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Cost Estimate Guidelines for Advanced Nuclear Power Technologies

C. R. Hudson II

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COST ESTIMATE GUIDELINES FOR ADVANCED NUCLEAR POWER TECHNOLOGIES

C. R. Hudson II

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This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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COST ESTIMATE GUIDELINES FOR ADVANCED NUCLEAR POWER TECHNOLOGIES

C. R. Hudson II

ABSTRACT

To make comparative assessments of competing technologies, consistent ground rules must be applied when developing cost estimates. This document provides a uniform set of assumptions, ground rules, and requirements that can be used in developing cost estimates for advanced nuclear power technologies.

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1. INTRODUCTION

Several advanced power plant concepts are currently under development. One measure of the attractiveness of a new concept is its cost. Invariably, the cost of a new type of power plant will be compared with other alternative forms of electrical generation. This report provides a common starting point, whereby the cost estimates for the various power plants to be considered are developed with common assumptions and ground rules. Comparisons can then be made on a consistent basis.

This report is designed to provide a framework for the preparation and reporting of costs. The cost estimates will consist of the overnight construction cost, the total plant capital cost, and the production or busbar generation cost. While providing a generic set of assumptions and ground rules, this document does not provide specific scenarios and reporting requirements. Thus, these guidelines may be used in a variety of studies when supplemented with specific scenario data.

Capital costs in this report will be developed using the U.S. Department of Energy (DOE) Energy Economic Data Base (EEDB) Program Code of Accounts that has evolved from the NUS Corporation Code of Accounts through modification and expansion over a 15-year period. The utilization of the EEDB Code of Accounts will allow for comparisons between the advanced concept cost estimate and costs of other plants reported in the

EEDB format. The levelized busbar generation costs will be developed using the methodology presented in the U.S. DOE *Nuclear Energy Cost Data Base* (NECDB).[1] All costs will be developed using the methods and tax rates applicable in the Tax Reform Act of 1986.

These ground rules will be updated as necessary to provide and maintain a common and consistent cost basis that is compatible with the EEDB Program. The DOE Office of Nuclear Energy (NE) is responsible for approving changes to this document. Requested changes should be made in writing to Department of Energy Assistant Secretary for Nuclear Energy, Office of Planning and Analysis, Washington, D.C. 20545.

The following definition of terms will provide the background necessary for understanding and interpreting the present guidelines.

Base construction cost. The base construction cost is the plant capital cost for the direct and indirect costs only. This cost is lower than the total capital cost because cost elements such as contingency, interest, and escalation are NOT included. The specific cost items omitted are listed in Table 2.1.

The direct costs are those costs directly associated on an item-by-item basis with the equipment and structures that comprise the complete power plant. The indirect costs are expenses for services applicable to all portions of the physical plant, such as Architect Engineer (AE) home office engineering and design, AE field office engineering and services, construction management, and taxes. Reactor manufacturer (RM) home office engineering and services are also included in a separate account (except as noted in Sect. 2.3).

Building block. A building block is a combination of one or more reactor modules and associated electrical generation equipment and structures that represent the smallest unit for electrical generation. Building blocks may be duplicated for capacity expansion.

Common plant facilities. Common plant facilities are those systems, structures, and components that are required to support the operation of a first building block at a new plant site and include such facilities as administration building, provisions for refueling, general warehouse, water supply, general fire systems, etc. These common plant facilities may be sized sufficiently so as to be shared by other building blocks added subsequently.

Constant dollars. Constant dollar cost is defined as the cost for an item measured in dollars that have a general purchasing power as of some reference date. As inflation is generally associated with the erosion of the general purchasing power of the dollar, constant dollar analysis is said to exclude inflation.

Equipment. Generally, equipment includes all manufactured items ordered by RM or AE. Such items may be procured on a design and build contract from qualified vendors, wherein design responsibility belongs to the seller (vendor) or is maintained by the buyer (RM or AE) on a "build-to-print" basis. All piping 2-1/2-in. and larger nominal pipe size is an equipment item with the exception of galvanized pipe; storm, roof, and floor drainage; and sanitary piping, which are site material.

Equipment module. An equipment module is a skid-mounted, factory-assembled package which includes (but is not limited to) equipment, piping, instrumentation, controls, structural components, and electrical items.

Force account. Force account involves the direct hiring and supervision of craftsmen to perform a construction activity by a prime contractor as opposed to the prime contractor hiring a subcontractor to perform these functions.

Large monolithic plant. A large monolithic plant is defined as a power plant consisting of a single, large NSSS having a power output at least two and possibly four times as large as a typical modular building block. In some instances, a plant of this size is referred to as an integrated plant.

Lead plant costs. Lead plant costs include all costs after conceptual design of a concept to the first commercial electricity-producing power plant of that type. Lead plant costs are to be subdivided into three categories: developmental costs, prototype facilities, and first commercial power plant. Developmental costs include additional research and development (R&D), engineering, and design after conceptual development. Prototype facilities include any test systems or facility that may be proposed, planned, or required prior to the first commercial power plant of that type. The first commercial power plant is the first plant of that type that is sold to an entity for the purpose of commercial production of electric energy. The lead plant costs shall include

all engineering, equipment, construction, licensing, tests, tooling, project management, and other costs unique to the lead plant, which will not be incurred for subsequent plants of the identical design.

Materials. Basically, materials include field-purchased (site material) and/or bulk items such as lumber, reinforcing concrete, structural steel, and plumbing items. All piping, less than 2-1/2-in. nominal pipe size, is a materials item with the exception of pipe for cryogenic fluids, which is an equipment item. Also all wire and cable and raceways are material items, including those in building service power systems.

Multi-block plant. A power plant consisting of multiple building blocks is referred to as a multi-block plant.

Nominal cost of money. The nominal cost of money is the percentage rate used in calculations involving the time value of money containing an inflation component. It explicitly provides for part of the return on an investment to be solely for the purpose of keeping up with inflation.

Nth-of-a-kind (NOAK) plant costs. The NOAK plant is the nth-of-a-kind or equilibrium commercial plant of identical design to the lead plant. NOAK plant costs include all engineering, equipment, construction, testing, tooling, project management, and any other costs that are repetitive in nature and would be incurred if an identical plant were built. The NOAK plant also reflects the experience of prior plants leading to the NOAK plant.

Reactor module. A reactor module is a single reactor and nuclear steam supply system (NSSS) able to generate thermal heat as an integral part of a building block of power production.

Real cost of money. The real cost of money is the percentage rate used in calculations involving the time value of money when no inflation component is to be included. Calculations using the real cost of money assume that the dollar maintains a constant value in terms of purchasing power, and, thus, no return on an investment is needed for inflation.

Replica plant costs. The replica plant is the second commercial plant of identical design to the lead plant. Replica plant costs exclude first-of-a-kind engineering, management, equipment, and construction costs that are incurred with the lead plant. The replica

plant does include all engineering, equipment, construction, testing, tooling, project management, and any other costs that are repetitive in nature and would be incurred in building subsequent plants of the identical design.

Single-block plant. A stand-alone power plant consisting of a single building block and all necessary common plant facilities is referred to as a single-block plant.

Total capital cost. The total capital cost is an all inclusive plant capital cost developed for the purpose of calculating the plant busbar electricity cost. This cost is the base construction cost plus contingency, escalation, and interest-related costs.

Total overnight cost. The total overnight cost is the base construction cost plus applicable contingency costs. It is referred to as an overnight cost in the sense that time value costs such as interest during construction are not included. Total overnight cost is expressed as a constant dollar amount in reference year dollars.

2. BASE CONSTRUCTION CAPITAL COST GROUND RULES

2.1 General Ground Rules

This section describes the ground rules to be followed in developing the base construction capital cost for the advanced concepts.

1. The U.S. DOE EEDB Program Code of Accounts will be the structure used for cost estimates and cost accumulation. The EEDB Code of Accounts is an evolutionary expansion and modification of the NUS-531 Code of Accounts. Sample EEDB Code of Accounts for the liquid-metal reactor (LMR) and the high-temperature gas-cooled reactor (HTGR) are given in Appendices A and B, respectively.
2. Detailed cost estimates will be reported in constant January 1 dollars for the year specified by DOE-NE. Current studies should be reported in constant January 1, 1987, dollars.
3. The cost estimates will reflect the plant requirements and design as detailed in the Design Requirements, System Design Descriptions (SDDs), and other formal design documentation. Individual system boundaries will be as defined in the SDDs.
4. The base construction cost estimates will be developed so that it is the expected cost for a particular EEDB cost entry without interest (AFUDC), escalation, or contingency allowance as defined in Sect. 3.
5. Assumed use of any government-owned or -operated facility shall be costed at full cost recovery, including all direct costs, related indirect costs, depreciation, and any other related general and administrative costs. Inquiries regarding prices and charges to be assumed for specific materials and services shall be made to the Office of Advanced Reactor Programs, DOE-NE.
6. All construction and installation costs may reflect a separated construction concept whereby nuclear-grade and Seismic Category I construction are separated from conventional (non-nuclear) construction. All costs of equipment, materials, storage, quality assurance (Q/A), quality control (Q/C), and labor productivity for the non-nuclear areas will reflect conventional commercial practice. The portions or fractions of the plant constructed under each construction grade shall be documented.

7. As an aid in establishing system-to-system boundaries for costing purposes, the following general guidelines are set forth:
   a. The cost estimate for a system, equipment, facility, or structure shall include those costs associated with fabricating, installing, and/or constructing the particular item described in the SDDs.
   b. For costing purposes, the boundaries of a system, facility, or structure are as defined in the SDDs and in the piping and instrumentation diagrams (P&IDs).
   c. The cost for all electrical power terminations, including connectors, shall be borne by the electrical power system. For the trace heating system, the interface with the electrical power system is the individual heater controllers. For building service power and lighting systems, the interface with the electrical power system is the individual power lighting panel.
   d. The expense for terminating instrumentation and control cabling and wiring shall also be included in the electrical power system. This includes terminations with individual sensors as well as providing electrical interconnections between panels, cabinets, consoles, data processing units, controllers, etc.
   e. Costs for routing and laying or pulling wire and cable in ducts, conduits, and trays shall be included in the electrical power system.
   f. The costs for attachments to structures (e.g., anchor bolts and auxiliary steel) shall be borne by the equipment item requiring the support. Embedments are included in the costs of structures.
8. If the NOAK plant utilizes a dedicated factory for producing construction modules for the NSSS and balance of plant (BOP), the bases for site-delivered cost assumptions should be reported and should include factory capitalization and amortization assumptions (e.g., number of units assumed for factory capital cost recovery).

2.2 Specific Cost-Estimating Assumptions

The following assumptions will be used in developing the base construction cost estimates.

1. Assumptions on the organizational structure to be used in developing the cost estimates are as follows:
   a. Overall project management will be provided by a utility.
   b. A single RM and a single AE contractor will be employed to design NSSS and other plant equipment, to design plant buildings and structures, to prepare all technical documentation and reports, and to support construction activities.
   c. A single construction manager (CM), which may also be the AE contractor, will be responsible for construction activities.
2. The following assumptions apply to costing the lead plant:
   a. Lead plant costs shall include all costs after conceptual design up to and including the first commercial electricity-producing power plant of that type. Lead plant costs are to be subdivided into three categories: developmental costs, prototype facilities, and first power plant. Developmental costs include additional R&D, engineering, and design after conceptual development. Prototype facilities include any test or demonstration systems or facilities that may be proposed, planned, or required prior to the first commercial power plant of that type. The first power plant is the first plant of that type that is sold to an entity for the purpose of commercial production of electric energy. The allocation of costs to the three categories should be according to purpose. The timing of all expenditures should be identified.
   b. The lead plant will include the cost of full plant licensing including the activities necessary to obtain standard plant final design approval and design certification. A prototype safety test is at the option of the developer. If a prototype test facility is assumed, its cost must be estimated and documented as discussed previously.

c. Changes to Nuclear Regulatory Commission (NRC) regulations or major codes such as American Society of Mechanical Engineers (ASME) or Institute of Electrical and Electronic Engineers (IEEE) may be assumed during the design and construction period. However, all assumed regulation and/or code changes must be fully described and their cost impact identified.

d. Lead plant costs include all engineering, equipment, construction, testing, tooling, project management costs, and any other costs that are required in building a first-of-a-kind (FOAK) plant. A sample listing of FOAK tasks is presented in Appendix C.

3. The following assumptions apply to costing the replica and NOAK plant:

   a. Design is identical to lead plant.

   b. The plant site is enveloped by the reference site conditions.

   c. No product improvements are incorporated; that is, the lead plant design is frozen.

   d. Equipment manufacture and plant construction are performed by the same contractors as for the first plant.

   e. There are no changes in NRC regulations or major codes and standards subsequent to the lead plant time frame.

   f. The cost estimate will include the cost for all site-specific licensing or prelicensed sites. A generic plant design approval should be assumed.

   g. Plant costs include all engineering, equipment, construction, testing, tooling, project management costs, and any other costs that are repetitive in nature and would be incurred in building an identical plant. A sample listing of repetitive engineering and management tasks is presented in Appendix D.

4. Labor rates for craftsmen employed to assemble equipment at the on-site fabrication shop will be the same as construction crew rates.

5. All plant construction will be accomplished by force account with exception of those tasks subcontracted by the AE. Costs for all tasks, including subcontracted tasks, must be reported as equipment cost, material cost, and labor hours and cost.

