

THE ADVANCED PASSIVE AP1000 NUCLEAR PLANT – COMPETITIVE AND ENVIRONMENTALLY FRIENDLY

W. E. Cummins, Director, Advanced Plant Development, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, PA 15668

ABSTRACT

The AP1000 advanced passive nuclear plant design activities are a natural extension of the AP600 program. AP600 engineering data was utilized as the basis for a two-loop plant with an electrical output exceeding 1,000 MWe. This AP1000 utilizes the AP600 safety design features already approved by the Nuclear Regulatory Commission. The NRC review of the AP600 culminated with the successful completion of the Design Certification process in December 1999.

The AP1000 program is currently completing engineering activities that will allow utilization of essentially all of the detailed design information generated for the AP600, including the test results, and, where changes are necessary to accommodate the higher power, proven systems designs and components are being employed.

The primary reason for developing the AP1000 was to lower electrical generation costs by significantly reducing the capital cost per kilowatt thereby making it immediately competitive with natural gas and combined cycle plants.

The AP1000 accomplishes this low cost goal by significantly reducing materials and components quantities compared to current and evolutionary plants and, at the same time, substantially reduces the construction schedule for the plant to 36 months from first concrete to fuel load. This is due to the reduced installation requirements associated with the plant simplification, and by extensive use of modules for both structural members and systems packages. Over 150 modules are currently utilized in the AP1000 plant, each being fabricated in a controlled shop environment as opposed to field construction.

Additionally, the utilization of the passive design approach for the key safety systems provides numerous benefits including improved safety (the PRA analysis shows a factor of 10 improvement in risk assessment over previous designs), and large reductions in volume of buildings which must meet the "safety/seismic" pedigree. The building volume reductions are approximately 45%.

The resulting generation costs for the AP1000 design are truly outstanding. Utilizing the extensive data base generated to estimate the cost of the AP600, and the best current industry results for fuel, operations and maintenance costs in the U.S., the AP1000 will generate electricity in the range of 3.0 to 3.5 cents (U.S.) per kilowatt-hr.

INTRODUCTION

For countries to begin or expand their nuclear programs, several prerequisites must be met. Nuclear energy must be economically competitive with alternative energy and, at the same time, acceptable to the public and the government of the country through a strong focus on plant safety. Such countries should look carefully at building an advanced passive nuclear power plant. Advanced passive technology captures the strategic goals of the worldwide nuclear community including increased safety, reliability, economics, environmental friendliness, and public acceptance.

The design strategy for Westinghouse passive plants was based on meeting globally recognized customer requirements such as the U.S. Advanced Light Water Reactor Utility Requirements (ALWR URD) or the European Utility Requirements (EUR). Designers also incorporated the extensive lessons learned from operating reactors in the U.S., Asia, and Europe. A concerted effort was made to simplify systems and components to facilitate construction, operation, and maintenance. Simplification enhances operational performance, increases reliability, and thereby improves economics. State-of-the-art, proven technology was used to solidify confidence in the high performance expectations of the passive plant designs.

Passive plant safety systems performance relies on the natural forces of gravity, natural circulation, and evaporation to shutdown and cool down the plant in the unlikely event of an accident. Passive systems also contribute to improved plant economy through simplification, while still meeting regulatory and public acceptance criteria.

Following the guidelines of the design strategy above, two advanced passive pressurized water reactor (PWR) plants were developed. The AP600 is a two-loop, 600-MWe plant designed in collaboration with the U.S. Department of Energy (DOE), Electric Power Research Institute (EPRI), the Advanced Reactor Corporation, and 22 other international partners. The AP1000, a two-loop, 1000-MWe configuration was developed using the AP600 to the maximum extent possible. The primary design objective of the AP1000 is to provide electrical generation economics that are competitive with all fuel sources used for base load generation.

This paper provides an overview of these two designs and the benefits they offer.

ADVANCED PASSIVE TECHNOLOGY DESIGN OBJECTIVES

The primary design objectives of the advanced passive technology is to provide greatly simplified nuclear plant designs that meet or exceed the latest regulatory requirements and safety goals, while being economically competitive with other fossil fuel power generation systems.

