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ECONOMIC ASSESSMENT OF S-PRISM INCLUDING DEVELOPMENT AND GENERATING COSTS

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S-PRISM is an advanced Fast Reactor plant design that utilizes compact modular pool-type reactors sized to enable factory fabrication and an affordable prototype test of a single Nuclear Steam Supply System (NSSS) for design certification at minimum cost and risk. (1, 2, 3).

S-PRISM retains all of the key ALMR design features including passive reactor shutdown, passive shutdown heat removal, and passive reactor cavity cooling that were developed under an earlier DOE program.

Key factors(4, 5, 6) that make S-PRISM competitive include:

- The use of passive safety systems that eliminate the need for diesel generators and hardened active heat sinks to assure that sufficient heat is removed from the core, reactor, and containment systems following design and beyond design basis events.
- A seven point advantage in the plant capacity factor (93 versus 86%) over a single large plant.
- A much shorter construction schedule (45%) made possible by a modular design that allows near parallel (sequenced) construction of three relatively small, simple factory fabricated NSSSs instead of one large complex NSSS.

1.0 INTRODUCTION

This paper describes the approach, methods, and results of an in-depth economic assessment of S-PRISM. The assessment found that the generation cost from an NOAK plant would be less than 3 cents/kW-hr and that a design certification could be obtained in less than 15 years at a cost of 2.1 billion dollars.

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2.0 Capital Cost

The S-PRISM plant capital cost estimates are based on the construction of a two-power-block plant with four reactor modules. There is one turbine-generator for each power block and one steam generator for each reactor module.

The NOAK plant costs are estimated by adjusting FOAK unit costs to take advantage of the effect of learning. Table 1 provides a summary of the capital cost estimates for each account category, specific cost in $/KWe, and a percentage of the total plant construction cost.

As shown in Table 1, the direct plant capital cost for a two-power-block plant is $1,593 million. The indirect capital cost including the owner's cost is $576 million. With revenue stream from power generation of the first power block, the indirect cost was reduced to $31 million. The resulting total plant construction cost is $2,200 million. This corresponds to a total construction cost of $1,335/kWe for the two-power-block 1651 MWe (gross) S-PRISM plant.

Table 1 S-PRISM Plant Cost Summary

System Identification	**S-PRISM - 2 Block Plant** 1651 MWe		
	1996$ million	$/Kwe	%
Civil & Structures	232	141	10.5
Reactor Plant Equipment	900	546	40.9
TG and Heat Rejection System	275	167	12.5
Electrical Plant Equipment	128	78	5.8
Miscellaneous Plant Equipment	39	23	1.8
Special Materials	20	12	0.9
Direct Subtotal	**1,593**	**967**	**72.4**
Construction Services	138	84	6.3
AE Home Office Engring & Service	69	42	3.1
Field Office Supervision & Service	79	48	3.6
Owner's Cost	290	176	13.2
Indirect Subtotal	**576**	**350**	**26.2**
Interest During Construction (IDC)	**31**	**19**	**1.4**
Total Construction Cost	**2,200**	**1,335**	**100.0**

The reference S-PRISM plant, which consists of three, rather than two, power blocks is expected to reduce the plant construction cost below $1,300/KWe.

The direct plant capital cost is about 72% of the total. The reactor plant equipment category includes the costs for the reactor auxiliary systems, waste treatment systems, monitoring and reactor control systems, sodium leak detection systems, maintenance equipment, and the cost of the NSSS constitutes about 41%, of the total. As a result of shorter plant construction schedule the need for the AE home support and field supervision and services are reduced. This has the effect of reducing the the indirect plant capital cost to less than 26% of the total plant construction cost.

Shorter construction schedule also contributes to the reduced interest cost during construction (IDC). However, the revenue stream from the startup of the first power block for electrical power generation contributes much more to the reduction of the IDC cost. The cost reduction would be higher if a market value for electricity instead of the power generation cost is used for this calculation.

3.0 Busbar Cost Estimate

The busbar cost or power generation cost is the key measurement of profitability for the plant owner. The busbar cost constitutes a number of plant characteristics including the plant output, capacity factor, construction cost, O&M cost, and fuel cost.

