of the inherent lack of design definition and detail.

The cost-estimating methodology discussed in Sects. 2.2 and 2.3 provides a credible and consistent cost-estimating approach compatible with the preconceptual level of design definition and detail. This methodology provides a framework for reporting cost data to build a fusion plant cost data base, based on actual cost experience from projects and other sources.

This section addresses the collection of raw cost data, refinement of the cost data to be compatible with the fusion plant costing framework, and cataloging of the refined cost data. The detailed refinement of cost data is essential because the intent of this accounting system is to ensure that the cost data obtained from various sources are reported in such a manner that the data can be used to estimate the costs of future projects. It is necessary to extract first-of-a-kind and other project-specific costs so that estimates of future costs can properly account for learning effects or other cost reductions.

4.2 COLLECTION AND REFINEMENT OF COST DATA

The Cost Data Base is being derived from actual cost experience within and outside the fusion community and includes engineering, equipment, and labor cost data for specific components/subsystems, in addition to project-level indirect cost data. Major sources of cost data can be categorized as follows:

1. fusion projects currently operating or under construction,
2. fusion component development projects,
3. fusion project cost estimates,
4. industrial manufacturers of fusion components/subsystems,
5. manufacturers' quotes/price lists, and
6. other nuclear projects.

Cost data are obtained from these sources via private communications, formal transmittals, and from the available documentation of project costs. The raw cost data received from the various sources vary greatly in detail, content, and format because of differences in project

organization, reporting systems, contracting arrangements, institutions involved, as well as the technical nature of the project or development program. These differences complicate the development of a common cost data base. As a result, it is sometimes necessary to evaluate the raw cost data in great detail to extract costs compatible with the definitions and procedures described in this report, an evaluation which requires considerable information in addition to the component/subsystem purchase price.

The cost elements that comprise the base constructed cost of a project are shown at the required reporting level in Fig. 3. These cost elements are defined in Sect. 2.1. The raw cost data obtained from the various sources are refined and reduced to the extent possible to correspond to the cost elements shown in Fig. 3. Indirect costs are project-level costs; as a result, the cost data base must be extracted from construction projects. The format used in reporting these indirect costs will differ between experimental facilities and the power industry. Generally, the four first-level elements of indirect costs are consistent with power industry practice, while the second-level subelements correspond to the indirect cost elements most commonly used by experimental projects.

Direct cost data pertain to specific components and are extracted from construction projects, component development programs, and industry. The extent and format of the cost data available for a specific component depend on the origin of the component. If the component is commercially available, then only the purchase price need be reported. If the component is specially fabricated, all applicable direct cost subelements (engineering cost, equipment cost, and labor cost) should be reported. The applicable subelements depend on the contracting method (build-to-print, build-to-specification, installed, etc.). In some instances, fabrication cost and fabrication engineering costs can be reported separately, depending on whether the manufacturer direct charges fabrication engineering or includes it in overhead.

ELEMENTS OF CONSTRUCTED COST

Fig. 3. Base constructed cost reporting level.

The most difficult cost data to refine for use in predicting the cost of future projects are those that come from first-of-a-kind component development programs. Account must be taken for certain costs associated with the development process that tend to artificially inflate the component cost. Figure 4 outlines the general methodology used to refine component development cost data. Program-unique costs are quantified and subtracted from the total contract cost to yield the cost of the next unit. These unique costs include costs incurred because of imposed budget and schedule constraints, costs attributable to unique requirements that would not be required in production units, and costs due to problems that would not be repeated on succeeding units. The cost of the next unit is then divided into recurring and nonrecurring cost elements. Subelements of nonrecurring costs are engineering and tooling. The recurring cost of the component includes the cost of fabrication and the cost of fabrication support engineering. The fabrication cost of the component/subsystem is broken down into its subelements, if necessary, and fabrication support engineering is prorated among these subelements. In cases where fabrication support engineering is not directly charged by the manufacturer, it should be included in the overhead rate applied to fabrication labor. An assumed learning curve is then applied to the subelement's cost, based on the desired quantity, and tooling cost is added to yield the cost of the production units. This same methodology can be used, to a lesser extent, to refine cost data from production units.

