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Cost Estimate Guidelines for Advanced Nuclear Power Technologies

C. R. Hudson II

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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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.

Prepared by the
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CONTENTS

	Page
ACKNOWLEDGMENTS	v
ABSTRACT	1
1. INTRODUCTION	1
2. OVERNIGHT CAPITAL COST GROUND RULES	6
2.1 General Ground Rules	6
2.2 Specific Cost-Estimating Assumptions	8
2.3 EEDB Cost Account Definitions	13
2.3.1 Direct cost accounts	13
2.3.2 Indirect cost accounts	14
2.4 Overnight Capital Cost Documentation	19
2.4.1 Cost reports	19
2.4.2 Plant bulk commodities data	19
2.4.3 Plant labor requirements data	22
2.4.4 Development/prototype costs	22
3. TOTAL CAPITAL COST	28
3.1 Contingency	28
3.2 Cash Flow	29
3.3 Escalation	29
3.4 Interest During Construction	29
3.5 Total Capital Cost	30
4. BUSBAR GENERATION COST	32
4.1 General Assumptions and Methodology	32
4.2 Capital Cost	33
4.3 O&M Costs	33
4.4 Fuel Costs	38
4.5 Decommissioning	39
4.6 Total Busbar Cost	41
5. ALTERNATIVE POWER PLANT COMPARISONS	42
5.1 Capital Cost	42
5.2 O&M Cost	43
5.3 Fuel Costs	45
5.4 Decommissioning	45
5.5 Total Busbar Cost	45

Page

5.6 Example Calculations 46

5.6.1 Cost calculation for a 400-MW(e) coal plant 46
5.6.2 Cost calculation for a two-unit 800-MW(e) coal plant 48
5.6.3 Cost calculation for a 800-MW(e) PWR plant 49

REFERENCES 52

APPENDIX A. EEDB CODE OF ACCOUNTS FOR LIQUID-METAL REACTOR (LMR) CONCEPT 53

APPENDIX B. EEDB CODE OF ACCOUNTS FOR HIGH-TEMPERATURE GAS-COOLED REACTOR (HTGR) CONCEPT 81

APPENDIX C. LISTING OF SAMPLE LEAD PLANT FOAK TASKS 89

APPENDIX D. REPLICA AND TARGET PLANT ENGINEERING AND MANAGEMENT TASKS 91

APPENDIX E. EEDB PROGRAM DESCRIPTION OF A STANDARD HYPOTHETICAL MIDDLETOWN SITE FOR NUCLEAR POWER PLANTS 93

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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*[1] (NECDB).

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.

Lead plant costs. Lead plant costs include all costs from 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 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.

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.

Target plant costs. The target plant is the nth-of-a-kind (NOAK) or equilibrium commercial plant of identical design to the lead plant. Target 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 target plant also reflects the factory experience of prior plants leading to the target plant.

Base construction cost. The base construction cost is the overnight plant capital cost for the direct and indirect costs only. This cost is lower than the total capital cost because cost components 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, and taxes. Reactor manufacturer (RM) home office engineering and services are also included in a separate account (except as noted in Sect. 2.3).

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.

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.

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.

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.

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.

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 greater than 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.

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.

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

Building block. A building block is a combination of one or more 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.

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

Large modular plant. A power plant consisting of multiple building blocks is referred to as a large modular plant.

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.

2. OVERNIGHT CAPITAL COST GROUND RULES

2.1 General Ground Rules

This section describes the ground rules to be followed in developing the overnight 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, 1986, 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, allocable 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 DOE-NE.
6. All construction and installation costs may reflect a separated construction concept whereby nuclear safety 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 contruction 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 developing, installing, and 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, 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 from 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. 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 target 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 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 onsite 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% <u>unit</u> 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 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.

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. 3.1.1). 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 handling, reprocessing, and manufacturing facilities will be assumed to be safety grade.
11. Site conditions for each plant are similar to those at the "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 target plants are defined in Appendices C and D.

15. Engineering Home Office and Services includes only the AE costs for design, engineering, procurement, cost engineering, Q/A—Q/C, reproduction services, etc. (Account 92).

