THE WESTINGHOUSE AP600 AN ADVANCED NUCLEAR OPTION FOR SMALL OR MEDIUM ELECTRICITY GRIDS

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ABSTRACT

During the early days of commercial nuclear power, many countries looking to add nuclear power to their energy mix required large plants to meet the energy needs of rapidly growing populations and large industrial complexes. The majority of plants worldwide are in the range of 1000 megawatts and beyond. During the 1970s, it became apparent that a smaller nuclear plants would appeal to utilities looking to add additional power capacity to existing grids, or to utilities in smaller countries which were seeking efficient, new nuclear generation capacity for the first time.

For instance, the Westinghouse-designed 600 megawatt Krsko plant in Slovenia began operation in 1980, providing electricity to inhabitants of relatively small, yet industrial populations of Slovenia and Croatia. This plant design incorporated the best, proven technology available at that time, based on 20 years of Westinghouse PWR pioneering experience.

Beginning in the early 1980s, Westinghouse began to build further upon that experience -- in part through the advanced light water reactor programs established by the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE) -- to design a simplified, advanced nuclear reactor in the 600 megawatt range. Originally, Westinghouse's development of its AP600 (advanced, passive 600-megawatt) plants was geared towards the needs of U.S utilities which specified smaller, simplified nuclear options for the decades ahead. It soon became evident that the small and medium sized electricity grids of the international markets could benefit from this new reactor. From the earliest days of Westinghouse's AP600 development, the corporation invited members of the international nuclear community to take part in the design, development and testing of the AP600 -- with the goal of designing a

reactor that would meet the diverse needs of an international industry composed of countries with similar, yet different, concerns.

HISTORY OF AP600 DEVELOPMENT

Westinghouse embarked upon the AP600 program in 1985 as a means to revitalize nuclear power in the U.S. Reactor size was fundamentally the outgrowth of surveys of U.S. utilities conducted by EPRI in the mid-1980s and verified recently. Much of the technology was driven by what the utilities were looking for in the next generation of plants. To control operation and maintenance costs, the utilities wanted a simple plant that is easy to run and easy to maintain. Other issues of concern to the utilities were construction schedule and licensing certainty.

In 1989, the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) initiated a design certification program to develop and commercialize advanced light water reactors (ALWRs) for the next round of power plant construction. Westinghouse accepted their challenge and formed an international team to develop a design that would satisfy the standards set by DOE. In 1996, that program between government and industry continues to nurture the development of advanced, simplified technology culminating in a simpler, more forgiving, and less costly reactor.

The AP600 design strikes a balance between the use of proven technology and new approaches. The result is a greatly streamlined plant that can meet safety regulations and reliability requirements, be economically competitive, and promote broader public confidence in nuclear energy. When its comprehensive test program was completed at the end of 1994, the Westinghouse AP600 became the most thoroughly tested advanced reactor design ever reviewed by the U.S. Nuclear Regulatory Commission (NRC).

THE AP600 TEAM

The AP600 has been influenced since its conception by the participation of the DOE, which considers the AP600 an integral part of America's national energy strategy; EPRI, one of the nuclear industry's premier institutions; and two industry teams from the U.S. -- the Advanced Reactor Corporation (ARC) and the ALWR Steering Committee.

Westinghouse designed the first commercial nuclear power plant more than 30 years ago and has been the leader in continued development ever since. More than half the world's nuclear electricity is produced by reactors built to the Westinghouse design.

The AP600 team reflects this experience, but also embraces the talents and historic accomplishments of numerous electric utility companies, engineering, architectural, and construction firms, plus the academic community.

A cornerstone of the AP600 Program has been the involvement of the nuclear utilities worldwide; the participation of 20 nations in addition to the U.S. has been an invaluable asset. The contributions of these countries range from contributing module analysis and design; participating in overall plant engineering; component engineering and testing; plant layout and detailed design work on balance-of-plant; and the support of plant layout efforts. The joint efforts of engineers from many nations ensure the capability of the AP600 to meet small- or medium-sized electricity generation needs worldwide. In addition, the AP600 -- with its simplified systems, enhanced safety margins and lower costs -- is designed to be more understandable and acceptable to the general public.

UTILITY REQUIREMENTS FOR NEW, SIMPLIFIED PLANTS

Through the very broad participation of numerous countries, the wealth of information that has been generated worldwide relating to nuclear power plant safety and operations has been focused in the EPRI's ALWR Utilities Requirements Document (ALWR URD). The purpose of the URD is to present a clear, complete statement of utility desires for their next generation of nuclear plants, and to this end, it consists of a comprehensive set of design requirements for future plants.

