GEFR-00940
UC-87Ta
March1995

The U.S. Advanced Liquid Metal Reactor Program

ALMR

Actinide Recycle System

BECHTEL Raytheon Babcock & Wilcox BORG WARNER

1994 Capital and Busbar Cost Estimates

Prepared for the U.S. Department of Energy
San Francisco Operations Office
Oakland, California

GE Nuclear Energy

GEFR-00940
UC-87Ta
March 1995

TITLE: 1994 ALMR CAPITAL AND BUSBAR COST ESTIMATES

EDITORS: Omer Gokcek, Pierre Babka, Greg Pavlenco, Frank Kemmerer

Approved: ______________________
J.E. Quinn, Manager
ALMR Projects

Prepared for the
United States Department of Energy
Under Contract No. DE-AC03-89SF17445

GE Nuclear Energy

Advanced Reactor Programs
San Jose, California 95125-1088

DISCLAIMER

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

1994 ALMR
CAPITAL AND BUSBAR COST ESTIMATES

1.0 INTRODUCTION AND SUMMARY

This report presents the capital and busbar costs estimated for the design of the Advanced Liquid Metal Reactor (ALMR). The previous bottom-up capital and busbar cost estimate for the ALMR was made in 1993 (Reference 1-1). Since that time there have been major changes in the plant design and steam cycle, as well as a comprehensive review of the 1993 cost estimates by an expert panel and issuance of a new, expanded set of DOE cost guidelines for advanced nuclear concepts (Reference 1-2). All of these changes and activities have impacted the costs in this 1994 estimate. With so many changes of different types, there has been no attempt made to identify the impacts of the individual changes in design and cost estimating methodology.

The reference design is a modification of the 1993 ALMR reference design described in the Summary Plant Design Description (Reference 1-3). The plant feature changes made to the 1993 design are the following:

1. The reactor module thermal rating has been increased from 471 to 840 MWt and the net electric output of each power block has been increased from 496 to 622 MWe.

2. Burner core instead of break-even core.

3. Elimination of IHTS isolation valves and associated support system.

4. Portion of the IHTS and SGS have been redesigned to be safety grade to compensate for the elimination of the main sodium isolation valves and associated subsystems. Additional valves were added to the steam/water system to accommodate safety grade requirements.

5. Change of sodium dump tank material to 2 1/4Co-1Mo to be compatible with the steam generator.

6. Change of IHTS pump elevation to simplify the IHTS piping design and cost.

7. The addition of the Primary Sodium Auxiliary Cooling System (PSACS) into the Primary Sodium Process System to facilitate maintenance at IHTS.

8. The adoption of a fixed localized reactor cover gas process system in place of the centralized reactor cover gas process system which requires a mobile unit to process and transport the cover gas between reactors and central process facility.

The methods used to estimate the capital and busbar costs have also been improved since 1991 in several areas. Most notable of these are more detailed or significantly modified estimates made of: a) Equipment costs for the intermediate heat transport system (IHTS); b) factory manufacturing costs of facility modules; c) indirect capital costs; d) owner's costs; e) contingencies; f) interest during construction; and, g) fuel costs.

Some of the modifications to the design and operation of the plant, as well as to the cost estimating methods and conditions, have sizable effects on the estimated costs. Examples are the addition of permanent refueling enclosures and larger turbine generator building which increase the direct capital costs. Another change that increases fuel busbar costs is the assignment of ownership of the fuel facilities to an industrial organization rather than a utility. Countering these increases are other changes which decrease the estimated values. The results of these changes for a 3-power block, NOAK plant in terms of 1994 dollars are as follows:

- The total capital costs decreased more than 17.5 percent in terms of dollars per kilowatt electric.
- The fuel costs increase by 52 percent in term of mills per kilowatt hour
- The total busbar costs decreased by only 3.7 percent (from 42.00 to 40.5 mills per kilowatt hour).

The reduction in total busbar costs from 1993 to 1994 for 3-block plants (in 1994 mills/kWh) are as follows:

- First Plant reduced from 51.6 to 47.9
- Nth Plant reduced from 42.0 to 40.5.

The 1994 results are summarized in this section. Sections 2 through 10 provide details of the estimates for the different components of the capital and busbar costs, and Section 11 is a compilation of all the busbar cost estimates.

1.1 Plant and Fuel Cycle Scenarios

The 1994 ALMR cost estimate includes the costs required to build and operate several configurations of ALMR plants, based on the reference design.

Busbar costs were computed for four scenarios (F1, F3, N1, and N3) as described in Table 1-1. The primary, two-character designator used for these scenarios has the following definition:

- The first character refers to the plant type (F = First Commercial; N = Nth-Of-A-Kind, or NOAK);
- The second character refers to the number of power blocks; and,

Four basic capital cost estimates were made, representing an expandable first power block commercial plant in Scenario F1, a full size three-power block first commercial plant in Scenario F3, a single-power block NOAK plant in Scenario N1, and a three-power block NOAK plant in Scenario N3. It is noted that Scenario F1 represents in fact the first power block of the three-power block first commercial plant (F3) and, therefore, it is based on common facilities sized for a full size plant. By contrast, Scenario N1 represents a single-power block NOAK plant which has common facilities sized only for one stand-alone power block.

All NOAK full size plant scenarios are based on the assumptions that the power blocks are brought on line with a minimum amount of time between them and represent capacity additions of essentially 1866 MWe at one time.

Portions of the First-Of-A-kind (FOAK) costs given in Section 2 (Developmental and Commercialization Costs) that must be recovered by the first commercial plants will be defined in the ALMR commercialization plan. None of these FOAK costs have been included in the capital and busbar costs for the first commercial plants .

1.2 Summary of Capital and Busbar Costs

Table 1-1 shows a summary of the total capital and busbar costs estimated for the ALMR in 1994. Four separate ALMR cases are shown corresponding to the plant scenarios discussed in Section 1-1.

1.3 Capital Costs

The reported capital costs represent the estimated costs to the utility which is purchasing the plant; that is, prices charged by the equipment suppliers and facility constructors. To arrive at these prices, the costs to fabricate, build and construct the equipment and facilities were first estimated. A 15% margin, specified by the DOE cost guidelines [Reference 1-2], was then added to the basic costs of the NSSS equipment and 7% for BOP suppliers.

In 1994, estimates of the NSSS equipment costs were based on an approach which reflects multiple product factories and is consistent with current learning curves used to estimate factory manufacturing costs for this type of equipment.

The basic costs for first units of the individual pieces of NSSS equipment were estimated by ALMR team members at Babcock & Wilcox, Foster Wheeler, and Westinghouse. Reductions in the NSSS factory equipment costs due to learning effects were then estimated by GE based generally on the default value of 94% for a unit learning curve applied to both labor and material. Costs for the shippable reactor module, the steam generator, the intermediate heat exchanger, and the EM pump were based on a 90% learning curve for labor and a 10% discount on materials for NOAK plants.

Reductions in the plant facility capital cost estimates due to field learning effects were estimated using the values in the DOE cost guidelines, i.e., 97% for field labor when building multiple power blocks on the same site and 98% from site to site. Also, unit costs for site labor, materials and commodities were those specified in the guidelines. Estimates of indirect costs were based on the experiences of Bechtel National, Incorporated

Table 1-2 presents a two-digit account summary of the total capital costs for the four basic plant scenarios, F1, F3, N1 and N3, described in Section 1.1. The total capital cost consists of the base construction capital cost plus contingency, escalation, and interest during construction (also referred to as Allowance for Funds Used During Construction, or AFUDC). The base construction cost is the sum of direct and indirect costs, including owner's cost and the overnight capital cost is defined as the base construction cost plus contingency. These costs are presented in constant January 1994 dollars using the EEDB tabular format and code of accounts and assuming real escalation is zero (no inflation).

The capital costs for the first commercial plant scenarios shown (F1 and F3) include only costs that are repetitive in nature. All costs unique to the first commercial plant that will not be incurred for subsequent plants of identical design are identified separately as First-Of-A-Kind (FOAK) costs in Section 2.

Tables 1-3 through 1-6 provide the total capital costs for the F1, F3, N1, and N3 plant scenarios. These tables show the capital costs subdivided into the two categories consistent with the separated construction approach. The Nuclear Island (NI) costs are defined as those associated with all equipment and facilities located within the nuclear safety region of the plant. The costs under Balance-Of-Plant (BOP) are based on industrial grade construction experience. NI and BOP contingency costs, shown separately, are the sum total of all contingency costs assessed on an individual account basis. Capital costs for the central fuel cycle facility are excluded from these tables since they are included in the fuel cycle portion of the busbar costs. Costs for special control and shielding assemblies are also included in the fuel cost section.

These distributions of the total capital costs show the effects of the large amount of factory fabrication and modular construction which is possible with the ALMR plant design. Costs are reduced by factory fabrication where labor productivity is higher, labor rates are potentially lower, learning curves are stronger, quality assurance and control are more efficient, reworking is less expensive, and automation is more applicable. Cost control also becomes more effective. Factory manufacturing allows a large reduction in field supervision costs due to the reduced craft labor requirements on-site. The low costs also result from plant standardization effects where the major portion of the cost of design of a power plant is FOAK cost with only a small engineering effort required for each subsequent plant to apply the standard design to a unique site. Details of the base construction costs and the bases of the estimates are given in Sections 3 through 7.

1.4 Busbar Costs

Levelized busbar costs are the primary economic measures used to compare alternatives being considered for future power generation capacity. Busbar costs were calculated for the ALMR using the results of the 1991 estimates made for the capital, O&M and fuel costs, and are presented in Table 1-7. A levelized plant capacity factor of 83% was used in all calculations for the first commercial plants, and a factor of 85% was used for the NOAK plants based on the high availability expected of the modular ALMR design.

Following a recommendation made by a utility panel, there was a major effort initiated in 1990 to factor actual nuclear plant experience into the estimates of both operating and maintenance (O&M) and owner's costs for the ALMR. Since that time, visits have been made to six nuclear sites to gain direct information on the staff levels, procedures, and approaches to O&M. This information was then reviewed in terms of: a) Required plant activities and staffing that had been overlooked in the ALMR estimates; and, b) differences between the ALMR and these water reactors with respect to design and general operating environments. Levels of ALMR staffing and O&M costs were re-estimated based on such considerations. In recent years, the staffing levels and O&M costs have been reviewed by DOE panels of experts (Reference 1-6) with little recommended change.

1.5 Cost Estimating Responsibilities

Since 1987, the capital and busbar cost estimates were generated by industrial personnel with many years of experience in estimating and evaluating costs of equipment and facilities for both nuclear and coal power plants. Argonne National Laboratory, responsible for developing the metal fuel process, provided technical information on the fuel cycle equipment and facilities. Corporate responsibilities for various parts of the estimates over the last six years included the following:

GE Nuclear Energy

Responsibilities:	Overall cost estimates, NSSS, fuel, O&M, busbar costs and Electro Mechanical pump design, fabrication and costs.
Experience:	Major manufacturer of NSSS and nuclear fuel for LWR's, major LMR contractor of 30 years experience, provider of plant services to operating LWR's.

Babcock and Wilcox

Responsibilities:	Shippable reactor module fabrication study and costs, steam generator costs.
Experience:	Major manufacturer of NSSS components and nuclear fuel for LWR's.

Burns and Roe Company

Responsibilities:	Fuel cycle facility layout and costs, ALMR plant maintenance staff assessments. BOP facilities costs.
Experience:	Major A/E firm for LWR, major LMR A/E.

Bechtel National. Inc.

Responsibilities:	NSSS and BOP Facilities Costs, Indirect Capital Costs, AFUDC, Integration of all capital costs.
Experience:	Major A/E firm for LWR, LMR, and fossil-fuel plants.

Foster Wheeler Energy Applications

Responsibilities:	Intermediate Heat Exchanger Costs, Factory Studies.
Experience:	Major manufacturer of NSSS and fossil-fuel plant equipment.

United Engineers & Constructors, Philadelphia, Pa.

Responsibilities:	Plant staffing and O&M costs, Capital Costs Support, Economic Evaluation Support.
Experience:	Major A/E firm for LWR and fossil-fuel plants, management of the DOE's EEDB Program and advanced reactors cost estimating.

Westinghouse Corporation

Responsibilities:	Control rods, ultimate shutdown assembly, IHTS/SAG equipment costs, In-vessel reactor shielding, and instrumentation.
Experience:	Major designer and manufacturer of NSSS and nuclear fuel for LWR's, major LMR contractor.

REFERENCES TO CHAPTER 1

1-1 Hutchins, B., Pavlenco, G. F., and, Babka, P; Editors, "1993 ALMR Capital and Busbar Cost Estimates," GE Nuclear Energy, GEFR-00915, March 1993 .

1-2 Delene, J. G. and C. R. Hudson II, "Cost Estimate Guidelines for Advanced Nuclear Power Technologies," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10071/R3, May 1993.

1-3 Oda, R. T., Editor, "ALMR Summary Plant Design Description," GE Nuclear Energy, GEFR-00909, March 1993.

1-4 Phase X Update (1989) Report of the Energy Economic Data Base Program, EEDB-X, UE&C-ORNL-890915, September 1989 (Draft).

1-5 Phase IV Update (1981) Report of the Energy Economic Data Base Program, EEDB-IV. UE&C-ANL-811130, November 1981.

1-6 "Review of the 1991 Cost Estimates for the Advanced Liquid Metal Reactor," Prepared by Oak Ridge National Laboratory for the U. S. Department of Energy, September 1992.

1-7 Delene, J. G., Fuller, L. C., Hudson, C. R., "ALMR Deployment Economic Analysis," Oak Ridge National Laboratory, Oak Ridge, TN, February 1993 (Preliminary).

Table 1-1

Summary of 1994 ALMR Plant Capital and Busbar Cost Estimates
(Constant January 1994 Dollars)

ALMR Scenario	Plant Capacity MWe	Total Capital Cost ($/kWe)	Total Busbar Costs (mills/kWh)
F1	622	2,394	59.5
F3	1,866	1,829	48.0
N1	622	1,895	47.9
N3	1,866	1,554	40.5

Table 1-2

ALMR Plant Capital Cost Summary
(Thousands of January 1994 Dollars)

EEDB Acct / Account Description	First Comm. Plant		NOAK Plants	
	Case F1 622 mWe	**Case F3** 1866 mWe	**Case N1** 622 mWe	**Case N3** 1866 mWe
20 Land and Land Rights	9,140	10,753	9,140	10,753
21 Structures and Improvements	136,689	306,580	120,242	296,892
22 Reactor Plant Equipment	403,028	981,926	318,838	817,101
23 Turbine Plant Equipment	95,424	280,556	92,698	276,522
24 Electric Plant Equipment	47,776	107,494	39,551	100,696
25 Miscellaneous Plant Equipment	25,787	36,469	20,390	35,548
26 Main Cond. Heat Reject. System	16,899	40,596	15,133	39,622
Total Direct Costs	**734,744**	**1,764,376**	**615,992**	**1,577,136**
91 Construction Services	83,108	178,132	72,348	157,820
92 Home Office Engr. and Services	57,967	72,908	32,770	47,790
93 Field Office Engr. and Serv.	49,347	99,308	40,119	87,211
94 Owner's Cost	146,694	340,965	122,103	304,250
95 RM Home Office Engr. and Services	0	0	0	0
Total Indirect Costs	**337,116**	**691,314**	**267,340**	**597,071**
Base Construction Cost	1,071,860	2,455,690	883,332	2,174,207
Unit Cost, $/kWe	1,723	1,316	1,420	1,165
Contingency	182,426	421,021	147,273	362,928
Total Overnight Cost	**1,254,286**	**2,876,711**	**1,030,605**	**2,537,135**
Unit Cost, $/kWe	2,017	1,542	1,657	1,360
Interest During Construction	235,050	536,910	147,930	362,130
Total Capital Cost	**1,489,336**	**3,413,621**	**1,178,535**	**2,899,265**
Unit Cost, $/kWe	2,394	1,829	1,895	1,554

Table 1-3

ALMR Plant Capital Cost Summary
Case F1 – Single Block 622 mWe First Commercial Plant
(January 1994 Dollars)

EEDB Acct / Account Description	Thousands of Dollars			$/kWe		
	Nuclear Island	**Balance of Plant**	**Total Plant**	**Nuclear Island**	**Balance of Plant**	**Total Plant**
20 Land and Land Rights	0	9,140	9,140	0	15	15
21 Structures and Improvements	105,518	31,171	136,689	170	50	220
22 Reactor Plant Equipment	403,028	0	403,028	648	0	648
23 Turbine Plant Equipment	1,371	94,053	95,424	2	151	153
24 Electric Plant Equipment	18,803	28,973	47,776	30	47	77
25 Miscellaneous Plant Equipment	11,314	14,473	25,787	18	23	41
26 Main Cond. Heat Reject. System	0	16,899	16,899	0	27	27
Total Direct Costs	**540,034**	**194,710**	**734,744**	**868**	**313**	**1,181**
91 Construction Services	53,970	29,138	83,108	87	47	134
92 Home Office Engr. and Service	27,618	30,350	57,967	44	49	93
93 Field Office Engr. and Serv.	29,486	19,862	49,347	47	32	79
94 Owner's Cost	105,585	41,109	146,694	170	66	236
95 RM Home Office Engr. and Serv.	0	0	0	0	0	0
Total Indirect Costs	**216,658**	**120,457**	**337,116**	**348**	**194**	**542**
Base Construction Cost	756,692	315,167	1,071,860	1,216	507	1,723
Contingency	150,290	32,136	182,426	241	52	293
Total Overnight Cost	**906,982**	**347,303**	**1,254,286**	**1,458**	**559**	**2,017**
Interest During Construction			235,050			378
Total Capital Cost			**1,489,336**			**2,394**

Table 1-4

ALMR Plant Capital Cost Summary
Case F3 – Three Block 1866 mWe First Commercial Plant
(January 1994 Dollars)

EEDB Acct / Account Description	Thousands of Dollars			$/kWe		
	Nuclear Island	**Balance of Plant**	**Total Plant**	**Nuclear Island**	**Balance of Plant**	**Total Plant**
20 Land and Land Rights	0	10,753	10,753	0	6	6
21 Structures and Improvements	255,312	51,268	306,580	137	27	164
22 Reactor Plant Equipment	981,926	0	981,926	526	0	526
23 Turbine Plant Equipment	1,631	278,926	280,556	1	149	150
24 Electric Plant Equipment	45,482	62,011	107,494	24	34	58
25 Miscellaneous Plant Equipment	15,730	20,739	36,469	9	11	20
26 Main Cond. Heat Reject. System	0	40,596	40,596	0	22	22
Total Direct Costs	**1,300,082**	**464,295**	**1,764,376**	**697**	**249**	**946**
91 Construction Services	118,710	59,422	178,132	63	32	95
92 Home Office Engr. and Service	31,769	41,139	72,908	17	22	39
93 Field Office Engr. and Serv.	59,579	39,730	99,308	32	21	53
94 Owner's Cost	250,277	90,688	340,965	134	49	183
95 RM Home Office Engr. and Serv.	0	0	0	0	0	0
Total Indirect Costs	**460,334**	**230,979**	**691,314**	**246**	**124**	**370**
Base Construction Cost	1,760,416	695,274	2,455,690	943	373	1,316
Contingency	354,314	66,707	421,021	190	36	226
Total Overnight Cost	**2,114,730**	**761,981**	**2,876,711**	**1,133**	**409**	**1,542**
Interest During Construction			536,910			288
Total Capital Cost			**3,413,621**			**1,829**

Table 1-5

ALMR Plant Capital Cost Summary
Case N1 – Single Block 622 MWe NOAK Plant
(January 1994 Dollars)

EEDB Acct / Account Description	Thousands of Dollars			$/kWe		
	Nuclear Island	**Balance of Plant**	**Total Plant**	**Nuclear Island**	**Balance of Plant**	**Total Plant**
20 Land and Land Rights	0	9,140	9,140	0	15	15
21 Structures and Improvements	96,372	23,870	120,242	155	38	193
22 Reactor Plant Equipment	318,838	0	318,838	513	0	513
23 Turbine Plant Equipment	746	91,951	92,698	1	148	149
24 Electric Plant Equipment	16,125	23,426	39,551	26	38	64
25 Miscellaneous Plant Equipment	8,815	11,575	20,390	14	19	33
26 Main Cond. Heat Reject. System	0	15,133	15,133	0	24	24
Total Direct Costs	**440,896**	**175,096**	**615,992**	**709**	**282**	**991**
91 Construction Services	49,425	22,924	72,348	79	37	116
92 Home Office Engr. and Service	15,482	17,288	32,770	25	28	53
93 Field Office Engr. and Serv.	24,681	15,438	40,119	40	25	65
94 Owner's Cost	87,491	34,612	122,103	140	56	196
95 RM Home Office Engr. and Serv.	0	0	0	0	0	0
Total Indirect Costs	**177,079**	**90,262**	**267,340**	**284**	**146**	**430**
Base Construction Cost	617,974	265,358	883,332	993	427	1,420
Contingency	121,163	26,110	147,273	195	42	237
Total Overnight Cost	**739,137**	**291,468**	**1,030,605**	**1,188**	**469**	**1,657**
Interest During Construction			147,930			238
Total Capital Cost			**1,178,535**			**1,895**

Table 1-6

ALMR Plant Capital Cost Summary
Case N3 – Three Block 1866 MWe NOAK Plant
(January 1994 Dollars)

	Thousands of Dollars			$/kWe		
EEDB Acct Account Description	**Nuclear Island**	**Balance of Plant**	**Total Plant**	**Nuclear Island**	**Balance of Plant**	**Total Plant**
20 Land and Land Rights	0	10,753	10,753	0	6	6
21 Structures and Improvements	246,446	50,447	296,892	132	27	159
22 Reactor Plant Equipment	817,101	0	817,101	438	0	438
23 Turbine Plant Equipment	1,569	274,953	276,522	1	147	148
24 Electric Plant Equipment	42,629	58,067	100,696	23	31	54
25 Miscellaneous Plant Equipment	15,399	20,148	35,548	8	11	19
26 Main Cond. Heat Reject. System	0	39,622	39,622	0	21	21
Total Direct Costs	**1,123,144**	**453,991**	**1,577,136**	**602**	**243**	**845**
91 Construction Services	102,562	55,258	157,820	55	30	85
92 Home Office Engr. and Service	20,705	27,085	47,790	11	15	26
93 Field Office Engr. and Serv.	50,528	36,683	87,211	27	20	47
94 Owner's Cost	218,297	85,953	304,250	117	46	163
95 RM Home Office Engr. and Serv.	0	0	0	0	0	0
Total Indirect Costs	**392,092**	**204,979**	**597,071**	**210**	**110**	**320**
Base Construction Cost	1,515,237	658,970	2,174,207	812	353	1,165
Contingency	300,606	62,322	362,928	161	33	194
Total Overnight Cost	**1,815,843**	**721,292**	**2,537,135**	**974**	**386**	**1,360**
Interest During Construction			362,130			194
Total Capital Cost			**2,899,265**			**1,554**

Table 1-7

Constant Dollar Busbar Costs
(1994 Mills/kWh)

Scenario	Capital	O&M	Fuel	Decommission	Total
F1	31.7	12.7	14.0	1.0	**59.5**
F3	24.0	9.0	14.0	1.0	**48.0**
N1	24.4	10.0	12.4	1.0	**47.9**
N3	20.0	7.1	12.4	1.0	**40.5**

2.0 DEVELOPMENTAL AND COMMERCIALIZATION COSTS

Developmental and commercialization costs refer to those expenditures that are required to get to the point of building the first commercial ALMR plant. They consist of the first six cost categories defined in Section 2.1, Cost Categories, of the DOE cost guidelines [Reference 2-1].