Power Output

Figure 1 shows the S-PRISM heat balance for each power block, which consists of two reactor modules. The design is based on a reactor core of 1000 MWt and 510°C core outlet temperature. The four primary sodium pumps in each reactor consume about 9.0 MWe of electrical power. Total heat loss from the RVACS and the sodium piping system is about 2.0 MWt. The gross output for each T-G is 825 MWe making the gross plant output for a two block plant 1651MWe. With an on-site load of 131 MWe, the net plant output is 1520 MWe, giving a net cycle efficiency of 37.9%.

Capacity Factor

A Markov model is used to calculate the plant capacity factor and down times. Figure 2 summarizes the calculated results for plant capacity factor and forced outages as a percentage of the total cycle time for both S-PRISM and a large six loop monolithic plant assuming that similar components have the same failure rate and repair times.

Figure 2 shows that S-PRISM with its completely independent nuclear steam supply systems will have a plant availability of more than 99% since at least one reactor module and one BOP will be available for the electrical power generation almost all the time. Failure of any component in a reactor will only affect that particular reactor module while the other three NSSS will continue to supply steam to the turbine-generators for the power generation. Subsequently, plant availability for the modular plant approaches 99.7% and the average capacity factor will exceed 93% for a S-PRISM plant composed of one, two, or three power blocks. This impressively high capacity factor contributes to the annual power output (kW-hrs) and reducing the busbar cost.

O&M Cost

The methodology used for the O&M cost estimates is based on the ORNL Cost Estimate Guidelines for Advanced Nuclear Power Technologies includes the following steps:

1. Development of a list of plant personnel required to support the plant operation and maintenance including administrative and security personnel.

2. Assessment of a mix of on-site, off-site, and contract labor for planned plant outage during normal operation and maintenance, refueling, reactor and IHTS/SGS peak maintenance, turbine-generator peak maintenance, BOP peak maintenance, in-service inspection and regulatory.

3. Escalate the cost base in the ORNL Cost Estimate Guidelines for both of the direct labor cost and the indirect material and general expenses including pension and benefits, *regulatory fees, and insurance premiums.*

Plant Staff

Table 2 lists the account categories, estimated number of personnel required to support O&M of a two-power-block plant, and the annual plant staffing costs. The estimated staffing requirement including both on-site and off-site personnel is 494 persons. The corresponding annual plant labor cost including tax and insurance is $29,571,000.

Table 2 Annual S-PRISM Plant Staffing Cost

Operational Responsibility	Number of Personnel	Annual Cost 1996 $k/Year
Administration	115	4,640.
Operating Division	68	4,392.
Maintenance Division	189	9,632.
Technical Division	61	3,724.
On-Site Staff	434	22,531.
Off-Site Staff	60	4,352.
Payroll Tax & Insurance @ 10%		2,688.
Total On-Site Staffing with Tax and Insurance		29,571.

Maintenance Materials and Supply Expenses

Maintenance materials are defined as replacement items, expendable materials, and services that are utilized in maintaining the plant. The estimated maintenance material cost is $7,123,000.

The Supplies and Expenses account includes consumable materials that are unrecoverable such as makeup materials, chemicals, gases, lubricants, office and personnel supplies, monitoring and recording supplies, training, data processing, and waste management. The fixed portion of the supplies and expenses account is estimated to be $9,290,000. The variable supplies and expenses cost is estimated to be $1,924,000. The annual plant supplies and expenses cost, therefore, is $11,213,000.

Waste treatment includes the management and operation of the waste treatment plants. The estimated annual radwaste and non-radwaste treatment costs are $2,712,000 and $736,000 for a total of $3,448,000.

Indirects and General Expenses

The indirects and general expenses include the pension and benefits, nuclear regulatory fees, nuclear insurance premiums, and general administrative costs. The pension and benefits account is assumed to equal 25% of the total on-site and off-site direct salaries, or $7,392,000.

The nuclear regulatory fees are required to perform safety, environmental, and health physics inspections to assure that the plant operation is being carried out as authorized by the plant operating license. The nuclear regulatory fees are estimated to be $3,276,000 for the NOAK plant.

Nuclear insurance is required for the utilities to protect themselves against liability claims in the event of nuclear accident. The public liability and property damage insurance premiums for the plant are estimated to be $6,910,000.