4.3 CATALOGING OF COST DATA

After the cost data have been refined, they are recorded in the Cost Data Base File, a catalog of cost coefficients, cost algorithms, and "component takeoff costs" formatted onto separate cost data sheets corresponding to specific components and subsystems. Each cost data sheet contains equipment, labor, and engineering cost data, in addition to pertinent design parameters, for different configurations and types

COST DATA REFINEMENT - COMPONENT DEVELOPMENT PROGRAM

Fig. 4. Methodology for refinement of component development program cost data.

of the specific component or subsystem. The Cost Data Base File is arranged to correspond to the Fusion Plant Code of Accounts. An example of a cost data sheet is shown in Fig. 5. The exact format used on the cost data sheets varies among the Code of Accounts elements, depending on the costing approach employed (unit cost, algorithm, or "component takeoff"). Indirect cost data are also cataloged in the Cost Data Base File.

5. CALCULATION OF COST OF ELECTRICITY

The levelized revenue requirement method is used for calculating the cost of electricity. This method is widely used by electric utilities for economic analysis of various plant options. The Department of Energy (DOE) has supported the use of this method in comparing fission and coal-fired power plants.³ The Electric Power Research Institute has adopted this method for economic analysis of research and development options.⁴

Theoretical development of the levelized revenue requirement method for calculating busbar cost of electricity is given in Refs. 3 and 4. Methods are presented in these references for obtaining factors for performing this calculation and for applying these factors to obtain levelized busbar cost of electricity.

This section describes the use of this method, provides a listing of typical financial parameters, and shows an example of applying these parameters to the STARFIRE⁵ cost data and to a light-water reactor.

At the beginning of each fusion plant study, participants should agree on a set of financial parameters for that study. This will ensure that the calculated cost of electricity is consistent among the participants.

COST DATA SHEET

DESCRIPTION	YR	EQPT	ENGRG	LABOR						BASIS

Fig. 5. Cost data sheet sample.

5.1 METHOD OF CALCULATION

The following equation may be used to calculate the levelized revenue requirement (or levelized busbar cost of electricity) for an electric power plant:

$$LRR = \frac{(LAFCR \cdot TCC) + (AOC \cdot LN_o) + (AFC \cdot LN_f)}{0.00876 \cdot MW \cdot CF},$$

where

LRR = Levelized revenue requirement (or COE) (mills/kWh),

LAFCR = Levelized annual fixed charge rate (Table 1),

TCC = Total capital cost of the plant (millions \$),

AOC = Annual operating and maintenance cost, including replacement components (millions \$/year),

AFC = Annual fuel costs (millions \$/year),

LN_o = Levelizing factor for operating cost (Table 1),

LN_f = Levelizing factor for fuel cost (Table 1),

MW = Plant net electrical output (megawatts),

CF = Plant capacity factor (fraction).

Some of these factors are explained in more detail below.

Table 1. Levelized annual fixed charge rate (LAFCR)
and levelizing factor (LN)

Inflation rate (%/year)	Effective cost of money(%/year)	LAFCR (%/year)	LN-30
0	4.2	8.0	1.000
2	5.8	9.7	1.272
4	7.4	11.6	1.588
6	9.0	13.6	1.950
8	10.6	15.8	2.361
10	12.2	18.1	2.822

Levelized Revenue Requirement is the constant price in mills per kWh such that the income received from the sale of electricity from the plant throughout the 30-year period will pay all operating expenses, taxes, and return on outstanding capital investment and will pay off the investment by the end of the plant life. The actual revenue requirement for the plant will change from year to year; however, the levelized revenue requirement method provides a single value that allows different plants to be compared on a consistent basis.

Levelized Annual Fixed Charge Rate is shown in Table 1. This fixed charge rate is based on financial parameters shown in Table 2. It includes return on capital, local property taxes of 2%/year, income taxes, book depreciation, investment tax credit, and tax writeoff.