These requirements are grounded in the proven technology of over 30 years of commercial U.S. and international experience, while incorporating new features that ensure a simple, robust, and more forgiving design. Since the inception of the AP600 program, incorporation of the requirements from the ALWR URD has been a key design goal.

BUILDING ON PROVEN TECHNOLOGY TO PRODUCE ENHANCED DESIGN FEATURES

The overall AP600 plant design follows in the decades-long tradition of Westinghouse two-loop, 600 MWe PWRs, which have operated with average lifetime availabilities that are 20 percent higher than the national U.S. average for operating plant availability. The core, primary components, instrumentation and controls, and natural, passive safety systems are all based on technology that has been proven in service, or by rigorous testing. The ALWR URD uses the large experience base from existing LWRs to minimize the risk to the plant owner, provide confidence relative to credibility of costs and schedules, and avoid the need for a plant prototype. This philosophy has been strictly followed from the beginning of the AP600 Program.

Design margins contribute significantly to plant safety through the avoidance of plant challenges. And, a fundamental AP600 design principle is that ample margins be included in the design as a means of ensuring plant reliability and tolerance for off-normal conditions. The low-power density core of the AP600 reactor will provide substantial margin between the fuel operating conditions and the experimentally established limits for ensuring fuel rod integrity. Similarly, corrosion protection measures and thermal design margins for the AP600 steam generators will increase the margin for primary to secondary plant pressure boundary integrity. The AP600 pressurizer has a 30 percent greater volume, which will contribute to the safety margin by providing the capacity to sustain a wide range of off-normal plant transients without approaching conditions that call for protective actions; for example, in case of a full load rejection, no pressurizer relief will be needed in order to prevent the primary system pressure from reaching the reactor trip setpoint.

Simplification is the key technical concept that drives the safety and economics of the AP600. These simplified, passive systems depend on the reliable natural forces of gravity, natural circulation, convection, evaporation, and condensation instead of AC power supplies and motor-driven components to achieve naturally safe systems. This new approach to safety simplifies plant systems and equipment, operation, inspections, maintenance, and quality assurance requirements by greatly reducing complex components, especially those most subject to regulation. The AP600 will use 50 percent fewer valves, 80 percent less safety-grade pipe, 70 percent less control cable, 35 percent fewer pumps, and 45 percent less seismic building volume than other conventional reactors.

Natural, passive safety systems, which rely on natural forces, provide the ultimate safety function of the AP600. They offer a simple method for meeting the same basic PWR safety functions that have traditionally been provided by active safety systems. The principal safety functions of primary coolant inventory control, liquid reactivity control, reactor residual heat removal, and fission product containment will be met with safety systems designed to use natural driving forces rather than rotating active equipment. The simplicity of these innovative safety systems, together with their diversity from the active, normally operating systems, will enhance the defense-in-depth approach to plant safety.

The AP600 design provides for multiple levels of defense for accident mitigation. The first level of defense uses the normal AP600 nonsafety systems. These simplified nonsafety systems automatically actuate to provide a first level of defense to reduce the likelihood of unnecessary actuation and operation of the safety-related systems.

The AP600 safety system for primary coolant inventory control uses gravity injection and nitrogen pressurized accumulators to provide primary coolant makeup for core cooling and reactivity control in the event a pipe rupture or other accident causes reduction in primary coolant volume. This system actuates automatically if the reactor protection system detects reduced coolant inventory and requires only a change in valve positions to achieve its safety function. Pumps, AC power sources, and operator realignment of equipment are not required for this system to achieve its safety function.

The AP600 safety system for reactor residual heat removal uses a natural circulation heat-exchange loop connected to the reactor and located inside containment. Using the natural circulation process to drive coolant flow, this system transfers heat generated in the reactor to a water pool heat sink inside containment. Heat entering the water pool results in steaming to the containment that is cooled by an evaporative cooling process on the outside of the steel containment vessel. This simple, naturally driven system, designed to withstand full system pressure, serves the same function as a conventional emergency feedwater system.

The AP600 steel containment vessel prevents radioactive releases to the environment and serves as the heat transfer path for reactor residual heat removal in the event of postulated accidents. Heat removal from the containment is by evaporative cooling of the outside of the steel vessel. This process is established by gravity flow of water onto the outer surface of the vessel and by the natural convection of outside air ducted by air baffles over the vessel outer surface. This system serves the same function as conventional systems with pumps, heat exchangers, and cooling towers.