PASSIVE SAFETY FEATURES

The passive safety systems use only natural forces, such as gravity, natural circulation, and compressed gas to guarantee plant safety. No pumps, fans, diesel generators, or other rotating machinery are used. A few simple valves align the passive safety systems when they are automatically activated. In most cases, these valves are *fail safe*; that is, they require power to remain in their normal, closed position. Loss of that power causes them to open to their safety alignment. These passive safety systems are significantly simpler than conventional light water reactor (LWR) safety systems.

In addition to being simpler, the passive safety systems do not require the large network of safety support systems needed in current generation nuclear plants, such as AC power, HVAC, cooling water systems, and the associated seismic buildings to house these components. These reductions in systems led to the elimination of safety-grade emergency diesel generators and their network of support systems, air start, fuel storage tanks and transfer pumps, and the air intake/exhaust system. Figure 1 illustrates these reductions in the AP600 design.

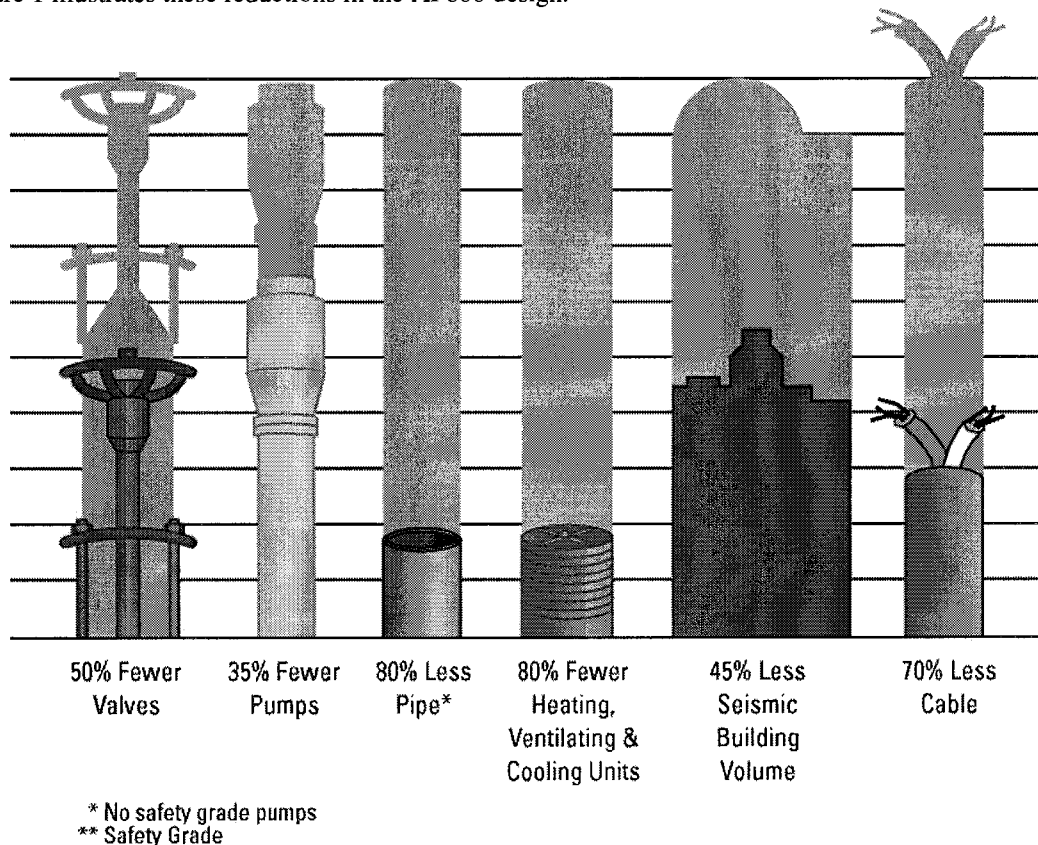


Figure 1 Compared To A Typical 600 MWe Plant, the AP600 Plant Requires Fewer Valves, Pumps, Piping, and Associated Equipment

Passive safety systems include: passive safety injection, passive residual heat removal, and passive containment cooling. All of these systems have been designed to meet the NRC single-failure criteria and other recent criteria, including Three Mile Island (TMI) lessons learned, as well as unresolved and generic safety issues. The use of Probabilistic Safety Assessments (PSAs) have also been key in evaluating system design tradeoffs and in quantifying the safety of the design.