Total Capital Cost of the plant is calculated from the base constructed cost described in Sect. 2. Base constructed cost is multiplied by the plant cost factors shown in Table 3 to account for interest and inflation during construction. In this table power plant escalation in excess of general inflation is assumed to be 0%. These factors have been calculated using the cumulative construction expenditure pattern shown in Refs. 1 and 4. It is recommended that plant costs be reported in dollars as of January 1 of the year of the estimate.

Annual Operating and Maintenance Cost includes costs associated with plant operating personnel, such as salaries, benefits, general and administrative expenses, overtime, travel, retraining, cost of contract personnel, workman's compensation insurance; cost of supplies, equipment, and interim replacement parts; coolant makeup; process material; licensing; liability insurance; and any miscellaneous costs, such as rental of equipment.

Annual Fuel Cost includes cost of fuel materials that must be replaced during operation.

Thirty-Year Levelizing Factor, shown in Table 1, levelizes an annual cost that may be subject to inflation so that the present value of the

Table 2. Financial parameters

	Inflation rate (%)					
	0	2	4	6	8	10
Capitalization, %						
Debt	50	50	50	50	50	50
Preferred stock	12	12	12	12	12	12
Common equity	38	38	38	38	38	38
Return on capitalization, %/yr						
Debt interest	3.8	5.9	8.0	10.0	12.1	14.2
Preferred dividend	2.8	4.9	6.9	9.0	11.0	13.1
Common equity return	7.6	9.8	11.9	14.0	16.2	18.3
Average cost of money, %/year	5.1	7.3	9.4	22.4	13.5	15.6
Federal income tax, %/year	46	46	46	46	46	46
State income tax, %/year	4	4	4	4	4	4
Effective (tax-adjusted) cost of money, %/year	4.2	5.8	7.4	9.0	10.6	12.2
Tax depreciation method	TEFRA			TEFRA		TEFRA
Tax depreciation life, years	10			10		10
Investment tax credit, %	8			8		8
Plant economic life, years	30			30		30

Table 3. Plant cost factors for interest
and inflation during construction

Inflation rate, %	Effective cost of money, %	Plant cost factors (PCF)			
		4-year construction	6-year construction	8-year construction	10-year construction
0	4.2	1.070	1.109	1.148	1.188
2	5.8	1.151	1.234	1.324	1.421
4	7.4	1.235	1.372	1.525	1.694
6	9.0	1.324	1.523	1.751	2.014
8	10.6	1.418	1.687	2.007	2.388
10	12.2	1.517	1.866	2.296	2.824

time-varying cost is equal to the present value of the resulting levelized cost. The factors shown in this table apply to costs that change at the same rate as inflation. If a cost has real escalation, then other factors should be used. These factors are available from the FEDC upon request.

5.2 EXAMPLES

Application to STARFIRE

To illustrate the use of the above methods, the STARFIRE cost of electricity was calculated using financial parameters shown in this section. Base costs were taken from the STARFIRE report⁵ and escalated at 7%/year to 1985 dollars. Results are shown in Table 4 for cases of 0 and 6%/year.

Comparison of STARFIRE to a LWR

Reference 3 contains estimates of capital cost for future light water reactor (LWR) fission plants. These estimates reflect regulatory reform and design standardization that are expected to reduce the cost of nuclear plant construction. These estimates are considerably lower than the cost of plants being constructed today. However, it is believed that before utilities will order new LWR plants, these cost reductions must be achievable.

Using this new LWR capital cost and fuel cycle cost data from Ref. 3, the cost of electricity from LWRs has been estimated using the financial parameters in this section. This allows the cost of electricity from STARFIRE to be compared to a LWR using consistent financial parameters. Results are shown in Table 4 for the constant 1985 dollar case and for the 6%/year inflation case.