6. Reductions in factory equipment costs due to learning effects may be recognized. Unless a different value is substantiated and documented, the estimator shall use a 94% unit learning curve for estimating individual factory equipment items. For costing equipment items for the NOAK plant, all concepts must assume that the NOAK plant is that unit whose manufacturing first places the cumulative production of that type of plant at or in excess of 4000 MW(e). The base or starting point for cost reduction due to learning will be equipment items for the first commercial power plant. The cost for a given equipment item for the NOAK plant should reflect the cumulative production history for that item as determined by the cumulative item requirements necessary to satisfy the NOAK unit definition above. The learning curve reductions shall apply only to items which are not commercially available, off-the-shelf items.
7. It will be assumed for the estimates that all engineering information, including specifications and drawings, will be released for construction in time for efficient planning and performance of the work and further that all equipment, material, and labor resources are available as required.
8. It will be assumed that the baseline construction requires no premium time (overtime) work to recover from schedule delays. Costs for possible schedule recovery overtime will be reflected in the contingency cost (see Sect. 3.1). The use of premium time for normal baseline construction, such as rolling 4 × 10 work weeks, should be identified.
9. It will be assumed that funding is available as required to support uninterrupted design, testing, construction, installation, checkout, and plant startup.
10. The nonsafety-related portion of each plant is designed and erected to the same standards as a conventional fossil-fired power plant. Only the safety-related structures and equipment require the more elaborate procedures, documentation, and Q/A–Q/C overview. On-site fuel manufacturing, handling, and reprocessing facilities will be assumed to be safety grade.

11. Site conditions for each plant are similar to those at the hypothetical "Middletown, U.S.A." site described in DOE's EEDB (see Appendix E):
    a. An adequate pool of qualified craft labor is available.
    b. There are no unique nuclear or conventional licensing restrictions that would affect plant design, construction, or operation.
    c. Estimates cover work within the plant security fence and include the river intake systems and structures.
    d. Soil and subsurface conditions are such that no unusual problems are associated with soil-bearing capacity or rock removal, major cut and fill operations, and dewatering.
12. Site land (Account 20) shall be based on the estimated site area including any buffer zones and a cost of $10,000/acre. It is to be assumed that the total land cost is incurred at the same time as the decision is made to build a plant.
13. Cost items to be excluded from the base construction cost estimate are listed in Table 2.1.
14. The assumptions to be used for the estimates of the Engineering and Home Office Services for the lead, replica, and NOAK plants are defined in Appendices C and D.
15. Engineering and Home Office Services includes only the AE costs for design, engineering, procurement, cost engineering, Q/A—Q/C, reproduction services, etc. (Account 92).

Table 2.1. Preferential and discretionary items excluded from base construction costs

Allowance for funds used during construction
Escalation
Contingency
Owner's discretionary items
Switchyard and transmission costs
Generator step-up transformer
Initial fuel supply

16. Nonrecurring engineering and home office services costs of the RM (Account 95) are assumed to be zero for the replica and NOAK plant. Any applicable recurring RM engineering costs are considered to be part of the NSSS equipment cost (Account 220A).
17. Composite wage rates (base rate plus fringes) to be used for the Middletown site in 1987 dollars are given in Table 2.2.
18. Capital costs shall be separated into two categories related to whether the equipment/construction is nuclear-grade or industrial-grade. Costs within each category will be reported in EEDB format as illustrated in Appendices A and B.
19. Although included and reported in the overall plant estimate, costs of common plant facilities will, in addition, be identified at the three digit account level and listed separately in EEDB format as discussed above.
20. In cases where equipment items or piping are combined with structural members to produce a factory-assembled equipment module, a work sheet documenting each module must be prepared. The work sheet will identify by three-digit EEDB account the applicable items and costs that comprise the module. For each three-digit account, the work sheet will provide the equipment and material costs, shop and field labor hours and costs, factory overhead and profit, freight, and total module cost. In addition, the text must describe the approach used to estimate each of the cost items. In regard to the total plant cost estimate, three-digit level costs for items that are part of a factory module must remain in the EEDB account that represents that particular item [i.e., costs for structural portions of a module should be reported in Account 21 and equipment/piping costs should be reported in the relevant system account (Accounts 22-26)]. The total factory cost, including shop labor and materials, should be recorded as factory equipment costs in the EEDB cost estimate format. Field labor to install a module should be recorded as site labor in the EEDB estimate format. Labor costs to produce and/or install a module may be pro-rated among the related three-digit EEDB accounts, if necessary. The wage rates for factory craft workers should be

Table 2.2. 1987 composite labor crews and rates

Effective date: January 1, 1987

COMPOSITE CREWS

Craft	Wage rate $/hr	Concrete		Structural		Earthwork		Mechanical equipment		Piping		Electrical & Instrumentation	
		Formwork, rebar, embeds, concrete		Str. steel, misc. iron & architectural		Clearing, excava., backfill		Installation		Installation		Installation	
		%	Contr.	%	Contr.	%	Contr.	%	Contr.	%	Contr.	%	Contr.
Boiler maker	$23.10							20	$4.62				
Carpenter	$21.19	40	$8.48	5	$1.06			5	$1.06	5	$1.06		
Electrician	$24.66							10	$2.47			95	$23.43
Iron Worker	$23.95	20	$4.79	75	$17.96			5	$1.20				
Laborer	$16.95	30	$5.09	5	$0.85	80	$13.56	5	$0.85	5	$0.85		
Millwright	$24.55							25	$6.14				
Operating Engr.	$21.94	5	$1.10	15	$3.29	15	$3.29	5	$1.10	5	$1.10		
Pipefitter	$25.33							25	$6.33	85	$21.53	5	$1.27
Teamster	$16.50					5	$0.83						
Others	$20.41	5	$1.02										
		100	$20.47	100	$23.16	100	$17.68	100	$23.76	100	$24.53	100	$24.69

based on the field craft labor data in Table 2.2 with adjustments as appropriate for any assumed wage differences due to productivity or environment. Any adjustments to the labor rates in Table 2.2 to reflect the factory environment must be fully supported in the cost estimate report.

21. For large factory equipment items such as the reactor vessel and internals, steam generators, heat exchangers, etc., supporting cost data by component must be available for review. The supporting data will include factory material cost, material weights, factory man-hours, reoccurring cost, and total cost for each equipment item.

22. The heat rejection system will be designed for the Middletown conditions as described in Appendix E such that the turbine exhaust pressure will be at or below the design value 91% of the time.

2.3 EEDB Cost Account Definitions

2.3.1 Direct cost accounts

Direct cost accounts include those construction and installation costs directly associated with the operating plant structures, systems, and components.

2.3.1.1 Equipment costs. Equipment costs include the costs for all design, analysis, fabrication, documentation preparation, predelivery testing, and follow-up engineering performed by equipment vendors; materials for all plant equipment; equipment; transportation and insurance expenses; provision of shipping fixtures and skids; warranties; preparation of maintenance and operations manuals and handling instructions; delivery of startup and acceptance test equipment; on-site unloading and receiving inspection expenses; and overhead expenses.

All plant equipment items, whether directly associated with the power generation systems or the facility systems, such as heating and ventilation, are included in this category.

For the equipment fabricated and/or assembled at an on-site fabrication facility, all the associated costs are included as equipment

costs, including the fabrication and/or assembly costs and the costs to move the equipment within the facility to its on-site receiving or storage point.

2.3.1.2 Site labor cost. The site labor portion of the construction and equipment installation costs includes all on-site activities related to permanent plant structures, systems, and equipment required for all aspects of power plant operation.

The direct costs of all work crews and foremen to excavate, backfill, erect, and finish structures and to place and install equipment, piping, wiring, modules, etc. are included.

Labor rates for this work include base rates, fringe benefits, and any travel or subsistence allowances.

All direct construction and installation costs are on a force account basis (see Sect. 1.1).

For this estimate, the costs associated with installing equipment items for both NSSS and BOP systems include the labor to transport the equipment from on-site storage or the on-site fabrication facility to the final resting place as well as the labor to align the equipment and physically attach it to the supporting structure. In addition, the labor costs for providing mechanical hookups and electrical connections between interfacing systems will be included.

2.3.1.3 Site materials cost. Site materials include all materials purchased in the field and/or bulk items such as paint, concrete, rebar, welding rod, formwork, etc. All piping, less than 2-1/2-in. nominal pipe size, is a materials item with the exception of pipe for cryogenic fluids. Also all wire, cable, and raceways are material items, including those in building service power systems.

2.3.2 Indirect cost accounts

The indirect cost accounts include those construction support activities required to design and build the structures and systems described in the direct cost accounts. At the two-digit account level of detail, the indirect cost accounts collect the costs for construction services, home office engineering and services, and field office engineering and services. It is preferred that indirect costs be

determined independently on a bottoms-up basis. Past cost estimates, when insufficient detailed information was available, have been estimated as a function of the direct costs. Using the direct-cost fraction approach, based on LWR and coal plant experience, makes it unlikely that non-LWR advanced concepts will receive adequate characterization of their intrinsic or unique attributes in the indirect costs. As an example, engineering man-hour estimates should reflect those concept-unique design features that may cause engineering hours to be greater or smaller than those for an LWR on an equivalent basis. In any case, the cost estimate procedure should be fully documented by the estimator.

The following subsections provide a description of the indirect costs by three-digit EEDB accounts.

2.3.2.1 Construction services costs (Account 91). Construction services (Account 91) includes costs for CM-related activities associated with construction as indicated below:

Temporary construction facilities (Account 911). This subaccount includes temporary structures and facilities, janitorial services, maintenance of temporary facilities, guards and security, roads, parking lots, laydown areas, and temporary electrical, heat, air, steam and water systems, general cleanup, etc.

Construction tools and equipment (Account 912). Construction tools and equipment include rental and/or purchase of construction equipment, small tools and consumables (fuel, lubricants, etc.), as well as maintenance of construction equipment.

Payroll insurance and taxes (Account 913). These expenses include insurance and taxes related to craft labor (direct and indirect including guards and janitors), such as social security taxes and state unemployment taxes, workmen's compensation insurance, and public liability and property damage insurance.

Permits, insurance and local taxes (Account 914). Consistent with other EEDB estimates, builders all-risk insurance will be the only cost included in Account 914. Payments to federal, state, and local governments for taxes, fees, and permits are to be included in Account 942 because they are plant specific.

2.3.2.2 Engineering and home office services costs (Account 92). Engineering costs as presented in this report include all AE management, engineering design, and associated support activities. This cost element includes activities as given below.

Engineering and home office expenses (Account 921). These costs include AE engineering and design (both field and home office), procurement and expediting activities, estimating and cost control, engineering planning and scheduling, reproduction services, and expenses associated with performance of the above functions (i.e., telephone, postage, computer use, travel, etc.). The costs for these services include salaries of personnel, direct payroll-related costs (DPC), overhead loading expenses, and fees for these services.

Home office quality assurance (Account 922). This account includes the services of home office QA engineers and staff personnel engaged in work on the project. Services include reviews, audits, vendor surveillance, etc. as required for design and construction of the nuclear safety-related portion of the facility. Costs for these services include salaries, DPC, overhead loading, and expenses (i.e., travel) of these individuals.

Home office construction management (Account 923). These services include those of the construction manager and his assistants. Services of construction planning and scheduling, construction methods, labor relations, safety, and security personnel are utilized as required. Costs for these services include salaries, DPC, overhead loading, and expenses.

2.3.2.3 Field supervision and field office services costs (Account 93). Field Supervision and Field Office Services (Account 93) includes costs for CM-related activities associated with on-site management of construction, site Q/A, startup and test, and the supporting costs for these functions as indicated below.

Field office expenses (Account 931). These expenses include costs associated with purchase and/or rental of furniture and equipment (including reproduction), communication charges, postage, stationery, other office supplies, first aid, and medical expenses.

Field job supervision (Account 932). This management function includes the resident construction superintendent and his assistants; craft labor supervisors; field accounting, payroll, and administrative personnel; field construction schedulers; field purchasing personnel; warehousemen; survey parties; stenographers; and clerical personnel. Costs of these services include salaries, DPC, overhead loading, relocation costs of key personnel, and fees.

Field QA/QC (Account 933). These services include those of personnel located at the job site engaged in equipment inspection, required documentation of safety-related equipment, inspection of construction activities, and construction training meetings. Costs included are salaries, DPC, and overhead loading.

Plant startup and test (Account 934). These services are associated with preparation of startup and plant operation manuals and test procedures, direction and supervision of testing of equipment and systems as the plant nears completion, and direction of startup of the facility. Costs of these services include salaries, DPC, overhead loading, and miscellaneous related expenses. Costs of any craft labor required for startup and testing activities are included in the appropriate direct-cost line items.

2.3.2.4 Owners' cost (Account 94). Owners' cost (Account 94) includes the costs of the owner for activities associated with the overall management and integration of the project and other costs not included in the direct capital costs incurred prior to start of commercial operations as follows:

Management, engineering, integration, and QA/QC (Account 941). These expenses include owner project management, engineering, integration, control, and QA/QC.

Taxes and insurance (Account 942). These expenses cover all owner's nuclear and other insurance premiums, state and local taxes (e.g., property taxes and sales taxes on purchased materials and equipment incurred during the course of the project), and permits, licenses, and fees. Builder's all risk insurance is included in Account 914.

Spare parts (Account 943). These expenses include the cost of all preoperational equipment spare parts required to support the startup phase and initial stock of supplies and spares at start of plant operation.

Training (Account 944). This expense includes the cost of all preoperational activities of the operating and maintenance staff. Items include instruction development, training materials and equipment, and training services support; also included is training for any off-site or on-site manufacturing required.

General and administrative (G&A) (Account 945). This account includes owner's preoperational G&A costs during the project.

Capital equipment (Account 946). This item includes costs for any special coolants for the initial loading of the plant systems.

It is preferred that owner's cost be estimated directly by consideration of the contents of each subaccount. If such an estimate is not possible, it is recommended that total owner's cost (Account 94) be estimated as 10% of the sum of the total direct and other indirect costs plus the cost of any special coolants.

2.3.2.5 Reactor manufacturer's engineering (Account 95). This account includes all the costs of RM services and support for the lead plant that are over and above the normal charges included in the cost of an NSSS package (EEDB Account 220A). This cost is assumed to be zero for the replica and NOAK plant.

2.4 Base Construction Capital Cost Documentation

Specific reporting requirements will be determined by DOE Program Management. The following documentation guidelines represent possible reporting requirements.

2.4.1 Cost reports

As determined by DOE, separate cost estimates for the FOAK, replica, and NOAK plant may be required. Each separate cost set will be documented using the EEDB tabular format and Code of Accounts. Typical Code of Accounts for the LMR and HTGR are provided in the Appendices.