Grand total for the plant indirect and general expenses, therefore, is $24,599,000.

Table 3 summarizes the annual O&M cost required to support S-PRISM plant operations. The annual O&M cost is estimated to be $75,954,000.

Table 3 S-PRISM O&M Cost

	1996$K/year 2 Blocks
Direct Power Generation Cost	
Plant Labor	29,571
Maintenance Materials	7,123
Supplies and Expenses	11,213
Waste Treatment	3,448
Subtotal Direct Costs	**51,355**
Adminstration & General Costs	
Penson and Benefits	7,021
Nuclear Rgulatory Fees	3,276
Nuclear Insurance Premiums	6,910
Indirect and general administration	7,392
Subtotal Indirect Costs	**24,599**
Annual O&M Cost	**75,954**

Fuel Cycle Cost

The LMR power generation cycle is started by using fissile fuel supplied by reprocessing spent LWR fuel. However, once the LMR fuel production capability reaches breakeven, all fuel is supplied by recycle of spent LMR fuel. Until fissile breakeven production is reached, a mixture of LWR-sourced fuel and LMR-sourced fuel is required to maintain the LMR power generation cycle.

The metal cycle facility costs are based on the ALMR industrial participation in the ANL pyroprocess technology development program. Within that effort, a detailed conceptual design of the recycle facility was developed and costed. The facility is optimized to provide fuel only for use in LMRs. Minor actinides (MA) are recycled with the fuel and returned to the reactor for continued transmutation. The current best-estimate facility costs only make adjustments to the ALMR program cost basis to adjust the plant and equipment for a particular facility throughput. Facilities are assumed to be centrally-located plants serving a number of LMRs.

Table 4 summarizes the cost elements of each LWR and LMR Spent Fuel Cycle Facility (SFRF). The two plants are similar in design and function and have about the same fissile mass throughput, however, the difference in enrichment (about a factor of 10) between LWR and LMR fuel results in a large difference in total heavy metal throughput for the two reprocessing plants.

The fuel cycle cost is computed as the mass-weighted average of the costs of fuel from both LWR and LMR spent fuel recycle sources. Using US financial assumptions for utility ownership and operation of the SFRFs, the reference, cost-optimized, metal core in S-PRISM power plants show a fuel cycle cost of 5.0 mills/kW-hr.

Table 4 Fuel Cycle Cost Components

S-PRISM Core	**Metal LWR-SFRF**	**Metal LMR-SFRF**
Facility Capacity (MTHM/yr)	1000	100
Facility ($ 10^6)	127	127
Equipment ($ 10^6)	107	82
Design ($ 10^6)	57	57
Exempt Labor ($ 10^6/yr)	18.2	15.2
(People)	(210)	(176)
Non-Exempt Labor ($ 10^6/yr)	13.1	11.1
(People)	(242)	(205)
Consumables ($ 10^6/yr)	17.9	6.1
Hardware ($ 10^6/yr)	52.4	25.6

Busbar Cost

Table 5 summarizes the busbar cost estimates for the S-PRISM plant. The levelized busbar cost include a sinking fund for decommissioning the plant when it has completed its operating life. The cost was assumed to be 1.0 Mill/KW-hr in accordance with the cost estimating guidelines.

For the two-power-block plant, the net plant output is 1520 MWe. With an average plant capacity factor of 93%, total annual power output is 12,383,136 MW-hr.

For a fixed charge rate of 0.0945, the annual capital cost charge will be $207 million, which is 16.8 mills/KW-hr. The O&M cost and fuel cycle cost are estimated to be 6.2 mills/KW-hr and 5.0 mills/KW-hr, respectively. This results in a busbar cost of 29.0 mills/KW-hr for a NOAK S-PRISM plant.