SUPERIOR PLANT GENERATION ECONOMICS

As identified earlier, improvement in electrical generation economics was a driving force for the advanced passive technology. The long-standing belief that nuclear power capital costs have been too high in most western countries has limited the growth of the nuclear option in those countries. Advanced passive plant engineering activities focused on simplification as a primary tenant of the design process, but also became a critical element in cost reduction. However, in addition to design simplification and the associated reductions listed in Figure 1, aggressive goals were set to find ways to significantly reduce the plant construction schedule, thereby reducing construction costs and their impact on power generation costs.

AP600 PASSIVE PLANT

As part of the cooperative effort sponsored by the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) Advanced Light Water Reactor (ALWR) Program, Westinghouse developed a safe, simplified, and economically competitive, two-loop, 600-megawatt passive plant design. A cut-away view of the AP600 is shown in Figure 2.

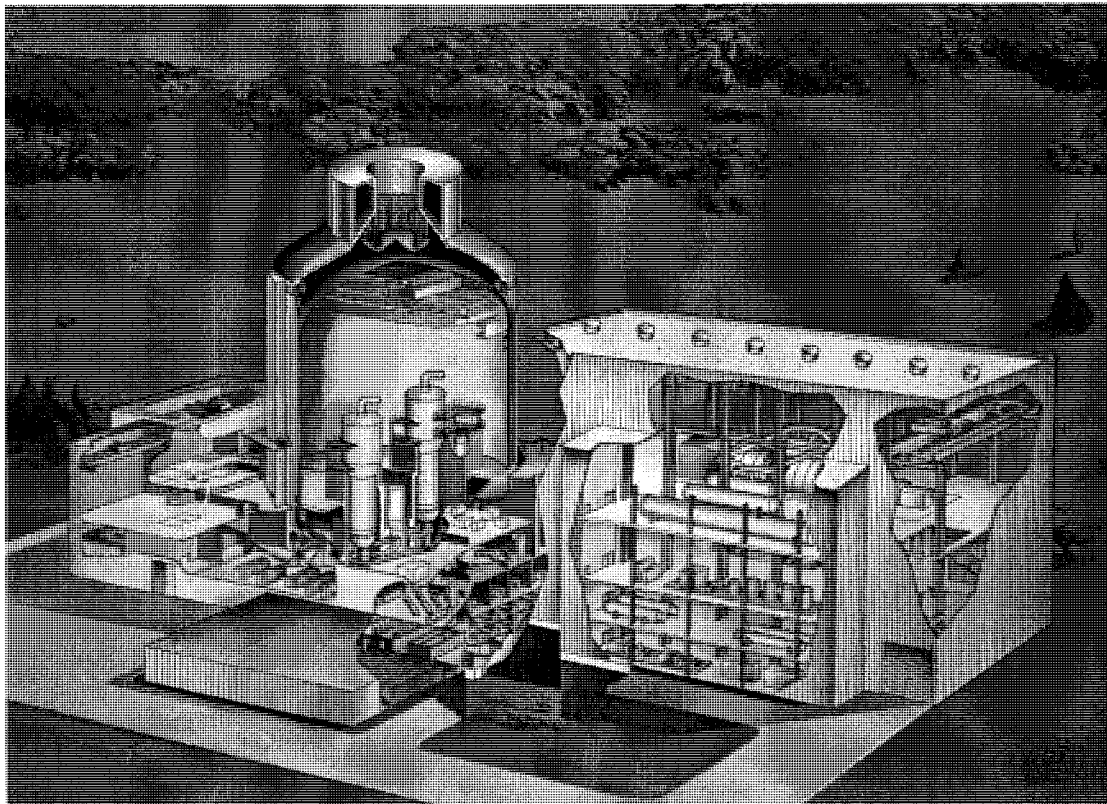


Figure 2 Westinghouse AP600 Nuclear Electric Power Plant

IMPROVED CONSTRUCTION STRATEGY

The AP600 has a site construction schedule of 36 months from first concrete to fuel load, as shown in Figure 3. This schedule is much shorter than current experience because of the reductions in bulk materials, components, and building volumes. Additionally, schedule reductions will be facilitated by the significant use of factory-built modules for both structural members and systems. Initiating factory construction of these modules would be approved consistent with site scheduler requirements. These modules are designed to be transported by rail or barged via waterways. Figure 4 shows how parallel efforts in the factory and onsite will facilitate this short construction schedule.