The ALMR program plan includes not only the design and certification of a standard 1866 MWe power plant and the necessary supporting R&D, but also the design of a standard fuel facility and the design, construction and testing of a 311 MWe prototype power plant utilizing a standard single reactor module and its nuclear heat supply system. These are all included in developmental and commercialization costs. However, except for R&D, costs for activities performed prior to the initiation of detailed design are excluded from these estimates.

Table 2-1 lists representative values of the total costs for each of the six developmental and commercialization categories. Standard plant design of the NSSS plus prototype specific design costs are included in the Prototype Facility and Test Category.

New estimates of the prototype capital and operating costs were made based on the 1994 NSSS equipment and facility design. A breakdown of these costs is given in Table 2-2. The construction costs include the manufacture of equipment for one NSSS, a 50% capacity plus the buildings and facilities required to perform the tests. Estimates are also given in Table 2-2 for the costs of the first core load of fuel. Operation and maintenance costs are listed for pre-operational training of the staff, preparation of the test program, and the full safety test program.

REFERENCES TO CHAPTER 2

2-1 J. G. Delene and C. R. Hudson II, "Cost Estimating Guidelines for Advanced Nuclear Power Technologies," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10071/R3, May 1993.

2-2 Hutchins, B., Pavlenco, G. F., and Babka, P; Editors, "1993 ALMR Capital and Busbar Cost Estimates," GE Nuclear Energy, GEFR-00915, March 1993.

Table 2-1

Total FOAK Costs

Component	*(Millions of Constant 1994 $)* **1994 Estimate**
R & D	149
Standard Plant Design	
– NSSS	165
– BOP	167
Prototype Facility & Test	1184
Standard Plant NRC Certification	26
Standard Fuel Cycle Facility Design	154
Factory FOAK	59
Total	**1904**

Table 2-2

ALMR Prototype Cost Estimate

Designator	*(Millions of Constant 1994 $)* 1994 Estimate
A. Prototype Unique Design	
– NSSS	*
– BOP	23
B. Construction Cost of Prototype	
– Direct Costs	466
– Indirect Costs	212
– Contingency	113
Total Overnight Construction Cost	791
C. Licensing Cost	34
D. Fuel Fabrication	91
E. Pre-Operation Cost (Certification Cost)	245
Total Cost of Prototype Test	**1,184**

* Included in NSSS Equipment Cost

3.0 NSSS EQUIPMENT COST

3.1 Introduction and Summary

ALMR NSSS costs were developed based on guidance provided by DOE [References 3-1 and 3-2], and results are summarized in Section 3.3. The results of the cost studies conducted for the ALMR NSSS during 1994 show several areas of significant change. A study was performed in 1993 to evaluate the most cost effective size for the ALMR reactor module. As a result of that study, a decision was made to increase the size and capacity of the reactor module from 471 MWt to 840 MWt. This new reference ALMR design was known as the "Mod-B" and includes a larger diameter reactor vessel, higher capacity heat transfer systems and steam generator. The net electrical output of each module was increased from 165 to 311 MWe, resulting in two modules per power block and six modules for a large plant. This change results in a 25% increase in the electrical output for both the single block and the large plant over the original design. Overall, after adjustment for inflation, the 1994 NSSS NOAK large plant costs including contingency show an increase of approximately 7.4% from those reported in 1993 [Reference 3-3]. In accordance with the DOE guidelines, the NSSS equipment costs in this report contain the specified 15% profit margin for the supplier.

An attribute of the ALMR is that all of the major nuclear steam supply system (NSSS) equipment including the reactor module can be assembled, inspected and tested at a factory, and shipped to the reactor site for immediate installation. The new reference ALMR vessel will require that it be shipped by barge and overland transportation which will restrict the potential reactor sites to about 60% of the known US sites. A factory designed for the manufacture of the basic reactor module with a stable work force and continuous shop loading leads to increased productivity, which together with lower labor rates than at the site, result in much lower manufacturing costs. Factory fabrication also lends itself to increased learning curve benefits, greater assurance that schedules will be met, and allows factory and site work to be performed in parallel, thereby reducing construction schedules.

A cost breakdown at the six-digit EEDB account level is included in Section 3.3. The NSSS equipment costs are presented for the four basic capital cost Scenarios F1, F3, N1, and N3. The plant equipment costs for the F1 scenario are an average of the first two NSSS's and those of the F3 scenario are an average of the first six NSSS's manufactured. The N1 and N3 scenario costs represent the 15th NSSS built. The first-of-a-kind non-repetitive costs include the factory capital equipment cost, factory special tooling, startup costs and initial reactor manufacturing (RM) engineering. These have been estimated by experienced manufacturers and are reported separately in Section 2, Developmental and Commercialization Costs.

3.2 Method of NSSS Equipment Cost Estimation

3.2.1 Basic Assumptions and Input Data

Reactor plant equipment costs were developed using previous experience, proven cost estimating practices, and manufacturer's estimates. Many of the costs were based on General Electric's experience in the manufacture and purchase of components for the boiling water reactor (BWR), and experience related to the design and fabrication of equipment for the Clinch River Breeder Reactor Project (CRBRP). These costs were supplemented by detailed bottoms-up estimates provided by other experienced equipment manufacturers such as Foster Wheeler, Babcock & Wilcox, Byron Jackson, and Westinghouse as well as Oak Ridge National Laboratory. Current estimates are based the equipment for the first module being purchased from established vendors. The modules for subsequent reactors will be manufactured in established highly utilized facilities.

In 1990, a detailed fabrication study of the basic shippable reactor module was conducted by Babcock & Wilcox. This study was updated in 1992 and 1993 to reflect changes in the design and a detailed cost estimate was prepared based upon that study. A significant increase was applied to the material costs to reflect current vendor quotations and an increase in the number of labor hours required for the module fabrication. The larger ALMR vessel diameter allowed the elimination of several of the previous internal radiation shields and a subsequent reduction in the estimated cost of the reactor module.

In 1990, a detailed fabrication study was conducted by Byron Jackson for the electromagnetic pump and a detailed cost estimate was prepared based upon that study. That study was modified to reflect a double stator design which was adopted in 1991. This modification resulted in both an increase in the material cost and an increase in the number of labor hours required for the pump fabrication. The cost of the EM pump has been increased to reflect the higher capacity required by the new reference ALMR design.

A detailed design and fabrication study of the Intermediate Heat Exchanger was conducted in 1989 by Foster Wheeler. That cost estimate has been adjusted each year to incorporate design and cost changes. In 1993 the cost estimate was revised to reflect a larger heat exchanger which is required for the new ALMR design. That cost was updated in 1994.

In addition to changes which were made in the reactor module, the EM Pump and the IHX, estimated costs for many other NSSS equipment items were changed in 1994. These changes were made in order to reflect better design definition, changes in the reference design, or improvements in the cost basis. The most significant cost changes were the elimination of the IHTS isolation valves, increases in the cost of the IHTS valves and piping, increases in the SWRPS system, the addition of the water dump system and additions to the steam systems. All of the IHTS and most of the Steam Generator system has been changed to safety-grade equipment which has increased the contingency by a significant amount.

The 1994 NSSS material discount taken for the NOAK units was limited to 10%. It is still felt that 10% is overly conservative since the conditions expected for NOAK plants should allow preferred supplier agreements with material vendors that are much more favorable.

In developing the NSSS equipment costs, a 94% learning curve was used for any equipment which lacked a detailed cost estimate. The fabrication studies for the reactor module, EM pump, steam generator and the IHX provided separate estimates of the FOAK labor and material costs. A learning curve of 90% was applied to the labor hours for this equipment and a learning curve of 97.3% applied to the material costs which represents the reduction of 10% for the NOAK units due to quantity discounts.

Learning for the NOAK plants was limited to the 15th (Nth) NSSS unit for most equipment such as the NOAK shippable module cost, which represents 4500 MWe cumulative construction of standard ALMR plants. For equipment involving multiple quantities for each module such as the CRDs, IHXs and EM pumps, the learning effect was based on higher numbers of units. However, this number was never taken to be greater than the 100th unit. For equipment which is produced once for each power plant such as the maintenance and ISI equipment the learning was limited to the fourth unit. After establishing appropriate unit costs for initial equipment and identifying the learning curve factors, the recurring costs of equipment were projected as a function of quantity.

In summary, NSSS equipment costs were developed with the help of inputs from experienced manufacturers and General Electric cost estimators. Highly utilized factory scenarios were assumed when estimating the initial equipment costs and to develop the learning factors which were applied for NOAK units.

3.2.2 First Commercial Plant Costs

Starting with the unit costs for the first units built, the appropriate learning curve factors were applied to calculate the costs for each subsequent unit. Thus the (F1) scenario values represent an average of the first two NSSS's and the (F3) scenario values an average of the first six NSSS's. These costs are shown in the first two columns of Tables 3-1 and 3-2.

3.2.3 NOAK Costs

The NOAK single block (N1) and NOAK large plant (N3) costs represent the 15th unit built for most of the more expensive equipment. The basis for the shippable reactor module costs is the fabrication study for a mature production rate of 8 modules per year. Resulting costs for the NOAK NSSS equipment are also shown in the last two columns of Tables 3-1 and 3-2. The NOAK estimates are based on the same first unit costs as were used to calculate the lead plant equipment costs.

3.3 Estimated NSSS Equipment Costs

A cost summary, which is broken down between the nuclear grade costs and the industrial grade costs, is shown in Table 3-1. Estimated costs for all the NSSS equipment are shown to the six digit EEDB account level in Table 3-2. These values include the 15% profit margin for the reactor manufacturer, as specified in the DOE guidelines.

Scenario (F1) equipment cost in the 1994 shows a increase of 5.0% from those reported in 1993. Scenario (F3) equipment cost shows a increase of 5.6% from those reported in 1993.

The 1994 Nth-of-a-Kind total NSSS equipment costs show a increase of 4.2% and 5.0% for the single block (N1) and large plants (N3), respectively, from those reported in 1993. A more detailed analysis is discussed in Section 3.4.

3.4 Discussion of NSSS Equipment Costs

The 5.0% increase in the NOAK large plant (N3) NSSS equipment cost estimate (in 1994 $) from 1993 to 1994 is a result of many factors involving adoption of the new larger ALMR design, design improvements, changes in the safety-grade design of the Steam Generator system, changes in the learning curve, more detailed estimating approaches, and improved unit cost data. These changes are discussed here. The equipment cost changes from 1993 for the NOAK Large plant (N3) are summarized in Table 3-3.

3.4.1 Reactor Module

Babcock & Wilcox made a detailed fabrication assessment in 1990 for the reactor module. That study was based on the designs which had evolved through the end of 1989 and on fabricating a single reactor module in an existing factory. The material costs were based upon vendor quotations and included the testing required to meet Section III of the ASME Code. The material quantities involved for one module are large; however, some reduction was taken to represent discounts for multiple unit fabrication over a long term material contract. It was assumed the material delivery schedule would be adjusted to meet the production schedule without maintaining a large material inventory.

The labor was estimated by detailed analyses of the operations required to fabricate each piece. These operations were then individually estimated based on shop standards and previous experience with Section III type fabrication. Factory nonrecurring costs were also estimated by Babcock & Wilcox and are reported separately.

The module study was updated in 1992 and 1993 to reflect changes in material costs and to incorporate design changes which have occurred since the original study was conducted. In the latest update which was for the larger ALMR design, much of the internal reactor shielding was eliminated due to the larger vessel diameter. Other cost impacts are due to changes in the fabrication method. The 1994 costs estimated for the reactor shippable module are 16.3% higher than those reported in 1993.

With some exceptions, the remaining reactor equipment costs have remained essentially the same as those used in previous estimates. The net change in the remaining reactor equipment cost is 9.4% more than those reported in 1993.

3.4.2 Heat Transport Systems

The cost of the intermediate heat exchanger and primary EM pumps were adjusted for the larger capacity and fewer units resulting in a net decrease of 8.5% in 1994. The IHTS mechanical sodium pump was replaced with dual EM pumps in 1994. The IHTS isolation valves were eliminated and the IHTS piping was redesigned to meet Class 2 requirements. This combined with fewer units, resulted in a decrease in the estimated cost of 6.7%.

The steam generator isolation subsystem was upgraded to a Class 1E system. A water dump subsystem was added to the design. Babcock & Wilcox estimated the cost of the superheat helical coil single-wall tube steam generator which was selected for the 1993 reference steam generator design. Because of the larger capacity and Class 1E design, the current steam generator estimated cost is 23.2% more than the 1993 cost. The piping and tanks were estimated in accordance with the commodities costs as provided in the cost estimating guidelines. These changes resulted in the total heat transport equipment cost being 3.4% higher in 1994 than reported in 1993.

3.4.3 Other Reactor Plant Equipment

In 1994, the total auxiliary system costs were decreased by about 1.2%.

3.4.4 Instrument and Control Equipment

Costs were reduced for the local control system because of the fewer reactor modules. The total estimated cost of the instrumentation and control equipment was decreased by 14.3%.

3.4.5 Support Engineering

The support engineering costs for the NOAK plants remained about the same as in 1993.

3.4.6 Contingency

The default values of 25% for nuclear grade equipment was applied in 1994 to all nuclear grade components including the reactor module cost. The default value of 15% for the industrial grade costs were used for the remaining NSSS costs. For purposes of calculating contingency, the support engineering is considered a part of the nuclear grade cost. Because the remaining IHTS components and most of the Steam Generator system components are now Safety-grade, the contingency increased by 18.6% over that which was reported in 1993.

REFERENCES TO CHAPTER 3

3-1 J.G. Delene and C.R. Hudson, II., "Cost Estimate Guidelines for Advanced Nuclear Power Technologies, "Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/TM-10071/R3, May, 1993.

3-2 Facsimile Message, J. Delene to O. Gokcek, sent December 14, 1994, to provide escalation data from 1992 to 1994.

3-3 B.A. Hutchins., G.F. Pavlenco., and P. Babka; Editors, "1993 ALMR Power Plant Capital and Busbar Cost Estimates," GE Nuclear Energy, GEFR-00915, March, 1993.

Table 3-1

1994 ALMR NSSS Cost Breakdown

(Thousands of January 1994 Dollars)

Account Description	First Single Block F1	First Large Plant F3	Nth Single Block N1	Nth Large Plant N3
NSSS - Nuclear Grade Cost	$340,793	$839,761	$265,407	$685,885
NSSS - Industrial Grade Cost	37,077	93,312	32,084	84,491
NSSS Cost	$377,870	$933,073	$297,491	$770,376
Contingency	90,760	223,937	71,164	184,145
TOTAL NSSS COST	$468,630	$1,157,010	$368,655	$954,521

Table 3-2

1994 ALMR NSSS Equipment Cost
(Thousands of January 1994 Dollars)

EEDB Account	Account Description	First Single Block F1	First Large Plant F3	Nth Single Block N1	Nth Large Plant N3
220A.2	Distributed NSSS Price	$341,670	$882,333	$265,501	$725,601
220A.21	Reactor Equipment	111,136	309,194	84,416	252,139
220A.211	Reactor Vessels	31,613	89,000	23,892	71,676
220A.212	Reactor Vessel Internals	63,094	175,628	47,035	139,996
220A.213	Control Rod Drives	10,339	28,536	8,569	25,707
220A.214	[redacted]	6,090	16,030	4,920	14,760
220A.22	Heat Transport System	162,425	453,003	122,251	366,748
220A.221	Primary Heat Xport System	41,480	113,899	32,095	96,284
220A.222	Intermediate Heat Xport Sys	30,016	86,324	26,184	78,548
220A.223	Steam Generator System	90,929	252,780	63,972	191,916
220A.23	Safeguards System	1,621	4,553	1,312	3,937
220A.231	Backup Heat Removal Sys	1,621	4,553	1,312	3,937
220A.25	Fuel Handling & Storage	7,236	12,688	6,159	10,688
220A.26	Other Equipment	40,769	61,926	35,290	55,672
220A.261	Inert Gas Rec & Process	880	2,503	730	2,190
220A.264	Sodium Stor., Rel., Makeup	1,640	4,029	1,375	3,513
220A.265	Sodium Purification System	7,099	19,703	5,808	17,422
220A.266	Na Leak Detection System	1,638	4,598	1,325	3,975
220A.268	Maintenance Equipment	24,380	24,380	21,542	21,542
220A.269	Impurity Monitoring	5,132	6,713	4,510	7,030
220A.27	Instrumentation & Control	18,483	40,969	16,073	36,417
220A.3	Undistributed NSSS Cost	36,200	50,740	31,990	44,775
220A.31	[redacted]	36,200	50,740	31,990	44,775
220A	Nuclear Steam Supply	$377,870	$933,073	$297,491	$770,376
	Contingency	90,760	223,937	71,164	184,145
	TOTAL NSSS COST	$468,630	$1,157,010	$368,655	$954,521

Table 3-3

NSSS Equipment Cost Reconciliations - Scenatio N3

(Constant 1994 Dollars in Thousands)

	1992 Cost Escalated to 1994 $	1994 Cost	Remarks
Reactor Equipment			
Shippable Module	$151,349	$175,952	Larger Reactor
Non-Module Equip	69,659	76,187	Larger Reactor
Heat Transport System	354,692	366,748	Larger IHTS and Stem Generator capacity, No IHTS Isolation valves
Reactor Safeguards	3,634	3,937	Larger vessel
Fuel Handling Equipment	10,688	10,688	Remained the same
Other Reactor Equipment	56,337	55,672	Cover gas in Bechtel cost
Instrument and Control	42,494	36,417	Fewer reactor modules
Support Engineering	44,839	44,775	
Total Direct Cost	$733,692	$770,376	
Contingency	155,274	184,145	More Safety-Grade Equipment
TOTAL NSSS COST	$888,966	$954,521	

4.0 PLANT FACILITIES COSTS

4.1 Introduction

This section describes the construction cost estimates made for plant facilities (other than NSSS). These costs, together with the estimates for the NSSS, constitute the ALMR direct construction costs. Tables in Section 8 list the direct cost estimates for four plant scenarios, separated into costs for the nuclear-grade portions of the plant (Nuclear Island) and those for the industrial-grade portion (Balance-of-Plant Area). Plant facilities costs for each plant portion are provided by a system using the three-digit EEDB code of accounts. The NSSS equipment cost estimates are included in these tables as factory equipment in Account 220 in order to provide total plant direct costs. The estimating approach and costs for NSSS equipment are described in Section 3.

An important feature of ALMR facilities construction cost is the use of factory-fabricated modules. These facility modules consist of varying mixtures of equipment, piping, wiring, instrumentation and structural elements. Such facility modules are used in the power block facilities (reactor, steam generator, turbine generator), and in the common facilities (reactor maintenance, radwaste, BOP service, and etc.). There are 125 modules per power block. The common facilities modules, mainly of the skid mounted type, are included in the scope of the equipment or system supplier (water treatment, HVAC, air handling units, sodium removal units, etc.). Therefore, they are not addressed here separately, since they are part of the equipment/system cost. Also, the common facilities modules represent only a small percentage of the overall plant modules. This cost estimate incorporates facility modules costs based on a detailed study of an automated fabrication factory for the facility modules.

Cost estimates for field-installed plant facilities, comprising equipment, site labor and site materials, were prepared in accordance with the new DOE guidelines (Ref. 4-1) which provide the basic commodity prices, unit installation rates and labor rates. The Ref. 4-1 commodity prices and labor rates were escalated from January 1992 dollars to January 1994 dollars using cost increases of 3.1% for 1992 to 1993 and 4.3% for 1993 to 1994, per Ref. 4-2. Costs not covered by the guidelines are estimates based on Bechtel experience in constructing both fossil and nuclear plants. The ALMR field scope estimates are considered replicated costs (without first-of-a-kind) because they best represent the experience base of Bechtel.

The cost estimates were developed for plants located at the reference EPRI site in Kenosha, Wisconsin. The fuel facility cost is excluded from the capital cost. It is now included in the fuel cost, Section 10. Addition of the PSACS and local reactor cover gas processing is included in the capital cost estimate.

4.2 Estimate Approach

The general approach to estimating the facilities costs is similar to the one used in the 1993 plant cost estimate (Ref. 4-3). The development of plant facilities costs for different plant scenarios involves the following sequential steps:

- Establishment of estimate basis and assumptions
- Development of quantities for equipment and materials (bulk commodities) separately for:
  - Factory module scope
  - Field scope.
- Development of field manhours
- Development of equipment, material and labor costs for field scope
- Development of factory module costs
- Establishment of a number of base case cost estimates
- Development and application of various factors to the base cost estimates
- Combining the factored base estimates to obtain the various plant scenario direct costs.

4.3 Estimate Basis and Assumptions

The factory and field facilities cost estimates reflect the reference ALMR design. These estimates were prepared using the Cost Estimate Guidelines for Nuclear Power Technologies by DOE (Ref. 4-1), including:

- The estimate is structured according to the Energy Economic Data Base (EEDB) Code of Accounts to allow cost comparisons with other plants.
- Capital costs are based on the separated construction concept, where the "Nuclear Island" work area is separated from the "Balance of Plant Area" or industrial-grade construction work area.

- Factory module costs for the various plant scenarios are based on a 94 percent unit learning curve.
- The cost of major commodities is per Table 2.2 escalated to January 1994 dollars
- The commodity unit hour installation rates are per Table 2.3
- The composite wage rates given in Table 2.1 escalated to January 1994 dollars
- The escalation factors are per Table 2.5 and Ref. 4-2

In addition, the estimate is also based on these assumptions:

- The following unit learning curve percentages are used for field construction labor:
  - 97 percent (plant by order)
  - 98 percent (add-on plant)
  - 98 percent from site to site.
- The plant is constructed using a rolling 4/10 work week, resulting in a significant schedule reduction when compared to the regular 5/8 work week.
- The generator step-up transformer, switchyard, and transmission costs are excluded; they are considered part of the Owner's costs.
- An access road is assumed to be available prior to the start of construction and thus not included in the estimate.
- The cost of the optional on-site Fuel Cycle Facility is excluded; this cost is reflected in the cost of the fuel.
- Factory modules are assembled in a highly-automated fabrication facility; see Section 4.7.1 for additional assumptions for the factory module estimates.

4.4 Commodity Quantity Development

The estimates are based on quantification of the field and factory scopes. For the power block facilities, the commodity quantities were developed separately for the field (stick-built) scope and the factory modules. Because of the major changes in the plant design and the site since the last cost estimate (Ref. 4-3), quantities were completely redeveloped for the entire plant. The methods of quantifying the various commodities depended on the commodity and on the degree of engineering data available at this conceptual stage of design. The approaches are described below for the major commodity categories. The quantities were developed by Burns & Roe and Bechtel for their respective scope.

Civil and Structural

The civil and structural quantities were determined by takeoffs from arrangement drawings, civil/structural calculations and other data. The steel quantities for the power block factory modules were determined separately for each module.

Excavation quantities were developed for a soft soil site such as the EPRI's Kenosha, Wisconsin site. Concrete quantities were determined based on walls and slabs dimensions, and their concrete thickness. Rebar quantities were calculated using the rebar density per cubic yard of concrete from civil/structural calculations or assumed based on similar structure values. Typical ratios of steel to concrete were used to define the embedded quantities. Structural steel quantities were developed by takeoffs from arrangement drawings and sizes from structural calculations.

Mechanical and Piping

The quantities were determined using systems descriptions, flow diagrams, general arrangement drawings, and data from other application nuclear and fossil plant designs.

For the power block facility factory modules, the equipment and piping quantities were developed individually for each module.

For the field scope, the site plot plan was used to conceptually route piping systems between the plant buildings. Pipe quantities were determined from these routings. Pipe quantities inside the various buildings were estimated from the general arrangement drawings and conceptual pipe routing.