Again using the data from Ref. 3, estimates were made of the cost of electricity from LWR plants going into commercial operation out to 2050. Considerable extrapolation of fuel costs was necessary to perform

Table 4. Cost of electricity, STARFIRE and LWR

	STARFIRE (1200 MWe)		LWR 1100 MWe)	
	1980 \$	1985 \$	1983 \$	1985 \$
<u>Data</u>				
Direct + indirect cost, millions	2124.0	2979.0	1270.0	1454.0
O&M, millions/year	19.4	27.2		
Component replacement, millions/year	17.4	24.3	a	a
Fuel, millions/year, mills/kWh	0.33	0.46		
Construction period, years	6	6	8	8
Capacity Factor, %	75	75	65	65
<u>Calculation</u>				
	STARFIRE		LWR	
	Constant 1985 \$	Current \$ 6%/year inf.	Constant 1985 \$	Current \$ 6%/year inf.
Annual fixed charge rate, %/yr	8.0	13.6	8.0	13.6
Plant cost factor	1.109	1.523	1.148	1.751
Levelizing factor	1.0	1.95	1.0	1.95
Total capital cost, millions	3304.0	4537.0	1669.0	2546.0
O&M costs, millions/year	27.2	38.6	48.0	68.2
Component replacement, millions/year	24.3	34.5	8.4	12.7
Fuel, millions/year mills/kWh	0.46	0.65	7.14 ^b	24.27 ^b
Cost of electricity	40.2	96.5	37.5	104.7

^a0.5% of total capital cost.^b30-year levelized cost.

this calculation. This estimate contains a 1.25%/year real escalation in the cost of uranium and a -1.7%/year real decrease in the cost of enrichment out to 2030. These two effects tend to offset each other to produce a near-level cost of fuel in constant dollars so that the constant-dollar fission cost of electricity is projected to be nearly constant out to 2030.

REFERENCES

1. S. C. Schulte et al., Fusion Reactor Design Studies - Standard Accounts for Cost Estimates, PNL-2648, Pacific Northwest Laboratories, May 1978.
2. The utility cost reporting system and Ref. 1 are based on the NUS guide, NUS 531, January 1969. Recent extensions and modifications of the code are incorporated in the Energy Economic Data Base Program reports (Phase V update, DOE/NE-0051, July 1983; or for detailed estimates, NUREG-0242, June 1977).
3. Nuclear Energy Cost Data Base, DOE/NE-0044/2, March 1984.
4. Technical Assessment Guide, EPRI P-2410, Summary Report, Electric Power Research Institute, Palo Alto, Calif., May 1982.
5. C. C. Baker et al., STARFIRE - A Commercial Tokamak Fusion Power Plant Study, ANL/FPP-80-1, Argonne National Laboratory, Argonne, Illinois, September 1980.

APPENDIX

EXAMPLE CODE OF ACCOUNTS FOR TOKAMAK AND TANDEM MIRROR REACTORS

A.1 TOKAMAK

Account Number	Account Title
2.	TOTAL DIRECT COST (TOKAMAK)
20.	Land and Land Rights
21.	STRUCTURES AND SITE FACILITIES
211.	Site Improvements and Facilities
212.	Test Cell
213.	Turbine Building
214.	REACTOR MAINTENANCE BUILDINGS
214.1	Hot Cell
214.2	Warm Cell
214.3	Mockup Building
215.	Tritium Building
216.	ELECTRICAL EQUIPMENT BUILDINGS
216.1	Field Power Supply Building
216.2	RF Power Supply Building
216.3	Motor-Generator Building
217.	OTHER BUILDINGS AND STRUCTURES
217.1	Administration Building
217.2	RAD-Waste Processing Building
217.3	Fabrication/Assembly/Maint Buildings
217.4	Diagnostics Building
217.5	Cryogenics Building
217.6	Plant Auxiliary Building
217.7	Switchyard
217.8	Vent Stack
217.9	Control Room Building
217.10	Security Building
217.11	Warehouse
217.12	Miscellaneous Buildings, Structures
22.	REACTOR PLANT EQUIPMENT
221.	REACTOR SYSTEM
221.1	FIRST WALL ASSEMBLY
221.1.1	PLASMA CHAMBER
221.1.1.1	First Wall Structure
221.1.1.2	First Wall Supports
221.1.1.3	First Wall Instrumentation
221.1.1.4	First Wall Heating & Cooling
221.1.2	Wall Modifiers
221.2	BLANKET ASSEMBLY
221.2.1	Blanket Structure
221.2.2	Breeder
221.2.3	Reflector
221.2.4	Multiplier
221.3	SHIELDING
221.3.1	BULK SHIELDING
221.3.1.1	Inboard Shield
221.3.1.2	Outboard Shield
221.3.1.3	Window Shield

