World Nuclear Association Annual Symposium
4-6 September 2002 - London

Future Commercial Nuclear Power Expansion in the US

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Introduction

For the past 20 years, the commercial nuclear electrical generation market has been void of significant and sustained orders for new plants. In countries such as Japan and Korea, new units have been continuously added to the electrical grid, but these additions have only been adequate to sustain their own country's nuclear infrastructure. Elsewhere around the world, suppliers of new nuclear plants have had to make dramatic shifts in the product portfolio to focus on fuel and service activities.

The global slowdown of interest in new nuclear plants may be over; vital signs within the electrical industry point to a rekindling of utility interest in nuclear power. The reasons are significant, and include the following.

- Nuclear economics of advanced passive plants are now competitive with the lowest cost energy sources, such as natural gas and combined cycle.
- Step improvements in nuclear plant safety are also providing significantly reduced economic risks associated with nuclear plant ownership and operation.
- Environmental benefits derived from nuclear power's elimination of greenhouse gas emissions are yielding high levels of public acceptance.

All three of the nuclear benefits mentioned above are embodied in the Westinghouse AP1000 plant design, currently under review by the US Nuclear Regulatory Commission (NRC) for ultimate Design Certification.

Incorporation of advanced passive systems – A necessary step to economic parity with natural gas plants

Alternative design approaches have been examined to determine the most effective way to reduce plant capital cost. Starting with an evolutionary plant and attempting to simplify the design yielded inadequate capital cost reductions to compete with the low cost leader - natural gas. Therefore, a rethinking of the designs was required to yield a plant that would take advantage of the steadily improving performance of current generation plants and, at the same time, significantly reduce the capital costs of the plant. The solutions designed into both the AP600 and AP1000 integrated two basic design approaches:

- Maintain and improve the reliability of plant normal control systems, but do not require these systems to have any direct responsibility for meeting safety criteria. Separate the plant safety functions from the control systems to eliminate costly and complex safety requirements, such as testing and separation, from consideration in the design of the control systems.
- Require that all safety functions be passive, thereby significantly simplifying safety systems and eliminating or reducing safety grade pumps, power supplies, and associated piping, valves, etc.

Figure 1 shows the safety systems incorporated into the AP1000 and AP600. Note that all the systems use only natural circulation, gravity feed, and gas pressure as driving forces for the safety system, thereby significantly simplifying the design and achieving large cost reductions. The same design philosophy was extended into the containment by using similar passive water sources and atmospheric cooling. The safety systems have been designed to perform without requiring operator action for design basis accidents.

Passive systems enhance safety

A logical question associated with the advanced passive plants deals with their safety relative to current generation operating and evolutionary designs. One measure was provided by the US Nuclear Regulatory Commission (NRC) when it approved the AP600. The NRC is currently reviewing the AP1000. Another more quantitative measure of plant safety is the evaluation of core damage frequency. *Figure 2* shows the core damage risk assessment compared to other plant designs. Note that the risk profile is between 10 to 100 times less than current generation plants.

Note also that to adequately perform a credible risk assessment, plant design and plant components involved in the plant safety assessments need to be *engineered* to a level that suppliers can meet. In addition, equipment must be capable of being priced to meet design specifications. Both the AP600 and AP1000 satisfy these design completion requirements. Also, both test and design calculations indicate that accidents beyond the design basis will not cause a failure of the advanced passive plants' reactor vessels, and, therefore, the core will not end up on the containment floor.

Detailed cost estimates validate AP1000 competitiveness

Numerous next generation plant designs have been showcased, each having achieved varying degrees of design completeness. Optimistic claims concerning the capital costs are also presented with each new design. However, there are several key elements needed to gain confidence in the cost evaluations:

- detailed plant cost data that include owner and site costs;
- design detail sufficient to accurately determine bulk material quantities;
- the availability of valid quotes for components, commodities, construction labour, etc.;
- the completion of a detailed and independently validated plant construction schedule developed with constructor inputs;

- a rational basis for establishing contingencies based on inputs from experts and included in final plant capital costs.