Electrical

Electrical equipment scope was taken from the electrical and control systems equipment lists and electrical single-line diagrams. The lists identified equipment, quantities and ratings for the various electrical systems. Electrical quantities were individually developed for each power block factory module. However, all safety-related cables and cables larger than 3/C#6 are assumed to be field pulled.

The number of cables was developed based on the ALMR power supply, controls and instrumentation lists. Average cable run lengths for both NI and BOP cables were estimated from the plant layout and used to calculate the linear footage of wires and cables (average run length times number of cables).

Raceway quantities for the cables including underground non-metallic conduit were developed primarily based on the conceptual raceway layout. Where not available ratio (from power plant experience) of linear feet of cable tray and linear feet of conduit per linear foot of cable were used.

Cable and raceway quantities for communications, grounding, heat tracing, cathodic protection and fire detection equipment were estimated based on experience from other representative plants.

4.5 Field Manhours

Labor rates (manhours/quantity) for all field-installed items are based on the rates provided in Table 2.3 of the Cost Guidelines (Ref. 4-1). For items not covered by the Guidelines, labor rates were defined based on Bechtel experience from fossil and nuclear power plant construction for a conventional 5/8 work week and reconciliation within the Guidelines. Using the separated construction concept, nuclear installation rates were applied within the nuclear island, and fossil or industrial grade rates were applied to BOP area work.

The field manhours for the NSSS equipment were prepared using available installation information as the basis. Projected manpower levels and durations were multiplied to provide manhours estimates.

Factory assembly manhours for the factory modules for the power block facilities (reactor, steam generator and turbine) were estimated separately (see Section 4.7.1).

Field installation of factory modules involves the following activities as applicable: unloading, temporary storage, moving the module to the facility, rigging, setting the module in place, anchoring the module, attaching to adjacent modules, weather sealing, connecting piping, raceways, wiring, and pouring concrete into forms and decks. Field manhours to perform these activities were estimated for a representative sample of factory modules and then applied to all factory modules.

4.6 Field Scope Equipment, Material and Labor Cost

Equipment Cost

Current Bechtel cost information was used in general to estimate field scope equipment costs. Different unit costs were used for the NI and BOP equipment and materials, as appropriate. Budgetary quotations for the following major equipment items were received:

- Turbine generator
- Main condenser
- Water treatment systems
- Mechanical draft cooling towers
- Turbine Building Crane
- Reactor upper containment
- Refueling cask transporter

An equipment cost allowance of $1.61 million is included for each maintenance cask transporter. The cost of the refueling cask is covered under NSSS equipment. There are two refueling and two maintenance cask transporters for a three power block plant.

Material Costs

Material unit costs were selected based on Table 2.2 of the Cost Guidelines (Ref. 4-1) wherever possible and escalated to January 1994 per Ref. 4.2. Otherwise, material costs were based on vendor data or Bechtel experience. Material costs were developed by multiplying quantities and associated unit costs .

An allowance of $3.98 million in site materials and 100,000 manhours for the plant security system has been included in the three power block replicated plant common facilities field scope cost.

Labor Cost

The composite field crew wage rates are given in Table 2.1 of the DOE Cost Guidelines (Ref. 4-1) for a regular 5/8 work week.

The 1992 crew wage rates from Table 2.1 were then adjusted in the plant scenario estimates for the rolling 4/10 work schedule on which the estimate is based (see Section 5.1).

These wage rates escalated to January 1994 based on Ref. 4-2 were used in calculating labor costs for both NI and BOP field work.

4.7 Factory-Fabricated Module Costs

Factory-fabricated modules are provided for the power block facilities (i.e., the reactor/steam generator complex and the turbine generator facility).

4.7.1 Power Block Module Costs

The estimate for the delivered cost of power block modules is based on UE&C Western Operations (formerly Stearns-Roger) experience in module factory fabrication. In a previous ALMR study effort, UE&C investigated and developed costs for an automated fabrication facility. Based on module fabrication experience and the results of this study, UE&C generated unit labor rates for the fabrication of modules on a work type/commodity basis (i.e., structural, piping, equipment installation, electrical, instrumentation, painting and insulation). These unit rates were applied to the commodity quantity base provided by Bechtel and Burns & Roe.

Direct costs in these estimates include equipment item costs, bulk materials priced on a carload lot basis, and production labor cost. Equipment costs were developed from a combination of vendor quotes and in-house historical pricing data for similar types of equipment. Costs of materials were based on Table 2.2 of the Cost Guidelines (Ref. 4-1) escalated to January 1994 and adjusted to account for automated labor. Labor rates of $14.09/hour were used based on prevailing rates for non-union shops located in the southeastern U.S. regions.

Overhead costs have been added to include payroll taxes and insurance, staff labor, G&A, space costs, equipment amortization, maintenance, property taxes, utility costs, telephone and telegraph, office furniture and supplies, travel, entertainment, consumables, small tools, and training. They represent 136.3% of direct labor cost. These costs were based on experience at the fabrication facility used by UE&C for many of their modular projects. This facility, located in Pocatello, Idaho, was also the basis for the factory automation study.

Profit was added to the direct plus overhead estimate on the basis of 15 percent profit on all value-added work; that is, on all direct labor and all overhead costs. A five percent profit was added to all materials and non-furnished equipment that pass through the facility.

Transportation costs, representing the cost to move the factory modules from the factory to the construction site, were estimated to be $12.87 per square foot of module for a distance of 1,338 miles from the factory to the Kenosha, Wisconsin site. These assumptions were based on the results of an ALMR study by UE&C which evaluated preferred locations for this facility based on probable markets.

The cumulative effects of the above resulted in delivered prices for the power block factory modules. Some assumptions made for this cost estimate are as follows:

- There is a commitment for 25 power blocks prior to starting work in an existing fabrication facility.

- The fabrication facility is equipped with automated equipment resulting in a 70 percent productivity factor over current manufacturing experience for the NOAK plant and 80 percent for the FOAK plant.

- Overhead costs are distributed over 3.7 million production hours per year, worked on a two-shift basis; the capital write-off period is five years.

The resulting costs are the predicted cost of modules shipped to the power generating plant site for installation. As indicated in the UE&C study referred to above, these costs reflect the use of extensive automation where applicable and factory manpower for the balance of the work.

The costs are presented in a dollar per production manhour format for 1,020 modules per year. It should be noted that this capacity is greater than the needed ALMR throughput (500 modules per year) for four power blocks (eight reactor modules). The costs represented in the estimate include all direct costs for labor and materials, as well as all variable indirect costs for the currently projected throughput of 500 modules. However, fixed overhead costs for the current state of planned capacity (3.7 million manhours) are not fully recovered in the estimate for 500 modules. It is assumed at this point that fixed overhead costs for excess planned capacity can be mitigated by additional recovery through module scope growth, fabrication of piping and structural bulk commodities for ALMR; and/or reduction by limited down-sizing of fixed factory overheads. No consideration is given to the concept of a non-dedicated modules factory with competing shop orders because of adverse effects to the overhead structure and schedule risks.

4.7.2 Distribution of Module Cost by EEDB Account

Module factory and shipping costs were assigned to the equipment cost of appropriate EEDB three-digit accounts. For each power block module, ratios (percentages of the total factory, shipping, and installation direct cost) for applicable EEDB accounts were estimated based on the direct costs of module equipment and commodities assigned to each account. These ratios were then used as multipliers to the module total costs to calculate the EEDB allocations.

4.7.3 Integration of Module Cost

Power block module factory and shipping costs assigned to EEDB three-digit accounts were treated as equipment costs; module field installation costs were assigned to field labor. When combined with the direct cost of the power block field scope cost in each three-digit account plus the NSSS costs, the total power block facilities direct cost resulted.

4.8 Site Land

The cost guidelines value of land (Ref. 4-1) escalated to January 1994 based on Ref. 4-2 is \$10,753 /acre. A site owner area of 850 acres for a single power block plant and 1,000 acres for a three power block plant were defined based on an exclusion area boundary of 0.5 mile around the nuclear island.

4.9 Base Case Cost Estimates

Four base case cost estimates were established for the purposes of estimating the direct costs of the various plant scenarios:

- Replicated (without first-of-a-kind costs) single power block facilities field scope using a conventional five day/eight hours per day work week

- NSSS equipment

  - First commercial single power block

- First commercial three power blocks
- NOAK single power block
- NOAK three power blocks.

- NOAK factory-fabricated single power block modules
- Replicated three power block common facilities field scope using a 5/8 work week.

The NSSS equipment costs were developed separately by GE; see Section 3.

The replicated single power block field scope case and the replicated three power block common facilities field scope case were assembled from the following data:

- Commodity quantities for field scope (module scope excluded) per Section 4.4
- Field manhours per Section 4.5
- Cost of equipment, material and labor per Section 4.6
- Cost of land per Section 4.8.

The factory-fabricated single power block module costs were estimated as described in Section 4.7.1. The direct costs obtained for the base cases were developed at the three-digit EEDB account level separately for the NI and BOP. The total direct costs for each base case are indicated in Table 4-1.

REFERENCES TO CHAPTER 4

4-1 Delene, J. G. and C. R. Hudson II, "Cost Estimating Guidelines for Advanced Nuclear Power Technologies", Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10071/R3, May 1993

4-2 Facsimile from Jerry Delene, Oak Ridge National Laboratory, to Omer Gokcek, General Electric, dated December 15, 1994.

4-3 Hutchins, B. A., et al, "1993 Capital and Busbar Cost Estimates", GE Nuclear Energy, GEFR-00915, March 1993.

Table 4-1

Base Case Total Direct Costs

(Cost in January 1994 Dollars)

Base Case	**Cost in $1,000**		
	Nuclear Island	**BOP Area**	**Total**
• Replicated single power block field scope	75,604	108,001	183,605
• NSSS			
– First commercial single power block	229,518	148,352	377,870
– First commercial three power blocks	528,839	404,234	933,073
– NOAK single power block	184,072	113,419	297,491
– NOAK three power blocks	441,884	328,492	770,376
• NOAK single power block factory modules	31,841	14,797	46,638
• Replicated three power block common facilities field scope	58,908	51,484	110,392

5.0 TOTAL DIRECT COSTS

5.1 Plant Scenario Base Case Adjustment Factors

Various factors for each cost estimate scenario were applied to base cost estimates to arrive at first commercial and NOAK plant field costs. The resulting cost estimate values were combined with the estimated costs of the factory modules and NSSS equipment to obtain the total plant direct construction costs.

Costs were developed for four plant scenarios:

- First commercial single power block (F1), but with large plant common facilities
- First commercial three power blocks (F3)
- NOAK single power block (N1) with small plant common facilities
- NOAK three power blocks (N3).

Composite plant scenario costs were obtained from the base case costs defined in Section 4.9 by combining appropriately-adjusted base case costs.

Four types of adjustment factors for plant facilities costs (except NSSS) were developed for this purpose:

- Plant size – single power block to three power blocks
- Work week – regular 5/8 to rolling 4/10
- Learning curve – replicated to first commercial and NOAK.

<u>**Plant Size**</u>

The field scope power block base costs were assembled for a single power block (622 MWe). Therefore, the power block size adjustment factor is 1.0 for the single power block scenarios F1 and N1, and 3.0 for the three power block scenarios F3 and N3.

The field scope common facilities base costs, which were developed for a three power block plant scenario, were scaled down as applicable for the N1 single power block case. The percentages used are given in Table 5-1.

Work Week

All base case field labor estimates were based on a regular 5/8 work week. Since the construction plan for all scenarios uses a rolling 4/10 work week, all site manhours were multiplied by a factor of 0.85 (reflecting an assumed 15 percent improvement in productivity); when combined with the overtime pay embedded in the rolling 4/10 wage rate, the resulting labor cost factor becomes 0.974. This adjustment factor was applied for each plant scenario.

Learning Curve

The field scope replicated base case labor costs are adjusted for learning curve factors as defined in Section 4.3, and based on an assumed lead plants sequence schedule shown in Table 5-2. Also, learning from the prototype to the first commercial plant was included for the reactor and steam generator facilities. The learning curve factors applied for the various plant scenarios are given in Table 5-3.

Factor Combinations

Table 5-4 summarizes the factors developed for the four plant scenarios.

5.2 Plant Scenario Cost Development

Using the base case costs estimated as described in Section 4.9 and the adjustment factors shown in Table 5-4, the direct costs were developed for the four plant scenarios at the three-digit EEDB account level.

5.3 Results

This section provides the direct cost estimate results, the bulk commodity quantities and the labor requirements.

5.3.1 Total Direct Costs

The total direct costs are provided for the four plant scenarios by three-digit EEDB accounts in the following tables included in Section 9:

- Table 8-1 – Scenario F1 (First commercial single power block)
- Table 8-2 – Scenario F3 (First commercial three power blocks)
- Table 8-3 – Scenario N1 (NOAK single power block)
- Table 8-4 – Scenario N3 (NOAK three power blocks).

5.3.2 Bulk Commodities and Labor Requirements

The bulk commodities quantities are provided in the following tables:

- Table 5-5 – Single Block with Small Common with Modules
- Table 5-6 – Single Block with Large Common with Modules
- Table 5-7 – Large Plant with Modules
- Table 5-8 – Reactor/Steam Generator Complex Modules
- Table 5-9 – Turbine Building Modules.

The quantities are presented for two-digit EEDB accounts and indicated by commodity.

The direct field and factory labor requirements are shown separately in Table 5-10 for the four plant scenarios at the two-digit EEDB account level.

5.4 Discussion of Results

The plant total direct costs presented in Section 5.3 are summarized in Table 5-11, along with plant unit costs ($/kWe).

Table 5-1
Single Power Block Common Facilities

Description	Percentage of Large Common Facilities	Scaling Factor
Structures and Improvements		
Yardwork	60	–
Turbine Generator Facility Crane	100	–
Security Buildings	72	0.3
Radwaste Facility	72	0.3
Fuel Service Facility (included in fuel cost)	80	0.2
Control Building	72	0.3
Admin Building Complex	64	0.4
Remote Shutdown Facility	64	0.4
Maintenance Facilities	100	–
Spent Component Storage	100	–
Misc. Foundations	72	0.3
BOP Support Systems Facility	58	0.5
Wastewater Treatment Building	52	0.6
Gas Turbine Facility	100	–
Personnel Service Buildings	100	–
Warehouses	72	0.3
Cask Transporter Garage	60	–
Assembly and Storage Facility	100	–
Reactor Plant Equipment		
Radwaste System	72	0.3
Fuel Handling	90	0.1
Other Reactor Plant Equipment	100	–
Reactor Instr. & Controls	64	0.4
Turbine Plant Equipment		
Other TG Plant Equipment	52	0.6
Electric Plant Equipment		
Switchgear	72	0.3
Station Service Equipment	72	0.3
Switchboards	64	0.4
Protective Equipment	64	0.4
Electric Struct. & Wiring Containers	64	0.4
Power & Control Wiring	64	0.4
Misc. Plant Equipment		
Transport & Lift Equipment	100	–
Air, Water & Steam Service System	72	0.3
Communications Equipment	72	0.3
Furnishings and Fixtures	72	0.3
Wastewater Treatment Equipment	72	0.3
Makeup Water System	72	0.3

Table 5-2
Lead Plants Schedule

Year →	1				2				3				4			
Quarter →	1	**2**	**3**	**4**	1	**2**	**3**	**4**	1	**2**	**3**	**4**	1	**2**	**3**	**4**
1st plant; 1,866MWe		1	1	1												
2nd plant; 1,866 MWe					1	1	1									
3rd plant; 1,866 MWe								1	1	1						
4th plant; 1,866 MWe											1	1	1			

Table 5-3
Learning Curves Factors Applied to Replicated Field Cost

		Power Blocks	
	Common Facilities	**Nuclear Island**	**BOP**
F1	1.0204	1.0000	1.0309
F3	1.0204	0.9850	1.0053
N1, N3	0.9800	0.9290	0.9351

Table 5-4

Multiplication Factors Used for Adjusting Base Case Estimates for Plant Scenario Estimates

	Plant Scenarios											
	F1 First Commercial Single Power Block Plant w/Large Common (622 MWe)			F3 First Commercial Three Power Block Plant (1866 MWe)			N1 NOAK Single Power Block Plant (622 MWe)			N3 NOAK Three Power Block Plant (1866 MWe)		
	(1)*	(2)*	(3)*	(1)*	(2)*	(3)*	(1)*	(2)*	(3)*	(1)*	(2)*	(3)*
Base Case Estimates												
Field Scope, Replicated Single Power Block (Equipment, Labor and Material)												
– Reactor and Steam Generator	1.0	0.974	1.0000	3.0	0.974	0.9850	1.0	0.974	0.9290	3.0	0.974	0.9290
– Turbine	1.0	0.974	1.0309	3.0	0.974	1.0053	1.0	0.974	0.9351	3.0	0.974	0.9351
NSSS Scope												
– First Comm. Single Power Block	1.0											
– First Comm. Three Power Block				1.0								
– NOAK Single Power Block							1.0					
– NOAK Three Power Block										1.0		
NOAK Factory Fabricated Single Power Block Modules	1.0		1.092	3.0		1.092	1.0			3.0		
Field Scope Replicated Three Power Block Common Facilities (Equipment, Labor and Material)	1.0	0.974	1.0204	1.0	0.974	1.0204	(4)	0.974	0.9800	1.0	0.974	0.9800

* Factors: (1) Plant size (3) Learning curve
(2) Work week (4) Varies; see Table 5-1.

Table 5-5

Plant Bulk Commodities
Single Block with Small Common with Modules

		21		22		23		24		25		26		Total		Total
	Units	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	Plant
Formwork	SF	711,031	115,640	0	0	0	0	0	16,000	0	0	0	70,850	711,031	202,490	913,521
Structural Steel	TN	4,367	2,314	0	0	0	0	0	0	0	0	0	120	4,367	2,434	6,801
Reinforcing Steel	TN	7,016	1,412	0	0	0	0	0	29	0	0	0	379	7,016	1,820	8,836
Embedded Steel	TN	367	18	0	0	0	0	0	2	0	0	0	6	367	26	393
Structural Concrete	CY	65,119	13,720	0	0	0	0	0	512	0	0	0	4,820	65,119	19,052	84,171
Concrete Fill	CY	1,334	0	0	0	0	0	0	0	0	0	0	0	1,334	0	1,334
CS< 2.5" Pipe	LB	0	0	2,800	0	0	14,780	0	0	6,880	12,838	0	910	9,680	28,528	38,208
SS< 2.5" Pipe	LB	0	0	2,780	0	1,230	0	0	0	0	1,580	0	0	4,010	1,580	5,590
CS> 2.5" Pipe	LB	0	0	0	0	1,290	19,126	0	0	4,400	16,265	0	5,724	5,690	41,115	46,805
SS> 2.5" Pipe	LB	0	0	3,520	0	1,520	0	0	0	700	940	0	0	5,740	940	6,680
CM> 2.5" Pipe	LB	0	0	0	0	110	2,755	0	0	0	0	0	0	110	2,755	2,865
Wire and Cable	LF	0	0	0	0	0	0	307,000	451,370	0	0	0	0	307,000	451,370	758,370
Wire and Cable Duct Runs and Containers	LF	0	0	0	0	0	0	42,640	115,540	0	0	0	0	42,640	115,540	158,180

Table 5-6

Plant Bulk Commodities
Single Block with Large Common with Modules

		21		22		23		24		25		26		Total		Total
	Units	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	Plant
Formwork	SF	778031	141,250	0	0	0	0	0	25,000	0	0	0	76,170	778,031	242,420	1,020,451
Structural Steel	TN	4,377	2,584	0	0	0	0	0	0	0	0	0	130	4,377	2,714	7,091
Reinforcing Steel	TN	7,488	1,536	0	0	0	0	0	45	0	0	0	400	7,488	1,981	9,469
Embedded Steel	TN	380	20	0	0	0	0	0	4	0	0	0	7	380-	31	411
Structural Concrete	CY	70,369	15,410	0	0	0	0	0	800	0	0	0	5,100	70,369	21,310	91,679
Concrete Fill	CY	1,444	0	0	0	0	0	0	0	0	0	0	0	1,444	0	1,444
CS< 2.5" Pipe	LB	0	0	2,800	0	0	15,890	0	0	7,920	15,754	0	910	10,720	32,554	43,274
SS< 2.5" Pipe	LB	0	0	2,780	0	2,000	0	0	0	0	2,200	0	0	4,780	2,200	6,980
CS> 2.5" Pipe	LB	0	0	0	0	1,290	20,316	0	0	5,800	19,754	0	7,504	7,090	47,574	54,664
SS> 2.5" Pipe	LB	0	0	4,070	0	2,920	0	0	0	700	1,300	0	0	7,690	1,300	8,990
CM> 2.5" Pipe	LB	0	0	0	0	110	2,755	0	0	0	0	0	0	110	2,755	2,865
Wire and Cable	LF	0	0	0	0	0	0	344,300	564,070	0	0	0	0	344,300	564,070	908,370
Wire and Cable Duct Runs and Containers	LF	0	0	0	0	0	0	52,940	149,340	0	0	0	0	52,940	149,340	202,280

Table 5-7

Plant Bulk Commodities
Large Plant with Modules

		21		22		23		24		25		26		Total		Total
	Units	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	Plant
Formwork	SF	1,479,333	261,450	0	0	0	0	0	25,000	0	0	0	190,510	1,479,333	476,960	1,956,293
Structural Steel	TN	11,431	5,492	0	0	0	0	0	0	0	0	0	320	11,431	5,812	17,243
Reinforcing Steel	TN	16,514	3,840	0	0	0	0	0	45	0	0	0	1,050	16,514	4,935	21,449
Embedded Steel	TN	936	46	0	0	0	0	0	4	0	0	0	15	936	65	1,001
Structural Concrete	CY	148,787	35,330	0	0	0	0	0	800	0	0	0	13,300	148,787	49,430	198,217
Concrete Fill	CY	2,712	0	0	0	0	0	0	0	0	0	0	0	2,712	0	2,712
CS< 2.5" Pipe	LB	0	0	8,400	0	0	43,050	0	0	16,360	26,450	0	2,730	24,760	72,230	96,990
SS< 2.5" Pipe	LB	0	0	8,340	0	2,800	0	0	0	0	2,200	0	0	11,140	2,200	13,340
CS> 2.5" Pipe	LB	0	0	0	0	3,870	55,988	0	0	7,400	29,244	0	9,812	11,270	95,044	106,314
SS> 2.5" Pipe	LB	0	0	8,310	0	2,920	0	0	0	2,100	1,300	0	0	13,330	1,300	14,630
CM> 2.5" Pipe	LB	0	0	0	0	330	8,265	0	0	0	0	0	0	330	8,265	8,595
Wire and Cable	LF	0	0	0	0	0	0	825,700	1,066,210	0	0	0	0	825,700	1,066,210	1,891,910
Wire and Cable Duct Runs and Containers	LF	0	0	0	0	0	0	101,420	260,220	0	0	0	0	101,420	260,220	361,640