221.3.2	PENETRATION SHIELDING
221.3.2.1	Pump Duct Shield
221.3.2.2	RF Shielding
221.3.2.3	Fuel Injector Shielding
221.3.2.4	Diagnostic Shielding
221.3.3	LOCALIZED SHIELDING
221.3.3.1	External Shielding
221.3.3.2	Platform Shielding
221.4	REACTOR STRUCTURE
221.4.1	REACTOR SUPPORT STRUCTURES
221.4.1.1	Base Support Structure
221.4.1.2	Bucking Cylinder/Post
221.4.1.3	Precompression Ring
221.4.2	VACUUM VESSEL ASSEMBLY
221.4.2.1	Vessel Structure
221.4.2.2	Vessel Support
221.4.2.3	Vessel Instrumentation
221.4.3	MAGNET STRUCTURAL SUPPORT
221.4.3.1	OH Coil Support
221.4.3.2	Inner PF Support
221.4.3.3	Outer PF Support
221.4.3.4	TF Support
221.4.3.5	TF Intercoil Support
221.4.4	MISCELLANEOUS SUPPORT STRUCTURES
221.4.4.1	PF Core Attachment
221.4.4.2	PF Outer Coils Attachment
221.4.4.3	TF Attachment
221.4.4.4	Vacuum Vessel Attachment
221.4.4.5	First Wall Attachment
221.4.4.6	Shield Attachment
221.5	IMPURITY CONTROL SYSTEMS
221.5.1	LIMITER
221.5.1.1	Limiter Structure
221.5.1.2	Limiter Protective Armor
221.5.1.3	Limiter Pump Duct
221.5.1.4	Limiter Instrumentation
221.5.2	DIVERTOR
221.5.2.1	Diverter Structure
221.5.2.2	Diverter Protective Armor
221.5.2.3	Diverter Pump Duct
221.5.2.4	Diverter Instrumentation
221.6	Particle Control Systems
221.7	Direct Energy Conversion Systems
222.	MAGNET SYSTEM
222.1	MAGNET ASSEMBLIES
222.1.1	TOROIDAL FIELD MAGNETS
222.1.1.1	TF COILS
222.1.1.1.1	Conductor
222.1.1.1.2	Winding
222.1.1.1.3	Case
222.1.1.1.4	Power Terminals/Coolant Feed

- 222.1.1.2 TF Insert
- 222.1.2 POLOIDAL FIELD MAGNETS
- 222.1.2.1 INNER PF COILS
 - 222.1.2.1.1 Conductor
 - 222.1.2.1.2 Winding
 - 222.1.2.1.3 Case
 - 222.1.2.1.4 Power Terminal/Coolant Feed
- 222.1.2.2 OUTER PF COILS
 - 222.1.2.2.1 Conductor
 - 222.1.2.2.2 Winding
 - 222.1.2.2.3 Case
 - 222.1.2.2.4 Power Terminal/Coolant Feed
- 222.1.2.3 OH SOLENOID
 - 222.1.2.3.1 Conductor
 - 222.1.2.3.2 Winding
 - 222.1.2.3.3 Case
 - 222.1.2.3.4 Power Terminal/Coolant Feed
- 222.2 CRYOSTAT ASSEMBLIES
- 222.2.1 TF COIL CRYOSTAT ASSEMBLY
 - 222.2.1.1 Vacuum Vessel
 - 222.2.1.2 Thermal Shield
 - 222.2.1.3 Cold Mass Support
- 222.2.2 PF COIL CRYOSTAT ASSEMBLIES
 - 222.2.2.1 INNER PF COIL CRYOSTAT ASSEMBLY
 - 222.2.2.1.1 Vacuum Vessel
 - 222.2.2.1.2 Thermal Shield
 - 222.2.2.1.3 Cold Mass Support
 - 222.2.2.2 OUTER PF COIL CRYOSTAT ASSEMBLY
 - 222.2.2.2.1 Vacuum Vessel
 - 222.2.2.2.2 Thermal Shield
 - 222.2.2.2.3 Cold Mass Support
 - 222.2.2.3 OH SOLENOID CRYOSTAT ASSEMBLY
 - 222.2.2.3.1 Vacuum Vessel
 - 222.2.2.3.2 Thermal Shield
 - 222.2.2.3.3 Cold Mass Supports
- 222.2.3 COMMON CRYOSTAT ASSEMBLY
 - 222.2.3.1 Vacuum Vessel
 - 222.2.3.2 Thermal Shield
- 223. POWER INJECTION SYSTEMS
- 223.1 ECRH SYSTEM
 - 223.1.1 RF Power Source
 - 223.1.2 Power Distribution System
 - 223.1.3 Launcher
 - 223.1.4 Ancillaries
- 223.2 ICRH SYSTEM
 - 223.2.1 RF Power Source
 - 223.2.2 Power Distribution System
 - 223.2.3 Launcher
 - 223.2.4 Ancillaries
- 223.3 LHRH SYSTEM
 - 223.3.1 RF Power Source
 - 223.3.2 RF Power Distribution System