In addition to tabular cost data, a complete text description of the methods and assumptions used in developing the costs shall be submitted with the cost data.

As determined by specific DOE guidance, supporting cost estimate worksheets may be required to be prepared in the format shown in Table 2.3. Separate tables will be prepared as necessary to present costs for lead, replica, or NOAK plants as indicated at the upper-right corner of the form. In some cases, the costs may apply to all conditions and only one set of forms need be supplied.

As discussed in Section 2.2, documentation on factory-produced equipment modules must include a work sheet for each different module which identifies cost by three-digit EEDB account. A suggested work sheet format is provided in Table 2.4.

2.4.2 Plant bulk commodities data

To make commodity comparisons with competing plant concepts, the commodities listed below should be supplied as indicated at the three-digit level with summaries to the two-digit level. If a more detailed breakdown is available, that should be provided.

- Formwork [square feet (SF)] — Both wooden and metal forms are included.
- Structural steel [tons (TN)] — All structural steel is included regardless of whether it is used in safety or nonsafety class structures.
- Reinforcing steel [tons (TN)] — The costs for cadwelds and wire fabric are not included.
- Embedded steel [tons (TN)] — All embedded steel is included regardless of whether it is used in safety or nonsafety class structures.
- Structural concrete [cubic yards (CY)] — The costs for removable concrete plugs and for curbs and walks are not included. All structural concrete is included regardless of whether it is used in safety-class or nonsafety-class structures, whether it is in internal or external walls, or whether it is in floor or elevated slabs.
- Concrete fill [cubic yards (CY)] — All fill concrete is included regardless of its location or purpose.

Table 2.3. Capital cost supporting data

SDD TITLE _____
SDD NUMBER _____

FOAK PLANT _____
REPLICA PLANT _____
NOAK PLANT _____

SPECIFIC EQUIPMENT, MATERIAL, OR COST ITEM/SAFETY CLASSIFICATION	EEDB ACCOUNT NO.	FACTORY EQUIPMENT		SITE				TOTAL COST (10^3 \$)
				LABOR		MATERIAL		
		QUANTITY[a]	COST (10^3 \$)	HOURS	COST (10^3 \$)	QUANTITY[a]	COST (10^3 \$)	
TOTAL								

[a]CY = cubic yards, EA = each, LB = pounds, LF = linear feet, LT = lot, SF = square feet, TN = tons, and MH = manhours.

Table 2.4. Factory module cost work sheet

Module _____

	Factory Cost							Field cost	
EEDB account	Equip.	MH	Labor	Matl.	Overhead & profit	Freight	Total	MH	Labor

- Piping [pounds (LB)] — The following subcategories are required:

  CS, SC, <2 1/2-in. pipe
  SS, SC, <2 1/2-in. pipe
  CS, SC, ≥2 1/2-in. pipe
  SS, SC, ≥2 1/2-in. pipe
  CM, SC, ≥2 1/2-in. pipe
  CS, NNS, <2 1/2-in. pipe
  SS, NNS, <2 1/2-in. pipe
  CS, NNS, ≥2 1/2-in. pipe
  SS, NNS, ≥2 1/2-in. pipe
  CM, NNS, ≥2 1/2-in. pipe

  where CS = carbon steel,
  SS = stainless steel,
  CM = chrome moly steel,
  SC = safety class,
  NNS = non-nuclear safety class.

  These ten categories of piping do not include the following:

  1. concrete, copper, cast iron, and galvanized pipe;
  2. roof and floor drains piping;
  3. sprinkler systems piping; and
  4. sanitary facilities piping.

- Wire and cable [linear feet (LF)] — This account consists of:

  1. power cable,
  2. control cable, and
  3. instrumentation cable.

- Wire and cable duct runs and containers [linear feet (LF)] — This account includes:

  1. underground and above ground,
  2. metallic and nonmetallic ducts, conduit, and
  3. cable trays.

Bulk commodities should be reported by EEDB Code of Accounts as shown in Table 2.5.

Table 2.5. Plant bulk commodities

FOAK PLANT _____
REPLICA PLANT _____
NOAK PLANT _____

EEDB ACCOUNT NO.	STRUCTURAL CONCRETE (CY)	CONCRETE FILL (CY)	FORMS (SF)	STRUCT STEEL (TN)	REINFORCED STEEL (TN)	EMBEDDED STEEL (TN)

Table 2.5 (continued)

FOAK PLANT _____
REPLICA PLANT _____
NOAK PLANT _____

EEDB ACCOUNT NO.	CS, SC <2 1/2 IN. (LB)	SS, SC <2 1/2 IN. (Lb)	CS, SC ≥2 1/2 IN. (LB)	SS, SC ≥2 1/2 IN. (LB)	CM, SC ≥2 1/2 IN. (LB)	CS, NNS <2 1/2 IN. (LB)

Table 2.5 (continued)

FOAK PLANT _____
REPLICA PLANT _____
NOAK PLANT _____

EEDB ACCOUNT NO.	SS, NNS <2 1/2 IN. (LB)	CS, NNS ≥2 1/2 IN. (LB)	SS, NNS ≥2 1/2 IN. (LB)	CM, NNS ≥2 1/2 IN. (LB)	WIRE AND CABLE (LF)	DUCT RUNS AND CONTAINERS (LF)

2.4.3 Plant labor requirements data

Craft and engineering labor requirements will be summarized by two- and three-digit direct and indirect cost accounts as well as by total plant. Specific, individual, manhour data will be provided for the following workers if utilized: boilermakers, bricklayers, carpenters, electricians, ironworkers, laborers, millwrights, operating engineers, painters, pipe fitters, sheet metal workers, teamsters, other craft labor, engineering, and other noncraft home and field office labor. An example format is shown in Table 2.6.

Table 2.6. Plant labor requirements

FOAK PLANT _____
REPLICA PLANT _____
NOAK PLANT _____

EEDB Account No.	Labor type	Manhours
xxx	Boiler makers	
	Bricklayers	
	Carpenters	
	Electricians	
	Ironworkers	
	Laborers	
	Millwrights	
	Operating engineers	
	Painters	
	Pipe fitters	
	Sheet metal workers	
	Teamsters	
	Other craft labor	
	Engineering	
	Other noncraft labor	

2.4.4 Development/prototype costs

As discussed in Sect. 2.2, lead plant costs are to be subdivided into the three categories of developmental costs, prototype facilities, and first commercial power plant. The first commercial power plant will

be reported as described in Sects. 2.4.1—2.4.3. Developmental and prototype costs will be itemized and expressed in constant dollars as defined in Sect. 2.1. The timing of each cost item shall be identified. The report format is given in Table 2.7.

Table 2.7. Development/prototype costs
(thousands of January 198_ dollars)

Task/Item Description	Year of Expenditure	Cost	
		Annual	Cumulative
Development Costs			
Prototype Costs			

3. TOTAL CAPITAL COST

This section provides the ground rules for preparing an estimate of the total capital cost of a power plant. The base construction capital cost as described in the previous section is the starting point for costs developed in this section.

3.1 Contingency

Contingency cost shall be calculated as a percentage of base construction cost. However, different percentages should be used for different systems or components in a plant because the amount of the contingency cost should be related to the stage or current level of design, the degree of technological advance represented by the design, and the quality/ reliability level of the given system/component. As an example, it should be possible to estimate the cost for a standard mechanical draft cooling tower system more accurately (therefore requiring less contingency) than the cost for a new, innovative NSSS. To obtain consistency between various cost estimates, the percentages and requirements for their use are defined as follows. For those systems that are innovative, that represent a substantial departure from previously built designs, or that require a high assurance of quality in construction and operation (e.g., nuclear-grade systems), a contingency cost of 25% of the applicable base cost shall be calculated. For systems or components that are standard, current, off-the-shelf technology items that are being applied in a normal, industrial-grade application, a contingency cost of 15% of the applicable base cost shall be calculated. The total contingency cost to be reported will be the sum of the contributions from each system or component category. Contingency amounts for indirect base costs shall be calculated as above, based on an estimation of the proportion of the above two categories reflected in that particular indirect cost. The assumptions used in classifying the direct and indirect base costs according to the two categories must be fully documented by the estimator in detail.

The contingency estimate will be expressed in the same year's dollars as the base construction costs.

3.2 Cash Flow

The cash flow requirements during the design and construction period will be determined on a quarterly basis for lead, replica, and NOAK plants as required. The cash flow should be expressed in the same year's dollars as the overnight costs and should indicate whether contingency costs are included. Contingency costs must be explicitly included in the cash flow data if it is not assumed that contingency cash flow is proportional to base cost cash flow. Time effects such as escalation and interest should not be included in the cash flow data. As a result of the escalation assumption that follows, the dates of cash flow may be expressed as either a relative or absolute date with respect to commercial operation.

3.3 Escalation

It is to be assumed that escalation during the design and construction period is occurring at the same rate as inflation; that is, there is no real escalation during this period. As the total cost is to be expressed in constant dollars for the year given in Sect. 2.1, escalation will be zero when expressed in constant dollars.

3.4 Interest During Construction

Interest costs will be calculated based on the real, average cost of money. The financial parameters given in Table 3.1 are from the DOE NECDB,[1] adjusted for the Tax Reform Act of 1986, and are to be assumed in determining interest during construction (IDC) costs. It should be noted that the Tax Reform Act of 1986 no longer allows bond interest as a tax deduction <u>during</u> construction but requires that it be fully capitalized. Thus, the average and not tax-adjusted cost of money must be used in calculating interest during construction.

Table 3.1. Financial parameters

Parameters	Cost
Capitalization, %	
Debt	50
Preferred stock	10
Common equity	40
Return on capitalization, %/year	
Debt interest	9.7
Preferred dividend	9
Common equity return	14
Average cost of money, %/year	11.35
Inflation rate, %/year	5.0
Real (inflation-adjusted) average cost of money, %/year	6.05

Interest will be calculated using the cash flow summaries developed in Sect. 3.2 and the real, inflation-free, cost of money shown in Table 3.1. All interest costs will be capitalized up to the commercial operation date using the following method.

$$\text{Interest during construction} = \sum_{t=0}^{T} C_t \, [(1 + i)^{T-t} - 1] \ ,$$

where

T = time of commercial operation,

C_t = cash flow at time t (from Sect. 3.2),

i = real cost of money.

If the cash flow data developed in Sect. 3.2 does not explicitly contain contingency costs, then the interest calculated using the cash flow summaries must be adjusted by the ratio of the total overnight cost to base construction cost as follows.

$$IDC_{total} = \frac{\text{base cost + contingency}}{\text{base cost}} \times IDC_{\text{base cost}}$$

3.5 Total Capital Cost

Total capital cost will consist of the base construction cost as developed in Sect. 2, contingency, escalation (when applicable), and interest during construction. All costs will be expressed in constant dollars in the year defined in Sect. 2.1 and separated into nuclear-grade, industrial-grade, and total cost. Table 3.2 provides the format to be used in reporting total capital cost.

Table 3.2. Plant total capital cost estimate
(thousands of January 198__ dollars)

EEDB Account No.	Account description	Nuclear grade cost	Industrial grade cost	Total cost
20	Land and land rights			
21	Structures and improvements			
22	Reactor plant equipment			
23	Turbine plant equipment			
24	Electric plant equipment			
25	Miscellaneous plant equipment			
26	Main condenser heat rejection system	____	____	____
	Total direct costs			
91	Construction services			
92	AE home office engineering and services			
93	Field office supervision and services			
94	Owner's expenses			
95	RM home office engineering and services	____	____	____
	Total indirect costs			
	BASE CONSTRUCTION COST — Total $ — $/kW(e)			
	CONTINGENCY			
	TOTAL OVERNIGHT COST — Total $ — $/kW(e)			
	ESCALATION			
	INTEREST DURING CONSTRUCTION			
	TOTAL CAPITAL COST — Total $ — $/kW(e)			

4. BUSBAR GENERATION COST

This section provides guidance for developing the total generation or busbar cost for a power plant consisting of one or more building blocks. The method is equally applicable to a large monolithic plant.

4.1 General Assumptions and Methodology

A total plant energy generation cost or busbar cost includes the capital, nonfuel operation and maintenance (O&M), fuel, and decommissioning costs and is generally expressed as a cost per unit energy. In this case, a constant dollar levelized busbar cost will be determined. In the constant dollar levelized approach, the year-by-year unit price of electricity is assumed to rise in nominal dollar terms at the rate of inflation. The method used to determine this unit price is to calculate the present value of all the plant costs and divide that amount by the present value of the energy generated over the life of the plant. A complete description of the levelized cost approach can be found in the U.S. DOE document NECDB.[1]

Following some general assumptions below, the treatment of each cost component will be discussed, and in Chap. 5, examples of the method with alternative plants will be given.

1. The levelized busbar cost will be expressed in constant dollars in the year defined in Sect. 2.1.
2. The economic operating life of each unit (block) is assumed to be 30 years for cost-estimating purposes.
3. The default capacity factor to be assumed is 70%. A concept-specific capacity factor may be used if it is properly substantiated.
4. The present-worth discount rate is 9.57%/year (nominal) and 4.355%/year (real). The general inflation rate is 5%/year.
5. Assumed use of any government-owned or -operated facility shall be costed at full cost recovery, including all direct costs, related indirect costs, depreciation, and any other related general and administrative costs. Inquiries regarding prices and charges to be

assumed for specific materials and services shall be made to the Office of Advanced Reactor Programs, DOE-NE.

6. Costs will be calculated in a manner consistent with the Tax Reform Act of 1986.

4.2 Capital Cost

Under the assumption of equal annual energy generation, the equation for calculating the constant dollar levelized capital cost can be expressed as

$$LCC = \frac{FCR \times \sum_i CAP_i/(1 + d)^{t_i - t_1}}{E \times \sum_i 1/(1 + d)^{t_i - t_1}} ,$$

where

LCC = levelized capital cost,

FCR = fixed charge rate,

CAP_i = total capital cost for unit i as determined in Sect. 3,

d = real cost of money,

t_i = commercial operation date for unit i,

E = annual energy generation for single unit.