Table 5 S-PRISM Busbar Cost

	1996 Levelized $
	2 Power Blocks
Net Power Output, MWe	1520
Capacity Factor, %	93
Annual Power Production, MW-hr	12,383,136
Total Capital Cost, K$	2,200,000
Annual Capital Cost Charge, K$	207,900
Annual O&M Cost, K$	76,280
Capital Cost, mills/KW-hr	16.8
O&M Cost, mills/KW-hr	6.2
Fuel Cycle Cost, mills/KW-hr	5.0
Decommission, mills/KW-hr	1.0
Busbar Cost, mills/kw-hr	**29.0**

4.0 S-PRISM R&D Requirements

The R&D program plan is an integral part of the S-PRISM commercialization plan as shown in Figure 3 The technology development tasks in the R&D plan support the design, development, licensing, construction, and operation and maintenance (O&M) of a prototype plant leading to the design certification of the standard plant. The objective of the technology development program is to validate design methods and data to be used for plant design, development, and licensing. The technology development program includes key features tests and prototype component and subsystem test to assuring structural integrity, to characterizing the reliability of safety systems and components, and to establishing margins for beyond design basis events.

Approach

The technology development work was identified in four phases corresponding to the plant design program as shown in Figure 4. The feasibility tests for the S-PRISM innovative features, have were carried out during the U.S. ALMR program. Therefore, a large portion of the technology development will be focused on safety analyses, key features tests, and prototype components tests.

Schedule

Key feature tests for S-PRISM will be initiated in the first year of the S-PRISM program plan and will be completed in five years. The characterization and qualification of the passive safety features and safety enhancing mechanisms including passive reactivity reduction, the passive shutdown heat removal, and the seismic isolation system will be completed by performing system tests during this time period. Then, it is followed by prototype testing of key plant components and/or subsystems for confirmation of their respective performance. The prototype component/subsystem testing will be completed in another four years. While the total R&D program plan is about nine years, most of the work to support plant design and licensing will be completed in the first eight years of the program plan.

Program Cost

The R&D program cost is summarized in Table 6. The total R&D cost for the S-PRISM development is about $300 million.

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Table 6 S-PRISM2 R&D Cost

(1996 $ million)

WBS Number	R & D Items	Conceptual Design		Preliminary Design			Detailed Design Phase					Sub-Total
		Year 1	2	3	4	5	6	7	8	9	10	$MM
1.0	Plant Design and Large Facilities		2.6	2.6	2.6	0.6	0.6					9
2.0	Safety and Licensing		5.0	7.0	7.0	6.0	4.0	1.0				30
3.0	Shielding and ALARA		0.5	0.5	0.5	0.5						2
4.0	Seismic		3.0	3.5	4.2	2.5	2.4	0.9	0.6			17
5.0	Reactor Core Reactivity		1.5	3.0	4.5	3.0	2.0	2.0				16
6.0	Fuel (Not part of reactor development)											0
7.0	Control Rod Drives	1.5	3.0	6.0	9.2	7.9	6.9	5.4	2.9	0.2		43
8.0	Reactor System			1.0	2.0	2.0	2.0	1.0				8
9.0	Reactor Thermal-Hydraulics		0.5	1.0	1.5	2.0	2.0	1.0				8
10.0	Pump and IHX	2.5	2.5	7.5	10.7	9.7	9.7	5.7	0.7			49
11.0	IHTS and SGS		3.0	3.0	3.5	5.0	1.5					16
12.0	Auxiliary Sodium Systems (No R&D Items)											0
13.0	Fuel Handling System	0.5	2.5	7.7	8.0	8.5	8.5	5.2				41
14.0	Instrumentation and Contorl	2.5	5.3	7.3	9.5	6.5	3.2	3.7	2.2			40
15.0	Materials and Structures		1.8	3.3	3.3	2.3	1.5	0.0				12
16.0	Maintenance and In-Service Inspection	0.3	1.0	1.5	1.5	1.5	1.5	1.0	0.5	0.3		9
17.0	Electrical Equipment (No R&D Items)											0
	Cost per Year, $MM ($million)	7.3	32.1	54.8	67.9	58.0	45.8	26.9	6.9	0.5		
	Total Cost in Million $ =											**300**