Table 5-8

Plant Bulk Commodities
Reactor/Steam Generator Complex Modules

	Units	21		22		23		24		25		26		Total		Total
		NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	NI	BOP	Plant
Formwork	SF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Structural Steel	TN	2,849	0	0	0	0	0	0	0	0	0	0	0	2,849	0	2,849
Reinforcing Steel	TN	1,044	0	0	0	0	0	0	0	0	0	0	0	1,044	0	1,044
Embedded Steel	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Structural Concrete	CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Fill	CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS< 2.5" Pipe	LB	0	0	0	0	0	0	0	0	2,420	0	0	0	2,420	0	2,420
SS< 2.5" Pipe	LB	0	0	1,380	0	0	0	0	0	0	0	0	0	1,380	0	1,380
CS> 2.5" Pipe	LB	0	0	0	0	1,290	0	0	0	0	0	0	0	1,290	0	1,290
SS> 2.5" Pipe	LB	0	0	2,060	0	0	0	0	0	0	0	0	0	2,060	0	2,060
CM> 2.5" Pipe	LB	0	0	0	0	110	0	0	0	0	0	0	0	110	0	110
Wire and Cable	LF	0	0	0	0	0	0	116,200	0	0	0	0	0	116,200	0	116,200
Wire and Cable Duct Runs and Containers	LF	0	0	0	0	0	0	12,540	0	0	0	0	0	12,540	0	12,540

Table 5-9

Plant Bulk Commodities
Turbine Building Modules

	Units	21 NI	21 BOP	22 NI	22 BOP	23 NI	23 BOP	24 NI	24 BOP	25 NI	25 BOP	26 NI	26 BOP	Total NI	Total BOP	Total Plant
Formwork	SF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Structural Steel	TN	0	367	0	0	0	0	0	0	0	0	0	0	0	367	367
Reinforcing Steel	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Embedded Steel	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Structural Concrete	CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concrete Fill	CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS< 2.5" Pipe	LB	0	0	0	0	0	6,640	0	0	0	2,365	0	0	0	9,005	9,005
SS< 2.5" Pipe	LB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS> 2.5" Pipe	LB	0	0	0	0	0	4,791	0	0	0	565	0	120	0	5,496	5,496
SS> 2.5" Pipe	LB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CM> 2.5" Pipe	LB	0	0	0	0	0	790	0	0	0	0	0	0	0	790	790
Wire and Cable	LF	0	0	0	0	0	0	0	100,620	0	0	0	0	0	100,620	100,620
Wire and Cable Duct Runs and Containers	LF	0	0	0	0	0	0	0	22,340	0	0	0	0	0	22,340	22,340

Table 5-10
Direct Labor Requirements
(Manhours in 1,000s)

Case F1, 622 MWe FOAK								
		Nuclear Island		Balance of Plant		Total		Grand
Acct	Description	Module	Field	Module	Field	Module	Field	Total
21	Structur& Improvements	90	1,225	4	443	94	1,668	1,762
22	Reactor Plant Equipment	12	263	0	0	12	263	275
23	Turbine Plant Equipment	0	38	36	235	36	273	309
24	Electric Plant Equipment	86	110	32	191	118	301	419
25	Misc Plant Equipment	2	138	1	172	3	310	313
26	Main Cond Heat Rej Sys	0	0	0	161	0	161	161
	Total – Case F1	**190**	**1,774**	**73**	**1,202**	**263**	**2,976**	**3,239**
Case F3, 1866 MWe FOAK								
		Nuclear Island		**Balance of Plant**		**Total**		**Grand**
Acct	**Description**	**Module**	**Field**	**Module**	**Field**	**Module**	**Field**	**Total**
21	Structure&Improvement	272	2,761	11	758	283	3,519	3,802
22	Reactor Plant Equipment	35	684	0	0	35	684	719
23	Turbine Plant Equipment	0	45	108	683	108	728	836
24	Electric Plant Equipment	258	221	97	292	355	513	868
25	Misc Plant Equipment	6	181	4	241	10	422	432
26	Main Cond Heat Rej Sys	0	0	0	372	0	372	372
	Total – Case F3	**571**	**3,892**	**220**	**2,346**	**791**	**6,238**	**7,029**
Case N1, 622 MWe FOAK								
		Nuclear Island		**Balance of Plant**		**Total**		**Grand**
Acct	**Description**	**Module**	**Field**	**Module**	**Field**	**Module**	**Field**	**Total**
21	Structure& Improvement	83	1,075	3	326	86	1,401	1,487
22	Reactor Plant Equipment	11	234	0	0	11	234	245
23	Turbine Plant Equipment	0	20	33	209	33	229	262
24	Electric Plant Equipment	79	86	29	134	108	220	328
25	Misc Plant Equipment	2	101	1	128	3	229	232
26	Main Cond Heat Rej Sys	0	0	0	134	0	134	134
	Total – Case N1	**175**	**1,515**	**66**	**931**	**241**	**2,447**	**2,688**
Case N3, 1866 MWe NOAK								
		Nuclear Island		**Balance of Plant**		**Total**		**Grand**
Acct	**Description**	**Module**	**Field**	**Module**	**Field**	**Module**	**Field**	**Total**
21	Structure& Improvement	248	2,595	10	702	258	3,297	3,555
22	Reactor Plant Equipment	32	661	0	0	32	661	693
23	Turbine Plant Equipment	0	45	99	619	99	664	763
24	Electric Plant Equipment	236	190	88	271	324	461	785
25	Misc Plant Equipment	5	171	4	226	9	397	406
26	Main Cond Heat Rej Sys	0	0	0	340	0	340	340
	Total – Case N3	**521**	**3,662**	**201**	**2,158**	**722**	**5,820**	**6,542**

Table 5-11
Total Direct Cost Summary

Scenario	1993 Total Direct Cost ($K)	1993 Total Direct Cost ($/kW)
F1: First commercial single power block –622 MWe	734,744	1,181
F3: First commercial three power blocks – 1,866 MWe	1,764,376	946
N1: NOAK single power block – 622 MWe	615,992	990
N3: NOAK three power blocks – 1,866 MWe	1,577,136	845

6.0 INDIRECT COSTS

6.1 Introduction and Summary

The indirect costs include the following categories per the Energy Economic Data Base (EEDB), accounts 91 through 95:

- Construction services costs (account 91)
- Engineering and home office services costs (account 92)
- Field supervision and field office services costs (account 93)
- Owner's costs (account 94)
- Reactor manufacturer's home office engineering and services costs (account 95).

The reactor manufacturer's indirect costs, account 95, are included in the NSSS equipment costs, which are addressed in Section 3.

6.2 Architect-Engineer Indirect Costs

The architect-engineer indirect costs, accounts 91 through 93, covers all costs which cannot be identified with any direct construction activity for a permanent plant facility. Nevertheless, these indirect costs, which cover items such as temporary facilities, construction services, design, engineering and startup are necessary for successful completion of the project.

6.2.1 Construction Services Costs

Construction services costs, account 91, incorporate provisions for temporary buildings, working areas and bays, roads, walkways, fences, electrical facilities, air, water, sewage, scaffolding, winterization and weather protection. They also include provision for job cleanup, maintenance of tools and equipment, material handling and warehousing, security, show up time, startup materials and manual labor support. Construction equipment, tools, consumable and purchased utilities are also included.

Bechtel experience on similarly sized pre-TMI nuclear plants and fossil power plants was utilized as the basis for developing construction services cost factors. The material costs were adjusted for escalation to January 1994 based on standardized indices. The results were used to develop factors to allow identification of craft labor manhours and material costs as a function of direct field labor manhours.

Additional adjustments were also made for plant capacity and construction schedules for FOAK and NOAK plants. Separate rates were developed for the nuclear and the balance of plant areas.

For construction equipment, additional rental cost for the specialized mobile crane to lift the large prefabricated modules are included. A reduction in lifting equipment costs was made for cranage which the specialized mobile crane replaces. The specialized mobile crane is available at the site from start of construction to mid-point of the construction schedule. The additive rental cost is allocated equally to the nuclear and balance of plant portion.

The account also includes provision for Taxes and Insurance for all manual labor (direct and indirect) allowed at 16.5% of manual labor cost.

Cost for inland transportation to the jobsite at 1.5% of factory equipment and site material costs is also included.

6.2.2 Engineering and Home Office Services Costs

Engineering and home office services costs, account 92, include site specific engineering and licensing, procurement, construction management, engineering support of construction and startup, and construction quality assurance. It is assumed that before any commercial plant is built, an ALMR standard plant documentation has been developed and a design certification has been obtained. All the non-recurring engineering and licensing necessary to develop the detailed design documentation for the ALMR standard plant and certification is part of the FOAK engineering costs, see Section 2.

The engineering and home office services costs were defined using a "bottoms up" estimating approach. Bechtel experience with nuclear and fossil power plant was used, as well as, recent experience with automation of engineering and construction services. For the ALMR, it is assumed that automation in design and construction services will be utilized to the maximum extent practical.

The engineering and home office services costs comprises the following major cost items:

- A "paperless" fully integrated information system with electronic exchange of data between home office engineering, field, clients, vendors, manufacturers,
- Consulting services for field specific tasks. contractors, regulatory agencies, etc.
- Management and supervision of plant construction activities
- Developing of project management, design and operations procedures
- Performing site specific design to adapt the standard plant the unique requirements of the project site and reflect specific client requirements
- Procurement of equipment and hardware, and contracting of construction tasks

Adjustments were made for NOAK plants. It is assumed (see Section 5.1) that four large identical plants have been constructed prior the NOAK plant. All generic conflicts, interferences and discrepancies have been resolved and there is a pool of personnel experienced in the construction of an ALMR standard plant. Separate cost were developed for the nuclear and the balance of plant areas.

6.2.3 Field Supervision And Field Office Services Costs (Account 93)

The field supervision and field office services costs include provision for:

- Field non-manual supervision, engineering, controls, procurement, administration, and quality assurance/quality control services
- Relocation expenses
- Startup engineering services. Startup material costs and manual labor support are excluded; they are included in the construction services costs.

Field supervision and field office services costs were developed from Bechtel construction experience for similarly sized pre-TMI nuclear and fossil projects as manhour and material cost unit rates of direct field labor manhours. After adjusting for escalation to January 1994, the rates were adjusted for the FOAK and NOAK construction schedules and plant ratings.

Separate cost were developed for the nuclear and the balance of plant areas. This account includes taxes and insurance for the non-manual labor.

6.3 Owner's Costs

The total owner's costs, account 94, were estimated as fifteen percent of the sum of the total direct costs and other indirect costs (accounts 91,92 and 93) and the cost of special coolant, per DOE estimating guidelines (Ref. 4-1). The total special coolant (sodium) inventory is 2.63 x 10^6 lbs per reactor. The price per sodium used is $1.5 per pound.

7.0 TOTAL CONTINGENCY, SCHEDULES, AND AFUDC

7.1 Contingencies

The ALMR plant is physically separated into the nuclear island (NI) and balance of-plant (BOP) area. The costs were developed separately for the NI and BOP area based on the geographic location of systems and structures.

Rather than using the DOE estimating guideline default values for contingencies, the approach taken was to evaluate the uncertainties in the major elements of direct cost estimate. Based on Bechtel power plant experience, the contingencies for facility cost estimates vary within the ranges given in Table 7-1. Based on this data, contingency values were assigned as indicated in Table 7-2 and contingencies were calculated. General Electric power plant experience was used to assign the NSSS contingencies.

7.2 Schedules

The estimated project schedules are based on the schedules developed for the 1994 reference design. Table 7-3 shows these schedules.

7.3 Cash Flow and AFUDC

For each cost scenario, a cash flow was prepared. The construction activity durations were assumed to be the same for each power block of a three block plant. After NSSS equipment, turbine generator and plant facility modules are ordered, progress payments are made as factory fabrication proceeds. This shifts the cash flow midpoint closer to the start of construction than the midpoint experienced with a conventional field-constructed plant. The effect is to increase the allowance for funds used during construction (AFUDC).

With the ALMR plant modularized construction plan, there are four major contributors to cost:

- NSSS equipment
- BOP plant equipment

- Factory-fabricated plant facility modules

- Field construction.

The cash flow projections were prepared by superimposing progress payments for NSSS and BOP equipment, and plant facility modules, upon a typical S-curve for field construction costs. Each quarterly cash flow includes overnight costs, owner costs, contingency and AFUDC. The results provide a quarter-by-quarter projection of cash flow needs from the time of the start of the project through procurement and shipment of equipment and modules, field construction, and power block startup. AFUDC by quarter was calculated from the beginning of each quarter with a quarterly interest rate of 6.05/4 percent.

The resulting cash flows for each plant scenario are shown tabulated in Tables 7-4 through 7-7. AFUDC is shown separately for each power block and for the total plant.

Table 7-1

Contingency Ranges

Cost Component	Contingency Range
Materials and Equipment	
Actual costs	0% – 1%
Commitments	0% – 2%
Firm quotations	2% – 5%
Budget bids	5% – 10%
Telephone quotation	5% – 15%
Catalog pricing	6% – 12%
Previous project data	8% – 20%
Previous estimating data	10% – 25%
Labor Related	
Direct manual labor	10% – 20%
Indirect manual labor	10% – 25%
Indirect material costs	10% – 20%
Non-manual labor	10% – 15%
Engineering services	10% – 20%
Engineering	10% – 30%

Table 7-2
Contingency Assessment
(In Millions of January 1994 Dollars)

Cost Category	Assigned Contingen.	FOAK-One Pwr Block Estimate	FOAK-One Pwr Block Contingen.	FOAK-3 Pwr Blocks Estimate	FOAK-3 Pwr Blocks Contingen	NOAK-One Pwr Block Estimate	NOAK-One Pwr Block Contingen	NOAK-3 Pwr Blocks Estimate	NOAK-3 Pwr Blocks Contingen
		PLANT SCENARIO							
Nuclear Island									
NSSS (safety-grade)	25%	340.8	85.2	839.8	209.9	265.4	66.4	685.9	171.5
NSSS (non-safety)	15%	37.1	5.6	93.3	14.0	32.1	4.8	84.5	12.7
Other factory equipment	10%	65.2	6.5	156.4	15.6	58.7	5.9	148.8	14.9
Site materials	10%	41.6	4.2	89.5	8.9	37.5	3.7	89.5	8.9
Direct labor	20%	55.4	11.1	121.1	24.2	47.2	9.4	114.6	22.9
Construction services	15%	54.0	8.1	118.7	17.8	49.4	7.4	102.6	15.4
Engin. & home office svc	15%	27.6	4.1	31.8	4.8	15.5	2.3	20.7	3.1
Field office services	15%	29.5	4.4	59.6	8.9	24.7	3.7	50.5	7.6
Owners costs	20%	105.6	21.1	250.3	50.1	87.5	17.5	218.3	43.7
Total Nuclear Island:		756.7	150.290	1760.4	354.314	618.0	121.163	1,515.2	300.606
Balance-of-Plant Area									
Turbine generator	5%	61.7	3.1	185.1	9.3	61.7	3.1	185.1	9.3
Other factory equipment	7%	61.3	4.3	152.5	10.7	55.2	3.9	146.8	10.3
Site materials	10%	24.5	2.5	42.6	4.3	19.6	2.0	43.1	4.3
Direct labor	15%	38.0	5.7	73.4	11.0	29.4	4.4	68.2	10.2
Construction services	12%	29.1	3.5	59.4	7.1	22.9	2.8	55.3	6.6
Engin. & home office svc	12%	30.4	3.6	41.1	4.9	17.3	2.1	27.1	3.3
Field office services	12%	19.9	2.4	39.7	4.8	15.4	1.9	36.7	4.4
Owners costs	15%	41.1	6.2	90.7	13.6	34.6	5.2	86.0	12.9
Land	10%	9.1	0.9	10.8	1.1	9.1	0.9	10.8	1.1
Total Balance-of-Plant:		315.2	32.136	695.3	66.707	265.4	26.110	659.0	62.322
Total Plant:		**1,071.9**	**182.426**	**2,455.7**	**421.021**	**883.3**	**147.273**	**2,174.2**	**362.928**
Total Contingency Percentage:			**17.0%**		**17.1%**		**16.7%**		**16.7%**

Table 7-3

Construction and Startup Schedule

(in term of quarters of a year)

Description	Plant Scenario			
	First Comm'l		NOAK	
	One Power Block	Three Power Blocks	One Power Block	Three Power Blocks
Construction	41	54	30	40
Startup Completion	11	14	9	11
Total Construction Schedule	**52**	**68**	**39**	**51**

Table 7-4 3/9/95

FOAK Single Block Plant Cash Flow (M$)

Quarters From Start of Constr	Capital Cost Cash Flow	Capital Cost Cumulative
–12	14	14
–11	4	18
–10	4	22
–9	4	26
–8	7	32
–7	8	40
–6	8	48
–5	9	58
–4	11	69
–3	11	79
–2	11	90
–1	63	153
1	76	228
2	84	312
3	89	402
4	111	513
5	118	630
6	116	746
7	142	889
8	141	1,030
9	79	1,109
10	79	1,187
11	74	1,261
12	44	1,305
13	39	1,343
14	38	1,381
15	37	1,418
16	36	1,453
17	36	1,489

Table 7-5 3/9/95

First Commercial Three Block Plant Cash Flow (M$)

Quarters From Start of Constr	First Block		Second Block		Third Block		Total Plant	
	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative
–12	16	16					16	16
–11	4	20					4	20
–10	4	24					4	24
–9	4	28	2	2			6	30
–8	7	34	2	5			9	39
–7	8	42	2	7			10	49
–6	8	51	2	9	2	2	13	62
–5	9	60	3	12	2	5	14	77
–4	11	70	3	15	2	7	16	93
–3	11	82	3	18	2	9	17	109
–2	11	92	3	22	3	12	17	126
–1	63	155	4	25	3	15	69	195
1	76	231	4	29	3	18	83	278
2	84	314	4	33	3	22	91	369
3	89	404	45	78	4	25	138	507
4	111	515	52	130	4	29	167	674
5	118	633	58	188	4	33	180	854
6	116	749	61	250	45	78	222	1076
7	142	891	77	327	52	130	271	1,348
8	141	1,032	80	407	58	188	280	1,627
9	79	1,111	79	485	61	250	219	1,846
10	79	1,190	99	584	77	327	254	2,100
11	74	1,263	97	681	80	407	251	2,351
12	44	1,307	48	729	79	485	170	2,521
13	39	1,346	49	778	99	584	186	2,707
14	38	1,383	46	824	97	681	181	2,888
15	37	1,420	26	849	48	729	110	2,999
16	36	1,456	23	872	49	778	107	3,106
17	36	1,492	23	895	46	824	105	3,211
18			22	917	26	849	48	3,258
19			22	939	23	872	45	3,303
20			22	961	23	895	45	3,348
21					22	917	22	3,370
22					22	939	22	3,392
23					22	961	22	3,414

Table 7-6

NOAK Single Block Plant Cash Flow (M$)

Quarters From Start of Constr	Capital Cost Cash Flow	Capital Cost Cumulative
–12		
–11		
–10	14	14
–9	3	17
–8	3	20
–7	3	23
–6	5	28
–5	6	34
–4	6	40
–3	8	48
–2	9	57
–1	53	110
1	76	186
2	87	273
3	112	385
4	119	504
5	152	655
6	157	813
7	96	909
8	81	990
9	49	1,039
10	41	1,079
11	35	1,114
12	32	1,146
13	32	1,179
14		

Table 7-7

NOAK Three Block Plant Cash Flow (M$)

Quarters From Start of Constr	First Block		Second Block		Third Block		Total Plant	
	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative	Capital Cost Cash Flow	Capital Cost Cumulative
–12								
–11								
–10	16	16					16	16
–9	3	19					3	19
–8	3	22	2	2			5	24
–7	3	25	2	4			5	29
–6	5	30	2	7	2	2	10	39
–5	6	36	2	9	2	4	10	49
–4	6	42	3	11	2	7	11	60
–3	8	50	3	14	2	9	13	73
–2	9	59	3	17	3	11	15	88
–1	53	112	3	21	3	14	59	148
1	76	188	4	24	3	17	83	230
2	87	275	41	66	3	21	131	362
3	112	387	58	124	4	24	174	535
4	119	506	65	189	41	66	226	761
5	151	657	85	274	58	124	295	1,055
6	158	815	90	364	65	189	313	1,368
7	96	912	117	481	85	274	298	1,667
8	81	992	123	604	90	364	294	1,960
9	49	1,041	70	673	117	481	235	2,195
10	41	1,081	57	730	123	604	220	2,415
11	35	1,116	32	763	70	673	137	2,552
12	32	1,149	27	790	57	730	117	2,669
13	32	1,181	24	814	32	763	88	2,757
14			23	837	27	790	50	2,807
15			23	859	24	814	47	2,854
16					23	837	23	2,877
17					23	859	23	2,899
18								
19								

8.0 TOTAL CAPITAL COSTS

The total capital costs include the total direct costs, indirect costs, contingencies, and the interest during construction (AFUDC). The total capital cost for the four scenarios considered are presented in the following tables:

- Table 8-1: Scenario F1- First Commercial Single Block Plant with Large Common Facilities
- Table 8-2: Scenario F3 - First Commercial Three Block Plant
- Table 8-3: Scenario N1 - NOAK Single Block Plant with Small Common Facilities
- Table 8-4: Scenario N3 - NOAK Three Block Plant

The direct costs are presented at the three-digit EEDB accounts and the indirect costs at the two-digit EEDB accounts. In addition, the costs are separated into the nuclear island and the BOP area. The base construction cost consists of the total direct costs and the total indirect costs. The overnight cost is the base construction cost plus the contingency. The relatively low AE indirect costs (accounts 91 through 93) for the ALMR result from transferring a substantial percentage of field labor, which needs to be supported by indirect field services, to fabrication facilities which requires no indirect field services. Also, the ALMR is a standardized plant with confirming prototype safety and operation performance tests completed prior to construction of the first commercial plant.