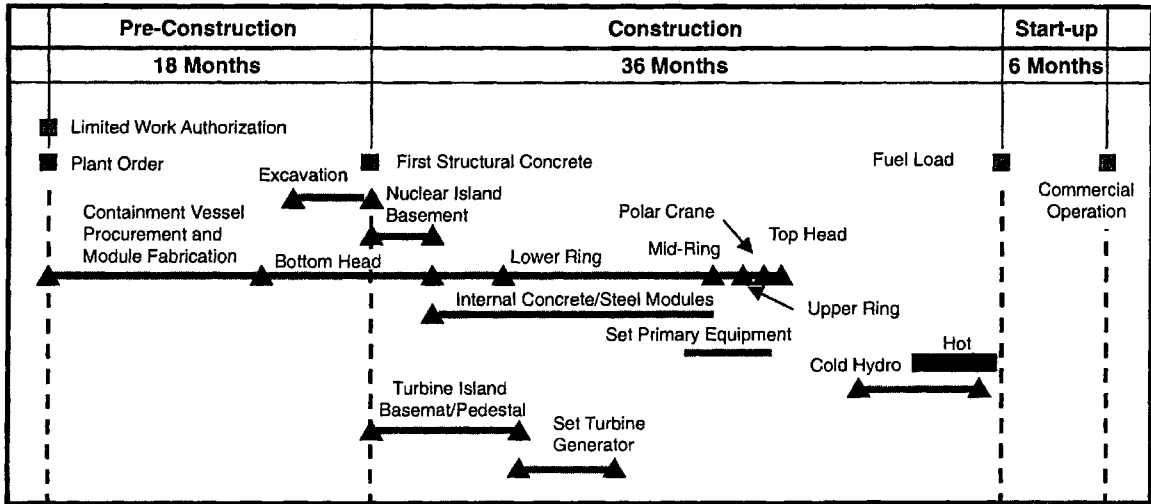


Figure 3 Schedule for a Standardized AP600 Plant – 60 Months

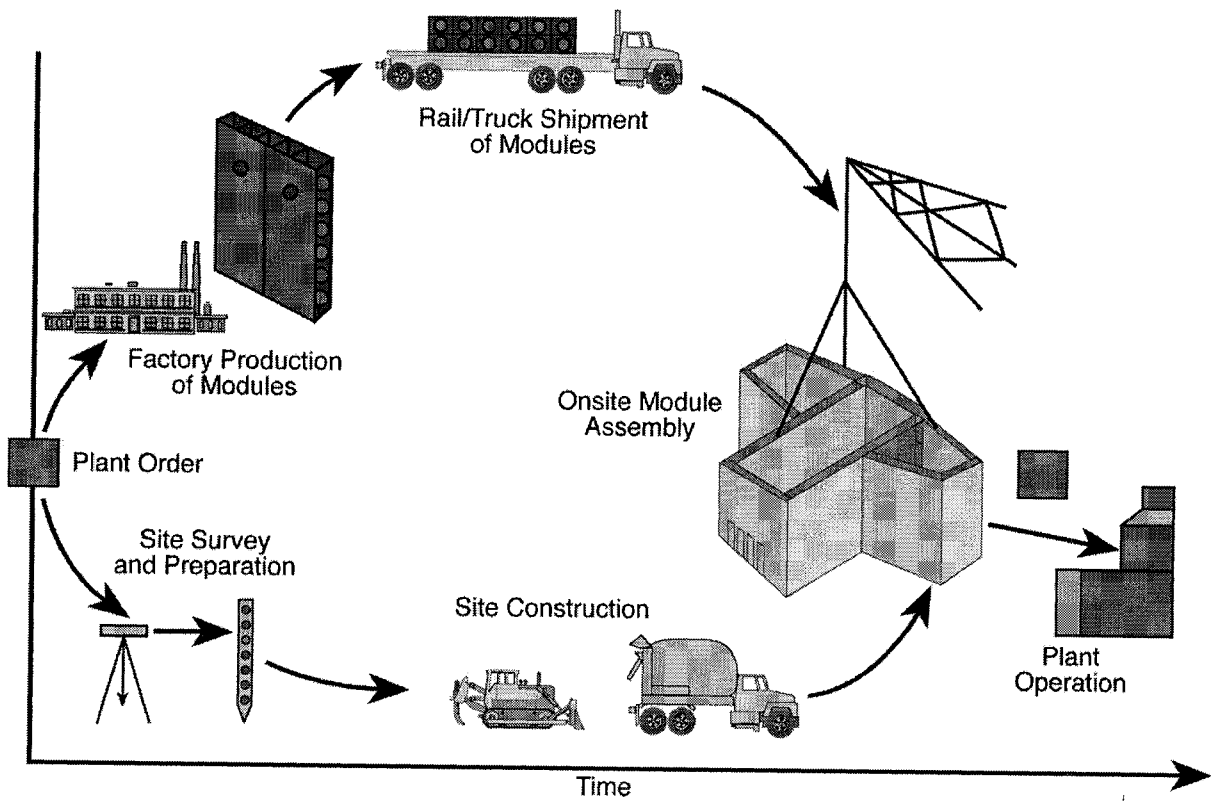


Figure 4 Parallel Tasks on Modular AP600 Shorten Construction Schedule

The economic results of these improvements in plant costs and construction timing have led to plant cost reductions of 20% to 30% compared to current evolutionary plant designs of similar size. Plant costs for the AP600 were confirmed by completing a detailed cost buildup using direct quotes in 1900 commodity categories for 25,000 specific items including components, materials, labor, indirect, and owners costs. This evaluation led to the following overnight plant completion costs, assuming a two-unit AP600 site.

- Direct and Indirect Costs \$1650 million
- Owners Costs \$205 million
- Total Cost \$1520/KWe

MEASURING SAFETY

Safety used to be measured in terms of redundancy and multiple levels of defense; i.e., the philosophy of “if one safety system is good, two are better.” With the advent of new risk assessment tools, such as the Probabilistic Safety Assessment (PSA), that mindset has changed. The AP600 was designed from the basemat up with PRA guiding the way. The AP600 plant design has achieved an improvement in safety by a factor of 10 to 100 over current and evolutionary generation plants. Figure 5 compares the AP600 total internal event PSA result with other standards.

