BALANCE OF PLANT IMPROVEMENTS FOR FUTURE REACTOR PROJECTS

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ABSTRACT

Many studies have shown that improvements in portions of the plant other than the reactor systems can yield large cost savings during the design, construction, and operation of future reactor power plants. This portion is defined as the Balance of Plant which includes virtually everything except the equipment furnished by the Nuclear Steam Supply System manufacturer. It normally includes the erection of the entire plant including the NSSS. Cost of BOP equipment, engineering and construction work is therefore most of the cost of the plant. Improvements in the BOP have been identified that will substantially reduce nuclear plant cost and construction time while at the same time increasing availability and operability and improving safety. Improvements achieved through standardization, simplification, three-dimensional (3D) computer-aided design, modular construction, innovative construction techniques, and applications for Artificial Intelligence Systems are described.

INTRODUCTION

The scope of Balance of Plant (BOP) work in a nuclear power plant project is not just the turbine plant and the support systems such as auxiliary cooling water. It also includes the structure, foundations, access routes and all services inside the containment as well. It normally extends to procurement of equipment and material, project construction (including NSSS installation), and startup support activities. At its broadest, the BOP scope can include 80% of the total plant capital cost. Therefore, improvements in the BOP can have a very large impact on cost as well as operability, reliability and maintainability of the plant. Recently, much attention has been placed on finding ways to make improvements both in BOP designs and in the process of designing and constructing the plant. Substantial improvements have already been identified and are planned for future plants which include not only light water reactors, but several different liquid metal-cooled reactor designs. Most of these improvements have proven successful in pilot operations or in other applications, so what is described in the following sections is clearly achievable.

This paper discusses improvements in the chronological order in which they are applied in a project, starting with the initial design concept. Plant standardization is followed by design improvements, which include simplification and a number of reliability improvements and constructability improvements. Next come enhancements employing three-dimensional (3D) Computer-Aided Design computer software; next improved construction techniques such as modular construction and rolling construction scheduling, and finally applications of Artificial Intelligence to improve maintenance and operation. Major impacts of these improvements will be reduced cost and increased availability.

STANDARDIZATION

Early in the 1970's, the idea and benefits of standardized designs began to be widely accepted. The Nuclear Regulatory Commission (NRC) issued a policy statement promoting standardization. NSSS vendors began to market and license standard plants (GESSAR, RESSAR, CESSAR, etc.). Architect-Engineers also began to standardize the BOP by offering standardized balance of plant packages. This led to such projects as the SNUPPS (Standardized Nuclear Unit Power Plant System) for which Bechtel was the Architect-Engineer. Originally planned as five identical units, it was finally finished as two units. Savings and benefits were apparent in unit cost, scheduling, and plant availability.[1] Figure 1 is a reproduction from Reference 1 which quantifies the savings.

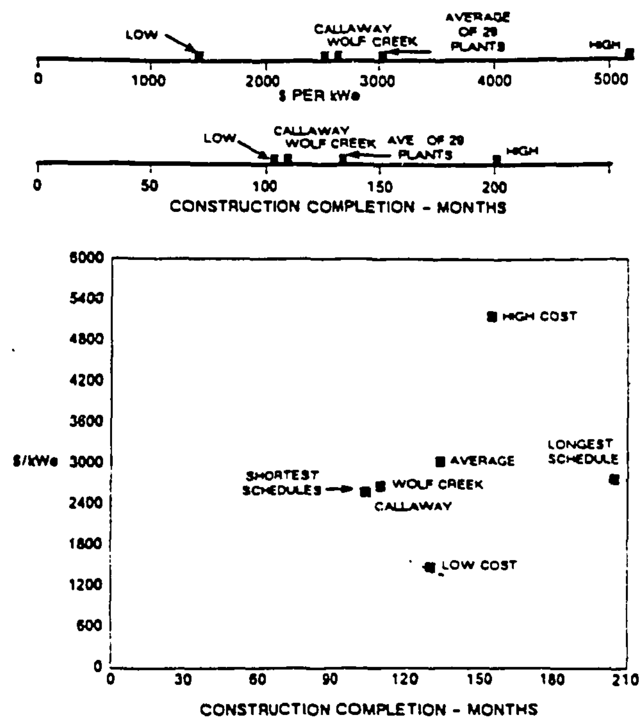

Fig. 1. Callaway and Wolf Creek Were Below Average Cost and Length of Schedule.