The AP1000 design derives a significant amount of its cost data from the cost report developed by Westinghouse on the AP600 for the Advanced Reactor Corporation (ARC) in 1997. Since approximately 80 percent of the AP1000 plant design remains the same as the AP600, most of the AP600 cost data is directly applicable.

The AP600 cost study was built upon over 1900 vendor quotes on over 25 000 components, bulk materials, commodities, labour rates, etc., and upon an extensive review of the cost data including uncertainties by independent experts in all major plant cost areas. The most significant categories within which plant costs were collected are presented in *Table 1*. In addition, Monte Carlo analyses of the uncertainties potentially having a major impact on plant costs were performed to determine appropriate contingency additions to the base costs necessary to reach a confidence level in the overnight capital cost.

Table 1 – Expected capital costs for twin-unit AP1000 plants

Cost Category	**Capital Cost per Kilowatt (US$ 2001)**
Equipment, Commodities, Materials, Installation, and Engineering	940
Site and Owner's Costs	180
Total Overnight Capital Cost in $ per Kilowatt	1120 to 1280

Adjustments were made to the AP600 costs to account for design changes made to the AP1000 plant. These changes were determined using supplier quotes. The major equipment and design changes are steam generator heat transfer area, reactor coolant pump flow, the turbine, and an increase in the height dimension of the containment. However, no changes to the AP600 nuclear island footprint were required, thus significantly increasing the amount of AP600 design that is directly applicable to the AP1000. Finally, additional first-time engineering costs were added to the plant price so that all cost elements were included in the final price.

The results include all plant owner and site costs, and the staffs for indirect functions such as payroll, customer project management, human resources, taxes, permits, licences, etc. The data included for site and owner's costs were provided by US power companies.

To ensure that costs for the labour associated with civil and erection work are accurately represented, detailed knowledge of the plant design is needed to determine the quantities of bulk materials, components and commodities to be installed. To this end, the level of design detail for the AP1000 is more than adequate to generate these quantities. Labour rates were determined by trade and by installation commodity assuming a typical US construction site. Also, to ensure that capital costs are being treated correctly, a construction schedule must be defined and validated. The schedule must include all major tasks so that labour staffing levels and project completion timing can be determined. The final plant cost to the power company varies, based on risk distribution amongst the participating companies. An expected range of capital costs (provided in Table 1) accounts for this variability and can be factored into the cost analysis.

Table 1 provides the AP1000 plant capital costs to the power companies, assuming a series of units. Note that the first-plant cost would be higher than others in the series due to the impact of first-time engineering not required by later units. The average cost assumes each of the plants shares the first time burden, thereby reducing the capital cost paid by the first-plant purchaser. Additional capital cost reductions are also included, starting with the second unit of the first plant. This effect is due to the learning curve impact that would be seen as suppliers and constructors become familiar with the plant design requirements.

Independent validation of the AP1000 capital costs

Numerous independent evaluations were performed on the costs database for the advanced passive designs. Accuracy and robustness were considered in these reviews. Included below are the highlights from these reviews and some of the areas analyzed, as well as comments concerning the design and cost basis. The most recent comments were provided by Bechtel, and deal with additional areas to be considered in the power company capital costs.

Table 2 identifies the participants in the independent cost and plant schedule reviews for the advanced passive designs.

Table 2 – Westinghouse advanced passive plant cost and construction schedule reviews

Reviewer	Area of Review Focus
Electric Power Research Institute	Cost Analysis, Robustness, and Accuracy
Obayashi Corporation	Construction Costs, Construction Schedule
Obayashi Corporation	Module Construction
Morrison Knudsen	Plant Construction Schedule
Bechtel Corporation	Plant Costs, Construction Schedule

Additionally, Westinghouse developed an advanced passive plant proposal for Hungary and again solicited supplier quotes for implementation. The new quotes were compared to those gathered as part of the cost study, and confirmed the accuracy of the original plant cost estimate.