16. Engineering Home Office and Services costs of the RM (Account 95) are assumed to be zero for the replica and target plant. Any applicable 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 1986 dollars are given in Table 2.2.

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

Table 2.2. Composite labor rates for 1986
effective date: January 1, 1986

Installation activity	Cost ($/MH)	Installation activity	Cost ($/MH)
Boiler equipment	22.94	Grading	20.01
Circulating water pipe (reinforced concrete)	22.13	HVAC system and ductwork	23.21
		Instrumentation	23.15
Circulating water pipe (steel)	23.10	Miscellaneous electrical work[a]	23.32
		Miscellaneous mechanical equipment[b]	23.63
Clear and grub	17.27	Pipe — drainage and sewage	21.82
Concrete	17.68	Process piping	23.70
Concrete chimney shell	19.68	Pumps and motors	24.33
Condenser	22.97	Railroad work	17.27
Demolition	18.19	Reinforcing steel	22.79
Ductwork	22.85	Roads — blacktops	17.86
Electrical equipment	23.10	Sidewalks — cement	18.59
Embedded steel	21.43	Structural steel and miscellaneous iron	22.93
Excavation — bulk	20.16		
Excavation — structural	18.61		
Fill — bulk	20.16	Tanks and heat exchangers	23.19
Fill — compacted	17.42	Turbogenerator units	23.36
Forms — metal	22.93	Yard piping	23.27
Forms — wood	19.54		

[a]Components for miscellaneous electrical work:

- Communication systems
- Conduit and cable tray
- Electrical containment penetrations
- Fire detection systems
- Grounding and cathodic protection
- Heat tracing and freeze protection
- Lighting and service power
- Security systems
- Wire and cable

[b]Components for miscellaneous mechanical equipment:

- Air separators
- Building service equipment (other than HVAC)
- Elevator and crane equipment
- Filters and strainers
- Fire suppression systems
- Fuel handling equipment
- Hydrogen recombiner
- Lube oil conditioning equipment
- Sewage treatment facilities
- Shop apparatus
- Water treatment equipment

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 costs to move the equipment within the facility and to its final on-site receiving 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, etc. are included.

Labor rates for this work include base rates, fringe benefits and 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 describe the 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. Table 2.3 shows the wide range of data covered in recent cost estimates based on this approach. 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. As mentioned, it is desirable to have indirect costs developed on a bottoms-up basis. In any case, the cost estimate procedure shall be fully documented by the concept proponent.

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

Table 2.3. Indirect cost percentages

EEDB Account No.	Account description	Nuclear construction (%)	Fossil construction (%)
91	Construction service[a]	62.5–81.2	47.5–48.2
911	Temporary construction facilities	30.0–38.8	16.6–18.0
912	Construction tools and equipment	12.0–19.1	10.0–12.3
913	Payroll insurance and taxes	20.0–22.7	18.8–19.0
914	Builders risk insurance	0.5	0.5
92	Home office engineering and service[b]	17.0–23.4	6.5–11.0
921	Home office services	16.0–22.1	6.0–9.9
922	Home office QA	0.5–0.8	0.0
923	Home office construction management	0.5	0.5–1.1
93	Field office engrineering and service[a]	28.0–39.8	14.9–18.0
931	Field office expenses	2.0–4.6	1.1–2.0
932	Field job supervision	20.0–28.3	13.0
933	Field QA/QC	2.0–3.0	0.0–0.4
934	Test and startup engineering	4.0	0.6–3.0

[a]Expressed as a percentage of total direct labor costs.

[b]Expressed as a percentage of total base cost excluding the NSSS/Steam Generator and Turbine Generator package costs.

2.3.2.1 Construction services costs (Account 91). Construction services (Account 91) includes costs for AE-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 for Account 92.

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 AE-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, and inspection of construction activities. 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 Q/A (Account 941). These expenses include owner project management, engineering, integration, control, and Q/A.

Taxes and insurance (Account 942). These expenses cover all owner's nuclear and other insurance premiums, state and local taxes, 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 target plant.

2.4 Overnight 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. 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 2.4. 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 needs be supplied.

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.

Table 2.4. Capital cost supporting data

SDD TITLE ______________
SDD NUMBER ______________

LEAD (FOAK) PLANT __________
REPLICA PLANT __________
TARGET (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.