Table 8-1

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

622MWe
F1-First Commercial Block With Large Common

		Nuclear Island					Balance of Plant					
EEDB Acct	**Description**	**Factory Equip**	**Site Hours**	**Site Labor**	**Site Matl**	**NI Total**	**Factory Equip**	**Site Hours**	**Site Labor**	**Site Matl**	**BOP Total**	**Total Cost**
20	Land and Land Rights	0	0	0	0	0	0	0	0	0	0	9,140
211	Yardwork	0	144	4,015	2,863	6,878	57	150	4,274	4,907	9,238	16,116
212	Reactor/Steam Gen Cmplx	29,602	692	21,533	20,949	72,804	0	0	0	0	0	72,084
213	Turbine Generator Fac.	0	0	0	0	0	1,132	127	4,070	4,477	9,678	9,678
214	Security Bldgs	566	28	862	644	2,072	0	0	0	0	0	2,072
216	Radwaste Bldg	960	20	630	567	2,157	0	0	0	0	0	2,157
217	Fuel Service Facility	0	0	0	0	0	0	0	0	0	0	0
218 A	Control Bldg	70	80	2,448	1,753	4,271	0	0	0	0	0	4,271
218 B	Administration Bldg Cmplx	0	0	0	0	0	565	62	2,002	2,191	4,759	4,759
218 D	Remote Shutdown Facility	88	53	1,640	1,841	3,568	0	0	0	0	0	3,568
218 N	Maintenance Facilities	2,201	121	3,835	2,750	8,785	144	29	943	1,215	2302	11,087
218 P	Spent Component Storage	0	18	527	540	1,118	0	0	0	0	0	1,118
218 Q	Misc.Tank Foundations	0	1	13	11	24	2	20	595	411	1,009	1,033
218 R	BOP Service Building	0	0	0	0	0	26	20	654	916	1,595	1,595
218 S	Waste Water Treat. Bldg	0	0	0	0	0	24	9	265	2221	511	511
218 T	Gas Turbine Facility	0	0	0	0	0	39	11	367	485	892	892
218 V	Personnel Service Bldg	40	22	703	969	1,711	0	0	0	0	0	1,711
218 W	Warehouses	16	11	347	369	731	19	15	492	678	1,188	1,919
218 X	Cask Transporter Garage	0	10	334	389	724	0	0	0	0	0	724
218 Z	Reactor Assembly Facility	0	25	758	637	1,395	0	0	0	0	0	1,395
21	Structures & Improvements	33,542	1,225	37;695	34,281	105,518	2,008	443	13,662	15,501	31,171	136,689
220	Nuclear Steam Supply (NSSS)	377,870	0	0	0	377,870	0	0	0	0	0	377,870
221	Reactor Equipment	0	68	2,095	0	2,095	0	0	0	0	0	2,095
222	Main Heat Transport Sys	2,086	29	902	44	3,032	0	0	0	0	0	3,032
223	Safeguards System	0	5	157	0	157	0	0	0	0	0	157
224	Radwaste System	811	21	640	4	1,455	0	0	0	0	0	1,455
225	Fuel Handling	10,754	2	52	0	10,805	0	0	0	0	0	10,805
226	Other Reactor Plant Equip	1,578	56	1,691	496	3,765	0	0	0	0	0	3,765
227	Reactor Instr & Control	0	62	2,060	807	2,867	0	0	0	0	0	2,867
228	Reactor Plant Misc Items	0	20	599	383	982	0	0	0	0	0	982
22	Reactor Plant Equipment	393,099	263	8,196	1,734	403,028	0	0	0	0	0	403,028
231	Turbine Generator	0	0	0	0	0	61,712	89	2,780	110	64,601	64,601
233	Condensing Systems	0	0	0	0	0	8,229	41	1,295	270	9,794	9,794
234	Feed Heating System	0	0	0	0	0	10,712	39	1,224	365	12,301	12,301
235	Other Turbine Plant Equip	65	38	1,199	108	1,371	4,010	61	1,921	357	6,288	7,659
236	Instrumentation & Control	0	0	0	0	0	808	5	182	79	1,069	1,069
237	Turbine Plant Misc Items	0	0	0	0	0	0	0	0	0	0	0
23	Turbine Plant Equipment	65	38	1,199	108	1,371	85,470	235	7,401	1,182	94,053	95,424

Table 8-1 (Continued)

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

622MWe
F1-First Commercial Block With Large Common

		Nuclear Island					Balance of Plant					
EEDB Acct	Description	Factory Equip	Site Hours	Site Labor	Site Matl	NI Total	Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cos
241	Switchgear	1,852	5	189	0	2,041	1,921	4	133	0	2,054	4,095
242	Station Service Equip	5,131	13	428	0	5,559	13,603	12	392	0	13,995	19,554
243	Switchboards	135	5	167	0	302	70	1	42	0	112	413
244	Protective Equipment	0	9	275	201	476	0	29	877	494	1,617	2,135
245	Elec Struct & Wiring Cont	3,710	47	1,615	362	5,688	2,057	79	2,644	844	5,545	11,233
246	Power & Control Wiring	3,196	31	1,048	451	4,695	2,260	64	2,160	1,231	5,651	10,346
24	Electric Plant Equipment	14,024	110	3,749	1,029	18,803	19,911	191	6,418	2,644	28,973	47,776
251	Transp & Lift Equip	1,049	3	84	0	1,133	2,000	4	124	0	2,125	3,257
252	Air, Wtr & Stm Svc Sys	321	51	1,606	348	2,274	2,545	81	2,537	1,433	6,516.	8,790
253	Communications Equip	103	74	2,505	4,034	6,642	135	44	1,494	372	2,000	8,642
254	Furnishings & Fixtures	876	7	214	7	1,097	876	14	445	27	1,348	2,445
255	Waste Wtr Treatment Equip	13	3	114	42	168	1,507	29	932	46	2,485	2,653
25	Misc Plant Equipment	2,362	138	4,522	4,431	11,314	7,063	172	5,532	1,878	14,473	25,787
261	Structures	0	0	0	0	0	0	0	0	0	0	0
262	Mechanical Equipment	0	0	0	0	0	8,576	161	5,020	3,304	16,899	16,899
26	Main Cond Heat Reject Sys	0	0	0	0	0	8,576	161	5,020	3,304	16,899	16,899
	Total Direct Costs	443,091	1,773	55,360	41,583	540,034	123,027	1,202	38,032	24,510	194,710	734,744
91	Construction Services					53,970					29,138	83,108
92	Engrg & H.O. Services					27,618					30,350	57,967
93	Field Office Services					29,486					19,862	49,347
94	Owners Costs					105,585					41,109	146,694
95	RM Engr & H.O. Services					0					0	0
	Total Indirect Costs					216,658					120,457	337,116
	Base Construction Cost					756,692					315,167	1,071,860
	Contingency					150,290					32,136	182,426
	Total Overnight Cost					906,982					347,303	1,254 ,286
	Interest During Constr.											235,050
	Total Capital Cost											1,489,336
	Construction Schedule Duration								52 Months			

Table 8-2

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

1866 MWe F3-First Commercial Three Power Block Plant												
		Nuclear Island					Balance of Plant					
EEDB Acct	Description	Factory Equip	Site Hours	Site Labor	Site Matl	NI Total	Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cos
20	Land and Land Rights	0	0	0	0	0	0	0	0	0	10,753	10,753
211	Yardwork	0	325	9,079	4,326	13,405	57	194	5,492	4,915	10,4164	23,869
212	Reactor/Steam Gen Cmplx	88,805	2,045	63,652	62,847	215,303	0	0	0	0	0	215,303
213	Turbine Generator Fac.	0	0	0	0	0	2,965	379	12,154	13,430	28,550	28,550
214	Security Bldgs	566	28	862	644	2,072	0	0	0	0	0	2,072
216	Radwaste Bldg	960	20	630	567	2,157	0	0	0	0	0	2,157
217	Fuel Service Facility	0	0	0	0	0	0	0	0	0	0	0
218 A	Control Bldg	70	80	2,448	1,753	4,271	0	0	0	0	0	4,271
218 B	Administration Bldg Cmplx	0	0	0	0	0	565	62	2,002	2,191	4,759	4,759
218 D	Remote Shutdown Facility	88	53	1,640	1,712	3,289	0	0	0	0	0	3,289
218 N	Maintenance Facilities	2,201	121	3,835	2,750	8,785	144	29	943	1,215	2,302	11,087
218 P	Spent Component Storage	0	18	578	540	1,118	0	0	0	0	0	1,118
218 Q	Misc. Foundations	0	3	35	35	71	2	39	595	411	1,009	1,080
218 R	BOP Service Building	0	0	0	0	0	26	20	654	916	1,595	1,595
218 S	Waste Water Treat. Bldg	0	0	0	0	0	24	9	265	221	511	511
218 T	Gas Turbine Facility	0	0	0	0	0	39	11	367	485	892	892
218 V	Personnel Service Bldg	40	22	703	969	1,711	0	0	0	0	0	1,711
218 W	Warehouses	16	11	347	369	731	19	15	492	678	1,188	1,919
218 X	Cask Transporter Garage	0	10	334	389	724	0	0	0	0	0	724
218 Z	Reactor Assembly Facility	0	25	758	637	1,395	0	0	0	0	0	1,395
21	Structures & Improvements	92,745	2,761	84,900	77,667	255,312	3,841	758	22,964	24,463	51,268	306,580
220	Nuclear Steam Supply (NSSS)	933,073	0	0	0	933,073	0	0	0	0	0	933,073
221	Reactor Equipment	0	201	6,192	0	6,192	0	0	0	0	0	6,192
222	Main Heat Transport Sys	6,257	85	2,665	133	9,055	0	0	0	0	0	9,055
223	Safeguards System	0	15	465	0	465	0	0	0	0	0	465
224	Radwaste System	811	21	640	4	1,455	0	0	0	0	0	1,455
225	Fuel Handling	11,135	2	52	0	11,187	0	0	0	0	0	11,187
226	Other Reactor Plant Equip	4,625	157	4,745	1,488	10,858	0	0	0	0	0	10,858
227	Rx Instr & Control	0	145	4,840	1,882	6,772	0	0	0	0	0	6,772
228	Rx Plant Misc Items	0	58	1,771	1,148	2,919	0	0	0	0	0	2,919
22	Reactor Plant Equipment	955,902	684	21,369	4,655	981,926	0	0	0	0	0	981,926
231	Turbine Generator	0	0	0	0	0	185,134	268	8,343	329	193,805	193,805
233	Condensing Systems	0	0	0	0	0	24,687	124	3,883	810	29,380	29,380
234	Feed Heating System	0	0	0	0	0	32,133	116	3,670	1,097	36,,900	36,900
235	Other Turbine Plant Equip	65	45	1,416	150	1,631	9,695	159	5,008	931	15,634	17,265
236	Instrumentation & Control	0	0	0	0	0	2,423	16	545	239	3,207	3,207
237	Turbine Plant Misc Items	0	0	0	0	0	0	0	0	0	0	0
23	Turbine Plant Equipment	65	45	1,416	150	1,631	254,071	683	21,448	3,407	278,926	280,556

Table 8-2 (Continued

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

1866 MWe
F3-First Commercial Three Power Block Plant

		Nuclear Island					Balance of Plant					
EEDB Acct	Description	Factory Equip	Site Hour	Site Labor	Site Matl	NI Total	Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cos
241	Switchgear	1,893	6	206	0	2,098	3,561	8	234	0	3,795	5,893
242	Station Service Equip	12,968	21	704	0	13,671	31,848	17	561	0	32,408	46,080
243	Switchboards	135	12	378	0	513	70	1	42	0	112	624
244	Protective Equipment	0	26	861	644	1,505	0	34	1,091	609	1,700	3,205
245	Elec Struct & Wiring Cont	11,128	87	2,992	664	14,784	6,172	116	3,894	1,230	11,296	26,080
246	Power & Control Wiring	9,586	69	2,333	991	12,910	6,782	116	3,935	1,984	12,700	25,611
24	Electric Plant Equipment	35,709	221	7,474	2,299	45,482	48,433	292	9,756	3,822	62,011	107,494
251	Transp & Lift Equip	1,643	4	125	0	1,769	2,699	6	176	0	2,875	4,644
252	Air, Wtr & Stm Svc Sys	864	73	2,299	517	3,680	4,884	139	4,362	2,190	11,436	15,116
253	Communications Equip	310	82	2,805	4,144	7,259	135	53	1,803	566	2,504	9,763
254	Furnishings & Fixtures	2,199	15	496	7	2,702	968	14	445	27	1,440	4,142
255	Waste Wtr Treatment Equip	39	7	234	48	321	1,507	29	932	46	2,485	2,805
25	Misc Plant Equipment	5,055	181	5,959	4,716	15,730	10,192	241	7,718	2,829	20,739	36,469
261	Structures	0	0	0	0	0	0	0	0	0	0	0
262	Mechanical Equipment	0	0	0	0	0	21,051	372	11,511	8,034	40,596	40,596
26	Main Cond Heat Reject Sys	0	0	0	0	0	21,051	372	11,511	8,034	40,596	40,596
	Total Direct Costs	1,089,476	3,892	121,119	89,487	1,300,082	337,588	2,346	73,398	42,555	464,295	1,764,376
91	Construction Services					118,710					59,422	178,132
92	Engrg & H.O. Services					31,769					41,139	72,908
93	Field Office Services					59,579					39,730	99,308
94	Owners Costs					250,277					90,688	340,965
95	RM Engr & H.O. Services					0					0	0
	Total Indirect Costs					460,334					230,979	691,314
	Base Construction Cost					1,760,416					695,279	2,455,690
	Contingency					354,314	20%			9.5%	66,707	421,021 17%
	Total Overnight Cost					2,114,730					761,981	2,876,711
	Interest During Constr.											536,910
	Total Capital Cost											3,413,621
	Construction Schedule Duration							68 Months				

Table 8-3

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

622MWe
N1-NOAK Single Block Plant

		Nuclear Island					Balance of Plant					
EEDB Acct	**Description**	**Factory Equip**	**Site Hours**	**Site Labor**	**Site Matl**	**NI Total**	**Factory Equip**	**Site Hours**	**Site Labor**	**Site Matl**	**BOP Total**	**Total Cost**
20	Land and Land Rights	0	0	0	0	0	0	0	0	0	9,140	9,140
211	Yardwork	0	116	3,227	2,005	5,232	34	94	2,664	2,945	5,644	10,875
212	Reactor/Steam Gen Cmplx	28,195	644	20,004	20,949	69,148	0	0	0	0	0	69,148
213	Turbine Generator Fac.	0	0	0	0	0	1,064	115	3,694	4,477	9,234	9,234
214	Security Bldgs	407	19	597	464	1,468	0	0	0	0	0	1,468
216	Radwaste Bldg	691	14	435	407	1,534	0	0	0	0	0	1,534
217	Fuel Service Facility	0	0	0	0	0	0	0	0	0	0	0
218 A	Control Bldg	50	55	1,693	1,262	3,006	0	0	0	0	0	3,006
218 B	Administration Bldg Cmplx	0	0	0	0	0	361	38	1,231	1,402	2,994	2,994
218 D	Remote Shutdown Facility	56	33	1,009	1,179	2,244	0	0	0	0	0	2,244
218 N	Maintenance Facilities	2,201	117	3,682	2,750	8,633	144	27	905	1,215	2,264	10,897
218 P	Spent Component Storage	0	17	555	540	1,095	0	0	0	0	0	1,095
218 Q	Misc. Foundations	0	1	11	11	23	1	16	475	370	846	869
218 R	BOP Service Building	0	0	0	0	0	15	11	364	531	910	910
218 S	Waste Water Treat. Bldg	0	0	0	0	0	11	4	133	115	259	259
218 T	Gas Turbine Facility	0	0	0	0	0	39	11	353	485	877	877
218 V	Personnel Service Bldg	40	21	674	969	1,683	0	0	0	0	0	1,683
218 W	Warehouses	11	8	240	265	517	13	10	340	489	841	1,358
218 X	Cask Transporter Garage	0	6	192	234	426	0	0	0	0	0	426
218 Z	Reactor Assembly Facility	0	24	728	637	1,365	0	0	0	0	0	1,365
21	Structures & Improvements	31,651	1,075	33,049	31,671	96,372	1,682	326	10,159	12,029	23,870	120,242
220	Nuclear Steam Supply (NSSS)	297,491	0	0	0	297,491	0	0	0	0	0	297,491
221	Reactor Equipment	0	63	1,946	0	1,946	0	0	0	0	0	1,946
222	Main Heat Transport Sys	1,911	27	838	44	2,793	0	0	0	0	0	2,793
223	Safeguards System	0	5	146	0	146	0	0	0	0	0	146
224	Radwaste System	584	14	443	3	1,029	0	0	0	0	0	1,029
225	Fuel Handling	8,367	2	52	0	8,419	0	0	0	0	0	8,419
226	Other Reactor Plant Equip	1,578	54	1,577	496	3,650	0	0	0	0	0	3,650
227	Rx Instr & Control	0	51	1,713	710	2,423	0	0	0	0	0	2,423
228	Rx Plant Misc Items	0	18	558	383	941	0	0	0	0	0	941
22	Reactor Plant Equipment	309,930	234	7,272	1,636	318,838	0	0	0	0	0	318,838
231	Turbine Generator	0	0	0	0	0	61,712	81	2,522	110	64,344	64,344
233	Condensing Systems	0	0	0	0	0	8,120	37	1,175	270	9,565	9,565
234	Feed Heating System	0	0	0	0	0	10,180	35	1,110	365	11,655	11,655
235	Other Turbine Plant Equip	33	20	646	67	746	3,422	51	1,589	324	5,335	6,081
236	Instrumentation & Control	0	0	0	0	0	808	5	165	79	1,052	1,052
237	Turbine Plant Misc Items	0	0	0	0	0	0	0	0	0	0	0
23	Turbine Plant Equipment	33	20	646	67	746	84,242	209	6,561	1,148	91,951	92,698

Table 8-3 (Continued)

ALMR COST ESTIMATE
(Manhours and Costs in 1,000s)
January 1994 Dollars

622 MWe
N1-NOAK Single Block Plant

EEDB Acct	Description	Nuclear Island: Factory Equip	Site Hours	Site Labor	Site Matl	NI Total	Balance of Plant: Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cos
241	Switchgear	1,338	4	133	0	1,471	1,613	3	102	0	1,715	3,186
242	Station Service Equip	4,498	10	329	0	4,826	11,420	9	288	0	11,708	16,535
243	Switchboards	86	4	136	0	221	45	1	25	0	70	291
244	Protective Equipment	0	8	276	215	491	0	20	649	372	1,021	1,512
245	Elec Struct & Wiring Cont	3,397	35	1,214	286	4,897	1,884	54	1,808	610	4,302	9,200
246	Power & Control Wiring	2,981	25	851	386	4,218	2,097	47	1,588	924	4,609	8,827
24	Electric Plant Equipment	12,300	86	2,938	887	16,125	17,060	134	4,461	1,905	23,426	39,551
251	Transp & Lift Equip	1,049	2	79	0	1,129	2,000	4	117	0	2,117	3,246
252	Air, Wtr & Stm Svc Sys	287	38	1,193	275	1,755	2,124	62	1,951	1,138	5,213	6,968
253	Communications Equip	103	52	1,769	2,919	4,791	97	32	1,067	294	1,458	6,249
254	Furnishings & Fixtures	816	6	182	5	1,003	696	10	307	18	946	2,026
255	Waste Wtr Treatment Equip	13	3	93	31	137	1,085	20	645	33	1,763	1,900
25	Misc Plant Equipment	2,269	101	3,316	3,230	8,815	6,002	128	4,087	1,486	11,575	20,390
261	Structures	0	0	0	0	0	0	0	0	0	0	0
262	Mechanical Equipment	0	0	0	0	0	7,921	134	4,171	3,041	15,133	15,133
26	Main Cond Heat Reject Sys	0	0	0	0	0	7,921	134	4,171	3,041	15.133	15,133
	Total Direct Costs	356,183	1,515	47,221	37,491	440,896	116,907	931	29,439	19,610	175,096	615,992
91	Construction Services					49,425					22,924	72,348
92	Engrg & H.O. Services					15,482					17,288	32,770
93	Field Office Services					24,681					15,438	40,119
94	Owners Costs					87,491					34,612	122,103
95	RM Engr & H.O. Services					0					0	0
	Total Indirect Costs					177,079					90,262	267,340
	Base Construction Cost					617,974					265,358	883,332
	Contingency					121,163					26,110	147,273
	Total Overnight Cost					739,137					291,468	1,030,605
	Interest During Constr.											147,930
	Total Capital Cost											1,178,535
	Construction Schedule Duration							39 Months				

Table 8-4

ALMR COST ESTIMATE

(Manhours and Costs in 1,000s)
January 1994 Dollars

1866 MWe
N3-NOAK Three Power Block Plant

		Nuclear Island					Balance of Plant					
EEDB Acct	Description	Factory Equip	Site Hours	Site Labor	Site Matl	NI Total	Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cost
20	Land and Land Rights	0	0	0	0	0	0	0	0	10,753	10,	10,753
211	Yardwork	0	288	8,587	4,295	12,882	57	183	5,177	4,915	10,150	23,032
212	Reactor/Steam Gen Cmplx	84,586	1,931	60,012	62,847	207,445	0	0	0	0	0	207,445
213	Turbine Generator Fac.	0	0	0	0	0	2,760	344	11,026	13,430	27,216	27,216
214	Security Bldgs	566	26	829	644	2,039	0	0	0	0	0	2,039
216	Radwaste Bldg	960	20	606	567	2,133	0	0	0	0	0	2,133
217	Fuel Service Facility	0	0	0	0	0	0	0	0	0	0	0
218 A	Control Bldg	70	76	2,350	1,753	4,173	0	0	0	0	0	4,173
218 B	Administration Bldg Cmplx	0	0	0	0	0	565	60	1,922	2,191	4,678	4,678
218 D	Remote Shutdown Facility	88	51	1,575	1,841	3,504	0	0	0	0	0	3,504
218 N	Maintenance Facilities	2,201	117	3,682	2,750	8,633	144	27	905	1,215	2,264	10,897
218 P	Spent Component Storage	0	18	555	540	1,095	0	0	0	0	0	1,095
218 Q	Misc. Foundations	0	2	30	35	69	2	36	1,088	932	2,022	2,091
218 R	BOP Service Building	0	0	0	0	0	26	19	628	916	1,570	1,570
218 S	Waste Water Treat. Bldg	0	0	0	0	0	24	8	255	221	500	500
218 T	Gas Turbine Facility	0	0	0	0	0	39	11	353	485	877	877
218 V	Personnel Service Bldg	40	21	674	969	1,683	0	0	0	0	0	1,683
218 W	Warehouses	16	11	332	369	716	19	14	472	678	1,168	1,884
218 X	Cask Transporter Garage	0	10	321	389	710	0	0	0	0	0	710
218 Z	Reactor Assembly Facility	0	24	728	637	1,365	0	0	0	0	0	1,365
21	Structures & Improvements	88,526	2,595	80,284	77,635	246,446	3.636	702	21,826	24,984	50,447	296,892
220	Nuclear Steam Supply (NSSS)	~~[illegible]~~	0	0	0	~~770,376~~		0	0	0	0	770,376
221	Reactor Equipment	0	190	5,839	0	5,839	0	0	0	0	0	5,839
222	Main Heat Transport Sys	5,730	81	2,514	133	8,376	0	0	0	0	0	8,376
223	Safeguards System	0	14	437	0	437	0	0	0	0	0	437
224	Radwaste System	811	20	615	4	1,430	0	0	0	0	0	1,430
225	Fuel Handling	10,754	2	52	0	10,805	0	0	0	0	0	10,805
226	Other Reactor Plant Equip	4,625	148	4,445	1,488	10,558	0	0	0	0	0	10,558
227	Reactor Instr & Control	0	152	4,577	1,882	6,459	0	0	0	0	0	6,459
228	Reactor Misc Items	0	54	1,671	1,148	2,820	0	0	0	0	0	2,820
22	Reactor Plant Equipment	~~458,967~~	545	16,484	4,661	~~480,102~~	269,504	0	0	0	269,504	~~749,606~~
231	Turbine Generator	0	0	0	0	0	185,234	243	7,567	329	193,030	193,030
233	Condensing Systems	0	0	0	0	0	24,360	112	3,524	810	28,694	28,694
234	Feed Heating System	0	0	0	0	0	30,541	105	3,328	1,097	34,966	34,966
235	Other Turbine Plant Equip	65	45	1,354	150	1,569	9,613	145	4,562	931	15,107	16,676
236	Instrumentation & Control	0	0	0	0	0	2,423	14	495	239	3,157	3,157
237	Turbine Plant Misc Items	0	0	0	0	0	0	0	0	0	0	0
23	Turbine Plant Equipment	65	45	1,354	150	1,569	252,071	619	19,476	3,407	274,953	276,522

Table 8-4 (Continued)

ALMR COST ESTIMATE
(Manhours and Costs in 1,000s)
January 1994 Dollars

1866 MWe
N3-NOAK Three Power Block Plant

		Nuclear Island					Balance of Plant					
EEDB Acct	Description	Factory Equip	Site Hours	Site Labor	Site Matl	NI Total	Factory Equip	Site Hours	Site Labor	Site Matl	BOP Total	Total Cost
241	Switchgear	1,893	6	196	0	2,089	3,561	7	216	0	3,777	5,866
242	Station Service Equip	12,088	17	668	0	12,756	29,569	16	525	0	30,094	42,850
243	Switchboards	135	10	358	0	493	70	1	40	0	110	602
244	Protective Equipment	0	24	813	664	1,457	0	32	1,045	609	1,654	3,111
245	Elec Struct & Wiring Cont	10,191	72	2,838	664	13,692	5,652	108	3,639	1,230	10,522	24,214
246	Power & Control Wiring	12,084	73	2,364	1,022	15,470	3,252	120	3,753	1,891	8,896	24,366
24	Electric Plant Equipment	33,248	190	7,083	2,299	42,629	45,143	271	9,102	3,822	58,067	100,696
251	Transp & Lift Equip	1,643	3	120	0	1,763	2,699	6	166	0	2,865	4,628
252	Air, Wtr & Stm Svc Sys	807	70	2,190	517	3,514	4,773	129	4,043	2,190	11,007	14,521
253	Communications Equip	310	79	2,686	4,144	7,140	135	50	1,707	566	2,407	9,547
254	Furnishings & Fixtures	2,199	13	469	7	2,675	968	13	426	27	1,421	4,096
255	Waste Wtr Treatment Equip	39	9	220	48	307	1,507	28	896	46	2,448	2,755
25	Misc Plant Equipment	4,998	171	5,686	4,716	15,399	10,081	226	7,238	2,829	20,148	35,548
261	Structures	0	0	0	0	0	0	0	0	0	0	0
262	Mechanical Equipment	0	0	0	0	0	21,051	340	10,537	8,034	39,622	39,622
26	Main Cond Heat Reject Sys	0	0	0	0	0	21,051	340	10,537	8,034	39,622	39,622
	Total Direct Costs	919,132	3,661	114,557	89,456	1,123,144	331,983	2,158	68,179	43,076	453,991	1,577,136
91	Construction Services					102,562					55,258	157,820
92	Engrg & H.O. Services					20,705					27,085	47,790
93	Field Office Services					50,528					36,683	87,211
94	Owners Costs					218,297					85,953	304,250
95	RM Engr & H.O. Services					0					0	0
	Total Indirect Costs					392,092					204,979	597,071
	Base Construction Cost					1,515,237					658,970	2,174,207
	Contingency					300,606					62,322	362,928
	Total Overnight Cost					1,815,843					721,292	2,537,135
	Interest During Constr.											362,130
	Total Capital Cost											2,899,265
	Construction Schedule Duration						51 Months					

9.0 ANNUAL NON-FUEL OPERATION AND MAINTENANCE COSTS

This section documents the annual non-fuel operation and maintenance (O&M) costs estimated for the ALMR plant concept. The O&M costs presented here are based on the 1993 ALMR O&M costs and include adjustments to account for the 1993-1994 design changes and escalation from January 1992 to January 1994 conditions. The staff salaries and indirect costs are according to the May 1993 edition of the DOE/ORNL cost estimating guidelines (Reference 9-1) as updated in February 1994 (Reference 9-la). An overall annual escalation rate of 3.1% and 4.3% were used to adjust all costs from January 1992 to January 1993 conditions and from January 1992 to January 1993 conditions respectively (Reference 9-1b). The current O&M cost estimate is the fourth update of a major revision in the ALMR O&M assessment methodology which was implemented in 1990.