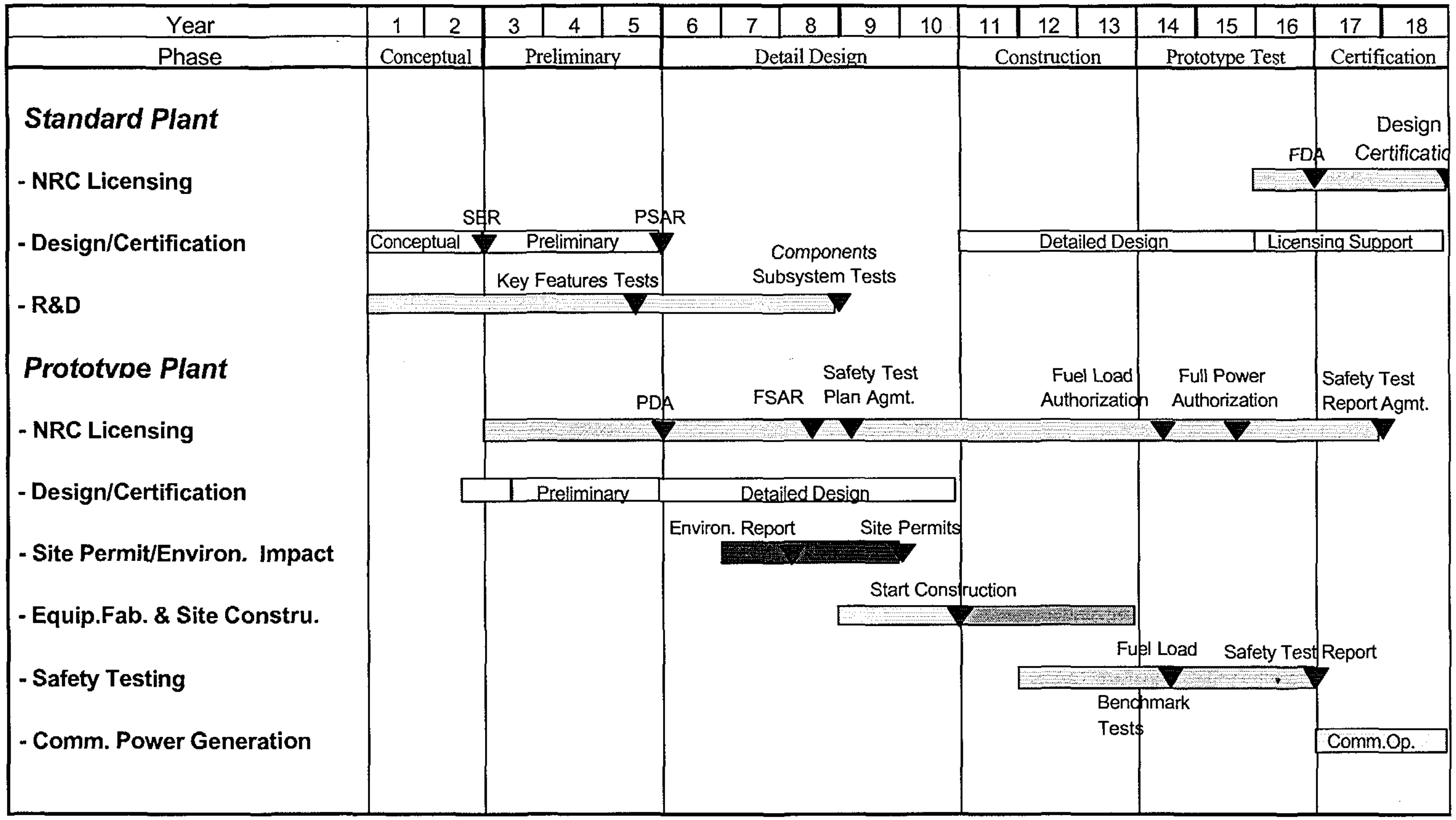


Figure 4 Development Plan

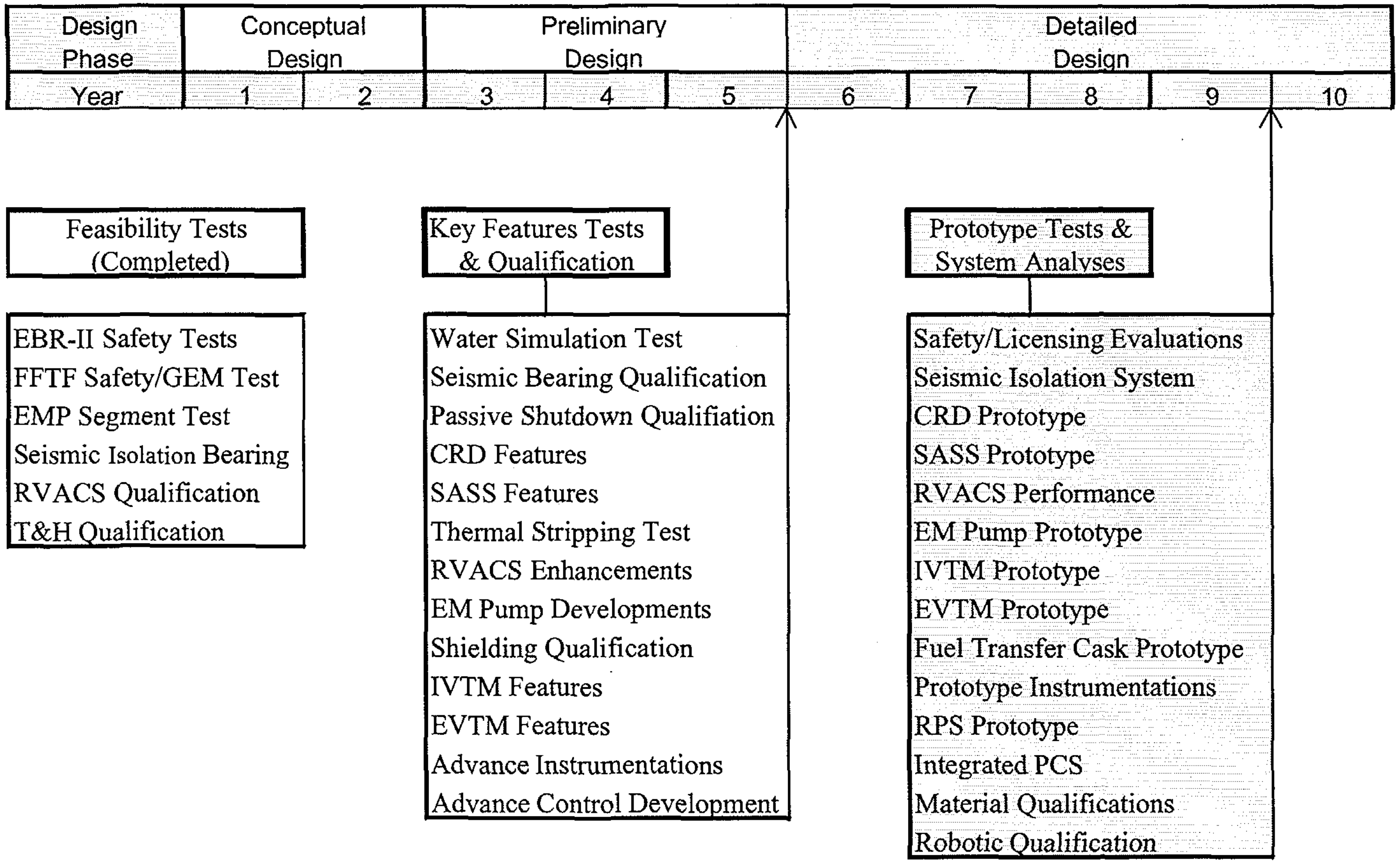


Figure 3 Overall R&D Effort

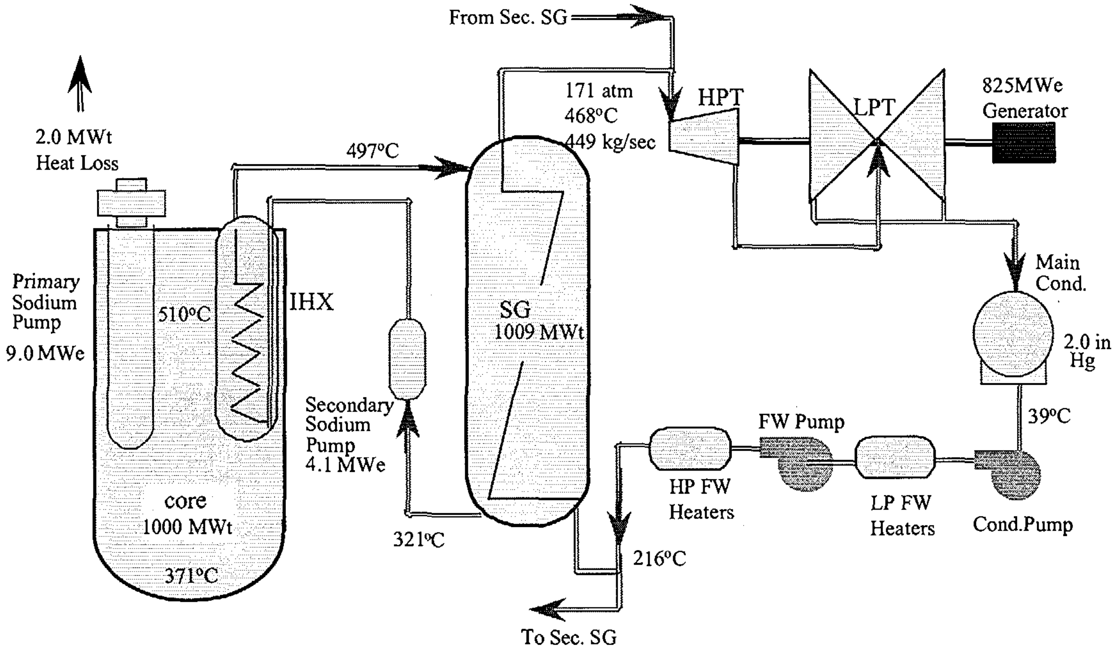