For a single-unit (block) plant, the previous equation reduces to

$$LCC = (FCR \times CAP)/E .$$

A fixed charge rate is used to properly account for depreciation, interim replacements, property tax, and income tax effects. The fixed charge rate is dependent upon the fraction of the total plant investment that is eligible for tax depreciation (tax depreciation may not be taken on equity financing costs). The relationship given below should be used to determine the applicable fixed charge rate based on the ratio of total interest during construction (including equity financing) to total capital cost (all expressed in constant dollar terms).

$$FCR = 0.015775 \times (IDC/TCC) + 0.093357$$

where

IDC = constant dollar interest during construction,

TCC = constant dollar total capital cost.

The input parameters given in Table 4.1 were used to develop the above relationship.

Table 4.1. Fixed charge rate input parameters

Parameters	Rate
Effective (tax-adjusted) cost of money, %/year	9.573
Inflation rate, %/year	5
Real cost of money, %/year	4.355
Federal income tax rate, %	34
State income tax rate, %	4
Combined state and federal tax rate, %	36.64
Property tax rate, % of capital investment/year	2
Interim replacement rate, % of investment/year	0.5
Book life, year	30
Tax depreciation duration, years,	15
Tax depreciation method	150% declining balance
Accounting method	Normalized

4.3 O&M Costs

This section provides guidance on the development of the nonfuel O&M costs. The O&M costs are incurred from commercial operation and throughout the operating life of the plant. For these studies only the first 30 years of operation will be considered.

Certain O&M costs, such as those for materials and supplies, can be at least partially dependent upon the amount of energy generated by the plant. These variable costs should be added to the fixed costs, which are independent of generation, to arrive at a total annual O&M cost.

The O&M cost estimate should provide, as a minimum, the detail shown in Tables 4.2 and 4.3 for fixed, variable, and total O&M costs as applicable. Site staff requirements data should also be reported as shown in Table 4.4. For multi-block plants, the annual O&M costs and staffing requirements are to be specified by block as well as for the total plant.

Table 4.2. Nonfuel O&M expense accounts

Account	Description
On-site staff	Includes all personnel assigned to the plant site. See Table 4.4 for typical categories.
Maintenance materials	Can be either variable or fixed costs. Consist of noncapitalized hardware used in normal maintenance activities.
Supplies and expenses	Can be either variable or fixed costs. Consist of consumable materials and other unrecoverable items such as make-up fluids, chemicals, gases, lubricants, office and personnel supplies, and monitoring and record supplies; costs for on-site radioactive and non-radioactive waste management activities.
Off-site technical support	Activities by personnel not assigned full time to the plant site; examples are safety reviews, off-site training, environmental monitoring, meteorological surveys, power planning, fuel studies, and other owner home office activities directly supporting the plant.
Administrative and general	Employee pensions and benefits (including workman's compensation insurance), nuclear regulatory fees, public liability insurance, property damage insurance, and other related expenses.

Table 4.3. Annual O&M cost format

Item	1987 $k/year		
	1 block	2 blocks	Etc.
Direct power generation			
On-site staff			
Maintenance materials			
Fixed			
Variable			
Supplies and expenses			
Fixed			
Variable			
Off-site technical support			
Administrative and general			
Pensions and benefits			
Nuclear regulatory fees			
Nuclear insurance premiums			
Other administrative and general expenses			
Total annual O&M costs			

The O&M cost estimate should be expressed in constant dollars in the year defined in Sect. 2.1. It is to be assumed that the escalation rate for O&M costs is equal to the rate of inflation, such that there is no real escalation for O&M costs. Certain O&M cost factors are design independent and/or owner related. Data for these factors are provided below and should be used in the development of the annual O&M costs. Annual on-site staff salaries to be assumed are shown in Table 4.4 with an additional 10% to be added for payroll tax and insurance. For off-site technical support, an annual salary of $51,000/person (1987$) should be assumed with an additional 70% added to the total (10% for payroll tax and insurance and 60% to reflect general off-site overhead). The pension and benefits account which includes workman's compensation

Table 4.4. On-site staff requirements

Category	Salary[a] 1987 $/yr	Number of persons		
		1 Block	2 Blocks	Etc.
Plant manager's office				
Manager	100,000			
Assistant	70,000			
Environmental control	44,000			
Public relations	44,000			
Training	49,000			
Safety and fire protection	41,000			
Administrative services	27,000			
Health services	27,000			
Security	24,000			
Subtotal				
Operations				
Supervision (excluding shift)	51,000			
Shifts	43,000			
Subtotal				
Maintenance				
Supervision	48,000			
Crafts	34,000			
Annualized peak maintenance	34,000			
Quality control	37,000			
Warehouse	31,000			
Subtotal				
Technical and engineering				
Reactor engineering	51,000			
Radiochem and water chem	48,000			
Engineering	44,000			
Technicians	36,000			
Health physics	36,000			
Subtotal				
Total staff				

[a]Add 10% to salaries for payroll tax and unemployment insurance.

insurance should be calculated as 25% of the sum of on-site and off-site direct salaries (excluding off-site overhead). Annual nuclear regulatory fees should be assumed to be $1,000,000 (1987$) per block (unit). Estimates of annual premiums for nuclear plant insurance for medium-sized (350-700 MWe) advanced nuclear plants are provided in Table 4.5. Finally, other administrative and general expenses should be calculated as 15% of the direct power generation accounts (i.e., 15% of the sum of on-site staff, maintenance materials, supplies and expenses, and off-site technical support costs).

Table 4.5. Annual premiums for nuclear power plant insurance for medium-sized (350-700 MWe) advanced nuclear plants

(January 1987 dollars)

	Number of blocks per site			
	1	2	3	4
Public liability				
Commercial ($160 million)	$ 500,000	$ 750,000	$1,000,000	$ 1,250,000
Self insurance	-0-	-0-	-0-	-0-
Plant property damage				
Primary ($500 million)	2,000,000	3,000,000	4,000,000	5,000,000
Secondary ($600 million)	1,000,000	1,250,000	1,500,000	1,750,000
Total	$3,500,000	$5,000,000	$6,500,000	$ 8,000,000

To obtain the constant dollar levelized cost for O&M, the present worth of the annual plant O&M costs must be determined by discounting at the real cost of money each year's O&M cost back to the commercial operation date of the first unit (block). In equation form

$$PWOM = \sum_n \frac{OM_n}{(1 + d)^{t_n}},$$

where

PWOM = present worth of O&M costs,

OM_n = annual total plant O&M costs,

d = real cost of money,

t_n = time relative to first block commercial operation.

This present-worth cost is then divided by the present worth of the total energy generation as shown below to arrive at the levelized cost.

$$LCOM = \frac{CRF \times PWOM}{E \times \sum_i 1/(1 + d)^{t_i - t_1}},$$

where

LCOM = levelized O&M cost,

PWOM = present worth of annual O&M costs,

E = annual energy generation for single block,

CRF = capital recovery factor for 30 years at the real cost of money $d(1 + d)^{30}/[(1 + d)^{30} - 1]$,

d = real cost of money,

t_i = commercial operation date for block i.

For a single-block plant, the levelized O&M cost is simply the annual O&M cost divided by the annual energy generation. Examples using this methodology are presented in Sect. 5.

4.4 Fuel Costs

Complete fuel cycle costs for 30 years of operation shall be estimated. The fuel cycle will be subdivided into its components, such as uranium, thorium or plutonium purchase, conversion, enrichment, fabrication, reprocessing, and waste disposal. Costs and quantities will be reported for each component over the assumed operating period. All assumptions, such as unit costs, processing losses, mass balance data, and lead and lag times for costs, shall be reported. A complete description of the fuel cycle cost analysis shall be prepared. Additional requirements are listed below.

1. Fuel management plans including mass flows and their timing into and out of the reactor must be provided for all fuel, blanket, and absorber elements.
2. For fuel recycle cases, the capital and O&M costs for the fuel recycle facilities must be estimated following the procedures given in Sections 3 and 4 of this document. This includes, but is not limited to, documenting the direct and indirect costs, the contingency cost, cash flow, and interest during construction in the capital cost of the fuel cycle facilities.
3. The economic lifetime of a co-located, integral fuel recycle facility shall not be in the excess of the time necessary to service a specific power plant site over its assumed economic life. (It is to be assumed that each power plant block has a 30 year economic operating life.)
4. The costs for absorber and other replaceable reflector/shield elements must be included in the fuel cycle cost estimates.
5. The cost for an equilibrium cycle fuel, blanket, shield, and absorber assembly shall be reported in $/assembly and $/kg HM. The costs must be further subdivided into components related to facility capital amortization, fuel facility O&M costs, hardware costs, and fresh heavy metal (as applicable).
6. It shall be assumed that spent fuel leaving the reactor has no economic value in that state. Only after reprocessing will the value of usable materials, including any excess fissile material, be recognized. The cost to a power plant for recycled fissile material should be an average cost based on the cost to reprocess (including related facility capital amortization) and the total fissile output of the fuel cycle facility.
7. Spent fuel removed during the final plant refuelings (fuel which will not be recycled into that particular power plant) will have no economic value to the current power plant. Costs/benefits of its use in subsequent power plants will be recognized by those subsequent plants.
8. No investment tax credits may be taken.

9. The cost of each batch of fuel will be capitalized and depreciated by either a 200% declining balance method over five years using the IRS half-year convention in the first year or a units-of-production (energy pro-ration) basis.
10. The combined federal and state tax rate to be assumed is 36.64%.

The following unit costs should be assumed in developing fuel cycle costs:

1. Uranium ore price in 1987 is $23.00/lb (1987 dollars) with real escalation of 2.0%/year.
2. Uranium conversion price in 1987 is $8.20/kg U (1987 dollars) with escalation equal to inflation (i.e., no real escalation).
3. Enrichment price in 1987 is $110/kg SWU (1987 dollars) with real de-escalation of 1.5%/year to 2005 and no real escalation thereafter.
4. Fuel fabrication price for extended burnup LWR fuel in 1987 is $245/kg HM (1987 dollars) with escalation equal to inflation (i.e., no real escalation).
5. Waste disposal fee is 1 mill/kWh (1987 dollars) with no real escalation.
6. Escalation will be at the rate of inflation for all other fuel cycle components (i.e., no real escalation).

Additional or revised cost assumptions may be provided by DOE.

Capital cost and amortization assumptions for all fuel cycle facilities (e.g., reprocessing/recycle facilities) shall be fully documented.

As each batch of fuel is capitalized for tax purposes, the fuel cycle analysis must be performed in nominal rather than constant dollar terms to properly reflect tax depreciation. Finally, all fuel cycle costs for the power plant should be present-worthed to the year indicated in Sect. 2.1 for use in developing the total busbar cost. The methodology to obtain the present worth of the fuel costs is provided in Sect. 3 of the NECDB.[1] A computer code such as REFCO-83 may be used to help calculate the fuel cycle costs.[2]

Similar to the calculation of levelized O&M costs, the constant dollar levelized fuel cost can be expressed as

$$LCFC = \frac{CRF \times PWFC}{E \times \sum_i 1/(1 + d)^{t_i - t_1}} ,$$

where

LCFC = levelized fuel cost,

PWFC = present worth of annual fuel costs,

E = annual energy generation for single block,

CRF = capital recovery factor for 30 years at the real cost of money,

d = real cost of money,

t_i = commercial operation date for block i.

4.5 Decommissioning

The cost for plant decommissioning should be estimated and included in the busbar cost. In the absence of a specific decommissioning estimate, a default cost that is a function of block (unit) size may be used. The default value is $143 million (1987 dollars) for an 1100-MW(e) unit. This value should be linearly scaled [i.e., $130.00/kW(e)] for blocks (units) of other sizes.

It should be assumed that an external sinking fund of tax-free state bonds yielding 6.5%/year nominally will be established over the operating life of the plant to accumulate the funds necessary for decommissioning. The present worth of this decommissioning fund can be calculated using the expression

$$PWDC = \frac{DC_o \times SFF(6.5,30) \times \sum_i 1/(1 + d)^{t_i - t_1}}{(1 + d)^{30} \times SFF(X,30)} ,$$

where

PWDC = present worth of total decommissioning costs;

DC_o = decommissioning cost in reference year's dollars for one block;

SFF(r,t) = sinking fund factor at rate r for t years, that is, $r/[(1 + r)^t - 1]$;

d = real cost of money;

X = tax-adjusted nominal cost of money;

t_i = commercial operation date for block i.

Following the treatment used for O&M and fuel costs, the constant dollar levelized cost of decommissioning can be expressed as

$$LCDC = \frac{CRF \times PWDC}{E \times \sum_i 1/(1 + d)^{t_i - t_1}},$$

where

LCDC = levelized decommissioning cost,

PWDC = present worth of total decommissioning costs,

E = annual energy generation for single block,

CRF = capital recovery factor for 30 years at the real cost of money,

d = real cost of money,

t_i = commercial operation date for block i.

An example of this calculation is given in Sect. 5.

4.6 Total Busbar Cost

The levelized total busbar cost is simply the sum of the levelized costs for capital, O&M, fuel, and decommissioning as determined previously. Examples of the development of total busbar costs for alternative plants are provided in the next chapter.

5. ALTERNATIVE POWER PLANT COST ESTIMATES

This chapter provides cost data for alternative power plant configurations and an explanation of the method used to estimate their busbar costs. The alternative plants were selected to provide representative values for coal and pressurized-water reactor (PWR) plants of various sizes starting commercial operation in the year 2000.

Coal-fired	Nuclear
400-MW(e) single unit	800-MW(e) PWR
600-MW(e) single unit	1200-MW(e) PWR
800-MW(e) single unit	
800-MW(e) two unit	
1200-MW(e) two unit	

The following general assumptions apply to the development of the levelized busbar generation costs for the alternative power plants:

1. The levelized busbar cost will be expressed in constant 1987 dollars.
2. The capacity factor for all alternative plants is assumed to be 70%.
3. The operating life of each unit is assumed to be 30 years for cost-estimating purposes.
4. The present-worth discount rate is 9.57%/year (nominal) and 4.36%/year (real). The general inflation rate is 5%/year.