223.3.3	Launcher
223.3.4	Ancillaries
223.4	NEUTRAL BEAM INJECTION SYSTEM
223.4.1	NEUTRAL BEAM ASSEMBLY
223.4.1.1	Source/Accelerator
223.4.1.2	Beamline
223.4.1.3	Neutral Beam Duct
223.4.1.4	Ancillaries
223.4.2	Neutral Beam Dump
224.	VACUUM SYSTEMS
224.1	PLASMA CHAMBER VACUUM SYSTEMS
224.1.1	High Vacuum Pumps
224.1.2	Pump Duct/Valves
224.1.3	Forepump System
224.1.4	Roughing System
224.1.5	Bakeout System
224.1.6	Instrumentation
224.2	VACUUM VESSEL VACUUM SYSTEM
224.2.1	High Vacuum Pumps
224.2.2	Pump Duct/Valves
224.2.3	Forepump System
224.2.4	Roughing System
224.2.5	Bakeout System
224.2.6	Instrumentation
224.3	SECONDARY VACUUM SYSTEMS
224.3.1	Diagnostics Vacuum System
224.3.2	Magnet Cryostat Vacuum System
224.3.3	Miscellaneous Vacuum Systems
224.3.4	Sec. Vacuum Sys. Instrumentation
225.	POWER CONDITIONING SYSTEMS
225.1	MAGNET SYSTEM POWER CONDITIONING
225.1.1	TOROIDAL FIELD POWER CONDITIONING
225.1.1.1	TF COIL POWER SUPPLY SYSTEM
225.1.1.1.1	Power Supply
225.1.1.1.2	Bus System
225.1.1.1.3	Protection System
225.1.1.2	TF Insert Power Supply System
225.1.2	POLOIDAL FIELD POWER CONDITIONING
225.1.2.1	Power Supply
225.1.2.2	Bus System
225.1.2.3	Protection System
225.2	POWER INJECTN SYS POWER CONDITIONING
225.2.1	ECRH Power Supply System
225.2.2	ICRH Power Supply System
225.2.3	LHRH Power Supply System
225.2.4	NBI Power Supply System
225.3	Direct Ener Conv Power Conditioning
225.4	Energy Storage System
225.5	Particle Cntrl Sys Power Conditioning
226.	HEAT TRANSPORT SYSTEM
226.1	BLANKET HEAT TRANSPORT