Advanced digital, microprocessor-based instrumentation and control (I&C) technology that Westinghouse has been developing since the late 1970s will provide many benefits to the AP600. Westinghouse digital I&C systems simplify and improve many aspects of plant operation, safety, and maintenance. They increase availability. They help to attain higher levels of productivity. They even help cut costs.

A digital, multiplexed control system takes the place of hardwired analog controls and cable-spreading rooms, accounting for a significant decrease in control cable (80 percent less control cable than current nuclear plants). I&C components feature built-in diagnostics and board level repair. Most faults can be repaired quickly by swapping a printed circuit card or instrument module. Other AP600 I&C features that enhance safety and reliability are: train separation, self-diagnostics, and equipment monitoring.

PROBABILISTIC RISK ASSESSMENT (PRA)

PRA is a powerful design tool and is one of the most significant technological advances in nuclear power today. Its great value lies in the capacity to dovetail plant safety and performance. Instead of sacrificing performance for safety, the use of PRA techniques in plant design allows a much better understanding of safety, while at the same time and from the same data, mechanisms to attain better capacity factors for the life of the plant.

Nuclear Electric's Sizewell B, a Westinghouse-designed plant now operating in England, is the first commercial LWR to use a complete PRA as a design tool. PRA has also been an integral part of the AP600 design process, being used to probe the design for features that could be improved from a risk standpoint.

Not only has PRA been an effective design tool, it also demonstrated that the AP600 design meets safety goals set by the U.S. Nuclear Regulatory Commission (NRC) and EPRI, with a core damage frequency of 3.4E-7 per year for at-power, internal events, using all AP600 systems. The AP600 is not overly dependent on operator actions, non-nuclear safety systems, or any one passive safety system. The passive safety systems in the design back up other passive safety systems, which are in turn backed up by active non-safety systems, creating an effective redundancy and diversity in plant protection.

AP600 TEST PROGRAM

Because an AP600 has not yet been built, the performance of these safety systems has to be assessed through detailed analysis using validated safety analysis computer codes. These computer codes predict the behavior of AP600's passive safety systems under a vast array of conditions. The AP600 design team had to develop a test program that would provide data to compare to these models, thus ensuring that the codes predict the way that the plant performs in transient situations.

When its comprehensive test program was completed at the end of 1994, the Westinghouse AP600 became the most thoroughly tested advanced reactor design ever reviewed by the U.S. Nuclear Regulatory Commission (NRC).

AP600 technology is supported by almost three years of rigorous testing, at a cost of $22 million USD to date. The test program is the single most visible portion of the AP600; it is a global effort, with the cooperation of the government, industry, and academic world. The results of the test program verified the performance of those tested components and systems unique to the plant whose operation is essential to the natural, passive safety concept upon which the AP600 is based. Of the tests, the two most critical involved testing of the passive containment cooling system and testing of the passive core cooling system.

Passive Containment Cooling System (PCS) Tests

The water distribution tests, which supported heat transfer testing, were used to establish water coverage on the vessel dome and walls, which ranged from full to partial coverage. When testing was completed, the results verified the design of the water delivery and distribution system on the containment dome.

The Westinghouse Science and Technology Center (STC) in the U.S., was prepared for the next phase of testing, which modelled and measured the effects of the internal heat transfer mechanisms, effects of non-condensables, and transient conditions similar to those that may be encountered in a severe accident scenario. Again, testing verified the computer codes.

The AP600 wind tunnel tests took place at both the University of Western Ontario's boundary layer wind tunnel, and the National Research Council of Canada's high speed wind tunnel. These tests were used to develop air baffle wind loads and have shown that the shield building air inlet\outlet configuration results in positive wind-induced cooling air flow. Results at high Reynold's numbers have confirmed test scaling. Testing was also performed on the effects of site terrain, with equally successful results.

Tests completed earlier at STC -- bench wind tunnel experiment, water film formation test, heated plate test, and the air flow path resistance test -- have all supported the results of the PCS tests mentioned above, verifying the AP600 containment integrity.

Passive Core Cooling System (PXS) Tests

Engineers constructed a complete one-quarter scale model of the AP600 at Oregon State University for the exhaustive scaled low-pressure test sequence. These tests investigated the behavior of the entire AP600 safety system performance with emphasis on the long-term cooling behavior. Experiments simulated the transition into long-term cooling with sump injection. Small breaks included cold leg/hot leg, cold leg balance line, direct vessel injection line, and pressurizer balance line. The combined integral systems tests demonstrated that the core was adequately cooled at all times during all loss-of-coolant accidents (LOCAs).