5.1 Capital Cost

Because multi-unit plants are being considered, nine capital cost estimates are needed for the seven alternative power plants listed previously. The total capital cost estimates are given in Table 5.1 and were calculated using the CONCEPT code and cost data developed in the DOE EEDB Program.[3,4] The procedure using the data in Table 5.1 to produce a cost estimate for an alternative is discussed in Sect. 5.6.

The assumed construction period for the coal and nuclear plants was 4 and 6 years, respectively. The commercial operation date is the year 2000 for single units and for the first unit of the two-unit plants. The second unit is assumed to follow the first by 1 year.

Table 5.1. Alternative power plant capital cost data

Plant type	Total capital cost (millions 1987$)
400-MW(e) single-unit coal	790
400-MW(e) first of two units coal	793
400-MW(e) second of two units coal	602
600-MW(e) single-unit coal	987
600-MW(e) first of two units coal	991
600-MW(e) second of two units coal	752
800-MW(e) single-unit coal	1160
800-MW(e) PWR	2021
1200-MW(e) PWR	2471

The coal-fired plants have precipitators and wet limestone scrubbers. The PWR plants conform to 1986 licensing standards. All plants use natural draft wet cooling towers.

The PWR costs shown reflect assumptions in the quantities of commodities, equipment, installation manhours, and indirect costs that are today only similar to the best cost experience for stations currently under construction. These costs are provided as representative values of typical future plants under an improved managerial and regulatory climate. To allow for comparisons to the industry's current median experience, the capital costs by two-digit EEDB account for a 1200-MW(e) median experience and best experience PWR are provided in Table 5.2.

5.2 O&M Cost

Seven O&M cost estimates are needed for estimating the alternative plant configurations under consideration. The O&M cost estimates were calculated using the OMCOST code[5] and are given in Table 5.3. The procedure using the data in Table 5.3 to produce a cost estimate for an alternative plant is discussed in Sect. 5.6.

Table 5.2. PWR capital cost estimates (millions 1987$)

EEDB Account No.	EEDB Account description	Median experience	Best experience
20	Land and land rights	5	5
21	Structures and improvements	353	229
22	Reactor plant equipment	404	324
23	Turbine plant equipment	286	236
24	Electric plant equipment	132	88
25	Miscellaneous plant equipment	77	50
26	Main conditioning heat reject system	61	52
Total direct costs		1318	984
91	Construction services	322	176
92	Home office engineering and service	484	211
93	Field office engineering and service	451	114
94	Owner's costs	256	147
Total indirect costs		1512	648
BASE CONSTRUCTION COST		2830	1632
	— [$/kW(e)]	2358	1360
CONTINGENCY[a]		553	319
TOTAL OVERNIGHT COST		3383	1951
	— [$/kW(e)]	2819	1626
ESCALATION		0	0
INTEREST DURING CONSTRUCTION[b]		1302	520
TOTAL CAPITAL COST		4685	2471
	— [$/kW(e)]	3904	2059

[a]Nuclear-grade construction assumptions: 65% Account 21, 100% Account 22, 50% Account 24, 50% Accounts 92–94.

[b]Based on 8-year construction time for median case and 6-year construction time for best case.

Table 5.3. Alternative power plant O&M cost data

Plant type	Annual O&M cost (millions 1987$)
400-MW(e) single-unit coal	24.0
600-MW(e) single-unit coal	26.3
800-MW(e) single-unit coal	28.5
800-MW(e) two-unit coal	36.3
1200-MW(e) two-unit coal	40.8
800-MW(e) PWR	72.2
1200-MW(e) PWR	78.7

5.3 Fuel Costs

The delivered price of coal is assumed to be $1.75/MBtu (1987 dollars) in 1987. The real escalation of coal is assumed to be 1.0%/year. For the PWR cases, an extended burn-up fuel (54,000 megawatt-days per metric ton) is used. The fuel cycle unit costs assumed are given in Table 5.4.

Table 5.4. Fuel cycle unit cost parameters

Fuel	1987 Price	Real escalation rate (%/year)
Uranium ore, $/lb	23	2.0
Conversion, $/kg U	8	0
Enrichment, $/kg SWU	110	−1.5 to 2005, 0 thereafter
Fabrication, $/kg HM	245	0
Waste disposal, mills/kWh	1	0

5.4 Decommissioning

The cost of decommissioning an 1100-MW(e) PWR plant is estimated to be $143 million in 1987 dollars. Decommissioning costs are assumed to vary linearly with size and escalate at the rate of inflation. A sinking fund similar to that described in Sect. 4.5 will be used to accumulate the necessary funds during the operation of the plant. An example of this method is given in Sect. 5.6.3.

5.5 Total Busbar Cost

The capital, O&M, fuel, and any decommissioning costs make up the total busbar cost. Each component as well as the total busbar cost itself can be expressed as a constant dollar levelized unit cost. The levelized unit cost for each cost component is obtained by dividing the present worth of the particular cost stream by the present worth of the energy generation discounted at the real cost of money. The total bus-

bar cost is then the sum of the levelized costs for all the components. A summary of these levelized costs for the alternative plant configurations is given in Table 5.5.

Table 5.5. Alternative power plant cost estimate summary

Plant	Levelized cost (1987 mills/kWh)				
	Capital	O&M	Fuel	Decommissioning	Total
400-MW(e) single-unit coal	31.6	9.8	21.9		63.3
600-MW(e) single-unit coal	26.3	7.1	21.7		55.1
800-MW(e) single-unit coal	23.2	5.8	21.5		50.5
800-MW(e) two-unit coal	28.0	7.5	22.0		57.5
1200-MW(e) two-unit coal	23.3	5.6	21.8		50.7
800-MW(e) PWR	39.8	14.7	6.7	0.6	61.8
1200-MW(e) PWR	32.5	10.7	6.7	0.6	50.5

5.6 Example Calculations

To further understand how the levelized costs are obtained, a description of the calculational procedure is provided below for three of the configurations. The remaining configurations are determined in an similar manner.

5.6.1 Cost calculation for a 400-MW(e) coal plant

This section will discuss the calculation of the constant dollar levelized cost for a single-unit 400-MW(e) coal-fired plant starting commercial operation in the year 2000. A constant dollar levelized cost for each cost component will be determined and then summed to obtain the total busbar generation levelized cost.

5.6.1.1 Capital cost. As given in Sect. 4.2, the levelized capital cost for a single-unit plant is found by multiplying the total capital cost by the fixed charge rate and dividing by the annual energy generation. The total capital cost for this plant is shown in Table 5.1 to be $790 million (1987 dollars). The constant dollar fixed charge rate to be used for the coal plant alternatives in this study is 0.0981. This fixed charge rate is determined using the methodology

presented in the NECDB.[1] This study assumes a constant annual energy generation at 70% capacity factor. For the 400-MW(e) plant, this corresponds to generation of 2.454 million MWh/year. Using these values, the constant dollar levelized capital cost is $31.60/MWh, which is equivalent to 31.6 mills/kWh.

5.6.1.2 O&M cost. As stated in Sect. 4.3, the levelized O&M cost for a single-unit plant in this study is the annual O&M cost divided by the annual energy generation. Using the annual O&M cost given in Table 5.3 ($24.0 million) and the annual energy generation (2.454 million MWh), the levelized O&M cost is calculated to be 9.8 mills/kWh.

5.6.1.3 Fuel cost. The basic procedure for obtaining the levelized fuel cost is described in Sect. 4.4. The present worth of the annual fuel costs must reflect a real escalation of 1.0%/year for coal. Given a real escalation and assuming constant annual energy generation, the present worth can be calculated as

$$PWFC = \frac{FC \times (1 + e)^L}{CRF(Z,30)} ,$$

where

PWFC = present worth of fuel cost,
FC = annual fuel cost in the reference year,
e = real escalation rate for fuel,
L = time between commercial operation and reference date,
CRF(Z,30) = capital recovery factor at rate Z for 30 years,
Z = combined escalation/discount rate defined as $(1 + d)/(1 + e) - 1$, where d is the real discount rate.

Using a coal price of $1.75/MBtu (1987 dollars), a plant heat rate of 9684 Btu/kWh, and annual generation of 2.454 million MWh, an annual FC of $41.59 million (1987 dollars) in the reference year is obtained. The time between the commercial operation date and the reference date is 2000 − 1987 or 13 years. The combined escalation/discount rate Z is 1.0435/1.01 − 1 or 3.32%. Substituting values into the previous equation yields

$$PWFC = \frac{41.59 \times 10^6 \times 1.1381}{0.0532} ,$$

or

$$PWFC = \$890 \times 10^6 \text{ (1987 dollars)} .$$

Using the equation in Sect. 4.4 and a capital recovery factor (CRF) of 0.0604, the levelized fuel cost is calculated as

$$\frac{0.0604 \times 890 \times 10^6}{2.4544 \times 10^6} = 21.9 \text{ mills/kWh} .$$

5.6.1.4 Total busbar cost. The total constant dollar levelized busbar cost is the sum of the three cost components derived above or 63.3 mills/kWh as shown in Table 5.5.

5.6.2 Cost calculation for a two-unit 800-MW(e) coal plant

This section will discuss the calculation of the constant dollar levelized cost for a two-unit 800-MW(e) coal plant. The commercial operation dates for the two units are 2000 and 2001.

5.6.2.1 Capital cost. The constant dollar levelized capital cost is given in equation form in Sect. 4.2. Substituting capital costs from Table 5.1, the equation becomes

$$LCC = \frac{0.0981 \times [793 + 602\ (1.0436)^{-1}]}{2.454 \times 10^6 \times [1 + (1.0436)^{-1}]} \times 10^6 ,$$

or

$$LCC = 28.0 \text{ mills/kWh} .$$

5.6.2.2 O&M cost. In this case, two different annual O&M costs are required from Table 5.3 to reflect the number of units operating at the plant site through time. For years 1 and 31, the annual O&M cost is \$24.0 million, while for all other years in between, the annual cost is \$36.3 million. Following the equation given in Sect. 4.3, the present worth of the O&M costs (PWOM) is calculated as \$596.1 million (1987 dollars). Using the levelized cost equation also given in Sect. 4.3 and an annual unit energy generation of 2.454 million MWh, the constant dollar levelized O&M cost is 7.5 mills/kWh.

5.6.2.3 Fuel cost. For a multi-unit coal plant that has real fuel cost escalation, the equation given in Sect. 5.6.1.3 has to be expanded to reflect the different commercial operation dates of the units. The expanded equation is

$$PWFC = \frac{FC \times (1 + e)^L \times \sum_i 1/(1 + Z)^{t_i}}{CRF(Z,30)} ,$$

where

PWFC = present worth of fuel cost,

FC = annual fuel cost in the reference year for one unit (block),

e = real escalation rate for fuel,

L = time between first unit commercial operation and reference date,

CRF(Z,30) = capital recovery factor at rate Z for 30 years,

Z = combined escalation/discount rate defined as $(1 + d)/(1 + e) - 1$, where d is the real discount rate,

t_i = relative time from the commercial operation of the first unit,

$\sum_i$ = summation over all units including the first unit.

Using the same cost data as Sect. 5.6.1.3, the present worth of the fuel cost is $\$1.75 \times 10^9$ (1987 dollars). Using this value and an annual per unit energy generation of 2.4544 million MWh, the levelized fuel cost as determined by the equation in Sect. 4.4 is

$$\frac{0.0604 \times 1.75 \times 10^9}{2.4544 \times 10^6 \times [1 + (1.0436)^{-1}]} = 22.0 \text{ mills/kWh} .$$

5.6.2.4 Busbar cost. The levelized busbar cost is the sum of the levelized component costs. In this case, the sum of the three cost components is 57.5 mills/kWh (1987 dollars).

5.6.3 Cost calculation for a 800-MW(e) PWR plant

Large monolithic light-water reactor power plants can also be considered as alternative energy sources. Discussed in this section are

the cost calculations for a 800-MW(e) PWR plant with commercial operation in the year 2000.

5.6.3.1 Capital cost. To calculate a levelized capital cost using the equation given in Sect. 4.2 for single-unit plants, the fixed charge rate, total capital cost, and annual energy generation must be known. For PWR plants in this study, the fixed charge rate is 0.0967. The total capital cost is given in Table 5.1 as $2021 million (1987 dollars), and the annual energy generation at 70% capacity factor is 4.909 million MWh. These values produce a constant dollar levelized cost of 39.8 mills/kWh (1987 dollars).

5.6.3.2 O&M cost. For a single-unit plant the levelized O&M cost is the annual O&M cost of $72.2 million from Table 5.3 divided by the annual energy generation or 14.7 mills/kWh.

5.6.3.3 Fuel cycle cost. The levelized fuel cycle cost for the PWR plant is described by the equation in Sect. 4.4. Using the fuel cycle unit cost parameters given in Table 5.4, the present worth of the fuel costs for 30 years of operation was calculated to be $545 million (1987 dollars). As shown in Sect. 4.4, dividing this amount by the annual energy generation and multiplying by the CRF for 30 years produces a levelized fuel cycle cost of 6.7 mills/kWh.

5.6.3.4 Decommissioning cost. The decommissioning cost is assumed to scale linearly with size from the reference point of $143 million for an 1100-MW(e) plant. The assumed cost is 143/1100 × 800 or $104 million (1987 dollars).

Using the equations given in Sect. 4.5 and an assumed decommissioning cost of $104 million in 1987 dollars with no real escalation, the present worth of the decommissioning cost can be written as

$$\mathrm{PWDC} = \frac{104 \times 10^6 \times 0.0116}{3.5925 \times 0.0066} ,$$

or

$$\mathrm{PWDC} = \$50.9 \text{ million (1987 dollars).}$$

Dividing this amount by the annual energy generation and the CRF for 30 years produces a levelized decommissioning cost of 0.63 mills/kWh.