In 1990, the ALMR O&M assessment was one of the several cost areas in which a major emphasis was placed on developing improved cost estimate bases, particularly in the area of plant staffing, through direct O&M discussions with LWR plant personnel. For this purpose, several visits to nuclear plants in the U.S. and Canada were made by an ALMR team in the fall of 1989 and the spring of 1990. As compared to the previous O&M assessment performed in 1987, a revised approach was developed and used in 1990 responding to suggestions made in the past by both DOE and utility review panels for improving our O&M cost estimate basis. That revised approach is described in this section.

In 1991, we initiated an O&M database as well as a comprehensive ALMR maintenance assessment both of which will be used in estimating future O&M costs. Two more plant visits also contributed to the database formation. The maintenance assessment resulted in the development of an ALMR specific database of manpower requirements for maintenance, inspection and refueling activities for all major plant components and systems. This maintenance assessment was started out of a need for this database which we will continue to improve in time. The next phase of this maintenance assessment will include a refinement of the database and a complete integration with the rest of the O&M assessment. Some of the methods developed in this maintenance study may also be used to better define staff requirements for other job functions in the plant organization. We plan to review the results of this bottoms up maintenance assessment with utility personnel on a continuing basis.

In 1993, we made several minor adjustments in the staffing levels which had the net effect of increasing the on-site staff size by eleven persons, from 565 to 576 relative to the 1991 cost estimate. The several minor adjustments in the plant staffing levels were made as a result of (1) recommendations made by the DOE Cost Review Panel in their report on the March 1992 review of the 1991 ALMR cost estimate (Reference 9-2) and (2) changes in the annualized contract labor requirements for refueling and peak maintenance because of several design improvements made in 1992. During 1992, the ALMR O&M team visited several other plants for direct O&M discussions with operating personnel. The plants visited were the experimental LMR facilities EBR-II and FFTF (July 1992) and the Duke Power Company's Oconee Nuclear Station and the coal-fired Marshall Steam Station (December 1992).

During our recent discussions with the operating personnel at Oconee nuclear station and especially at the Marshall steam station we obtained first-hand knowledge about the main reasons for which the on-site staff sizes of nuclear plants (and correspondingly their non-fuel O&M costs) are so much larger than those of equivalent coal-fired plants run by the same utility. As a particular example, we found out that the ratio between the staff sizes at Oconee and Marshall is about ten and so is the ratio of their respective non-fuel O&M costs. This may be somewhat of an extreme case since Marshall does not have any scrubbers because it burns very good low-sulfur coal. But even if the staff size of Marshall is adjusted upwards to account for scrubbers, the Oconee nuclear plant staff size would still remain many times larger than that of Marshall's.

Because the ALMR plant design provides for a physical separation between the nuclear island (NI) and the balance-of-plant (BOP), the conventional energy conversion equipment located in the BOP is designed to be in many way similar to that of a coal-fired plant. In the future, we plan to evaluate the extent to which the ALMR BOP O&M staffing levels and costs could be reduced further by incorporating some of the coal-plant operating experience that may be applicable.

In 1994, we adjusted the staffing levels and the O&M costs to reflect the change from the 1993 ALMR design (nine reactor modules grouped in 3 x 496 MWe power blocks) to the 1994 ALMR design (six reactor modules grouped in 3 x 622 MWe power blocks). The net effect of increased in plant capacity (from 1488 MWe to 1866 MWe) combined with the decrease in the number of reactor modules from nine to six was a slight on-site staff reduction from 576 to 567.

The cost improvements in the O&M data base made in the detailed ALMR maintenance assessment initiated in FY 1991 could not be incorporated in the O&M cost estimates yet because the development of the maintenance assessment is still in progress. However, it is planned that these improvements will be incorporated in future cost updates together with adjustments to reflect utility personnel comments on the ALMR O&M cost and staff estimates. There are some preliminary indications that some reductions in the staffing levels are possible in some areas. We believe that, when completed, our comprehensive maintenance assessment will increase the credibility of our O&M cost estimate.

9.1 Summary and Conclusions

The O&M costs presented in this report are based on the ALMR O&M costs developed in 1993 and include adjustments to account for the ALMR design changes and escalation from January 1992 to January 1994 conditions.

All on-site staff adjustments which were made in 1993 in response to recommendations of the DOE Cost Review Panel (Reference 9-2) have been retained in the 1994 staffing estimate. These on-site staff adjustments were recommended following the review of the ALMR cost estimate in March 1992 and included small increases in the staffing levels of the shift operators, HP technicians, and the annualized contract level for refueling and peak maintenance.

9.1.1 Summary

The O&M staff levels were estimated based on a detailed examination of the ALMR plant operating needs and through comparisons with current and early LWR and HWR plants from the U.S., Canada and other foreign countries. The basic premises of the O&M cost estimate included the ALMR intrinsic design characteristics such as passive safety features, use of sodium as the reactor coolant instead of water, modular construction, design standardization and certification, and the assumption that standardized O&M procedures and spare parts pools will be used.

Annual non-fuel O&M costs were estimated for four ALMR plant configurations including the first commercial single block plant and three Nth-of-a-kind (NOAK) plants consisting of one power block, two power blocks and three power blocks. The projected O&M costs in January 1993 dollars for these four ALMR plants are 57.6, 46.6, 72.5 and 98.3 millions of dollars per year or 12.7, 9.9, 7.7 and 7.0 mills/kWh, respectively. Breakdowns of the annual O&M costs by major cost categories are summarized in Table 9-1.

The projected on-site staff for the first commercial plant is 372 personnel. The on-site staff requirements projected for the single power block, two power block and three power block NOAK plants are 303, 435 and 567, respectively. The projected off-site support staff requirements for these four plant configurations are 50, 40, 60 and 80 personnel, respectively.

9.1.2 Conclusions

The following conclusions were reached in the course of the O&M assessment:

- As compared to the 1993 ALMR O&M assessment, the 1994 O&M estimate resulted in small reductions of 0.8% in the on-site staff and of 0.9% in the annual non-fuel O&M

costs expressed in January 1994 dollars. These are insignificant changes compared to the increases made in the 1990 O&M assessment relative to the 1987 ALMR O&M assessment, when the improved cost estimating bases used resulted in increases of 34% and 60% in the on-site staff and off-site support staff, respectively, and of 20.9% in the annual non-fuel O&M costs expressed in January 1992 dollars.

- In terms of mills/kWh, the small savings in the 1994 total annual non-fuel O&M costs, as compared to 1993, were further amplified by the increase in the plant capacity (from 1488 MWe to 1866 MWe) which was the result of the adoption of the ALMR design as the new reference. Thus, in the 1994 cost estimate, there was a reduction of 1.75 mills/kWh or 20.9% relative to 1993 (from 8.85 mills/kWh to 7.1 mills/kWh).

- Relative to the 1987 O&M assessment, the higher staff and O&M cost estimates are the result of a number of factors which include use of improved methods for developing staffing estimates, increased awareness of current actual operating conditions through site visits and direct O&M discussions with utility personnel at selected plants, and more comprehensive technical assessments of maintenance staff requirements. The 1994 estimates, also, incorporate changes suggested by utility personnel who reviewed the results of our 1990 and 1991 O&M assessments.

- Although the 1990, 1991, 1993 and 1994 estimates of the ALMR staff and annual non-fuel O&M costs are significantly higher than those estimated in 1987, these estimates are still best practices relative to the corresponding values predominant in the current LWR plants in the U.S. The projected staffing required for a full size 1866 MWe ALMR NOAK plant is 567 persons or approximately 0.31 employees per MWe (net). This is comparable with the staffing levels experienced in some of the best-run plants in the U.S. and in most foreign nuclear plants where design standardization and certification features similar to those proposed for the ALMR are used.

- The ALMR has the potential for lowering the operating and maintenance costs and for being more immune to future cost increases being projected for the current generation of conventional nuclear plants because of its focus on licensing and certification of a standard design.

9.2 Methodology and Assumptions

9.2.1 Methodology

Responding to suggestions for improving the O&M cost estimate basis made in the past by both DOE and utility review panels, the ALMR O&M assessment team developed and used a revised approach for preparing the projected O&M costs for the 1992 reference design. Compared to the 1987 O&M assessment, the new approach included the following activities:

1. Site visits to six PWR and BWR nuclear power stations (Byron, Point Beach, Yankee Rowe, Pickering, LaSalle, and Oconee), two experimental LMR facilities (EBR-II and FFTF), and one coal-fired power station (Marshall).

2. Development of a detailed organization chart for the ALMR plant based on O&M needs identified as specific to ALMR plants and comparisons with organization charts of plants visited.

3. Maintenance staff assessment for the purpose of identifying the size of maintenance staff and determining outage durations and manpower requirements for planned and unplanned outages. This was a top level assessment of the maintenance requirements by major plant system including: reactor refueling, nuclear island, IHTS—steam generator, turbine generator set, balance of plant, and regulatory.

4. Assessment of a cost effective mix of on-site and contract labor for planned outages and determination of annualized contract labor requirements for refueling, reactor and IHTS/SG peak maintenance, turbine-generator peak maintenance, BOP peak maintenance, in-service inspection and regulatory.

5. Operations staff assessment for the purpose of determining the size and composition of the shift complement and the number of shifts needed. This assessment considered the level of automation built into the ALMR design and the operator training requirements.

6. Security personnel assessment which identified the requirements for both utility company staff and contract labor.

7. Development of staff estimates for all remaining plant staff positions identified in the plant organization chart in the administrative, operations, maintenance and technical divisions. Detailed estimates were developed at first for one power block and then for the increments needed to expand the plant operation to two block and three block capacity levels.

8. Engineering judgments of the impact on the O&M staff levels of the differences and similarities between PWR, BWR, HWR and ALMR plants in terms of plant design, operational licensing requirements, and level of design standardization and certification.

9. Group reviews of results and overall comparisons with past and present PWR, BWR and HWR plant O&M experience in the U.S. and foreign countries.

9.2.2 O&M Assumptions

The estimated O&M staff levels were developed based on a detailed examination of the ALMR plant operating needs and through comparisons with current and early LWR and HWR plants from the U.S., Canada and other foreign countries.

The O&M cost and staff data and the organization charts collected through the site visits to Byron, Point Beach, Yankee Rowe, Pickering, LaSalle, and Oconee nuclear power stations were very useful in establishing benchmarks for comparing differences and similarities between the ALMR and conventional nuclear plants and making adjustments as necessary to reflect the same.

The plants visited provided good ranges in terms of unit sizes, plant ages, number of units per site, type of reactors (PWR, BWR and PHWR), degree of design standardization and replication, management practices, approach to the conduct of operations and maintenance, and management labor relations. For example, plant capacities range from 167 to 4120 MWe, plant ages from 4 to 30 years, and number of units from one to eight on a site.

Since all plants visited represent well-run nuclear power stations in the U.S. and Canada, it was considered appropriate to use the information obtained from them as a basis for developing O&M cost estimates for the ALMR.

The projected O&M costs were developed by taking into account the ALMR intrinsic design characteristics such as passive safety features, use of sodium as the reactor coolant instead of water, modular construction, design standardization and certification, and the assumption that standardized O&M procedures and spare parts pools will be used.

In arriving at the on-site and off-site staffing and O&M cost estimates, several design related innovative assumptions were made which are consistent with the current reference ALMR design, as follows:

- One central control room with one control console operator per power block plus one relief reactor operator per control room.
- Non-safety grade control room.
- Site layout is optimized for operation and maintenance activities while minimizing the required security forces.
- On-line simulator to provide control room operator training during normal shift (regular control room operators remain on duty).
- Passive safety design reduces the number of safety systems.

In addition, the following moderation assumptions, applicable to any concept, were made consistent with the reference ALMR design:

- Computerized and automated record keeping information and security systems.
- High level of automation using state of the art digital techniques.
- On-line maintenance.
- More efficient use of maintenance teams because of specialization and automatic maintenance diagnostics.

The relaxations made from the current light water reactor requirements are considered justified because of the specific ALMR inherent safety characteristics, design standardization and certification, and highly automated information gathering and control systems.

9.2.3 Overview of Current Operating Plant Staff Information

A 1990 Nucleonics Week Special Report entitled "Outlook on Personnel Costs" (Ref. 9-3) provided a comprehensive assessment of the current status of the nuclear O&M costs in the U.S. and several foreign countries including Canada, France, Japan, and the U.K. This industry survey identified many of the reasons which caused the deterioration of the nuclear O&M costs in the U.S. and of those reasons which, by contrast, permitted several foreign countries to achieve much lower nuclear O&M costs. Some of the facts that are relevant to the assessment of the projected ALMR costs are discussed below.

The special report stated that "... there appears (to be) no disagreement that the increase in (O&M) costs is being led by increases in staffing... the average plant staff has doubled, from about 400 to about 800, from 1981 through 1988, while all O&M costs increased by 80% (adjusted for inflation). ... EPRI attributed 30% to 60% of O&M cost to NRC requirements."

Whereas the report also states that "some recent studies have given some hope that O&M costs might be stabilizing," it is likely that the current upward trend might get worse before it gets better.

The report also states that "among the big uncertainties that could push up staffs in the future... are the (proposed but not adopted yet) NRC maintenance policy, severe accident analyses to show plants have no recognized accident risks,... increased QA efforts to root out fraudulent and substandard parts,... configuration management, design basis reconstitution for older plants with poor original documentation, and more rigorous in-service inspection."

Discussing the French utility Electricite de France (EdF) experience, for example, the same special report states that design standardization has beneficial effects on staffing levels in several areas as follows:

- Centralization of a variety of functions that must be carried out site-by-site in the U.S.;
- Training, because only three to five people are responsible for training on an EdF nuclear site, versus 40-50 people at a typical U.S. site;
- Planning quality maintenance programs is done at headquarters by central staff for all similar plants;

Relative to the Canadian experience with operating nuclear plants, the same Nucleonics Week special report quotes an Ontario Hydro official as saying that "Our staff is consistently running about 50% of the staff in the U.S. nuclear prográm per installed gigawatt terms... The bottom line is... that even with (recent) significant increases in nuclear resourcing approved by the (company) board, we are still running a very Spartan operation compared to the U.S. nuclear program. We are making more effective use of our people."

Examination of the past and potentially future causes for O&M cost increases in the current generation of nuclear plants in the U.S. shows that, because of its specific nature, innovative design, and licensing certification philosophy discussed above, the ALMR justifies much lower staff levels than current nuclear plants and that, in addition, it has the potential to hold the line against future increases. In fact, the ALMR built-in advantages are entirely consistent with the primary reasons which led to the successful O&M experience realized in some foreign countries.

9.3 Development of O&M Cost Estimates

The O&M cost estimates are patterned after the procedures developed by ORNL for light water reactors (Ref. 9-4) and follow the guidelines for staff salaries and indirect costs given in the DOE/ORNL Cost Estimate Guidelines for Advanced Nuclear Power Technologies (References 9-1 and 9-la). A 7.530% escalation rate was used to update the 1992 ALMR cost data on supplies and expenses to January 1994 conditions.

Estimates for the operating cost for refueling are included as O&M costs. The costs are subdivided into expenditures for personnel, consumable supplies and materials, and indirect costs. The direct costs include the on-site staff, maintenance materials, supplies and expenses, and off-site support services. Variable costs are allocated in two subaccounts, variable maintenance materials and variable supplies and expenses. All other costs are considered to be fixed, although there is no rigorous definition of the allocation between fixed and variable costs. The cost estimates for maintenance activities do not include allowances for major retrofitting or modifications that have been required in the past due to changing environmental and safety regulations.

9.3.1 On-Site Staff

The estimated staffing requirements for the first commercial single block ALMR plant, and for one, two and three ALMR NOAK power blocks are 372, 303, 435 and 567 persons, respectively. Expressed in terms of manpower per MWe (net), these staff levels are equivalent to approximately 0.60, 0.49, 0.35 and 0.31, respectively.

The staffing requirement of 0.31 people per MWe (net) projected for the full size 1866 MWe ALMR NOAK plant is comparable with those levels experienced in some of the best-run plants in the U.S. as well as in most foreign nuclear plants where design standardization and certification features similar to those proposed for the ALMR are used.

Breakdowns of the total staff by organizational division and major staff category are summarized in Table 9-2 for each plant configuration analyzed.

Table 9-3 summarizes the estimated annual salaries for the on-site staffing requirements corresponding to the four plant configurations analyzed. These annual salaries are based on the DOE/ORNL cost estimate guidelines (References 9-1 and 9-la) and include a 7.53% escalation from January 1992 to January 1994 conditions.

9.3.1.1 Administrative Division

The personnel in the Administrative Division perform the following functions: environmental control, emergency planning and public relations, training, safety and fire protection, central file (records) management, health services, personnel administration, financial and accounting services, clerical support, MIS computer services, training and security.

The security force is provided on a five-shift basis. Breakdown of the security personnel by staff position for each of the four plant configurations analyzed are shown in Table 9-4. A more detailed assessment of the security personnel is presented in Reference 9-7.

The Administrative Division staffing levels for the four plant configurations analyzed are shown in Table 9-2. The estimated Administrative Division staff for the first commercial plant is 104 personnel. The equivalent staff levels estimated for the one block, two block and full size three block NOAK plants are 90, 116 and 142 persons, respectively.

9.3.1.2 Operations Division

The Operations Division has the responsibility for operating all plant system and equipment, monitoring and optimizing plant performance, controlling all sodium and water parameters, and supporting on-going maintenance activities. The organization of the Operations Division is shown in Table 9-4.

Shift staffing is provided on a five-crew basis, each crew working a 12-hour shift, followed by 24-hour off time. In 1993, we reduced the number of operating crews from six to five, reverting back to the shift staffing arrangement we were using in 1987. The change back to a five-crew shift basis was made based on recommendations made by Duke Power Company personnel during the March 1992 ALMR cost review. Duke has been using the five-crew shift staffing in all their nuclear plants with very good results. A five-crew arrangement works out well both for the company and for the employees and provides ample time for operator training, relief, and additional maintenance support when needed. Duke uses a four-crew basis for shift staffing in their coal-fired plants where training requirements are much lighter.

In 1990, we made a change in the ALMR shift staffing from a five-crew to a six-crew basis after discussions with operating plant personnel of other utilities whose nuclear plants we visited earlier. During the last year or so, however, Duke Power Company's operating procedures and also their recent model of personnel reorganization have been adopted by several other utility companies. In 1993, we also adopted the Duke model and went back to a five-crew shift staffing.

The reduction in the number of crews from six to five has made it possible for the ALMR crew size to be increased by three people (from 14 to 17), as recommended by the March 1992 Cost Review panel, while holding the total number of operators practically the same. The total staff of the Operations Division was increased only from 87 to 88 people or a net increase of one operator per three block plant. The three new positions added to each of the five operating crews are as follows:

1. One Control Room Supervisor, increasing the number of shift supervisors from two to three.

2. One Relief Control Room Operator, increasing the number of control room operators from three to four for a three block Plant.

3. One additional Maintenance Support Operator, increasing the number of maintenance support operators from three to four for a three block plant.

The Operations Division staffing levels for the four plant configurations analyzed are shown in Table 9-5. The estimated operations staff for the first commercial plant is 54 personnel. As compared to the NOAK plants, the shift staffing of the first commercial single block plant was supplemented by one senior supervisory position per crew consisting of a Plant Supervisor. This operations staff position is considered necessary for the first commercial ALMR plant to help establish standard operating procedures that will be then used in all subsequent ALMR plants. Thus, the operations staff for a single NOAK power block plant was reduced from 54 to 48 persons. The estimated operations staff levels required for the two block and full size three block NOAK plants are 68 and 88 persons, respectively.

These staffing levels were established by considering past and present utility practice, the perceived degree of plant automation and good operating experience. It was assumed that the control room for the ALMR plant was staffed with one operator per power block, plus a relief operator, a shift supervisor, and a control room supervisor. Each reactor and each turbine plant is staffed with one operator-tender. One more operator is provided per power block plus one additional operator per plant to support maintenance on all shifts. These operators are supervised by the assistant shift supervisors who also provide relief for the shift supervisor and the control room supervisor in the control room. Because of the passive safety features inherent to the ALMR design, no Shift Technical Advisor is considered necessary.

Two engineers are provided as non-shift personnel to evaluate the data provided by the automated control system and to monitor the presented actions.

9.3.1.3 Maintenance Division

The Maintenance Division is responsible for the effective administration, implementation and control of preventive and corrective maintenance activities carried out to minimize station and equipment downtime.

The Maintenance Division staffing for the four plant configurations analyzed are shown in Table 9-6. The estimated maintenance staff for the first commercial plant is 156 persons. The maintenance staff for a single NOAK power block plant was reduced from 156 to 122 persons primarily because of reductions in the crafts requirements. This reduction was considered justified because of learning effects and streamlining of maintenance procedures achieved by utilities operating and maintaining identical ALMR power blocks. The estimated maintenance staff levels required for the two block and full size three block NOAK plants are 189 and 256 persons, respectively.