- 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.
- 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 aboveground,
  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.

2.4.3 Plant labor requirements data

Craft and engineering labor requirements will be summarized by two- and three-digit cost accounts as well as by total plant. Specific, individual, manhour data will be provided for the following workers: 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.

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 summarized by estimated year of expenditure and expressed in constant dollars as defined in Sect. 2.1. A sample format is given in Table 2.7.

Table 2.5. Plant bulk commodities

LEAD (FOAK) PLANT ________
REPLICA PLANT ________
TARGET (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)

LEAD (FOAK) PLANT ____________
REPLICA PLANT ____________
TARGET (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)

LEAD (FOAK) PLANT ____________
REPLICA PLANT ________________
TARGET (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)

Table 2.6. Plant labor requirements

LEAD (FOAK) PLANT ____________
REPLICA PLANT ________________
TARGET (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	

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

Year of expenditure	Developmental costs		Prototype facilities	
	Annual	Cumulative	Annual	Cumulative

3. TOTAL CAPITAL COST

This section provides the ground rules for preparing an estimate of the total capital cost of a power plant. The overnight base 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 overnight base 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 proponent in detail.

The contingency estimate will be expressed in the same year's dollars as the overnight capital 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, effective tax-adjusted cost of money. The financial parameters given in Table 3.1 are from the DOE NECDB[1] and are to be assumed in determining interest during construction (IDC) costs.

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.

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

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
Federal income tax rate, %	46
State income tax rate, %	4
Effective (tax-adjusted) cost of money, %/year	9.0
Inflation rate, %/year	5.0
Real (inflation-adjusted) cost of money, %/year	3.8

where

T = point 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 capital 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. 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	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 conditioning heat rejection system	____
	Total direct costs	
91	Construction services	
92	AE home office engineering and service	
93	Field office supervision and service	
94	Owner's expenses	
95	RM home office engineering and service	____
	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 current 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%/year (nominal) and 3.8%/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, allocable 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 DOE-NE.

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.

A fixed charge rate is used to properly account for depreciation, interim replacements, and income tax effects. The fixed charge rate is dependent upon the fraction of the total plant investment that is eligible for tax depreciation (depreciation may not be taken on AFUDC). This fraction is, in turn, dependent upon the construction time length. Fixed charge rates for various construction lengths are provided in Table 4.1 as calculated using the computer code described in Appendix B of the NECDB.[1] Other input parameters used in determining the fixed charge rate are given in Table 4.2.

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

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

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

Table 4.1. Capital cost fixed charge rates

Construction length (months)	Tax depreciation allowance (% of as-spent investment)	Constant dollar fixed charge rate
36	83.74	0.0920
42	81.32	0.0930
48	79.37	0.0938
54	76.78	0.0948
60	74.77	0.0956
66	72.63	0.0964
72	71.13	0.0970

Table 4.2. Fixed charge rate input parameters

Parameters	Rate
Investment tax credit, %	8
Effective (tax adjusted) cost of money, %/year	9
Inflation rate, %/year	5
Real cost of money, %/year	3.81
Combined state and federal tax rate, %	48.16
Property tax rate, % of capital investment/year	2
Interim replacement rate, % of investment/year	0.5
Book life, year	30
Tax depreciation duration, years, TEFRA	10
Tax depreciation component, % of investment	See Table 4.1
Accounting method	Normalized

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 Table 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.

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. For multiblock plants, the annual O&M costs are to be specified by block as well as for the total plant.

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

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

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.

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

Table 4.3. 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 makeup fluids, chemicals, gases, lubricants, office and personnel supplies, and monitoring and record supplies; costs for on-site radioactive and nonradioactive waste management activities.
Regulatory fees, inspections, and review expenses	NRC annual fees and review costs as well as other routine safety, environmental, and health physics inspections.
Off-site support services	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	Administrative and general salaries and related expenses, welfare and pension costs, commercial and government liability insurance, property damage insurance, and replacement power insurance.