5.6.3.5 Busbar cost. The levelized busbar cost is the sum of the levelized component costs. In this case, the sum of the four cost components is 61.8 mills/kWh (1987 dollars).

REFERENCES

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3. C. R. Hudson, *CONCEPT-5 User's Manual*, ORNL-5470, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., January 1979.

4. *Energy Economic Data Base (EEDB) Program, Phase VIII Update Report*, DOE/NE-0079, December 1986.

5. M. L. Myers, L. C. Fuller, and H. I. Bowers, *Nonfuel Operation and Maintenance Costs for Large Steam-Electric Power Plants — 1982*, ORNL/TM-8324, Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., September 1982.

Appendix A

EEDB CODE OF ACCOUNTS FOR LIQUID-METAL REACTOR (LMR) CONCEPT

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Lead (FOAK) Plant _____
Replica Plant _____
NOAK Plant _____

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
20	LAND & LAND RIGHTS					
21	STRUCTURES & IMPROVEMENTS					
22	REACTOR PLANT EQUIPMENT					
23	TURBINE PLANT EQUIPMENT					
24	ELECTRIC PLANT EQUIPMENT					
25	MISCELLANEOUS PLANT EQUIPMENT					
26	MAIN COND. HEAT REJECT. SYSTEM					
	TOTAL DIRECT COSTS					
91	CONSTRUCTION SERVICES					
92	AE HOME OFFICE ENGR. & SERVICE					
93	FIELD OFFICE SUPV. & SERVICE					
94	OWNERS' EXPENSES					
95	RM HOME OFFICE ENGR. & SERVICES					
	TOTAL INDIRECT COSTS					
	TOTAL COST					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
211	YARDWORK					
212	REACTOR MODULE STRUCTURE					
213	TURBINE GENERATOR BUILDINGS					
214	SECURITY BUILDING AND GATE HOUSE					
215	REACTOR SERVICE BUILDING					
216	RADWASTE BUILDING					
218A	CONTROL BUILDING					
218B	ADMINISTRATION BUILDING					
218D	FIRE PUMP HOUSE					
218E	STEAM GENERATOR BUILDINGS					
218H	NONESSEN. SWGR BUILDING					
218N	PLANT WAREHOUSE AND MAINTENANCE SHOP					
218R	NON-IE D/G AND AUXILIARY BOILER BLDG.					
218S	WASTEWATER TREATMENT BUILDING					
218T	GAS TURBINE BUILDING					
218U	RECEIVING AND ASSEMBLY BLDG.					
218V	BOP PERSONNEL SERVICE BLDG.					
218W	WAREHOUSE					
218X	EQUIPMENT VAULT					
218Y	REACTOR MODULE SERVICE ROADWAY					
219A	OFF-SITE TECHNICAL CENTER					
219K	SODIUM UNLOADING FACILITY					
21	STRUCTURES & IMPROVEMENTS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
220A	NUCLEAR STEAM SUPPLY (NSSS)					
220B	NSSS OPTIONS					
221	REACTOR EQUIPMENT					
222	MAIN HEAT TRANSPORT SYSTEM					
223	SAFEGUARDS SYSTEM					
224	RADWASTE PROCESSING					
225	FUEL HANDLING					
226	OTHER REACTOR PLANT EQUIPMENT					
227	RX INSTRUMENTATION & CONTROL					
228	REACTOR PLANT MISC. ITEMS					
22	REACTOR PLANT EQUIPMENT					
231	TURBINE GENERATOR					
233	CONDENSING SYSTEMS					
234	FEED HEATING SYSTEM					
235	OTHER TURBINE PLANT EQUIP.					
236	INSTRUMENTATION & CONTROL					
237	TURBINE PLANT MISC. ITEMS					
23	TURBINE PLANT EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
241	SWITCHGEAR					
242	STATION SERVICE EQUIPMENT					
243	SWITCHBOARDS					
244	PROTECTIVE EQUIPMENT					
245	ELECT. STRUC. & WIRING CONTNR.					
246	POWER & CONTROL WIRING					
24	ELECTRIC PLANT EQUIPMENT					
251	TRANSPORTATION & LIFT EQUIPMENT					
252	AIR, WATER, & STEAM SERVICE SYS.					
253	COMMUNICATIONS EQUIPMENT					
254	FURNISHINGS & FIXTURES					
255	WASTEWATER TREATMENT EQUIP.					
25	MISCELLANEOUS PLANT EQUIP.					
261	STRUCTURES					
262	MECHANICAL EQUIPMENT					
26	MAIN COND. HEAT REJECT SYS.					
	TOTAL DIRECT COSTS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
911	TEMPORARY CONSTRUCTION FAC.					
912	CONSTRUCTION TOOLS & EQUIP.					
913	PAYROLL INSURANCE & TAXES					
914	PERMITS, INS., & LOCAL TAXES					
91	CONSTRUCTION SERVICES					
921	ENGR. & HOME OFFICE EXPENSES					
922	ENGR. HOME OFFICE QA					
923	ENGR. HOME OFFICE CONSTRCTN. MGMT.					
92	ENGR. & HOME OFFICE SERVICES					
931	FIELD OFFICE EXPENSES					
932	FIELD JOB SUPERVISION					
933	FIELD QA/QC					
934	PLANT STARTUP & TEST					
93	FIELD OFFICE & SERVICES					
941	MGMT., ENGR., & QA					
942	TAXES & INSURANCE					
943	SPARE PARTS					
944	TRAINING					
945	G&A					
946	CAPITAL EQUIPMENT					
94	OWNERS' COSTS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
951	HOME OFFICE SERVICES					
952	HOME OFFICE QA					
95	RM HOME OFFICE ENGR. & SERVICE					
	TOTAL INDIRECT COSTS					
	TOTAL COST					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
21	STRUCTURES & IMPROVEMENTS					
211	YARDWORK					
211.1	GENERAL YARDWORK					
211.4	RAILROADS					
211.7	STRUCTURAL ASSOC. YARDWORK					
	211 YARDWORK					
212	REACTOR MODULE STRUCTURE					
212.1	BUILDING STRUCTURE					
212.2	BUILDING SERVICES					
	212 REACTOR MODULE STRUCTURE					
213	TURBINE GENERATOR BUILDING					
213.1	BUILDING STRUCTURE					
213.2	BUILDING SERVICES					
	213 TURBINE GENERATOR BLDG.					
214	SECURITY BUILDING AND GATEHOUSE					
214.1	BUILDING STRUCTURE					
214.2	BUILDING SERVICES					
	214 SECURITY BUILDING AND GATEHOUSE					
215	REACTOR SERVICE BUILDING					
215.1	BUILDING STRUCTURE					
215.2	BUILDING SERVICES					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
216	RADWASTE BUILDING					
216.1	BUILDING STRUCTURE					
216.2	BUILDING SERVICES					
	216 RADWASTE BUILDING					
218A	CONTROL BUILDING					
218A.1	BUILDING STRUCTURE					
218A.2	BUILDING SERVICES					
	218A CONTROL BUILDING					
218B	ADMINISTRATION BUILDING					
218B.1	BUILDING STRUCTURE					
218B.2	BUILDING SERVICES					
	218B ADMINISTRATION BLDG.					
218D	FIRE PUMP HOUSE					
218D.1	BUILDING STRUCTURE					
218D.2	BUILDING SERVICES					
	218D FIRE PUMP HOUSE					
218E	STEAM GENERATOR BUILDINGS					
218E.1	BUILDING STRUCTURE					
218E.2	BUILDING SERVICES					
	218E STEAM GENERATOR BUILDINGS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
218H	NONESSENTIAL SWGR BUILDING					
218H.1	BUILDING STRUCTURE					
218H.2	BUILDING SERVICES					
	218H NONESSENTIAL SWGR BUILDING					
218N	PLANT WAREHOUSE AND MAINTENANCE SHOP					
218N.1	SHOP STRUCTURE					
218N.2	SHOP SERVICES					
	218N PLT. WAREHOUSE & MAINT. SHOP					
218R	NON-IE D/G AND AUXILIARY BOILER BUILDING					
218R.1	BUILDING STRUCTURE					
218R.2	BUILDING SERVICES					
	218R NON-IE D/G AND AUX. BOIL. BLDG.					
218S	WASTE WATER TREATMENT BLDG.					
218S.1	BUILDING STRUCTURE					
218S.2	BUILDING SERVICES					
	218S WASTE WATER TREATMENT BLDG.					
218Y	REACTOR MODULE SERVICE ROADWAY					
218Y.1	BUILDING STRUCTURE					
	218Y REACTOR MODULE SERVICE ROADWAY					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
219A	OFF-SITE TECHNICAL CENTER					
219A.1	BUILDING STRUCTURE					
219A.2	BUILDING SERVICES					
	219A OFF-SITE TECHNICAL CENTER					
219K	SODIUM UNLOADING FACILITY					
219K.1	STRUCTURE					
219K.2	SERVICES					
	219K SODIUM UNLOADING FACILITY					
	21 STRUCTURES & IMPROVEMENTS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
22	REACTOR PLANT EQUIPMENT					
220A	NSSS					
220A.1	QUOTED NSSS PRICE					
220A.2	DISTRIBUTED NSSS COST					
220A.21	REACTOR EQUIPMENT					
220A.211	REACTOR VESSELS					
220A.212	REACTOR VESSEL INTERNALS					
220A.213	CONTROL ROD SYSTEMS					
220A.22	HEAT TRANSPORT SYSTEM					
220A.221	PRIMARY HEAT TRANSPORT SYSTEM					
220A.222	INTERM. HEAT TRANSPORT SYSTEM					
220A.223	STEAM GENERATOR SYSTEM					
220A.23	SAFEGUARDS SYSTEMS					
220A.231	BACKUP HEAT REMOVAL SYSTEMS					
220A.25	FUEL HANDLING & STORAGE					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
220A.26	OTHER EQUIPMENT					
220A.261	INERT GAS RECEIVING & PROCESSING					
220A.262	SPECIAL HEATING SYSTEM					
220A.264	SODIUM STORAGE, RELIF. MAKEUP					
220A.265	SODIUM PURIFICATION SYSTEM					
220A.266	Na LEAK DETECTION SYSTEM					
220A.267	AUXILIARIES COOLING SYSTEM					
220A.268	MAINTENANCE EQUIPMENT					
220A.27	INSTRUMENTATION & CONTROL					
220A.3	UNDISTRIBUTED NSSS COST					
	220A NSSS					
220B	NSSS OPTIONS					
221	REACTOR EQUIPMENT					
221.1	REACTOR VESSEL & ACCESSORY					
221.11	REACTOR & GUARD VESSEL SUPPORT					
221.12	VESSEL & GUARD VESSEL STRUCTURE					
221.13	VESSEL INTERNALS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
221.2	REACTOR CONTROL DEVICES					
221.21	CONTROL ROD SYSTEM					
	221 REACTOR EQUIPMENT					
222	MAIN HEAT TRANSPORT SYSTEM					
222.1	PRIMARY HEAT TRANSPORT SYSTEM					
222.11	FLUID CIRCULATION DRIVE SYSTEM					
222.12	REACTOR COOLANT PIPING SYSTEM					
222.13	INTERM. HEAT EXCHANGER EQUIPMENT					
222.15	PRIMARY COOLANT PIPE WHIP RESTRNT.					
222.2	INTERM. HEAT TRANSPORT SYSTEM					
222.21	FLUID CIRCULATION DRIVE SYSTEM					
222.22	INTERM. COOLANT PIPING SYSTEM					
222.23	EXPANSION TANK					
222.24	COOLANT PIPE WHIP RESTRNT.					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
222.25	Na/H2O REACTION PROTECTION SYS.					
222.253	TANKS					
222.255	PIPING					
222.257	PIPING — MISCELLANEOUS ITEMS					
222.258	INSTRUMENTATION & CONTROL					
222.259	FOUNDATIONS					
222.3	STEAM GENERATION SYSTEM					
222.31	FLUID CIRCULATION DRIVE SYSTEM					
222.33	STEAM GENERATOR EQUIPMENT					
	222 MAIN HEAT TRANSPORT SYSTEM					
223	SAFEGUARDS SYSTEM					
223.1	AUXILIARY HEAT TRANSPORT SYSTEM					
223.11	ROTATING EQUIPMENT					
223.12	HEAT TRANSFER EQUIPMENT					
223.13	TANK & PRESSURE VESSEL					
223.15	PIPING					
223.16	VALVES					
223.17	PIPING — MISCELLANEOUS ITEMS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
223.18	INSTRUMENTATION & CONTROL					
223.19	FOUNDATIONS					
	223 SAFEGUARDS SYS.					
224	RADWASTE PROCESSING					
224.1	LIQUID WASTE PROCESSING					
224.2	GAS DISTRIBUTION & PROCESS SYSTEM					
224.3	SOLID WASTE SYSTEM					
	224 RADWASTE PROCESSING					
225	FUEL HANDLING					
225.1	FUEL HANDLING MECHANISMS					
225.2	FUEL HANDLING EQUIPMENT					
225.3	INSPECTION EQUIPMENT					
225.4	CORE COMPONENT STORAGE					
	225 FUEL HANDLING					
226	OTHER REACTOR PLANT EQUIPMENT					
226.1	INERT GAS SYSTEM					
226.2	SPECIAL HEATING SYSTEMS					
226.3	LM REC. STORAGE & PROC. SYSTEM					
226.7	AUXILIARY COOLING SYSTEM					
226.8	MAINTENANCE EQUIPMENT					
226.9	SAMPLING EQUIPMENT					
	226 OTHER REACTOR PLANT EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
227	RX INSTRUMENTATION & CONTROL					
227.1	BENCHBOARD, PANELS & RACKS, ETC.					
227.2	PROCESS COMPUTERS					
227.3	MONITORING SYSTEMS					
227.4	PLANT CONTROL & PROTECTION SYSTEM					
	227 RX INSTR. & CONTROL					
228	REACTOR PLANT MISCELLANEOUS ITEMS					
228.1	FIELD PAINTING					
228.2	QUALIFICATION OF WELDERS					
228.3	STANDARD NSSS VALVE PACKAGE					
228.4	REACTOR PLANT INSULATION					
	228 REACTOR PLANT MISC. ITEMS					
	22 REACTOR PLANT EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
23	TURBINE PLANT EQUIPMENT					
231	TURBINE GENERATOR					
231.1	TURBINE GENERATOR & ACCESSORY					
231.2	FOUNDATIONS					
231.4	LUBRICATING OIL SYSTEM					
231.5	GAS SYSTEMS					
231.6	MSTR. SEPRTR./REHTR. DRAIN SYSTEM					
	231 TURBINE GENERATOR					
233	CONDENSING SYSTEMS					
233.1	CONDENSER EQUIPMENT					
233.12	HEAT TRANSFER EQUIPMENT					
233.2	CONDENSATE SYSTEM					
233.21	ROTATING EQUIPMENT					
233.23	TANKS & PRESSURE VESSELS					
233.25	PIPING					
233.26	VALVES					
233.27	PIPING — MISCELLANEOUS ITEMS					
233.28	INSTRUMENTATION & CONTROL					
233.29	FOUNDATIONS					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
233.3	GAS REMOVAL SYSTEM					
233.4	TURBINE BYPASS SYSTEM					
233.5	CONDENSATE POLISHING					
	233 CONDENSING SYSTEMS					
234	FEED HEATING SYSTEM					
234.1	FEEDWATER HEATERS					
234.12	HEAT TRANSFER EQUIPMENT					
234.2	FEEDWATER SYSTEM					
234.21	ROTATING MACHINERY					
234.25	PIPING					
234.26	VALVES					
234.27	PIPING — MISCELLANEOUS ITEMS					
234.28	INSTRUMENTATION & CONTROL					
234.29	FOUNDATIONS					
234.3	EXTRACTION SYSTEM					
234.4	FWH VENT & DRAIN SYSTEM					
	234 FEED HEATING SYSTEM					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
235	OTHER TURBINE PLANT EQUIPMENT					
235.1	MAIN VAPOR PIPING SYSTEM					
235.2	TURBINE AUXILIARIES					
235.3	TB CLOSED COOLING WATER SYSTEM					
235.4	DEMIN. WATER MAKEUP SYSTEM					
235.5	CHEMICAL TREATMENT SYSTEM					
235.6	NEUTRALIZATION SYSTEM					
	235 OTHER TURBINE PLANT EQUIP.					
236	INSTRUMENTATION & CONTROL					
236.1	PROCESS INSTR. & CONTROL EQUIPMENT					
236.2	PROCESS COMPUTER					
236.3	TURBINE PLANT INSTR. & CONTROL TUBING					
	236 INSTRUMENTATION & CONTROL					
237	TURBINE PLANT MISCELLANEOUS ITEMS					
237.1	FIELD PAINTING					
237.2	QUALIFICATION OF WELDERS					
237.3	TURBINE PLANT INSULATION					
	237 TURBINE PLANT MISC. ITEMS					
	23 TURBINE PLANT EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
24	ELECTRICAL PLANT EQUIPMENT					
241	SWITCHGEAR					
241.1	GENERATOR EQUIPMENT SWITCHGEAR					
241.2	STATION SERVICE SWITCHGEAR					
	241 SWITCHGEAR					
242	STATION SERVICE EQUIPMENT					
242.1	STATION SERVICE & STARTUP EQUIP.					
242.2	UNIT SUBSTATIONS					
242.3	AUXILIARY POWER SOURCES					
	242 STATION SERV. EQUIPMENT					
243	SWITCHBOARDS					
243.1	CONTROL PANELS					
243.2	AUXILIARY POWER & SIGNAL BOARDS					
	243 SWITCHBOARDS					
244	PROTECTIVE EQUIPMENT					
244.1	GENERAL STATION GROUND SYSTEM					
244.2	FIRE DETECTION & SUPPRESSION					
244.3	LIGHTNING PROTECTION					
244.4	CATHODIC PROTECTION					
244.5	HEAT TRACING & FREEZE PROT.					
	244 PROTECTIVE EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
245	ELECT. STRUCTURE & WIRING CONTAINERS					
245.1	UNDERGROUND DUCT RUNS					
245.2	CABLE TRAYS					
245.3	CONDUITS					
	245 ELECT. STRUCT. & WIRING					
246	POWER & CONTROL WIRING					
246.1	GENERATOR CIRCUITS WIRING					
246.2	STATION SERVICE POWER WIRING					
246.3	CONTROL CABLE					
246.4	INSTRUMENT WIRE					
246.5	CONTAINMENT PENETRATIONS					
	246 POWER & CONTROL WIRING					
	24 ELECTRICAL POWER EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
25	MISCELLANEOUS PLANT EQUIPMENT					
251	TRANSPORTATION & LIFT EQUIPMENT					
251.1	CRANES & HOISTS					
	251 TRANSPORTATION & LIFT					
252	AIR, WATER, & STEAM SERV. SYSTEM					
252.1	AIR SYSTEMS					
252.2	WATER SYSTEMS					
252.21	PLANT SERVICE WATER SYSTEM					
252.22	NORMAL FIRE PROTECTION SYSTEM					
252.23	PROCESS CHILLED WATER SYSTEM					
252.24	POTABLE WATER SYSTEM					
252.3	AUXILIARY STEAM SYSTEM					
252.4	PLANT FUEL OIL SYSTEM					
252.5	SODIUM FIRE PROTECTION SYSTEM					
	252 AIR, WATER, & STEAM SERV. SYS.					
253	COMMUNICATIONS EQUIPMENT					
253.1	LOCAL COMMUNICATIONS SYSTEMS					
253.2	SIGNAL SYSTEMS					
	253 COMMUNICATIONS EQUIPMENT					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
254	FURNISHING & FIXTURES					
254.1	SAFETY EQUIPMENT					
254.2	CHEMICAL LAB & INSTR. SHOP					
254.3	OFFICE EQUIPMENT & FURNISHINGS					
254.4	CHANGE ROOM EQUIPMENT					
254.5	ENVIRONMENTAL MONITORING EQUIPMENT					
254.6	DINING FACILITIES					
254.7	MAINTENANCE SHOP EQUIPMENT					
	254 FURNISHINGS & FIXTURES					
255	WASTEWATER TREATMENT SYSTEM					
	25 MISCELLANEOUS PLANT EQUIPMENT					
26	MAIN COND. HEAT REJECTION SYSTEM					
261	STRUCTURES					
261.1	MAKEUP WATER & DISCH. STR.					
261.2	CIRC. WATER PUMP HOUSE					
261.3	MAKEUP WATER PRETREATMENT BUILDING					
261.4	COOLING TOWER SWITCHGEAR BUILDING					
	261 STRUCTURES					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
262	MECHANICAL EQUIPMENT					
262.1	HEAT REJECTION SYSTEM					
	262 MECHANICAL EQUIPMENT					
	26 MAIN COND. HEAT REJECT. SYS.					
91	CONSTRUCTION SERVICES					
911	TEMPORARY CONSTRUCTION FACILITIES					
911.1	TEMPORARY BUILDINGS					
911.2	TEMPORARY FACILITIES					
	911 TEMP. CONSTRCTN FACILITIES					
912	CONSTRUCTION TOOLS & EQUIPMENT					
912.1	MAJOR EQUIPMENT					
912.2	MISCELLANEOUS VEHICLES					
912.3	PURCHASE OF SMALL TOOLS					
912.4	EXPENDABLE SUPPLIES					
912.5	SAFETY EQUIPMENT & INSPECTION					
	912 CONSTRCTN. TOOLS & EQUIPMENT					
913	PAYROLL INSURANCE & TAXES					
914	PERMITS, INSURANCE, & LOCAL TAXES					
	91 CONSTRUCTION SERVICES					