The conclusions to be drawn from the above studies are: (1) the Westinghouse advanced passive plants have a documented and verifiable cost basis; and (2) the 36-month construction schedule developed by Westinghouse can be used in the planning for new baseload electrical generation.

Using the plant cost analyses for an AP1000 discussed above, the capital cost contribution to electrical generation can be determined. Assumptions used in the transformation of the capital cost data to generation cost are critical in that they must be consistent with those used by power companies considering the nuclear option. *Table 3* provides a list of economic assumptions used in this paper for this calculation of generation costs.

The fuel and operations and maintenance data in Table 3 are representative of the performance of the top quartile Westinghouse plants today. With the continuing improvement in the performance and cost competitiveness of most operating units, the performance parameters should be typical within a few years.

Table 3 – Generation cost input parameters (constant US$)

Evaluation Parameter	Value or Assumption
Number of Units	2
Unit Capacity, MWe	1117
Fuel Cycle Length, Months	18
Capacity Factor, %	93
Operations, Maintenance, Costs $/MW-hr	5
Fuel Cost, $/MW-hr	5
Plant Economic Lifetime, Years	20
Plant Design Lifetime, Years	60

Figure 3 takes the data presented in Table 3 and provides a range of after-tax internal rates of return (IRR) for those parameters and a variable capital cost assumption. Note that after-tax IRRs are in the range of acceptability to US power companies, for busbar costs of approximately $35 to $45 per megawatt hours (in constant US$). Therefore, the Westinghouse AP1000 will be competitive with natural gas and combined cycle plants even with favourable future natural gas cost assumptions.

Table 4 provides the generation costs for various advanced passive designs and competitive alternatives to nuclear power. Obviously, in today's environment with highly volatile natural gas prices, the relative competitiveness of various fuel sources depends on long-term fuel cost assumptions. However, for essentially any assumption concerning natural gas prices, the AP1000 plant will be competitive. Furthermore, for even small increases in natural gas prices, the AP600 will also be competitive without any credits provided to nuclear power as an emission-free technology.

Table 4 – Electric power generation costs – cents per kilowatt-hour (US$ 2001)

Plant	Fuel Type	Fuel Cost	Generation Cost
AP600	Nuclear	0.5 c/kW-hr	4.7 cents/kW-hr
AP1000	Nuclear	0.5 c/kW-hr	3.5 cents/kW-hr
Combine Cycle	Natural gas	$3.50/MMBTU	3.5 cents/kW-hr
Combine Cycle	Natural gas	$4.50/MMBTU	4.14 cents/kW-hr
Scrubbed Coal	Coal	$1.4/MMBTU	4.08 cents/kW-hr

The re-emergence of nuclear in the United States

Over the course of the last several years, the US environment for the construction of new nuclear plants has moved in a positive direction. This is not to say that new plants will begin construction in the near term, but positive signals have been forthcoming from many quarters. Several key positive factors have resulted from actions taken by the US government. The energy policy direction coming from the executive branch clearly identifies nuclear power as a major contributor to future electrical generation, an endorsement that was sorely lacking from previous administrations. Additionally, the congressional approval for the Yucca Mountain Project has provided both breadth and depth to the federal government support for nuclear power. These votes of confidence did not come easily or quickly, but an analysis of the rationale behind this turnaround pinpoints several factors as the main driving forces:

- a recognition that the global warming problem is not going to disappear;
- the wild cycling of natural gas prices suggesting the energy price stability cannot be counted upon without a broad selection of energy producing options;
- a recognition of the potential problems caused by the increasing US reliance on imported oil.