Table 4.4. On-site staff requirements

Category	Number of persons
Plant manager's office	
Manager	
Assistant	
Quality assurance	
Environmental control	
Public relations	
Training	
Safety and fire protection	
Administrative services	
Health services	
Security	______
Subtotal	
Operations	
Supervision (excluding shift)	
Shifts	______
Subtotal	
Maintenance	
Supervision	
Crafts	
Peak maintenance (annual average)	______
Subtotal	
Technical and engineering	
Reactor	
Radiochemical	
Engineering	
Performance, reports, and technicians	______
Subtotal	______
Total staff	

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.

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

1. Uranium ore price in 1986 is $34/lb (1986 dollars) with real escalation of 1.0%/year.
2. Uranium conversion price in 1986 is $8/kg U (1986 dollars) with escalation equal to inflation (i.e., no real escalation).
3. Enrichment price in 1986 is $115/kg SWU (1986 dollars) with real de-escalation of 3.4%/year to 2005 and no real escalation thereafter.
4. Waste disposal fee is 1 mill/kWh (1986 dollars) with no real escalation.
5. 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. Capital cost estimates for such facilities shall include a contingency cost as described in Sect. 3.1 of this report.

Some components of the fuel cycle may be capitalized for tax purposes rather than expensed. If any component of the fuel cycle is capitalized, then the analysis should be performed in current 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 percent 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 \$140 million (1986 dollars) for an 1100-MW(e) unit. This value should be linearly scaled [i.e., \$127.27/kW(e)] for blocks (units) of other sizes.

It should be assumed that an external sinking fund of U.S. government securities earning 8.5%/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

$$PWDC = \frac{DC_o \times SFF(8.5,30) \times \sum_i 1/(1 + d)^{t_i - t_1}}{(1 + d)^{30} \times SFF(X,30)} ,$$

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 COMPARISONS

The economic competitiveness of advanced nuclear power technologies will be compared relative to other alternative power plants. 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 1986 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%/year (nominal) and 3.81%/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 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

Table 5.1. Alternative power plant capital cost data

Plant type	Total capital cost (millions 1986$)
400-MW(e) single-unit coal	730
400-MW(e) first of two units coal	733
400-MW(e) second of two units coal	556
600-MW(e) single-unit coal	913
600-MW(e) first of two units coal	917
600-MW(e) second of two units coal	696
800-MW(e) single-unit coal	1071
800-MW(e) PWR	1733
1200-MW(e) PWR	2123

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.

The coal-fired plants have precipitators and wet limestone scrubbers. The PWR plants conform to 1984 licensing standards. All plants use mechanical 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 1986$)

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

[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 1986$)
400-MW(e) single-unit coal	22.9
600-MW(e) single-unit coal	25.0
800-MW(e) single-unit coal	27.1
800-MW(e) two-unit coal	34.6
1200-MW(e) two-unit coal	38.9
800-MW(e) PWR	47.4
1200-MW(e) PWR	47.8

5.3 Fuel Costs

The delivered price of coal is assumed to be $1.75/MBtu (1986 dollars) in 1986. 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	1986 Price	Real escalation rate (%/year)
Uranium ore, $/lb	34	1.0
Conversion, $/kg U	8	0
Enrichment, $/kg SWU	115	−3.4 to 2005, 0 thereafter
Fabrication, $/kg HM	240	0
Waste disposal, mills/kWh	1	0

5.4 Decommissioning

The cost of decommissioning an 1100-MW(e) PWR plant is estimated to be $140 million in 1986 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 decommissioning costs for the PWR 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 busbar 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 (1986 mills/kWh)				
	Capital	O&M	Fuel	Decommissioning	Total
400-MW(e) single-unit coal	27.90	9.33	22.19		59.42
600-MW(e) single-unit coal	23.26	6.79	21.97		52.02
800-MW(e) single-unit coal	20.47	5.52	21.74		47.73
800-MW(e) two-unit coal	24.69	7.13	22.30		54.12
1200-MW(e) two-unit coal	20.60	5.34	22.08		48.02
800-MW(e) PWR	34.24	9.66	6.96	0.42	51.28
1200-MW(e) PWR	27.97	6.49	6.96	0.42	41.84