Table A.1. LMR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
92	ENGR. & HOME OFFICE SERVICES					
921	HOME OFFICE EXPENSES					
922	HOME OFFICE QA					
923	HOME OFFICE CONSTRCTN. MGMT.					
	92 ENGR. & HOME OFFICE SERVICES					
93	FIELD OFFICE & SERVICES					
931	FIELD OFFICE EXPENSES					
932	FIELD JOB SUPERVISION					
933	FIELD OFFICE QA/QC					
934	PLANT STARTUP & TESTING					
	93 FLD. SUPERVISION & FLD. OFFICE SERV.					
94	OWNERS' COSTS					
941	MANAGEMENT, ENGINEERING, & QA					
942	TAXES AND INSURANCE					
943	SPARE PARTS					
944	TRAINING					
945	G&A					
946	CAPITAL EQUIPMENT					
	94 OWNERS' COSTS					
95	RM HOME OFFICE ENGINEERING & SERVICE					
951	HOME OFFICE SERVICES					
952	HOME OFFICE QA					
	95 RM HOME OFFICE ENGINEERING & SERVICE					

Appendix B

EEDB CODE OF ACCOUNTS FOR HIGH-TEMPERATURE GAS-COOLED REACTOR (HTGR) CONCEPT

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198__ dollars without contingency)

Lead (FOAK) Plant _____
Replica Plant _____
NOAK Plant _____

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
20	LAND & LAND RIGHTS					
21	STRUCTURES & IMPROVEMENTS					
22	REACTOR PLANT EQUIPMENT					
23	TURBINE PLANT EQUIPMENT					
24	ELECTRIC PLANT EQUIPMENT					
25	MISCELLANEOUS PLANT EQUIPMENT					
26	MAIN COND. HEAT REJECT. SYSTEM					
	TOTAL DIRECT COSTS					
91	CONSTRUCTION SERVICES					
92	HOME OFFICE ENGR. & SERVICE					
93	FIELD OFFICE SUPV. & SERVICE					
94	OWNERS' EXPENSES					
95	RM HOME OFFICE ENGR. & SERVICES					
	TOTAL INDIRECT COSTS					
	TOTAL COST					

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
211	YARD WORK					
212	REACTOR BUILDING					
213	TURBINE BUILDING					
214	OPERATION CENTER					
215	REACTOR SERVICE BUILDING					
216	RADIOACTIVE WASTE MANAGEMENT BUILDING					
218A	PERSONNEL SERVICES BUILDING					
218C	MAKEUP WATER TREATMENT & AUXILIARY BOILER BUILDING					
218D	FIRE PUMP HOUSE					
218E	HELIUM STORAGE BUILDING					
218G	HYOROGEN STORAGE AREA					
218H	GUARD HOUSE					
218I	NUCLEAR ISLAND WAREHOUSE					
218J	ECA WAREHOUSE					
218K	MAINTENANCE BUILDING					
218U	STANDBY POWER BUILDING					
218X	NUCLEAR ISLAND COOLING WATER BUILDING					
218Z	REACTOR AUXILIARY BUILDING					
21	STRUCTURES & IMPROVEMENTS					

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
221	REACTOR SYSTEMS					
222	VESSEL SYSTEM					
223	HEAT TRANSPORT SYSTEM					
224	REACTOR CAVITY COOLING SYSTEM					
225	SHUTDOWN COOLING SYSTEM					
226	FUEL HANDLING, STORAGE & SHIPPING SYSTEMS					
227	REACTOR SERVICE SYSTEMS					
228	PLANT CONTROL, DATA AND INSTRUMENTATION SYSTEM					
229	REACTOR PLANT MISCELLANEOUS ITEMS					
22	REACTOR PLANT EQUIPMENT					
231	TURBINE GENERATOR					
233	CONDENSING SYSTEM					
234	FEEDWATER SYSTEM					
235	OTHER TURBINE PLANT EQUIP.					
236	INSTRUMENTATION & CONTROL					
237	TURBINE PLANT MISC. ITEMS					
23	TURBINE PLANT EQUIPMENT					

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
241	SWITCHGEAR					
242	STATION SERVICE EQUIPMENT					
243	SWITCHBOARDS					
244	PROTECTIVE EQUIPMENT					
245	ELECT. STRUC. & WIRING CONTAINERS					
246	POWER & CONTROL WIRING					
24	ELECTRIC PLANT EQUIPMENT					
251	TRANSPORTATION & LIFT EQUIP.					
252	AIR, WATER, & STEAM SERVICE SYSTEMS					
253	COMMUNICATIONS EQUIPMENT					
254	FURNISHINGS & FIXTURES					
25	MISCELLANEOUS PLANT EQUIPMENT					
261	STRUCTURES					
262	MECHANICAL EQUIPMENT					
26	MAIN COND. HEAT REJECT. SYS.					
	TOTAL DIRECT COSTS					

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
911	TEMPORARY CONSTRUCTION FAC.					
912	CONSTRUCTION TOOLS & EQUIP.					
913	PAYROLL INSURANCE & TAXES					
914	PERMITS, INS., & LOCAL TAXES					
91	CONSTRUCTION SERVICES					
921	ENGR. & HOME OFFICE EXPENSES					
922	ENGR. HOME OFFICE QA					
923	ENGR. HOME OFFICE CONSTRCTN. MGMT.					
92	ENGR. & HOME OFFICE SERVICES					
931	FIELD OFFICE EXPENSES					
932	FIELD JOB SUPERVISION					
933	FIELD QA/QC					
934	PLANT STARTUP & TEST					
93	FIELD OFFICE & SERVICES					
941	MGMT., ENGR., & QA					
942	TAXES & INSURANCE					
943	SPARE PARTS					
944	TRAINING					
945	G&A					
946	CAPITAL EQUIPMENT					
94	OWNERS' COSTS					

Table B.1. HTGR plant cost estimate by EEDB cost account
(thousands of Jan. 198_ dollars without contingency)

Account No.	Account description	Factory equipment	Site labor hours	Site labor	Site material	Total $
951	HOME OFFICE SERVICES					
952	HOME OFFICE QA					
95	RM HOME OFFICE ENGR. & SERVICES					
	TOTAL INDIRECT COSTS					
	TOTAL COST					

Appendix C

LISTING OF SAMPLE LEAD PLANT FOAK TASKS
(Applicable to total FOAK plant)

C.1 Engineering and Management

- Prepare engineering specifications and drawings (layouts, design, manufacturing, installation, and interface control drawings).
- Prepare overall plant technical documents and maintenance and operating manuals.
- Prepare management plans, directives, and procedures.
- Prepare test plans, specifications, and procedures including definition of startup systems and turnover plans and procedures.
- Conduct analyses (stress, thermal, reliability, maintainability, availability, thermal hydraulics, loads, seismic failure mode analysis, and safety).
- Conduct design review meetings.
- Prepare verification and validation plans and conduct verification tests and analyses.
- Develop computer programs.
- Prepare vendor bid packages, including preparation of RFPs, bid evaluations, owner interface activities, and award of contract.
- Prepare plant construction model.
- Obtain design certification/license.