Standardization can save on schedule delays caused by pre-construction licensing hearings as well as economy of procurement of components. Standardizing also will work great savings in engineering costs and minimize the industry propensity for reinventing the wheel at each power plant.

DESIGN IMPROVEMENTS

The BOP itself can be designed to simplify operation and to partially isolate the NSSS from the effect of upsets in such systems as the condensate system while at the same time improving water chemistry.

Improvements in turbine island design are specific to thermal power plants and particularly beneficial to LWRs, and the improvements in the arrangements and structure of the nuclear portion of the plant are of course peculiar to the LWR itself. Some of the other LWR BOP improvements are the result of technology developments that benefit other types of power plants and large, capital-intensive industrial projects.

A. Simplification

The design of existing plants has been complicated by systems and features added to accommodate safety concerns identified after their basic design was fixed. These concerns were in part the result of original design margins which necessitated rapid response of engineered safeguard systems and other back-ups to ensure timely response to malfunctions. Future NSSS systems are expected to include larger design margins so that response of engineered safeguard systems and of the BOP systems need not be so fast. Some engineered safety systems may be eliminated entirely. The increased design margins in the NSSS will permit substantial simplifications in the BOP.

As an example, in a PWR a deaerating feedwater heater permits elimination of the heater drain pump while at the same time providing a tank containing a 5-minute storage of water so that trip of a condensate pump does not lead to an immediate reactor runback. Prop , designed, the deaerator storage tank provides time for hydrazine to scavenge oxygen and thereby protect the steam generators from oxygen-induced corrosion.

A technical evaluation of the feedwater and condensate systems of a PWR aimed at incorporating the lessons learned in operating plants as well as obtaining simplification led to the following major improvements in addition to incorporation of a deaerator[2]:

- o Recirculation lines to permit system cleanup prior to admitting feedwater to the steam generators
- o Eliminating of the heater drain pumps (made possible by adding the deaerator)
- o A titanium-tubed condenser with welded tube-to-tubesheet joints or grooved or double tube sheets to reduce the risk of circulating water ingress.
- o Replacing a complicated deep-bed condensate polisher with a simple precoat filter, a change made possible in a plant with fresh circulating water by the more reliable condenser
- o Eliminating the use of copper in feedwater heater and reheater tubes to protect the steam generators, where corrosion is catalyzed by copper oxide (permitting an increase in the feedwater pH to reduce erosion/corrosion of carbon steel in steam lines, extraction lines, drains, condensate and feedwater lines)
- o Frequency-controlled variable speed electric drive feedwater and condensate pumps, eliminating the auxiliary turbine steam system and permitting continuous operation at reduced speed of the three half-capacity condensate pumps so that trip of one pump will not lead to loss of condensate flow
- o Reduction of the number of trips originating in the feedwater and condensate system, a change made possible by the addition of

the deaerator whose storage tank provides a 5-minute reservoir of water to feed the steam generators during short condensate pump upsets.

The results of this system study showed that a substantial reduction in complexity was possible. The system required fewer valves, had increased availability and reduced maintenance. Cost reduction below that of a typical PWR designed in accordance with earlier practice was estimated at between 12 and 20 million 1984 dollars.

B. Protection for PWR Steam Generators

PWR steam generators have suffered severely from corrosion failures. The new generation of steam generators, some of which are already in service as retrofits, are much more resistant to corrosion than those in most operating PWR plants. In addition, several of the BOP changes listed above together with improved deaeration of make-up feedwater and better air in-leakage control are intended to eliminate the contaminants that cause the corrosion.

C. Improved Reliability of BWR Piping

Stainless steel BWR recirculation piping has suffered severely from stress corrosion cracking. This has led to much lost time in retrofits, very tight water chemistry specifications and even the addition of hydrogen to reduce the oxygen levels that cause the damage. Improved piping material not subject to stress corrosion cracking is now available, so the complications of hydrogen water chemistry can be avoided.

D. Reduction in Trips

An important way to improve safety is to eliminate unnecessary plant trips, which commonly lead to challenges of the engineered safeguard systems. Plant trips, in turn, are often caused by transients in the feedwater and condensate system, or trip of a heater drain pump. Incorporating a deaerator in the PWR system eliminates many possible transients and so reduces trips.

In addition, a systematic review of trip functions in two designs (one of them an operating plant) disclosed many trips that could either be eliminated entirely or made much less likely by moving their settings farther away from normal operating values. This discloses the great value to operability of increasing margins.