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 analogous 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 $730 million (1986 dollars). The constant dollar fixed charge rate to be used for the coal plant alternatives in this study is 0.0938. 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 \$27.90/MWh, which is equivalent to 27.90 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 (\$22.9 million) and the annual energy generation (2.454 million MWh), the levelized O&M cost is calculated to be 9.33 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 (1986 dollars), a plant heat rate of 9684 Btu/kWh, and annual generation of 2.454 million MWh, an annual FC of \$41.59 million (1986 dollars) in the reference year is obtained. The time between the commercial operation date and the reference date is 2000 − 1986 or 14 years. The combined escalation/discount rate Z is 1.038/1.01 − 1 or 2.78%. Substituting values into the previous equation yields

$$PWFC = \frac{41.59 \times 10^6 \times 1.1495}{0.0496} ,$$

or

$$PWFC = \$964 \times 10^6 \text{ (1986 dollars)} .$$

Using the equation in Sect. 4.4 and a capital recovery factor (CRF) of 0.0565, the levelized fuel cost is calculated as

$$\frac{0.0565 \times 964 \times 10^6}{2.4544 \times 10^6} = 22.19 \text{ mills/kWh} .$$

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 59.42 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

$$LCC = \frac{0.0938 \times [733 + 556 \ (1.0381)^{-1}]}{2.454 \times 10^6 \times [1 + (1.0381)^{-1}]} ,$$

or

$$LCC = 24.69 \text{ mills/kWh} .$$

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 $22.9 million, while for all other years in between, the annual cost is $34.6 million. Following the equation given in Sect. 4.3, the present worth of the O&M costs (PWOM) is calculated as $608.25 million (1986 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 7.13 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

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

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 = 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 $\$1.9 \times 10^9$ (1986 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

$$\frac{0.0565 \times 1.9 \times 10^9}{2.4544 \times 10^6 \times [1 + (1.0381)^{-1}]} = 22.3 \text{ mills/kWh} .$$

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 54.12 mills/kWh (1986 dollars).

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

Large monolithic light-water reactor power plants are also to 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 0.097. The total capital cost is given in Table 5.1 as $1733 million (1986 dollars), and the annual energy generation at 70% capacity factor is 4.909 million MWh. These values produce a constant dollar levelized cost of 34.24 mills/kWh (1986 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 $47.4 million from Table 5.3 divided by the annual energy generation or 9.66 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 $604.7 million (1986 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 6.96 mills/kWh.

5.6.3.4 Decommissioning cost. The decommissioning cost is assumed to scale linearly with size from the reference point of $140 million for an 1100-MW(e) plant. The assumed cost is 140/1100 × 800 or $101.8 million (1986 dollars).

Using the equations given in Sect. 4.5 and an assumed decommissioning cost of $101.8 million in 1986 dollars with no real escalation, the present worth of the decommissioning cost can be written as

$$\text{PWDC} = \frac{101.8 \times 10^6 \times 0.008051}{3.0698 \times 0.007336} ,$$

or

$$\text{PWDC} = \$36.39 \text{ million (1986 dollars).}$$

Dividing this amount by the annual energy generation and the CRF for 30 years produces a levelized decommissioning cost of 0.42 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 51.28 mills/kWh (1986 dollars).

REFERENCES

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4. *Energy Economic Data Base (EEDB) Program, Phase VII Update Report*, United Engineers and Constructors, UE&C-ORNL-850621, June 1985.