226.1.1	Fluid Circulation System
226.1.2	Piping
226.1.3	Heat Transfer Equipment
226.1.4	Storage Systems
226.1.5	Treatment System
226.1.6	Blanket H.T.S. Instrumentation
226.2	SHIELD HEAT TRANSPORT
226.2.1	Fluid Circulation System
226.2.2	Piping
226.2.3	Heat Transfer Equipment
226.2.4	Storage Systems
226.2.5	Treatment System
226.2.6	Shield H.T.S. Instrumentation
226.3	CRYOGENIC COOLING SYSTEMS
226.3.1	HELIUM SYSTEM
226.3.1.1	Refrigerator/Liquefier/Compressor
226.3.1.2	Auxillaries
226.3.1.3	Distribution System
226.3.1.4	Storage System
226.3.2	NITROGEN SYSTEM
226.3.2.1	Reliquefier
226.3.2.2	Distribution System
226.3.2.3	Storage System
226.3.3	Cryogenic System Instrumentation
226.4	WATER COOLING SYSTEM
226.4.1	Fluid Circulation Equipment
226.4.2	Storage Systems
226.4.3	Heat Transfer Equipment
226.4.4	Piping
226.4.5	Purification & Treatment Systems
226.4.6	Water Cooling Sys. Instrumentation
226.5	Gas Cooling/Heating System
227.	FUEL HANDLING
227.1	FUEL INJECTION SYSTEMS
227.1.1	Gas Injector
227.1.2	Pellet Injector
227.2	FUEL PROCESSING & PURIFICATION SYS
227.2.1	Fuel Cleanup
227.2.2	Isotope Separation
227.2.3	Gaseous Tritium Waste Treatment
227.2.4	Solid Tritium Waste
227.2.5	Instrumentation & Control
227.3	STORAGE & RECEIVING SYSTEMS
227.3.1	Receiving Glove Box
227.3.2	Uranium Storage Beds
227.3.3	Glove Box Detritiation Unit
227.3.4	Tritium Analysis & Accountability
227.4	ATMOSPHERIC RECOVERY SYSTEMS
227.4.1	Test Cell System
227.4.2	Hot Cell System
227.4.3	Tritium Building System

227.4.4	Rad Waste System
227.4.5	Tritium Monitors
227.5	Water Recovery Systems
227.6	BLANKET RECOVERY SYSTEMS
227.6.1	Tritium Removal System
227.6.2	Corrosion Product Removal System
228.	INSTRUMENTATION & CONTROL SYS
228.1	Data Acquisition System
228.2	Man-Machine Interface Systems
228.3	Diagnostics
228.4	Central Data Processing
228.5	Software
229.	MAINTENANCE EQUIPMENT
229.1	Manipulator Systems
229.2	Transport Systems
229.3	Inspection/Viewing/Testing Systems
229.4	Remote Cutting/Welding/Machne Tools
229.5	Mockup Equipment
229.6	Miscellaneous Tools
229.7	Decontamination Equipment
229.8	Rad-Waste Treatment/Disposal
229.9	Maintainability Assurance
23.	TURBINE PLANT EQUIPMENT
231.	Turbine Generators
232.	Main Steam System
233.	Condensing System
234.	Feedwater Heating
235.	Other Turbine Plant Equipment
236.	Turbine Plant I & C
24.	ELECTRIC PLANT EQUIPMENT
241.	SWITCHGEAR
241.1	Utility Line Switchgear
241.2	13.8 kv Distribution Switchgear
241.3	4.16 kv Distribution Switchgear
241.4	Generator Switchgear
242.	STATION SERVICE EQUIPMENT
242.1	High Voltage Substation Transformer
242.2	Medium Voltg Substation Transformer
242.3	Load Centers
242.4	Backup Power System
242.5	Uninterruptable Power Supply
242.6	Power Factor Correction Equipment
243.	Switchboards
244.	Protective Equipment
245.	ELECTRL STRUCT & WIRING CONTAINERS
245.1	Tunnels
245.2	Cable Trays & Supports
245.3	Conduit
246.	POWER & CONTROL WIRING
246.1	High Voltage Cable & Bussing
246.2	15 kv Cable & Bussing