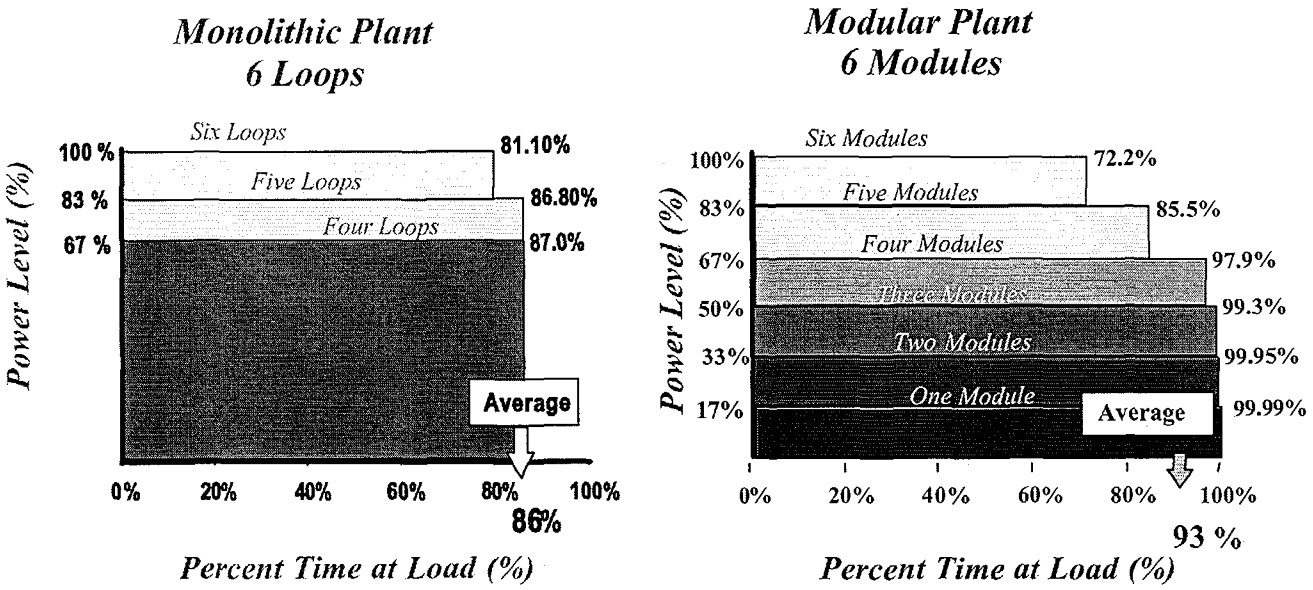


Figure 1 S-PRISM Heat Balance



<u>The Seven Point Advantage is due to:</u>

- *Relative simplicity of each NSSS (one SG rather than six)*
- *Ability to operate each NSSS independently of the others*

Figure 2 Comparison of Monolithic versus Modular Plant Capacity Factors