C.2 Equipment Manufacturer

- Develop tooling and fixtures for fabrication and assembly of components.
- Fabricate or purchase special component shipping fixtures and conditioning equipment.
- Conduct component development tests.
- Fabricate special test fixtures.
- Purchase or fabricate special test equipment.
- Fabricate or purchase any special component/material handling or transportation equipment used for equipment fabrication.

C.3 Construction

- Prepare construction planning documentation.
- Fabricate any special forms or scaffolding required for construction of the first plant.
- Fabricate or purchase any special component and/or material handling or transportation equipment used on the first construction site.

Appendix D

REPLICA AND NOAK PLANT ENGINEERING AND MANAGEMENT TASKS
(Applicable to total replica and NOAK plant)

- Prepare site-related engineering specifications and drawings (layouts, design, manufacturing, installation, and interface control drawings).
- Identify and retab nonsite drawings (design, manufacturing, installation, and interface control drawings), technical documents, specifications, and manuals to show applicability to the current plant.
- Update and maintain technical work packages.
- Provide support at vendor's plant to witness factory acceptance testing.
- Support the constructor during plant construction and acceptance testing.
- Provide support to the Materials Review Board (MRB).
- Provide support as specifically requested to PSAR and FSAR (including emergency response) to show that the plant is identical is design.
- Support vendor bid evaluations and negotiations as requested by Procurement.
- Support the Constructor in the resolution of any field problems.
- Prepare site-specific licensing documents, such as ER and SAR.
- Repeat plant planning and scheduling and administrative, quality assurance, procurement, and industrial and public relations activities.
- Provide engineering necessary to excavate and lay out the site for construction. This includes excavation drawings; dewatering calculations and analyses; and design and layout of access roads, parking lots, utilities, etc.
- Provide project management associated with the above tasks.

Appendix E

EEDB PROGRAM DESCRIPTION OF A STANDARD HYPOTHETICAL MIDDLETOWN SITE FOR NUCLEAR POWR PLANTS*

E.1 General

This site description provides the site and environmental data, derived from the *Guide for Economic Evaluation of Nuclear Reactor Plant Designs*,[1] modified to reflect current nuclear power plant siting requirements. These data form the site-related bases of the criteria used to develop the conceptual designs of the nuclear power plant technical data models for the EEDB Program, including evaluation of the routine and accidental release of radioactive and other liquids and gases to the environment. The site is representative of locales found in the northeastern United States.

E.2 Topography and General Site Characteristics

The site is located on the east bank of the North River at a distance of 25 miles south of Middletown, the nearest large city. The North River flows from north to south and is ~0.5 mile (2600 ft) wide adjacent to the plant site. A flood plain extends from both river banks an average distance of 0.5 mile, ending with hilltops generally 150 to 250 ft above the river level. Beyond this area, the topography is gently rolling, with no major critical topographical features. The plant site itself extends from river level to elevations of 50 ft above the river level. The containment building, other Seismic Category I structures, primary non-Seismic Category I structures, and the switchyard are located on level ground at an elevation of 18 ft above the mean river level. According to U.S. Army Corps of Engineers' studies of the area, this elevation is 10 ft above the 100-year maximum river level.

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*Developed by United Engineers & Constructors, Inc., for the U.S. DOE EEDB Program.

To optimize land area requirements for the nuclear power plant site, maximum use of the river location is employed. The containment structure is located ~400 ft from the east bank of the river. The site land area is taken as ~500 acres.

E.3 Site Access

Highway access is provided to the hypothetical site by 5 miles of secondary road connecting to a state highway; this road is in good condition and needs no additional improvements. Railroad access is provided by constructing a spur that intersects the B&M Railroad. The length of the required spur from the main line to the plant site is assumed to be 5 miles. The North River is navigable throughout the year with a 40-ft-wide by 12-ft-deep channel. The distance from the shoreline to the center of the ship channel is 2000 ft. All plant shipments are assumed to be made overland except that heavy equipment (such as the reactor vessel and the generator stator) may be transported by barge. The Middletown Municipal Airport is located 3 miles west of the State highway, 15 miles south of Middletown, and 10 miles north of the site.

E.4 Population Density and Land Use

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

Miles	Cumulative population
0.5	0
1.0	310
2.0	1,370
5.0	5,020
10.0	28,600
20.0	133,000
30.0	1,010,000

There are five industrial manufacturing plants within 15 miles of the hypothetical site. Four are small plants, employing <100 people

each. The fifth, near the airport, employs 2500 people. Closely populated areas are found only in the centers of the small towns so that the local land area used for housing is small. The remaining land, including that across the river, is used as forest or cultivated crop land, except for railroads and highways.

E.5 Nearby Facilities

Utilities are available as follows:

1. Natural gas service is available 2 miles from the site boundary on the same side of the river.
2. Communication lines are furnished to the project boundaries at no cost.
3. Power and water for construction activities are available at the southwest corner of the site boundary.
4. Two independent off-site power sources (one at 500 kV or 230 kV for the generator connection and one at 230 kV or 115 kV for the reserve auxiliary transformer connection) are available at the switchyard.

E.6 Meteorology and Climatology

E.6.1 Ambient temperatures

The winters in the Middletown area are moderately cold, with average temperatures in the low 30s (°F). The summers are fairly humid with average temperatures in the low 70s (°F) and with high temperatures averaging ~82°F. The historic maximum wet bulb and dry bulb temperatures are 78 and 99°F, respectively.

The year-round temperature duration data for the dry bulb and coincident wet bulb temperatures are provided in Fig. E.1 and Table E.1.

E.6.2 Prevailing wind

According to Weather Bureau records at the Middletown Airport, located 10 miles north of the site on a low plateau just east of the North River, surface winds are predominantly southwesterly at 4 to 10

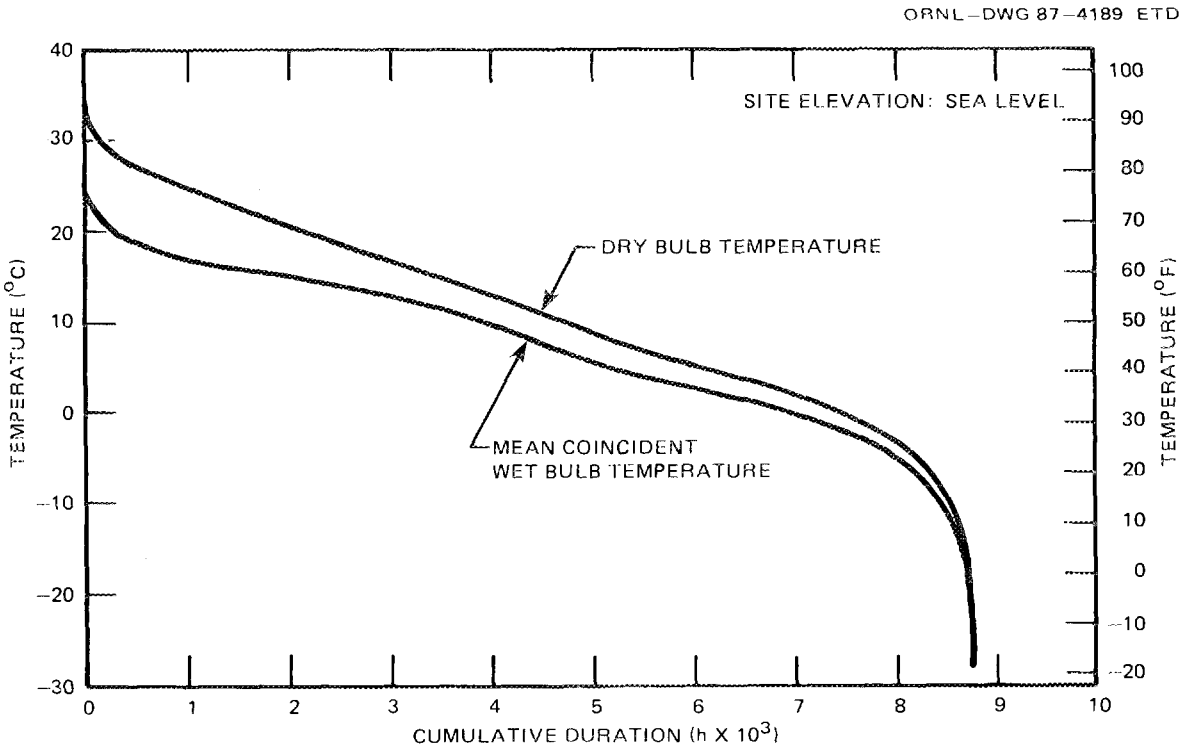

Fig. E.1. Temperature duration curves for Middletown, U.S.A.

knots during the warm months of the year and westerly at 6 to 13 knots during the cool months.

There are no large diurnal variations in wind speed or direction. Observations of wind velocities as a function of altitude indicate a gradual increase in mean velocity and a gradual veering of the prevailing wind direction from southwesterly and westerly near the surface to westerly and northwesterly aloft.

In addition to the above, studies of the area indicate that there is a significant channeling of the winds below the surrounding hills into the north-south orientation of the North River. It is estimated that winds within the river valley blow approximately parallel to the valley orientation >50% of the time.

E.6.3 Atmospheric diffusion properties

During the warm months of the year, according to an analysis of Weather Bureau records, the atmospheric conditions near the surface are

Table E.1. Annual temperature duration data for Middletown, U.S.A.

Cumulative duration (h/yr)	Dry bulb temperature (°F)	Mean coincident wet bulb temperature (°F)
≤1	99	78
10	94	76
75	89	74
225	85	69
400	82	67
788	79	64
1,353	74	61
2,086	69	59
2,800	64	56
3,535	59	53
4,228	54	48
4,872	49	43
5,598	44	39
6,409	39	35
7,214	34	30
7,786	29	26
8,167	24	21
8,421	19	15
8,581	14	11
8,686	9	6
8,733	4	1
8,749	-1	-3
8,756	-6	-8
8,759	-11	-13
8,760	-16	-19

25% unstable (Pasquill A, B, and C), 40% neutral (Pasquill D), and 35% stable (Pasquill E and F). Average wind speeds are ~6 mph during unstable conditions, 10 mph during neutral conditions, and 4 mph during stable conditions.

During the cool months of the year, atmospheric conditions are 15% unstable, 50% neutral, and 35% stable. Average wind speeds are 6 mph during unstable conditions, 12 mph during neutral conditions, and 4 mph during stable conditions.

E.6.4 Severe meteorological phenomena

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

The area near the site experiences an average of 35 thunderstorms a year, with maximum frequency in early summer. High winds near 60 mph, heavy precipitation, and hail are recorded about once every 4 years. The 10-year, 24-h rainfall for the site is defined as 4.9 in.

In 40 years of record keeping, there have been 20 tornadoes reported within 50 miles of the site. This moderately high frequency of tornado activity indicates a need to design Seismic Category I structures at the site for the possibility of an on-site tornado. Maximum tornado frequency occurs during the months of May and June.

During the past 40 years, there have been ten storms in which freezing rain has caused power transmission line disruptions. Most of these storms have occurred in early December.

E.6.5 Potential accident release meteorology

Use the latest Nuclear Regulatory Commission (NRC) requirements.[2]

E.7 Hydrology

The North River provides an adequate source of raw makeup water for the station. The average maximum temperature is 75°F, and the average minimum is 39°F. The mean annual temperature is 57°F.

U.S. Army Corps of Engineers' studies indicate that the 100-year maximum flood level rose to 8 ft above the mean river level. Near the site there are no dams that could fail and cause the river to rise above the 8-ft level.

E.8 Geology and Seismology

E.8.1 Soil profiles and load-bearing characteristics

Soil profiles for the site show alluvial soil and rock fill to a depth of 8 ft, Brassfield limestone to a depth of 30 ft, blue-weathered shale and fossiliferous Richmond limestone to a depth of 50 ft, and bedrock to a depth of >50 ft. Allowable soil bearing is 6,000 psf, and rock-bearing characteristics are 18,000 and 15,000 psf for Brassfield and Richmond strata, respectively. No underground cavities exist in the limestone.

E.8.2 Seismology

The site is located in a generally seismically inactive region. Historical records show three earthquakes have occurred in the region between 1870 and 1984. A safe shutdown earthquake (SSE) with a horizontal ground acceleration of 0.25 g provides conservative design margin. For design purposes, the horizontal and vertical component Design Response Spectra given in NRC *Regulatory Guide 1.60* (Ref. 3) are linearly scaled to a horizontal ground acceleration of 0.25 g.

E.9 Sewage and Radioactive Waste Disposal

E.9.1 Sewage

Sewage generated on-site must receive primary and secondary treatment before discharge into the North River. Nonradioactive wastewater must be discharged in compliance with Environmental Protection Agency (EPA) effluent standards as promulgated in 40 CFR 423.

E.9.2 Gaseous and liquid radioactive wastes

Gaseous and liquid effluent releases at the site must comply with 10 CFR 20 and the intent of Appendix I of 10 CFR 50.

E.9.3 Solid radioactive wastes

On-site storage of solid radioactive wastes to permit radioactive decay is permissible, but ultimate disposal on-site is not planned.

References

1. U.S. Atomic Energy Commission, "Appendix A," *Guide for Economic Evaluation of Nuclear Reactor Plant Designs*, NUS-531.

2. *NRC Regulatory Guide 1.145*, February 1983.

3. *NRC Regulatory Guide 1.60*, October 1973 (rev. December 1973).

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