E. Improved Turbine Island Design

Currently operating low pressure turbines in nuclear plants have frequently suffered cracking of the low pressure rotor disks at the keyways where they are connected to the shift. The cracking has been attributed to oxygen-induced stress corrosion. Since oxygen cannot be eliminated from BWR steam and is difficult to avoid in the low pressure turbines even in PWRs, the most obvious solution is to eliminate the keyway. Low-pressure turbine rotors that do so by making the disk integral with the shaft are becoming available.

Current 1300 MW units conventionally have three low pressure turbines arranged in tandem. A new design that substitutes two larger diameter turbines will reduce the volume of the turbine building and accordingly its cost. It will also permit easy reduction from three strings of low pressure feedwater heaters in the condenser neck to two, and thereby eliminate numerous valves as well as the string of feedwater heaters. This development requires longer last-stage turbine blades, and therefore (other things being equal) imposes higher centrifugal forces on the blades. The larger diameter turbine has already been developed and built for application in a 50 hertz system, where the centrifugal forces are only 70% of those in a 60 hertz system, and manufacturers have expressed willingness to build it for the more difficult 60 hertz application.

Main turbine-generator pedestal design based on the use of fabricated steel plate reinforced concrete provide for optimum use of structural steel while avoiding the need for removable concrete forms in difficult areas. These so called "sandwich steel" construction pedestals are of great interest. They have a lower initial cost and much shorter construction schedule than the existing all-concrete pedestal. They do not benefit the overall plant schedule as the pedestal is not on the critical path but they greatly facilitate work management in the turbine building, thereby reducing cost.

Because this pedestal design can be built of large shop fabricated preassemblies they reduce the amount of field labor required and reduce the skills needed by that labor. Since the design is simpler, it is also less prone to construction deficiencies and is more readily built to higher quality standards.

Constructability and reliability of current plants have been adversely affected by pipe snubbers, which take up much space and have often blocked access routes. Bechtel has recently developed and is incorporating a unique plant component designed to reduce the problems that arise with snubbers. Figure 2 is a schematic of the Bechtel Energy Absorber.

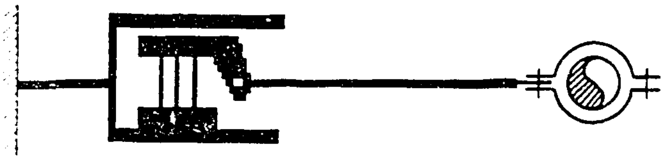

Fig. 2. Bechtel Energy Absorber*
*U.S.A. and Foreign Patents Pending.

Bechtel's Energy Absorber is a system of energy absorbing flexible plates made of low-stiffness ductile steel in an X-shape. One end attaches to the piping system; the other attaches to the building. Having no internal moving parts or hydraulic fluids, the absorber requires little maintenance and no complicated periodic testing. The plates flex as elastic springs to allow movement during thermal expansion of the piping system. In an earthquake, more dynamic energy is absorbed by controlled yielding. Figures 3 and 4 show the deformation and force-displacement behavior for the Energy Absorber.

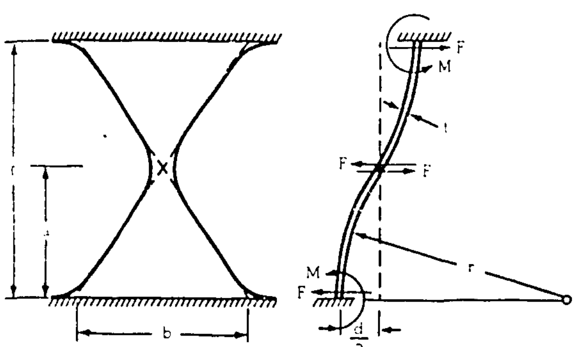

Fig. 3. Deformation Model for X-Type Energy Absorber

For new plants, the use of Energy Absorbers significantly reduces the number of pipe supports, thus reducing capital and construction costs. Research shows that nearly all snubbers, with their costly in-service inspection and maintenance requirements, can be replaced by the more reliable and economical Energy Absorbers. In addition, the Energy Absorber's simple yet effective design decreases the maximum load at a dynamic restraint by 40 to 50 percent and the total load transmitted to a structure by 25 percent, for a given dynamic event. Figure 5 compares the reductions for both an NSSS and a BOP system.