The maintenance staff has been defined to provide preventive and corrective maintenance as well as surveillance of the various plant components. The annualized refueling and peak maintenance personnel are also included in the maintenance category.

As compared to the 1991 O&M cost estimate, the current estimate update includes revisions to reflect the impact of several design improvements made during 1992 and 1993 which affect plant operation and maintenance costs. These design changes are as follows:

(1) Overall plant:

- Rail mounted component transporter
- Compact IHTS/SGS arrangement
- Permanent refueling enclosure

(2) Core:

- Reduced refueling interval from 24 months to 16 months and the refueling outage from 21 days to 17 days
- Non-vented ducts
- 930 F (500°C) core outlet temperature

(3) Reactor system:

- Fixed shielding
- USS design and material
- Reactor support system

(4) IHTS/SGS:

- Decreased the IHTS/SG in-service inspection outage interval from 243 to 216 months and the outage duration from 50 days to 40 days.
- Revised SWRPRS
- Superheat steam cycle
  - Increased capacity of a 3-block plant from 1395 MWe to 1488 MWe
  - Eliminated the Water Dump Tank
  - Added a Hot Standby Tank
  - Revised the Steam Side Isolation and Blowdown System
- Two EM pumps vs one mechanical

(5) BOP facilities:

- Single TG building in stacked modular style

– Decreased the minor TG maintenance interval from 27 to 24 months

– Decreased the major TG maintenance interval from 81 to 72 months

(6) NI facilities:

– Bolted seismic bearings

(7) I&C:

– Revised control system for superheat cycle

– Added separate maintenance console in OSC

In addition to the design improvements listed above which had been already reflected in the March 1993 O&M cost estimate, the 1994 O&M cost estimate also accounts for the adoption of the ALMR design as the new ALMR reference design. The ALMR design changes consisted mainly of the increased size and rating of the reactor module (20 to 31 feet and 471 to 840 MWt) and the reduction of the number of reactor modules per power block from three to two. For a three-block ALMR plant, this resulted in an increase in the overall plant capacity from 1488 to 1866 MWe and a reduction in the total number of reactor modules from nine to six.

These design improvements have the potential to reduce the maintenance personnel requirements especially for the BOP because of smaller TG equipment (superheat steam cycle instead of saturated steam cycle), adoption of a single enclosed TG building and of a compact IHTS/SGS arrangement. However, to be conservative, no reductions in the permanent staff as a result of these design improvements were made at this time with one exception, as discussed below. A quantitative analysis of the potential reductions in the maintenance manpower requirements due to the adoption of a superheat steam cycle and the other major design changes is planned to be carried out in the next phase of the ALMR maintenance assessment.

The impact on the maintenance personnel requirements of the changes in the refueling and peak maintenance intervals, however, was reflected in the current O&M cost estimate. Since refueling and peak maintenance are performed mostly by contract labor, the impact of these design changes was reflected only in the annualized contract personnel levels. A small increase of six people (from 42 to 48 people, annualized) was estimated as the net change necessary in the annualized contract personnel requirements for refueling and peak maintenance.

The refueling and peak maintenance personnel were determined by staffing dedicated teams based on experience and rotating these teams among the various nuclear steam supply systems and turbine generator plants. Table 9-7 presents the estimated planned outage staff required and the outage frequencies for a full size 1866 MWe ALMR plant showing the breakdown between the on-site utility staff and the annualized contract labor.

The required outage maintenance time was determined by taking into account the total number of hours and staff needed for the three distinct phases of an outage as follows:

Phase I – Advance planning and scheduling plus
– Pre-outage coordination and preparation

Phase II – Actual outage works

Phase III – Post-outage cleanups and spare parts inventory

The annualized contract labor requirements were determined after subtracting the time spent by the utility personnel permanently assigned to refueling and outage maintenance from the total maintenance outage time estimated. The planned outage activities considered are listed in Table 9-7. Similarly, Table 9-8 shows the estimated planned outage staff for the four ALMR plant configurations considered.

In addition to the mechanical, electrical and I&C maintenance crafts, the Maintenance Division includes the radwaste, quality assurance, work planning, grounds and housekeeping, and the warehouse departments. The estimated staff and organization for these departments are given in Table 9-6.

The maintenance staff estimates are based on an assessment of the ALMR maintenance staff requirements presented in Reference 9-8 and on comparative analysis of staffing data obtained through site visits to six operating nuclear power stations and other sources.

9.3.1.4 Technical Division

The Technical Division is responsible for providing the technical expertise required for complying with regulatory requirements and for achieving optimal economic performance of the plant. The personnel of the Technical Division consists of highly qualified engineers and technicians required to meet the regulatory requirements, to carry out plant engineering and to monitor plant performance.

This division provides personnel assigned to shift coverage in the areas of reactor engineering, process engineering, radiochemistry, and health physics. The shift personnel operates and controls the automated plan process and equipment statusing systems. Additional staff is provided on day shift for programming and updating the automated systems as well as supervision. Shift coverage personnel is provided on a five-crew basis.

The Technical Division staffing for the four plant configurations analyzed are shown in the summary Table 9-2. The estimated technical staff for the first commercial plant is 54 personnel. The technical staff for a single NOAK power block plant was reduced from 54 to 42 personnel primarily because of reductions in the number of engineers and technicians required. This reduction was considered justified because after the first few power blocks are commissioned into operation and experience from operating identical units is accumulated, it is expected that the need,for on-site technical support will diminish. As shown later in Section 9.3.4, adequate off-site technical and engineering support staff will be provided. A 20% reduction in the off-site support staff levels (from 50 to 40 personnel) was assumed to occur between the first commercial single block and NOAK single block plants. The estimated Technical Division levels required for the two block and full size three block NOAK plants are 61 and 80 personnel, respectively.

The Technical Division includes the engineering, chemistry and health physics departments. The engineering department consists of technical personnel for licensing and regulatory assurance, fuel handling, electrical, mechanical and I&C engineering.

The chemistry department is responsible for carrying out both the radiological and water chemistry activities. For shift coverage, one radiochemist has been assigned per shift per power block.

The health physics department is responsible for the radiation monitoring, external dosimetery program, compliance with and implementation of the established health physics procedures, radiation protection training of plant personnel, outage planning support, and ALARA reviews. A health physics technician has been assigned per shift per plant for routine radiation surveys. In response to the recommendations of the March 1992 DOE Cost Review Board, the total HP staff size was increased from 14 to 18 persons, a net increase of four persons.

9.3.2 Maintenance Materials

Maintenance materials are defined as expensed replacement items, expendable materials, and services that are utilized in maintaining the plant throughout its lifetime. They do not include large replacement items and improvements that are capitalized and amortized over a period of years.

The total annual expense for maintenance materials is estimated to be equal to the annual salaries for maintenance staff, i.e., supervision, crafts, and annualized peak. This is separated into a fixed component, which does not vary with plant output, calculated as 0.75 times the salaries, and a variable component calculated as 0.25 (at 86% capacity factor) times the salaries, which is directly proportional to energy generation. Since the capacity factors of the first commercial plant is expected to be somewhat lower (83%), the variable component fraction used for this plant was determined by multiplying 0.25 with the ratio of the actual capacity factor to 86%. The derivation of the maintenance materials costs is shown in Table 9-9.

9.3.3 Supplies and Expenses

The supplies and expenses account includes consumable materials that are unrecoverable after use and contract services for nonmaintenance activities. These include makeup materials, chemicals, gases, lubricants, office and personnel supplies, monitoring and record supplies, training, data processing, rents, and waste management.

The estimates for supplies and expenses are based on judgment in comparison with LWRs as shown in Table 9-10. The smaller plant size, passive safety features, and lower levels of radioactivity are considered to lead to lower costs, especially in the areas of training and radioactive waste management. For base-loaded plants, it is expected that the variable component of supplies and expenses will be small; an allowance was set at 0.149 mill/kWh for the first commercial single block plant and 0.144 mill/kWh for the NOAK plants. The costs for supplies and expenses for one power block were directly replicated for two and three power blocks.

9.3.4 Off-Site Support Services

The off-site technical support staff provides support to the nuclear power plants operated by the utility in areas of nuclear design, engineering, quality assurance, fuels, and research and development on specific problems.

The estimate for off-site technical support services for the first commercial single block ALMR power block is based on the full time services of 50-person engineering staff.

The off-site technical support staff estimated for a single NOAK power block plant is equal to 40 personnel which is 20% less than the support staff considered for the first commercial single plant block. This reduction was considered justified because after the first few power blocks are commissioned into operation and experience from operating identical units is accumulated, it is expected that the need for off-site technical support will diminish. This is about 30% to 40% of the off-site staff required currently for LWRs, and is judged to be reasonable for a nuclear plant of a certified, standard design, not requiring extensive backfitting.

An average annual salary of $66,712 per person was assumed, as recommended by the DOE cost guidelines. The payroll taxes and insurance are calculated at 10% of the total salaries and the overhead allowance for office space, utilities, and miscellaneous expenses at 60% of the total salaries. The offsite staff for the two and three power blocks was increased to 60 and 80 personnel, respectively, as shown in Table 9-11.

9.3.5 Pension and Benefits

The pensions and benefits account which includes the workman's compensation insurance was calculated as 25% of the sum of on-site and off-site direct salaries (excluding off-site overhead).

9.3.6 Nuclear Regulatory Fees

Safety, environmental, and health physics inspections for nuclear power plants are performed routinely by the NRC to assure that operation is being carried out as authorized by the terms of the operating license. The frequency of inspections (and resulting fees) depends on the activities underway, the perceived potential safety hazards, and problems experienced by the plant on previous inspections and reviews.

The nuclear regulatory fees were assumed to be $2.9 million for the first single block commercial plant, and $1.45 million per power block, for the NOAK plants, as recommended by the DOE/ORNL cost estimate guidelines.

9.3.7 Nuclear Insurance Premiums

Utilities are required to carry public liability insurance to protect themselves against liability claims which may arise from a nuclear accident. This protection is provided through a two-layer combination of commercial insurance and self insurance as defined by the Price-Anderson Act which was extended in 1988. The limit of liability of a nuclear accident is set at $7 billion per loss.

Under the first layer, the maximum coverage currently available from commercial insurers is $200 million. The estimated premium is about $620,000 per year. The second layer is a mandatory industry-wide program of self insurance. Under the second layer of insurance, nuclear power plant licensees can be assessed for each operational reactor owned an amount not to exceed $5 million in any one year for each nuclear accident and not to exceed $10 million in the event of more than one accident. There are no requirements for annual payments or premiums to cover this second layer liability, and to date no assessments have been made, including payments of claims from the Three Mile Island accident (Ref. 9-2).

Utilities are also required to carry plant property damage insurance to provide funds for plant cleanup following a nuclear accident. This protection is provided in two layers of commercial insurance. The minimum amount of insurance currently required by NRC is $500 million primary coverage and $85 million excess, or secondary, coverage for a total of $585 million, although the maximum excess coverage currently available is approximately $600 million for a total of $1.1 billion. For cost estimating purposes it is assumed that utilities will purchase the maximum protection available.

The estimated premiums for public liability insurance and plant property damage were based on the recommendations of the DOE/ORNL cost estimate guidelines as presented in Table 9-12.

9.3.8 Other Administrative and General Expenses

Other administrative and general expenses were estimated as 15% of the total of the sum of the direct power generation cost accounts (i.e., on-site staff, maintenance materials, supplies and expenses, and off-site technical support costs). These expenses consist of utility executive salaries and related expenses, legal expenses, and non-NRC regulatory expenses, which are to be allocated to the generation costs.

9.3.9 Total Annual Non-fuel O&M Costs

The estimated total annual non-fuel O&M costs for the four ALMR plant configurations analyzed are summarized in Table 9-13. These total annual costs are estimated to be $57.6, $46.6, $72.5 and $98.3 million per year, or 12.7, 9.9, 7.7, and 7.0 mills/kWh, for the first commercial single block plant, and for the one, two and three NOAK power blocks, respectively.

9.4 Comparison of 1987, 1990, 1991, 1993 and 1994 O&M Costs

The 1994 estimates of the ALMR staff and annual non-fuel O&M costs are very similar to those estimated in 1993. A cost reduction of 0.8% was possible in 1994 because of a staff reduction of nine people in the total on-site staff. This small staff reduction was the net result of the ALMR adjustments made to account for: (1) the increase in the reactor module size (from 20 to 31 feet in diameter), (2) the increase in the turbine generator size (from 496 to 622 MWe), (3) the reduction in the total number of reactor modules per three-block plant (from nine to six), and (4) the 25% increase in plant capacity (from 1488 to 1866 MWe).

The 1993 estimates of the ALMR staff and annual non-fuel O&M costs were practically equal to those estimated in 1991. A slight cost increase of 1.3% was necessary in 1993 because of an increase of eleven persons in the total on-site staff. This increase in the on-site staff was the net result of the adjustments made to implement the recommendations of the March 1992 DOE Cost Review Panel and to reflect the design improvements made in 1992.

The 1991 estimates of the ALMR staff and annual non-fuel O&M costs were also virtually unchanged from those estimated in 1990. In 1991, there were no major design changes to impact the O&M manpower requirements. Only a slight cost reduction of 0.3% compared to 1990 resulted in 1991 because the peak maintenance requirements was reduced by two persons (annualized). This, in turn, was the result of increasing the refueling interval from 18 months to 20 months and the related changes in the TG and IHTS/SGS peak maintenance intervals to achieve the optimum balance between plant equivalent availability and fuel utilization.

On the other hand, the 1990 estimates of ALMR staff and annual O&M costs were significantly higher than those estimated in 1987. Those changes were the result of a number of factors which included use of improved methods for developing staffing estimates, increased awareness of current actual operating conditions through site visits and direct O&M discussions with utility personnel at selected plants, and more comprehensive technical assessments of annualized peak maintenance requirements.

Table 9-14 shows a comparison among the 1987, 1990, 1991, 1993 and 1994 ALMR staffing and O&M cost estimates. All costs are expressed in January 1994 dollars.

As seen in the table, compared to the 1987 results, the improved cost estimating bases of the 1990 O&M assessment resulted in significant increases of 34% and 60% in the on-site staff and off-site support staff, respectively, and of 20.9% in the annual non-fuel O&M costs expressed in January 1994 dollars.

Similarly, compared to the 1990 results, the minor reduction in the annualized peak maintenance requirements from 34 to 32 made in the 1991 O&M assessment resulted in slight reductions of 0.4% in the on-site staff and of 0.3% in the annual non-fuel O&M costs expressed in January 1993 dollars.

Compared to the 1991 results, the small increase of eleven persons made in 1993 following the implementation of the March 1992 DOE Cost Review Panel and the design improvements made in 1992 resulted in slight increases of 1.4% in the on-site staff and of 1.3% in the annual non-fuel O&M costs expressed in January 1994 dollars.

Finally, compared to the 1993 results, the small staff reduction of nine persons made in 1994 following the implementation of the ALMR design improvements made in 1993 resulted in small reductions of 1.6% in the on-site staff and of 1.2% in the annual non-fuel O&M costs expressed in January 1994 dollars.

The 1987 staffing and O&M cost estimates are based on the results given in Reference 9-9 (expressed in January 1987 dollars) which were adjusted for inflation to the January 1992 conditions. The assumed rates of escalation from January 1987 to January 1990 were 11.6% for maintenance materials and 12.1% for supplies and expenses. Straight escalation rates of 4%, 3.5%, and 3.0% were applied to the same costs to further adjust them for the inflation from 1990 to 1991, 1991 to 1992, and 1992 to 1993, respectively. Annual salaries for the on-site and off-site staff were calculated using the 1987 staffing levels and the salaries recommended in the DOE/ORNL Costs Estimate Guidelines (References 9-1 and 9-la). Nuclear regulatory fees and nuclear insurance were taken as equal to the values recommended in the DOE/ORNL Cost Estimate Guidelines.

The 1990, 1991, and 1993 staffing and O&M cost estimates are based on the results presented in Reference 9-10 (expressed in January 1992 dollars). Annual salaries for the on-site and off-site staff were calculated using the respective 1991 and 1993 staffing levels and the salaries recommended in the DOE/ORNL Costs Estimate Guidelines (References 9-1 and 9-la). Nuclear regulatory fees and nuclear insurance were taken equal to the values recommended in the DOE/ORNL Cost Estimate Guidelines. A 3% escalation rate was used to adjust all 1992 costs to January 1993 conditions.

REFERENCES TO SECTION 9

9-1 Delene, J.G. and C.R. Hudson II, "Cost Estimating Guidelines for Advanced Nuclear Power Technologies," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10071/R3, May 1993.

9-1a Williams, K.A., and J.G. Delene, "Vendor Data Requirements and Updated Cost Estimating Guidelines for Phase II Cost Estimates for Reactor Disposition of Weapons Plutonium," Oak Ridge National Laboratory, Oak Ridge, February 1994.

9-2 Delene, J.G., Editor and Review Team Chairman, "Review of the 1991 Cost Estimate for the Advanced Liquid Metal Reactor," Oak Ridge National Laboratory, Oak Ridge, TN, Prepared for the U.S. Department of Energy under Contract No. DE-AC05-84OR21400, June 1, 1992.

9-3 Ryan, M.L. et al., "Outlook on Personnel Costs," Special Report of Nucleonics Week, McGraw-Hill, Inc., June 28, 1990.

9-4 "Projected Costs of Generating Electricity from Power Stations for Commissioning in the Period 1995-2000," Organization for Economic Cooperation and Development (OECD), Nuclear Energy Agency, Paris (1989).

9-5 Myers, M.L., L.C. Fuller and H.I. Bowers, "Non-Fuel Operation and Maintenance Costs for Large Steam-Electric Power Plants - 1982," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-8324, September 1982.

9-6 Bowers, H.I., L.C. Fuller, M.L. Myers, "Cost Estimating Relationships for Nuclear Power Plant Operation and Maintenance," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10563, November 1987.

9-7 Snyder, C.R. et al., "ALMR Safeguards and Security Assessment," Bechtel National, Inc., San Francisco, CA, Report No. BNI-8902, November 1989.

9-8 Potocnik, A. and C.S. Ehrman, "Maintenance Staff Assessment for an Advanced Liquid Metal Reactor," Burns and Roe Corporation, Oradell, NJ, June 1990 (Draft).

9-9 Wadecamper, D.C. and G.L. O'Neill, "PRISM Operating and Maintenance Assessment," General Electric Company, San Jose, CA, GEFR-00814, September 1987.

9-10 Hutchins, B.A., G.F. Pavlenco, P. Babka, Editors, "1993 ALMR Power Plant Capital and Busbar Cost Estimates," GE Nuclear Energy, GEFR-00915, March 1993.

Table 9-1
Summary of Estimated Annual Non-fuel O&M Costs
(January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
No. of Power Blocks	1	1	2	3
Plant Capacity, MW(e)	622	622	1244	1866
Capacity Factor, %	83	86	86	86
Annual Generation, 10E6 MWh/year	4.52	4.69	9.37	14.06
On-site Staff	372	303	435	567
Off-site Technical Support Staff	50	40	60	80
Direct Power Generation Costs (10E6 $/year)				
On-site Staff	19.6	15.9	22.8	29.5
Maintenance Materials	5.8	4.3	6.7	9.1
Supplies and Expenses	7.4	6.4	12.6	19.0
Off-site Support Services	5.6	4.5	6.8	9.1
Subtotal Direct Costs	38.5	31.1	49.0	66.7
Administrative and General Costs (10E6 $/year)				
Pension and Benefits	5.7	4.7	6.8	8.8
Nuclear Regulator Fees	3.0	1.6	3.0	4.6
Nuclear Insurance Premiums	4.5	4.5	6.4	8.2
Other Administrative and General Expenses	5.7	4.7	7.3	10.0
Subtotal Indirect Costs	19.1	15.3	23.5	31.6
Total Annual O&M Costs				
Total (10E6 $/year)	57.6	46.5	72.5	98.3
Total (mills/kWh)	12.7	9.9	7.7	7.0

Table 9-2
Estimated On-Site Staffing

Job Title	Number of Persons			
	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Plant Manager	1	1	1	1
Administrative Division				
Manager	1	1	1	1
Environmental Control	1	1	1	1
Emerg. Plan. & Publ. Rel.	2	2	2	2
Training	13	7	11	15
Safety and Fire Protection	1	1	2	3
Admin & Finance Services	33	24	31	38
MIS Services	4	3	4	5
Health Services	1	1	2	3
Security	51	50	62	74
Subtotal	107	90	116	142
Operations Division				
Manager	1	1	1	1
Shift Supervision	20	15	15	15
Shift Operators	30	30	50	70
Results Engineering	3	2	2	2
Subtotal	54	48	68	88
Maintenance Division				
Manager	1	1	1	1
Supervision	20	18	22	26
Diagnostic Engineering	3	3	3	3
Crafts (mech., elec., I&C, ISI)	70	48	84	120
Annualized Peak Maintenance	21	13	23	33
Annualized Refueling	7	5	7	9
Radwaste	6	6	8	10
Quality Assurance	5	5	7	9
Planning	8	8	12	16
Grounds & Housekeeping	8	8	13	18
Warehouse	7	7	9	11
Subtotal	156	122	189	256
Technical Division				
Manager	1	1	1	1
Reactor Engineering	2	2	3	4
Radiochem & Water Chemistry	9	9	15	21
Licensing & Reg. Assurance	5	3	4	5
Engineering	15	11	15	19
Technicians	8	4	8	12
Health Physics	14	12	15	18
Subtotal	54	42	61	80
Total On-site Staff	372	303	435	567
Total Annualized Contract Labor	28	18	30	42
Total Less Annualized Contract Labor	344	285	405	525
Total On-site Staff (Employees/MWe)	0.60	0.49	0.35	0.30

*Annualized values are based on contracting for labor during peak times.