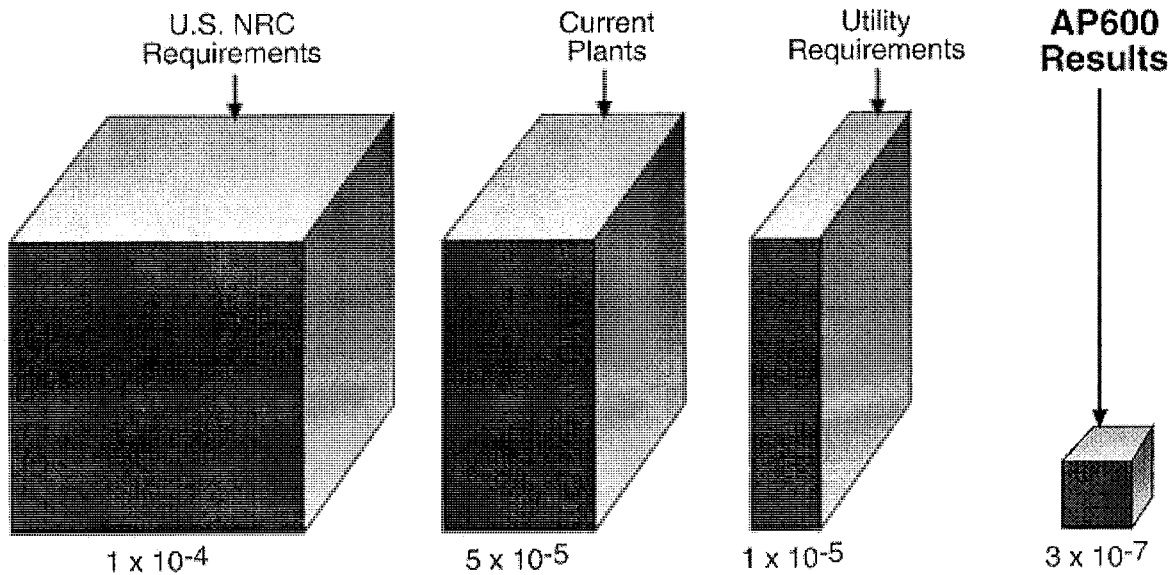


Figure 5 Core Damage Frequency per Year (Internal Events)

In addition, common-mode-failures (CMFs) can also be evaluated using the PRA design tools. Results of these analyses have led to the use of diversity of functions using passive systems, thereby significantly reducing the two main sources of CMF concerns: maintenance error and component failure. Figure 6 shows the LOCA protection systems that incorporate diverse valves.