Besides the Yucca Mountain decision, the US government has strongly signalled that it would be willing to support promising new nuclear plant designs and to overcome the hurdles of completing first-of-a-kind design issues such as licensing, first plant engineering costs, etc. The key to unlocking the potential government support will be strong and broad-based industry involvement in completing a new nuclear plant for operation in year 2010. The Nuclear Initiative 2010, which is supported by Department of Energy (DOE) funding, addresses these issues.

Meeting this DOE objective will not be easy, however. Not only does it require the availability of Design Certifications and Early Site Permits, but it also requires combining these two regulatory approvals into a Combined Operating Licence and plant construction/startup within the next 8 years - a sizable task.

Three Design Certifications already exist, and one, the AP1000, has been accepted for review by the NRC. Also, three Early Site Permit applicants (Dominion, Entergy, and Exelon) have begun the process of gaining regulatory approval for the respective sites. Thus, several of the necessary pieces are in place to move forward with the next phase of nuclear power in the US.

The expected number of new plants to be completed over the next 10 to 20 years is speculative at this point, but several projections have been offered by US energy experts. The Nuclear Energy Institute (NEI) has identified the need for 50 GW of new plant power coming from additional nuclear units. Furthermore, to maintain the current percentage of power being generated by nuclear power, 10 GW of new nuclear power will need to come from the uprating and improved performance of existing nuclear plants.

Although optimistic, the NEI projection identifies the extent of new reactor construction that must begin quickly just to maintain the nuclear percentage of the current fleet, if the relatively conservative projections for future power needs used by the Institute are considered appropriate. If global warming data continue to identify the need to curb greenhouse gases, the NEI estimate for new nuclear plants may be substantially too low.

A second indication from the US is less specific, but centres around the Nuclear Power 2010 Initiative identifying new nuclear plants beginning to operate within eight years. This schedule also suggests rapid deployment of new nuclear plants, consistent with the NEI projections.

Conclusion

Significant progress has been made in reducing capital costs through simplification of advanced nuclear plant designs such as the Westinghouse AP600 and AP1000. Key reductions have been in the areas of components, commodities, and bulk materials, which improve the plant construction schedule by using a parallel and independent path approach for site work and module manufacture. An important element of optimizing these concurrent activities is the completion of a detailed plant schedule that pre-plans the completion requirements for installation into the site construction activities. This detailed schedule has also been developed and independently validated for the AP600 and AP1000. The results have led to a construction time window of 36 months from first concrete to fuel load.

The generation costs calculated for the AP1000 demonstrate that it will be competitive with any baseload fuel source for new electrical generation, even using very conservative estimates of future fossil fuel prices. Assuming that busbar electricity prices of US$35 per megawatt hour must be met for a deregulated power company to be competitive, competitive after-tax IRRs are demonstrable for the Westinghouse AP1000.

Clearly, there has been progress on all fronts towards starting a new nuclear plant programme in the US. The timing of the AP1000 Design Certification review by the NRC fits well in a schedule for plant construction beginning in the year 2005 or 2006. Initiating construction within this timeframe would put the DOE's goal for plant startup, expressed in the Nuclear Power 2010 Initiative, within reach. However, a quick initiation of a Combined Operating Licence process is also necessary. Although it is difficult to project the exact time when construction will begin, the pieces needed to proceed are beginning to come together, and plant construction could conceivably meet the DOE’s aggressive goal.