Table 9-3
Estimated Annual Salaries, Staffing and Costs for On-Site Staffing
(January 1994 Dollars)

Job Title	Annual Salary (K$/yr)	Number of Persons: First Plant 1 Block	Number of Persons: NOAK Plant 1 Block	Number of Persons: NOAK Plant 2 Blocks	Number of Persons: NOAK Plant 3 Blocks	Cost of Personnel (K$/yr): First Plant 1 Block	Cost of Personnel (K$/yr): NOAK Plant 1 Block	Cost of Personnel (K$/yr): NOAK Plant 2 Blocks	Cost of Personnel (K$/yr): NOAK Plant 3 Blocks
Plant Manager	122.0	1	1	1	1	131.2	131.2	131.2	131.2
Administrative Division									
Manager	85.0	1	1	1	1	91.5	91.5	91.5	91.5
Environmental Control	54.0	1	1	1	1	58.0	58.0	58.0	58.0
Emerg. Plan. & Publ. Rel.	54.0	2	2	2	2	116.1	116.1	116.1	116.1
Training	59.0	13	7	11	15	825.2	444.3	698.2	952.1
Safety and Fire Protection	50.0	1	1	2	3	53.8	53.8	53.8	53.8
Admin & Finance Services	32.4	33	24	31	38	1,150.7	836.9	1,081.0	1,325.1
MIS Services	32.4	4	3	4	5	139.5	104.6	139.5	174.4
Health Services	32.4	1	1	2	3	34.9	34.9	69.7	104.6
Security	29.1	51	50	62	74	1,597..3	1,566.0	1,941.9	2,317.7
Subtotal		107	90	116	142	4,067.0	3,306.1	4,303.4	5,300.8
Operations Division									
Manager	85.0	1	1	1	1	91.5	91.5	91.5	91.5
Shift Supervision	62.6	20	15	15	15	1,346.8	1,010.1	1,010.1	1,010.1
Shift Operators	52.5	30	30	50	70	1,694.4	1,694.4	2,824.1	3,953.7
Results Engineering	52.5	3	2	2	2	169.4	113.0	113.0	113.0
Subtotal		54	48	68	88	3,302.1	2,908.9	4,038.6	5,168.2
Maintenance Division									
Manager	85.0	1	1	1	1	91.5	91.5	91.5	91.5
Supervision	58.1	20	18	22	26	1,248.6	1,123.8	1,373..5	1,623..2
Diagnostic Engineering	52.5	3	3	3	3	169.4	169.4	169.4	169.4
Crafts (mech., elec., I&C, ISI)	41.3	70	48	84	120	3,105..9	2,129.8	3,727.1	5,324..5
Annualized Peak Maintenance	41.3	21	13	23	33	931.8	576.8	1,020.5	1,464..2
Annualized Refueling	44.7	7	5	7	9	336.2	240.1	336.2	432.2
Radwaste	41.3	6	6	8	10	266.2	266.2	355.0	443.7
Quality Assurance	44.7	5	5	7	9	240.1	240.1	336.2	432.2
Planning	44.7	8	8	12	16	384.2	384.2	576.3	768.4
Grounds & Housekeeping	29.5	8	8	13	18	253.9	253.9	412.6	571.3
Warehouse	38.0	7	7	9	11	285.7	285.7	367.4	449.0
Subtotal		156	122	189	256	7,313.6	5,761.6	8,765.6	11,769.7
Technical Division									
Manager	85.0	1	1	1	1	91.5	91.5	91.5	91.5
Reactor Engineering	62.6	2	2	3	4	134.7	134.7	202.0	269.4
Radiochem & Water Chemistry	58.1	9	9	15	21	561.9	561.9	936.5	1,311.1
Licensing & Reg. Assurance	53.6	5	3	4	5	288.1	172.9	230.5	288.1
Engineering	53.6	15	11	15	19	864.4	633.9	864.4	1,095.0
Technicians	43.6	8	4	8	12	375.0	187.5	375.0	562.5
Health Physics	44.8	14	12	15	18	673.8	577.5	721.9	866.3
Subtotal		54	42	61	80	2,989.4	2,359.9	3,421.9	4,483.8
Total w/o Payroll Tax & Insurance		372	303	435	567	17,803.3	14,467.7	20.660.7	26,853.7
Payroll Tax & Insurance (@ 10%)						1,780.4	1,446.8	2,066.1	2,685.4
Total with Payroll Tax & Insurance						19,583.7	15,914.5	22,726.8	29,539.1

Table 9-4
Estimated Security Staffing

Job Title	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Security Chief	1	1	1	1
Shift Supervisor	5	5	5	5
Security Instructor	1	1	1	1
Clerk	3	2	4	6
Locksmith	1	1	1	1
Control Alarm Station	10	10	10	10
Secondary Alarm Station	5	5	5	5
Security Guards (*)	25	25	35	45
Total	51	50	62	74

* Provide armed response force, access control, and patrol.

Table 9-5
Estimated Operations Division Staffing

Job Title	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Manager	1	1	1	1
Shift Supervision				
Plant Supervisor	5			
Shift Supervisor	5	5	5	5
Assistant Shift Supervisor	5	5	5	5
Control Room Supervisor	5	5	5	5
Shift Operators				
Control Room Operator	10	10	15	20
Reactor Plant Operator	5	5	10	15
Turbine Plant Operator	5	5	10	15
Maintenance Support Operator	10	10	15	20
Results Engineering	3	2	2	2
Total	54	48	68	88

Table 9-6
Estimated Maintenance Division Staffing

Job Title	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Manager	1	1	1	1
Supervision	20	18	22	26
Diagnostic Engineering	3	3	3	3
Crafts (mech, elec., I&C, ISI)				
Mechanical	46	30	53	76
Electrical	11	7	13	19
Instr. & Control	13	11	18	25
Annualized Peak Maintenance	21	13	23	33
Annualized Refueling	7	5	7	9
Radwaste	6	6	8	10
Quality Assuance	5	5	7	9
Planning	8	8	12	16
Grounds & Housekeeping	8	8	13	18
Warehouse	7	7	9	11
Total	156	122	189	256

Table 9-7
Frequency of Planned Maintenance Outages
and Estimated Planned Outage Staff for a Three Block ALMR Plant

Activity	Task Freq. per Component Serviced	Number of Components per 3 Block Plant	Avg. Outage Frequency per 3 Block Plant	Planned Outage Staff		
				On-site Staff	Annualized Contract Labor	Total Staff
Refueling	16 mos	6	2 2/3 mos	5	9	14
NI (Reactor) Maintenance	16 mos	6	2 2/3 mos	5	12	17
IHTS/SG Maintenance	10 2/3 yrs	6	21 1/3 mos		6	6
TG Maintenance	16 mos	3	5 1/3 mos		6	6
BOP Maintenance	16 mos	3	5 1/3 mos		3	3
IS & Regulatory	16 mos	6	16 mos	1	6	7
Total				11	42	53

Table 9-8
Estimated Planned Outage Staff for ALMR Plants

	On-site Staff				Annualized Contract Labor				Total Planned Outage			
	First Plant	NOAK Plant			First Plant	NOAK Plant			First Plant	NOAK Plant		
Activity	1 Block	1 Block	2 Blocks	3 Blocks	1 Block	1 Block	2 Blocks	3 Blocks	1 Block	1 Block	2 Blocks	3 Blocks
Refueling	5	5	5	5	7	5	7	9	12	10	12	14
NI (Reactor) Maintenance	5	5	5	5	8	6	9	12	13	11	14	17
IHTS/SG Maintenance					3	2	4	6	3	2	4	6
TG Maintenance					4	2	4	6	4	2	4	6
BOP Maintenance					3	1	2	3	3	1	2	3
ISI & Regulatory	1	1	1	1	3	2	4	6	4	3	5	7
Total	11	11	11	11	28	18	30	42	39	29	41	53

Table 9-9
Estimated Annual Costs for Maintenance Materials
(January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
No. of units (power blocks)	1	1	2	3
Plant capacity, MW(e)	622	622	1244	1866
Capacity factor, %	83	86	86	86
Factor				
Fixed cost	0.750	0.750	0.750	0.750
Variable cost (Note 1)	0.241	0.250	0.250	0.250
Annual Cost (K$/year) (Note 2)				
Fixed	4,413	3,249	5,039	6,829
Variable	1,420	1,083	1,680	2,276
Total cost	5,832	4,332	6,718	9,095

Notes: (1) Variable cost factor is 0.25 at 86% capacity factor; for other capacity factors, this factor is adjusted by multiplying 0.25 with the ratio of the actual capacity factor to the reference 86% capacity factor.

(2) Based on annual salaries for maintenance staff (i.e., supervision, crafts, and annualized peak)

Table 9-10
Estimated Annual Costs for Supplies and Expenses
(January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
No. of Power Blocks	1	1	2	3
Plant capacity, MW(e)	622	622	1244	1866
Capacity factor, %	83	86	86	86
Annual generation, 10E6 MWh	4.52	4.69	9.37	14.06
On-site Staff	372	303	435	567
Fixed Costs, K%/year				
Miscellaneous				
Potable Water				
Lubricants				
Communications				
Security				
Transportation				
Laboratory Chemicals				
Clothing				
Lamping				
Gases				
Office Supplies				
Etc.				
Subtotal	1,907	1,602	3,204	4,807
Makeup Materials				
Primary Coolant				
Purge Gases				
Water Treatment				
Subtotal	1,275	1,057	2,115	3,172
Training	992	817	1,635	2,452
Data Processing	992	817	1,635	2,452
Rad. Waste Management	1,493	1,253	2,507	3,760
Non-Rad. Waste Management	381	327	654	981
Total Fixed Costs, K$/year	7,041	5,875	11,750	17,625
Variable Costs, mils/kWh	0.162	0.157	0.157	0.157
Total Variable Costs, K$/year	736	737	1,473	2,209
Total Supplies & Expenses, K$/year	7,777	6,612	13,222	19,834

Table 9-11
Offsite Technical Support Staff Manpower Total Cost Estimates
(K$/year, January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Number of Staff	50	40	60	80
Average Annual Direct Salary	72.7	72.7	72.7	72.7
Total Annual Direct Salaries	3,636	2,909	4,363	5,817
Payroll Tax & Ins. (@ 10% of Direct Salaries)	364	291	436	581
Overhead (@ 60% of Direct Salaries)	2,181	1,746	2,617	3,490
Total	6,181	4,944	7,417	9,889

Table 9-12
Offsite Annual Premium for Nuclear Power Plant Insurance
(K$/year, January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
Public Liability				
Commercial ($200 million)	647	647	971	1,295
Self Insurance	0	0	0	0
Plant Property Damage				
Primary ($500 million)	2,558	2,558	3,915	5,272
Secondary ($600 million)	1,295	1,295	1,503	1,723
Total	4,500	4,500	6,389	8,289

Table 9-13
Estimated Annual Non-fuel Operation and Maintenance Costs
(January 1994 Dollars)

	First Plant	NOAK Plant		
	1 Block	1 Block	2 Blocks	3 Blocks
No. of Power Blocks	1	1	2	3
Plant Capacity, MW(e)	622	622	1244	1866
Capacity Factor, %	83	86	86	86
Annual Generation, 10E6 MWh/year	4.52	4.69	9.37	14.06
On-site Staff	372	303	435	567
Off-site Support Staff	50	40	60	80
Direct Power Generation Costs (10E6 $/year)				
On-site Staff	19.6	15.9	22.8	29.5
Maintenance Materials				
Fixed	4.4	3.2	5.0	6.8
Variable	1.5	1.0	1.7	2.3
Subtotal	5.8	4.3	6.7	9.1
Supplies and Expenses				
Fixed	6.8	5.6	11.3	16.9
Variable	0.7	0.7	1.5	2.1
Subtotal	7.4	6.4	12.6	19.0
Off-site Support Services	5.6	4.5	6.8	9.1
Subtotal Direct Power Gen. Costs				
Fixed	36.4	29.3	45.8	62.3
Variable	2.1	1.8	3.1	4.4
Subtotal Direct Costs	38.5	31.1	49.0	66.7
Administrative and General Costs (10E6 $/year)				
Pension and Benefits	5.7	4.7	6.8	8.8
Nuclear Regulator Fees	3.0	1.6	3.0	4.6
Nuclear Insurance Premiums	4.5	4.5	6.4	8.2
Other Administrative and General Expenses	5.7	4.7	7.3	10.0
Subtotal Indirect Costs	19.1	15.3	23.5	31.6
Total Annual O&M Costs				
Fixed	55.5	44.7	69.3	94.0
Variable	2.1	1.8	3.1	4.4
Total (10E6 $/year)	57.6	46.5	72.5	98.3
Total (mills/kWh)	12.7	9.9	7.7	7.0

Table 9-14
Comparison of 1987, 1990, 1991, 1993 and 1994 O&M Cost Estimates
Scenario Large (Three Block) NOAK Plants
(Costs in January 1994 Dollars)

	Cost Estimate Year					Change From/To 1987 – 1990		1990 – 1991		1991 – 1993		1993 – 1994	
	1987	1990	1991	1993	1994	Total	%	Total	%	Total	%	Total	%
No. of Power Blocks	3	3	3	3	3								
Plant Capacity, MW(e)	1,395	1395	1395	1488	1866					93	6.7	378	25.4
Capacity Factor, %	86.0	86	86	86	86								
Annual Generation, 10E6 MWh	10.51	10.51	10.51	11.21	14.06					0.70	6.7	2.85	25.4
On-site Staff	423	567	565	576	567	144	34.0	-2	-0.4	11	1.9	-9	-1.6
On-site Support Staff	50	80	80	80	80	30	60.0						
Direct Power Generation Costs (10E6 $/year)													
On-site Staff	22.47	29.52	29.42	30.03	29.54	7.10	31.40	-0.10	-0.40	0.63	2.10	-0.52	-1.60
Maintenance Materials													
Fixed	6.80	7.11	7.04	7.25	6.83	0.31	4.70	-0.10	-1.00	0.21	2.90	-0.42	-5.70
Variable	2.22	2.35	2.32	2.39	2.28	0.10	5.70	-0.00	-1.00	0.10	2.90	-0.10	-4.80
Subtotal	9.01	9.46	9.36	9.64	9.10	0.42	4.90	-0.10	-1.00	0.31	2.90	-0.52	-5.50
Supplies and Expenses													
Fixed	16.07	16.93	16.93	16.93	16.88	0.84	5.40					-0.10	-0.30
Variable	1.18	1.59	1.59	1.69	2.12	0.42	34.60			0.10	6.70	0.42	25.40
Subtotal	17.24	18.52	18.52	18.63	19.00	1.25	7.40			0.10	0.60	0.42	2.00
Off-site Support Services	5.62	9.06	9.06	9.06	9.07	3.45	61.40						
Subtotal Direct Power Gen. Costs													
Fixed	50.94	62.63	62.45	63.28	62.33	11.69	23.00	-0.21	-0.30	0.84	1.30	-0.94	-1.50
Variable	3.39	3.93	3.90	4.08	4.40	0.52	15.70	-0.00	-0.60	0.21	4.50	0.31	7.70
Subtotal Direct Costs	54.33	66.57	66.36	67.35	66.71	12.21	22.50	-0.21	-0.30	0.94	1.50	-0.63	-0.90
Administrative and General Costs (10E6 $/year)													
Pension and Benefits	5.88	8.80	8.77	8.93	8.80	2.92	49.70	-0.00	-0.30	0.10	1.70	-0.10	-1.40
Nuclear Regulatory Fees	4.54	4.54	4.54	4.54	4.54								
Nuclear Insurance Premiums	8.29	8.29	8.29	8.29	8.29								
Other Administrative and General Expenses	8.15	9.98	9.95	10.11	10.01	1.88	22.50	-0.00	-0.30	0.10	1.50	-0.10	-0.90
Subtotal Indirect Costs	26.86	31.61	31.56	31.85	31.64	4.80	17.70	-0.10	-0.20	0.31	1.00	-0.21	-0.70
Total Annual O&M Costs													
Fixed	77.80	94.25	94.01	95.13	93.96	16.50	21.10	-0.21	-0.20	1.15	1.20	-1.15	-1.20
Variable	3.39	3.93	3.90	4.08	4.40	0.52	15.70	-0.00	-0.60	0.21	4.50	0.31	7.70
Total (10E6 $/year)	81.19	98.18	97.92	99.21	98.36	17.02	20.90	-0.21	-0.30	1.25	1.30	-0.84	-0.90
Total (mills/kWh)	7.73	9.34	9.31	8.85	6.99	1.62	20.90	-0.02	-0.30	-0.47	-5.00	-1.86	-20.9

10.0 FUEL COSTS

10.1 Fuel Recycle Facility

Because the 1994 ALMR burner core consumes more Pu than it breeds, it is necessary to have a continuous source of transuranics (TRU) to support continued ALMR operation. This is done in an integrated Spent Fuel Recycle Facility (SFRF). The SFRF is designed to be colocated at the site of each 1,866 MWe ALMR power plant. It provides startup cores, initial reload cores, and replacement fuel for the lifetime of the power plant.

The SFRF process is based on a dual-purpose processing requirement to manufacture ALMR fuel from spent LWR/ALWR fuel or from spent ALMR fuel. The facility has to operate during three different phases of plant operation: startup, transition, and equilibrium. During startup and transition, the facility produces ALMR fuel assemblies from spent LWR/ALWR fuel. During the equilibrium phase, the facility will process spent ALMR assemblies and will utilize spent LWR/ALWR fuel assemblies to makeup the deficit of fissile material.

The complete fuel cycle services include:

- The supply of complete fuel assemblies ready for insertion into the ALMR.
- The receipt of spent fuel assemblies removed from the ALMR cores.
- The processing of the spent fuel assemblies and removal of the fission products and other waste material from the spent fuel assemblies.
- The receipt and processing of LWR spent fuel to provide the TRU material required for the startup cores, initial reload cores, and replacement fuel assemblies.
- The packaging and storing of the waste produced by processing the LWR spent fuel and the LMR spent fuel (mineral waste (HLW), metal waste (HLW), fission gas waste (HLW), and miscellaneous low level wastes (LLW)).
- The packaging and storing of the uranium byproduct from the processing of LWR spent fuel.

This is a significant change in the design approach from 1993. Last year, the fuel recycle facilities were not colocated with each ALMR power plant. Rather, a large Central Fuel Recycle Facility (CFRF) recycled spent ALMR fuel and provided new fuel assemblies to eight ALMR plants. In addition, a large LWR Spent Fuel Processing Facility (LWR SFPF) supplied initial cores and two reloads to two power blocks (four reactors) each year. Thus, over its 60 year life, the LWR SFPF supported 40 ALMR plants. As the core was a breakeven design, there was no need for makeup Pu; sufficient Pu was breed in the blankets of each ALMR core to make up all losses.

Six principal changes were made in the design of the fuel recycle facilities over the past year:

- LWR spent fuel processing, ALMR spent fuel processing and ALMR fuel fabrication are now colocated at each ALMR plant.
- As a consequence of the colocation, the Fuel Service Facility (previously a part of the ALMR plant) has been moved to be the front end of the SFRF.
- Core design was changed from breakeven (BR=1.06) to burner (BR=0.8).
- Argonne National Laboratory made major modifications in the pyroprocess and the design of the process equipment. The cost of the LWR spent fuel process equipment increased greatly, while the cost of the ALMR spent fuel process equipment decreased.
- High level waste (HLW) storage on-site is now done for ten years rather than two, in order to better integrate with the HLW repository.
- ORNL made changes in estimating guidelines.

10.2 Estimating Conditions and Approach

The fuel cycle cost estimating approach follows that used last year and reported in the 1993 capital and Busbar Cost Estimate report.

The ALMR busbar cost outputs from the deployment analyses are levelized values for an ALMR 1866 MWe power plant consisting of six reactors, with two reactors (one power block) brought on-line each six months. The SFRF is co-located at the site and provides all fuel required for the 60 year life of the plant.

The basic assumptions applied for these cost estimates are the following:

- The ALMR plants are TRU burners (Breeding ratio of 0.8).
- All initial cores (six) and the first eight reloads use fissile material from spent LWR fuel.
- Later reloads use fissile material from spent ALMR fuel with the required makeup being supplied from spent LWR fuel.
- Cost of fissile recovery from LWR spent fuel is 365 $/kg of heavy metal (HM).
  be first-of-a-kind (FOAK) facilities.

- The SFRFs are owned and operated by industry.

10.3 Fuel Busbar Cost Results

Table 10-1 shows the contribution of the fuel cycle costs to the estimated total busbar costs for the ALMR. The first-of-a-kind (FOAK) costs have been worked out in detail. The Nth-of-a-kind (NOAK) costs are generated from the FOAK costs using the following learning curve factors:

- Equipment, waste containers and misc. supplies 0.89
- Facility 0.97
- Manpower 0.90
- Hardware 0.75

Table 10-1 also shows the impacts of the principal fuel cycle facility design changes made over the past year.

Table 10-1

ALMR Fuel Cycle Busbar Costs

(1994 Mills/kWhr)

	Utility Parameters	Industrial Parameters
First-of-a-kind Facility		
93 - Central Fuel Recycle Facility	**8.45**	**10.22**
Delta Changes, 1993 to 1994		
Colocation		2.00
FSF Integr. w/SFRF		0.90
Burner Core		0.43
Pyroprocess Equipment		0.14
10 Yr HLW Storage		0.57
ORNL Comm. Guidelines		-0.30
Total Changes	2.62	3.74
94 - Spent Fuel Recycle Facility	**11.07**	**13.96**
Nth-of-a-kind Facility		
93 - Central Fuel Recycle Facility	**9.6**	10.5
94 - Spent Fuel Recycle Facility		**12.41**

11.0 BUSBAR COSTS

11.1 Cost Basis

Evaluation of the ALMR economics relative to other advanced power generation concepts is based primarily on comparisons of the estimated generation busbar costs, i.e., utility revenue requirements for power generation. Busbar costs are defined in general as the annual costs for generation of electricity by a given plant, divided by the amount of electricity annually generated by that plant. The units are mills/kWh or $/MWh, and the values compared have been levelized over the operating lifetimes of the plants. Since evaluations of this type are not made for a specific utility system, the busbar costs are usually estimated for a stand-alone plant, i.e., without specific consideration of replacement power costs from other plants.

Since busbar costs provide for an overall economic evaluation of different power generation concepts they are derived from the specific cost components estimated for a given plant. Thus, for the ALMR, plant total capital costs from Section 8 and annual operating and maintenance costs from Section 9 were primary input quantities to the busbar costs. The values for fuel were computed separately because of specific complexities in the timing of the costs and the economic treatment of them. Fuel busbar costs were taken from Section 10 and included in the total values presented here.

Calculations of the busbar costs were performed largely in accordance with the 1993 DOE Cost Estimate Guidelines for Advanced Nuclear Power Technologies (Reference 11-1).

The levelized busbar costs presented here also include a sinking fund for decommissioning of the plant when it has completed its operating life. These components of the costs were determined in accordance with the DOE cost guidelines.

The plant capacity factor is particularly important in estimating the busbar costs. It is defined as the actual kW-hours generated by a given plant over a period of time, such as a year, divided by the number of kW-hours that would have been generated if the plant operated continuously at full capacity over that period of time. In the estimation of busbar costs the capacity factor defines the average kW-hours generated each year. Thus, the values obtained for the capital and O&M components of the busbar costs vary inversely with the capacity factor.

The equivalent availability for the 1994 ALMR burner core design is estimated to be 93% for the nth-of-a-kind plant. Since the ALMR availability is an equivalent value, its capacity factor should be based on the one to two percent difference seen for LWR's between equivalent availability and capacity factor. This difference is due to utility optimization of plant operation within the utility systems and depends largely on relative fuel and operating costs. But an 85% fuel burn-up is used in the 1994 ALMR burner core design. Since the plant capacity factor can not be greater the fuel burn-up rate, an 85% capacity factor is used for nth-of-a kind plant busbar cost evaluation.

While the evaluation was done for a full 1866 MWe ALMR plant, it is not expected that the capacity factor would be any different for a single block plant. The base availability value is the same for a single block as for three blocks and the remaining corrections are small. Thus, the value of 85% was applied to the NOAK ALMR cases evaluated. For the first commercial plant cases, the capacity factor is expected to be lower in the early years of operation and a value of 83% was applied.

Table 11-1 lists the busbar costs in constant 1994 dollars for the four plant scenarios described in Table 11-2.

REFERENCES TO CHAPTER 11

11-1 J.G. Delene and C.R. Hudson II, "Cost Estimate Guidelines for Advanced Nuclear Power Technologies," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-10071/R3, May 1993.

11-2 "Licensed Operating Reactors Status Summary Report," NUREG-0020, U.S. Nuclear Regulatory Commission, Issues from 1976 through 1985.

11-3 "Generating Availability Data Systems (GADS), Analyses and Reports for 1982," North American Electric Reliability Council, 1982.

Table 11-1

CONSTANT DOLLAR BUSBAR COSTS
(1994 Mills/kWh)

Scenario	**Capital**	**O&M**	**Fuel**	**Decommission**	**Total**
F1	31.7	12.7	14.0	1.0	**59.5**
F3	24.0	9.0	14.0	1.0	**48.0**
N1	24.4	10.0	12.4	1.0	**47.9**
N3	20.0	7.1	12.4	1.0	**40.5**

Table 11-2

ALMR PLANT CONSTRUCTION SCENARIOS

Scenario	**Plant Type**	**Power Blocks**
F1	First Comm.	1 (1st of 3)
F3	First Comm.	3 (Add two blocks to F1)
N1	NOAK	1
N3	NOAK	3