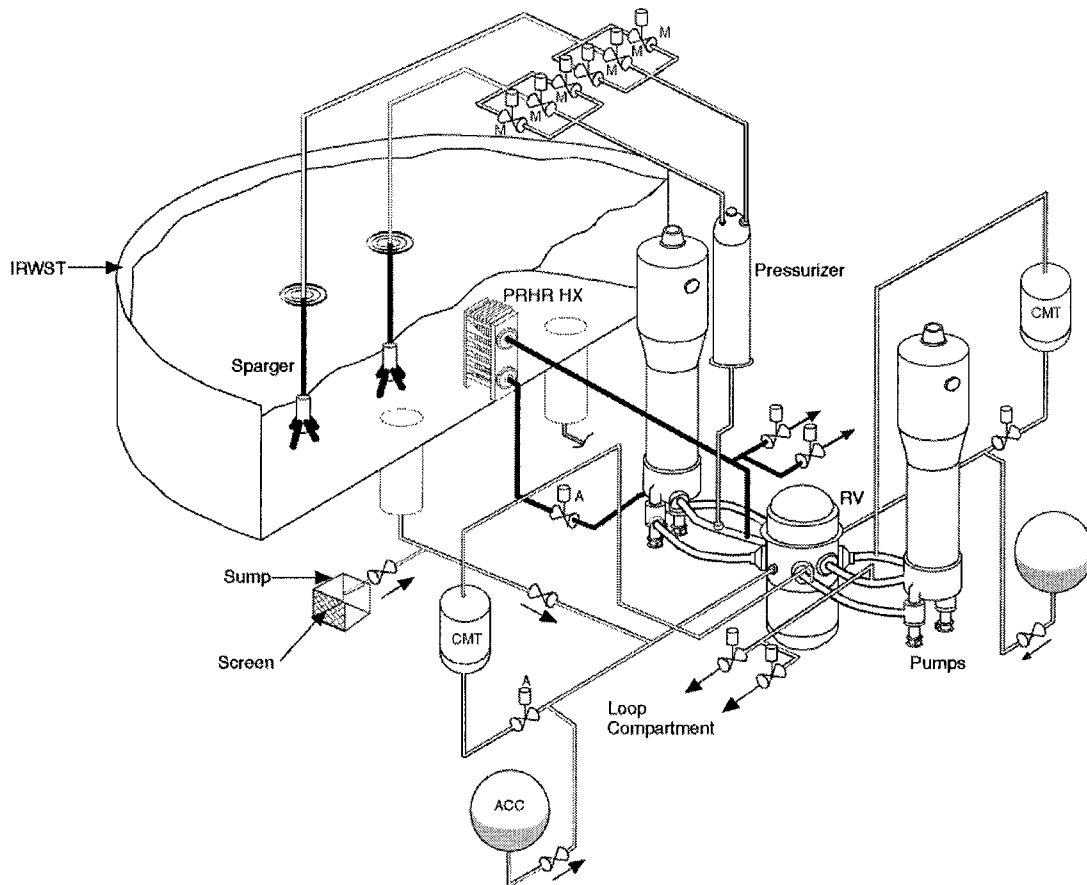


Figure 6 Passive Core Cooling

THE CURRENT SAFETY ASSESSMENT OF THE AP600

In June of 1992, Westinghouse submitted the Safety Analysis Report and PRA to the U.S. Nuclear Regulatory Commission (NRC). The NRC replied with a Draft Safety Evaluation Report, listing its questions, to which Westinghouse responded. In May 1996, the NRC issued a supplement to the Draft Safety Evaluation Report on the AP600 computer codes and testing program. All issues were resolved to the NRC's satisfaction, and they issued their Final Design Approval in September 1998. After an additional year for public rulemaking, the NRC issued a Design Certification in December 1999.

AP1000 PASSIVE PLANT

The AP1000 is a logical extension of the AP600 design activities. Many of the studies coming from these earlier efforts provided a high-confidence level that a two-loop configuration of the passive technology could produce over 1000 MWe with minimal changes in the AP600 design. In fact, maintaining as many aspects of the AP600 design as possible became a design objective of the AP1000. The obvious purpose of moving forward with the AP1000 was to optimize the power output, thereby reducing the resulting power generation costs. The objective has been met, and has led to a plant that is competitive with all types of fossil and renewable generation options.

The AP1000 is a two-loop, 1000 MWe plant that keeps the same basic design of the AP600 (see Figure 7) — the nuclear island footprint stays the same. The main differences between the AP600 and AP1000 are shown in Figure 8. Those component changes that impact the plant the most are the increase of the size of the steam generator, from a delta-75 to a delta-125, and the higher flow reactor coolant pump, from 51,000-gpm capacity to 75,000-gpm. One of the added benefits of larger reactor coolant pumps is a higher inertia as compared to the AP600, which allows increased margin for departure from nucleate boiling (DNB) for loss-of-flow events, by providing increased coastdown flow to the core. The containment is also larger, but only in height, to accommodate the greater mass and energy of the reactor coolant system.

All of the plant components use proven technology.