These tests were conducted using the SPES test loop at the SIET facilities in Piacenza, Italy. This series of 13 tests, covering a range of small-break LOCAs, complemented the low-pressure tests conducted in Oregon. Conducted at 1/395 power and volume scale, this series comprised the extensive integral systems testing of AP600. The SPES-2 facility consisted of a full-height, full-pressure simulation of the AP600 primary and passive core cooling systems.

A core makeup tank test facility was built at the Westinghouse Waltz Mill site. This series of tests investigate the thermal hydraulic behavior of the core makeup tank under a wide range of conditions including heat up, heat transfer, steam condensation, drain down, and mixing.

Testing of the in-containment refueling water storage tank (IRWST) and sparger was completed as part of the automatic depressurization system test conducted at the VAPORE facility in Casaccia, Italy. It demonstrated the sparger performance and resulting IRWST loads. This testing took place in two major phases, totaling 21 steam blowdowns and 24 steam and water blowdowns.

The AP600 test program also comprises extensive component design testing. All of the tests performed had one result in common the tests showed that the computer codes for AP600 are accurate and under all predictable circumstances the AP600 will react as its designers had planned.

DESIGN CERTIFICATION AND FIRST-OF-A-KIND ENGINEERING

The Design Certification Program related to AP600 is directed toward the goal of official certification by the U.S. Nuclear Regulatory Commission. This certification will replace the need for the Regulatory Commission. This certification will replace the need for the individual plant licensing process formerly required in the United States. Westinghouse has been submitting all required documentation, test results and reports to the U.S. regulatory authorities -- with the goal of attaining final design approval in 1997.

On June 26, 1992, as part of the AP600 design certification program, Westinghouse met the NRC's deadline for submittal of the AP600 Standard Safety Analysis Report (SSAR) and probabilistic risk assessment report. Westinghouse submitted the Inspections, Tests, Analysis, and Acceptance Criteria (ITAAC) in December 1992. The ITAAC is a new, formal part of the licensing process that enables the design to be certified prior to construction; it provides the means to ensure, during construction, that the plant technology is true to the criteria that have already been certified. It is the final chapter in standardization, and the last chance for an intervenor to halt plant operation.

The highly technical certification process will continue through much of 1996. When Westinghouse has resolved all the issues to the NRC's satisfaction, they will issue their final safety analysis report. This action will document the NRC's acceptance of AP600 safety, and at that point, the AP600 will be saleable in international markets.

ECONOMIC ADVANTAGES

Plant capital cost -- coupled with maintenance and operating expenses -- have been major concerns of utilities worldwide during the past two decades. The advanced, simplified technology of the AP600 reduces traditional PWR capital, operating, and maintenance costs by eliminating equipment that is expensive to purchase, operate, maintain, and which is subject to regulation. For a single 600 MWe unit, the AP600 can be built (in the U.S.) at a capital cost of $1500/kW (1993 U.S. dollars), 27 percent lower than a conventional 600 MWe unit, and $1365/kW (1993 U.S. dollars) for a twin unit, 9 percent lower than a single AP600 unit. Economies of scale prove that multiple AP600 units can be more economically constructed.

In addition to capital reductions, the AP600's low power density core, with an increased total weight of fuel loading, but lower enrichments, can achieve a fuel cycle cost saving of 14 percent. Similarly, the standardized, simplified passive design with the removal of redundant active safety systems and increased plant availability can lower operating costs by an estimated 30 percent, representing a savings of nearly 25 percent over the current industry average.

Westinghouse is also participating in the First-of-a-Kind Engineering Program (FOAKE), one of the building blocks of the U.S. ALWR Program. The goal of FOAKE is to complete engineering of the design in sufficient detail to define firm cost and schedule estimates in preparation for construction. Currently, Westinghouse is 70 percent complete with the FOAKE Program undertaken for AP600.

CONCLUSION

As the need for power increases and the consequences of burning fossil fuels and dependence on imported oil and gas become better understood, the world is realizing the necessity of reviving the nuclear power option. Simplicity, proven safety, and modular construction techniques make the AP600 the leading technology for small and medium electricity grids.

In a future where the demand for electricity will increase as countries accelerate their economic progress, the AP600 advanced, simplified plant, with its proven technology, extensive testing, and government and utility support, is the best option with global applications for achieving safe, cost-competitive, reliable, and environmentally sound power generation.

Westinghouse plans to be ready to support worldwide needs for environmentally sound growth in electric power generation with more clean, safe, economical nuclear power plants.