Figure 1. AP1000 and AP600 passive core cooling system

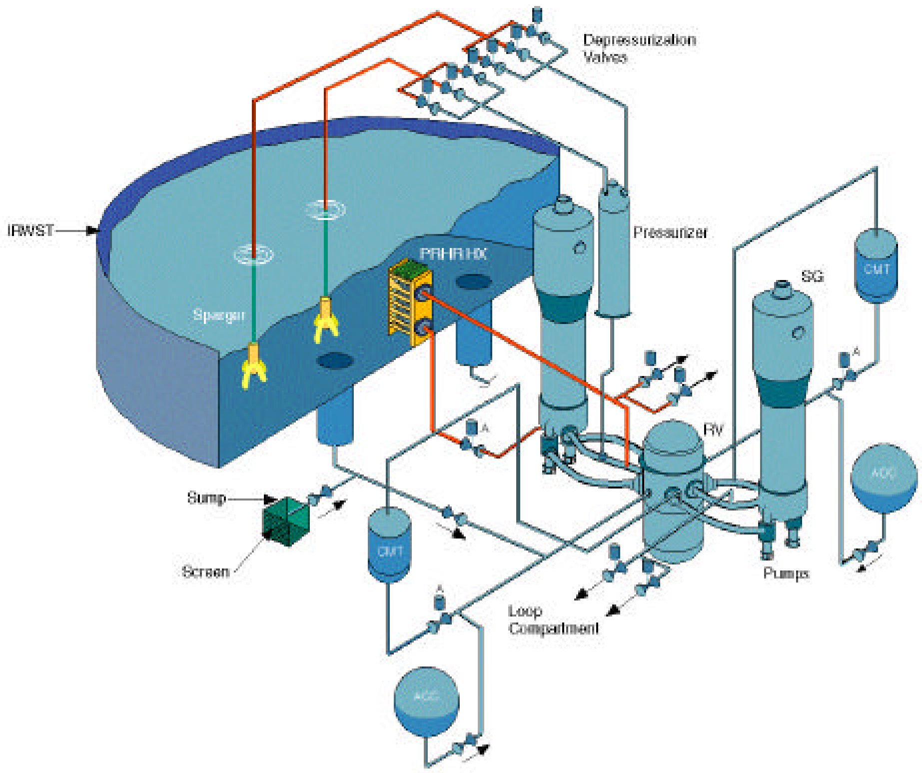

Figure 2. AP1000 provides safety and investment protection

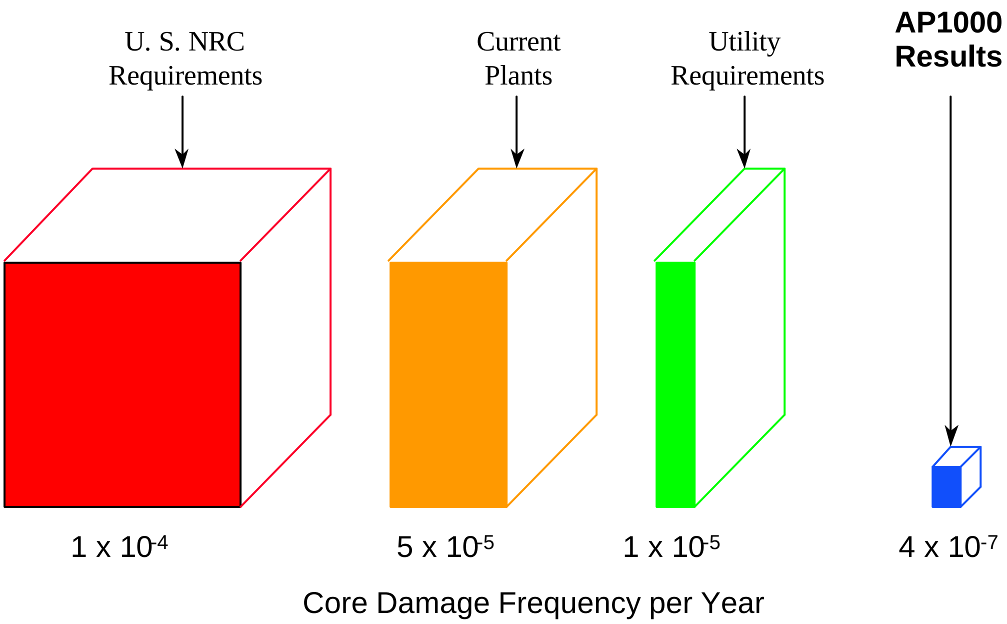

Figure 3. AP1000 business plan model impact of analysis length on equity IRR