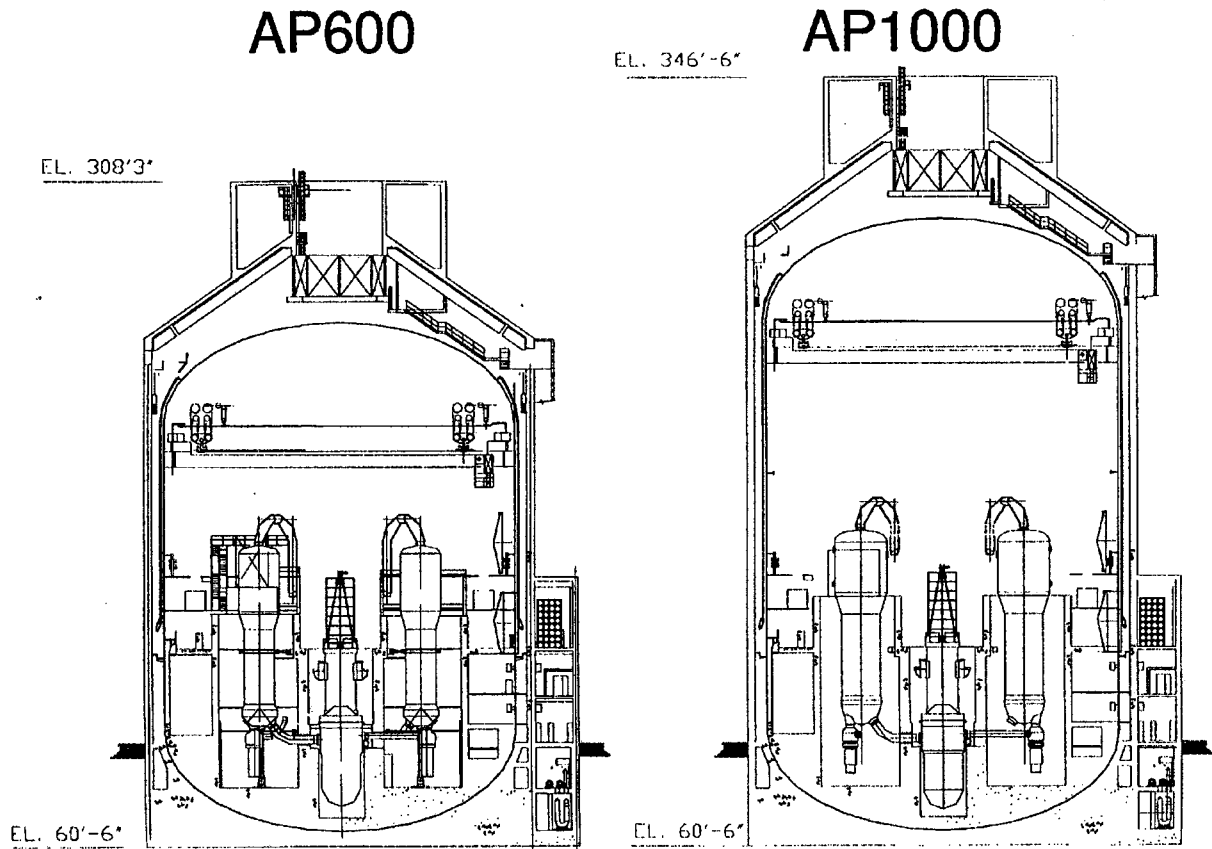


Figure 7 AP1000 General Arrangement (Containment Section View)

Parameter	AP600	AP1000
Net Electric Output, MWe	600	>1000
Reactor Power, MWt	1933	3400
Number of Fuel Assemblies	145	157
Type of Fuel Assembly	17x17	17x17
Active Fuel Length, ft.	12	14
Core Loading, MTU	66.90	84.50
Linear Heat Rating, kW/ft.	4.10 (13.5 kW/m)	5.03 (16.6 kW/m)
Average Power Density, kW/liter	78.82	96.6
R/V I.D., inches	157 (3988 mm)	157 (3988 mm)
Steam Generator	$\Delta 75$	$\Delta 125$
Reactor Coolant Pump Flow, gpm	51,000	75,000

Figure 8 Comparison of Selected Parameters

Proven Technology of New AP1000 Components

- Steam Generators Arkansas 2, Ulchin 5 & 6
- Digital Instrumentation & Control Sizewell B, Ulchin 5 & 6
- Fuel South Texas 1 & 2, Doel 3, Tihange 4
- Reactor Coolant Pumps U.S. Nuclear Navy

SAFETY ASSESSMENT

Using the test data developed for the AP600 and similar designs, the AP1000 is capable of meeting higher power output requirements with proven technology. The PRA shows that the plant simplifications embodied in the Westinghouse advanced passive plant design and providing enhanced safety are not power-level dependent.

COMPETITIVE ELECTRIC GENERATION

Calculating expected economic performance requires establishment of plant performance parameters, fuel cycle assumptions, and plant cost data. The following parameters are consistent with current plant operations in the U.S. Using this data yields generation costs in the range of 3.0 cents to 3.5 cents (U.S.)/kWhr, 3.2¢/kWhr for twin AP1000 units constructed at a single site. The bottom line is that the AP1000 will be very competitive with generation using other types of fossil and renewable fuels.

Generation Cost Assumptions

- Forty-year economic lifetime - AP1000 is designed for 60-year operation
- Approximately 10% added to capital costs for first time engineering
- O&M and fuel costs equal to efficient U.S. utilities
- One year between commercial operation of Units 1 and 2

CURRENT SAFETY ASSESSMENT OF AP1000

Westinghouse has met with the NRC and they have agreed to identify fundamental assumptions and areas of review that are necessary to obtain Design Certification for the AP1000 beyond those already accepted by the NRC in the AP600 Design Certification process. Interest in the AP1000 has led to support from the DOE and EPRI, primarily to facilitate the completion of the plant's safety case review.

CONCLUSION

So there are bright spots for the future of nuclear power as a source of new electrical generation in the U.S. and elsewhere. To date, advanced passive technology has met and resolved all of the challenges that have been put before it.

The Introduction of this paper identifies the key requirements for the next generation of nuclear plants as safety, low-generation cost, environmental cognizance, and public acceptance. The advanced passive plant design as embodied by the AP600 and AP1000 meets or exceeds these requirements.