246.3	5 kv Cable & Bussing
246.4	Low Voltage Wiring
247.	Miscellaneous Electrical Equipment
25.	MISCELLANEOUS PLANT EQUIPMENT
251.	Transportation & Lifting Equipment
252.	Air & Water Service Systems
253.	Communications Equipment
254.	Furnishings & Fixtures
255.	Bulk Materials
26.	HEAT REJECTION SYSTEM
261.	STRUCTURES
261.1	Cooling Tower Basin
261.2	Water Treatment Building
261.3	Pump House
262.	MECHANICAL EQUIPMENT
262.1	Cooling Tower Package
262.2	Fluid Circulation Equipment
262.3	Piping/Valves
9.	INDIRECT COST
91.	Construction Services & Equipment
92.	HOME OFFICE ENGINEERING & SERVICES
921.	Project Management
922.	Project Systems Engineering
923.	Project Quality Assurance
924.	Project Safety/Environ Engineering
93.	FIELD OFFICE ENGINEERING & SERVICES
931.	Construction Management
932.	Inspection
933.	Pre-Operational Testing
94.	OWNER'S COST
941.	Engineering/Management
942	Staff Training & Plant Startup
943.	Inventories & Spares
	SUBTOTAL CONSTRUCTED COST
	Contingency
	TOTAL CONSTRUCTED COST

A.2 TANDEM MIRROR

Account Number	Account Title
2.	TOTAL DIRECT COST (Mirror)
20.	Land and Land Rights
21.	STRUCTURES AND SITE FACILITIES
211.	Site Improvements and Facilities
212.	Reactor Building
213.	Turbine Building
214.	REACTOR MAINTENANCE BUILDINGS
214.1	Hot Cell
214.2	Warm Cell
214.3	Mockup Building
215.	Tritium Building
216.	ELECTRICAL EQUIPMENT BUILDINGS
216.1	Field Power Supply Building
216.2	RF Power Supply Building
216.3	Motor-Generator Building
217.	OTHER BUILDINGS AND STRUCTURES
217.1	Administration Building
217.2	RAD-Waste Processing Building
217.3	Fabrication/Assembly/Maint Buildings
217.4	Diagnostics Building
217.5	Cryogenics Building
217.6	Plant Auxiliary Building
217.7	Switchyard
217.8	Vent Stack
217.9	Control Room Building
217.10	Security Building
217.11	Warehouse
217.12	Miscellaneous Buildings, Structures
22.	REACTOR PLANT EQUIPMENT
221.	REACTOR SYSTEM
221.1	FIRST WALL ASSEMBLY
221.1.1	PLASMA CHAMBER
221.1.1.1	First Wall Structure
221.1.1.2	First Wall Supports
221.1.1.3	First Wall Heating & Cooling
221.1.1.4	First Wall Instrumentation
221.1.2	Wall Modifiers
221.2	BLANKET ASSEMBLY
221.2.1	Blanket Structure
221.2.2	Breeder
221.2.3	Reflector
221.2.4	Multiplier
221.3	SHIELDING
221.3.1	Bulk Shielding
221.3.2	PENETRATION SHIELDING
221.3.2.1	RF Shielding
221.3.2.2	Neutral Beam Shielding

221.3.2.3	Fuel Injector Shielding
221.3.2.4	Diagnostic Shielding
221.3.3	LOCALIZED SHIELDING
221.3.3.1	Choke Coil Shield
221.3.3.2	Transition Coil Shield
221.3.3.3	Anchor Coil Shield
221.3.3.4	Plug Coil Shield
221.3.3.5	Recircularizer Coil Shield
221.3.3.6	Recircularizer Solenoid Shield
221.3.3.7	Axicell Shield
221.4	REACTOR STRUCTURES
221.4.1	REACTOR SUPPORT STRUCTURES
221.4.1.1	Central Cell
221.4.1.2	End Cell
221.4.1.3	Axicell
221.4.2	VACUUM VESSEL ASSEMBLY
221.4.2.1	Central Cell Vessel
221.4.2.2	End Cell Vessel
221.4.2.3	Axicell Vessel
221.4.2.4	Direct Converter Vessel
221.4.2.5	Vessel Instrumentation
221.4.3	MAGNET STRUCTURAL SUPPORT
221.4.3.1	Central Cell Magnet Support
221.4.3.2	End Cell Magnet Supports
221.4.3.3	Axicell Magnet Supports
221.4.4	MISC. SUPPORT STRUCTURES
221.4.4.1	Central Cell Magnet Attachment
221.4.4.2	Choke Coil Attachment
221.4.4.3	Transition Coil Attachment
221.4.4.4	Anchor Coil Attachment
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