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 ______________
Target (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 & SERVICE					
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/H20 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 AND 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 ____________
Target (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	YARDWORK					
212	REACTOR BUILDING					
213	TURBINE BUILDING					
214	SECURITY BUILDING					
215	REACTOR SERVICE BLDG.					
216	RADIOACTIVE WASTE BLDG.					
217	FUEL STORAGE AREA					
218A	CONTROL BLDG.					
218B	ADMINISTRATION BLDG.					
218C	AUXILIARY BOILER BLDG.					
218D	FIRE PUMP HOUSE					
218E	HELIUM & MISC. GAS STORAGE AREA					
218F	MAKEUP WATER TREATMENT BLDG.					
218G	CONFINEMENT FILTRATION BLDG.					
218H	MAIN STEAM & FEEDWATER PIPING STRUC.					
218I	WAREHOUSE					
218L	HELIUM PURIFICATION					
218N	SPENT FUEL STORAGE AREA					
218R	RADWASTE MANAGEMENT BLDG.					
218S	HOLDING POND & CONTROL HOUSE					
218U	1E POWER BUILDING					
218W	PERSONNEL SERVICES BLDG.					
218X	ENCLOSURE COOLING FACILITY BLDG.					
218Y	REACTOR MAINTENANCE ENCLOSURE					
218Z	AUXILIARY REACTOR AREA					
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 AND VESSEL SYSTEMS					
222	HEAT TRANSPORT SYSTEM					
223	SHUTDOWN COOLING SYSTEM					
224	RADWASTE PROCESSING SYSTEMS					
225	FUEL HANDLING, STORAGE, AND SHIPPING SYSTEM					
226	OTHER REACTOR SERVICE SYSTEMS					
227	PLANT CONTROL, DATA, AND INSTRUMENTATION SYSTEMS					
228	REACTOR PLANT MISC. 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 & SERVICE					
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. & SERVICE					
	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 model construction.

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 TARGET 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 Target 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 in 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 POWER 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.

To optimize land area requirements for the nuclear power plant site, maximum use of the river location is employed. The containment structure

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

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 curves for the dry bulb temperatures and coincident wet bulb temperatures are shown in Fig. 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 knots during the warm months of the year and westerly at 6 to 13 knots during the cool months.

ORNL--DWG 86--4366 ETD

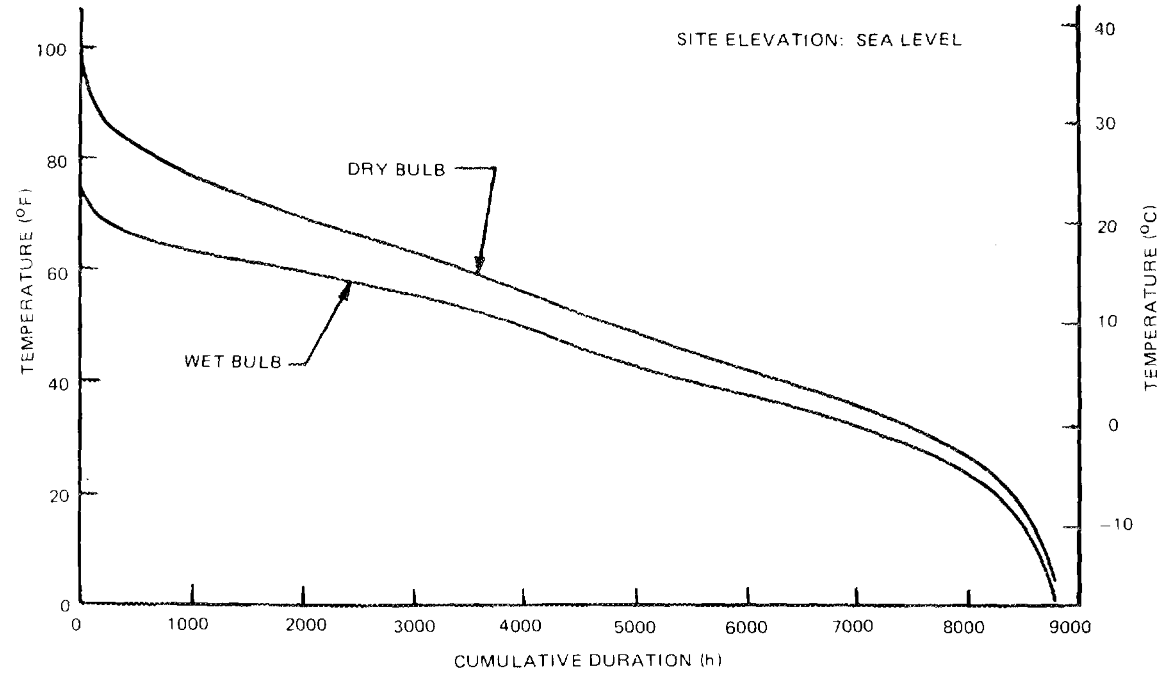

Fig. E.1. Temperature duration curves for Middletown, U.S.A.

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 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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