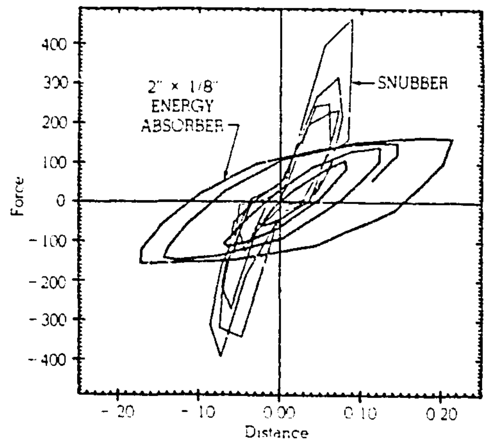

Fig. 4. Force-Displacement Behavior Snubber vs Energy Absorber.

THREE-DIMENSIONAL COMPUTER-AIDED DESIGN

Application of three-dimensional (3D) software for computer-aided design (CAD) began about four years ago. This is a successor to the highly successful plastic scale models used in design of a number of existing nuclear plants. It can provide all of the capability to avoid interferences and safeguard access routes and equipment removal space that was provided by the model. It allows a great deal of flexibility in trying alternate arrangements and seeing their consequences. In addition to improving physical arrangements, it can be used to generate data sheets for equipment, instrument indexes and material take-offs. These items can be produced in less time and with greater accuracy than in current LWR projects.

Three-dimensional CAD can also be used much more effectively than a model in the production process because, unlike a model, it can simultaneously be used at the construction site for construction planning and problem resolution, and in the engineering office for engineering work. This should make it much easier to adjust details of designs to make them more producible than with the current system of drawings. Three-dimensional CAD should also speed up resolution of problems found at the site through more effective communication and rapid reaction by changing the 3D model simultaneously at both locations.

	Plant 1, RHR Head Spray System*		Plant 2 Main Steam System	
	W/Snubber	W/Energy Absorber	W/Snubber	W/Energy Absorber
Fundamental Frequency (Hz)	23	4	7.9	4
Total Snubbers	15	0	42	3
Total Energy Absorbers	0	12	0	26
Maximum Dynamic Support Load, Inertia (Kips)	9	5.7	188	91
Total Dynamic Load on the Building, Inertia (Kips)	57	43	2340	1762
Seismic Anchor Movement Loads on Snubbers/Energy Absorbers	Additive	Not Additive	Additive	Not Additive

* This is a hot system with a large thermal anchor movement connected to the reactor head, which experiences very high seismic acceleration.

Fig. 5. Reduction of Snubbers by Using Energy Absorbers.

One 3D CAD program even allows a user to simulate a walk-through of a plant. This can be used in a variety of ways to improve BOP design and construction. For example, the program would allow a construction superintendent to walk down a system and check the location of welds for accessibility.

IMPROVED CONSTRUCTION METHODS

Shortening the construction schedule as well as alleviating the congestion that arises from putting thousands of workmen on a site will yield cost savings resulting from a shorter schedule as well as enhanced efficiency and quality of product. A number of techniques have been developed to promote this, including modular construction and level manning 7 days a week.

A. Modular Construction

There is a clear trend toward using factory-fabricated modules, which are transported to the construction site and erected. Equipment modules on the order of 2500 tons are becoming common and 4000 tons may be the current upper limit. While constraints such as lifting equipment capability and proximity to water transport exist, two Bechtel jobs (North Slope of Alaska and the New Zealand gas-to-gasoline project) showed lower labor costs in the factory environment and a saving in schedule because more assembly work could be done in parallel with on-site activity. Factory fabrication also has greater potential for automation. The overall cost, even if transportation costs are high, should be reduced because of a shortened construction schedule alone.

Two recent reactor construction studies support this appraisal. Modular construction on the liquid metal reactor BOP design was estimated at a lower cost than that of current LWRs constructed in the conventional manner.[3] In a study of the Power Reactor Inherently Safe Module (PRISM) construction, BOP modules were designed which consisted of structures and equipment, piping, electric wiring, and related components.[4] Each of the modules was designed to have a high density of equipment, including area lighting and ventilation. Interfaces with adjacent modules were designed for ready connection in the field. The results of this study indicated such modules were feasible and would result in a cost savings over conventionally constructed LWRs.

B. Continuous Construction Work

Because of the high cost of capital, the completion of the plant in the shortest possible time is the most important single factor in holding its cost down. If the work can continue uninterrupted seven days a week without tiring the work crews, this has an obvious payoff. It has been found possible to do this by careful planning of material and support services, good lighting of the jobsite and protecting key areas from the weather, and having work crews operate on what is called the "rolling 4 tens" schedule. The men work 4 days for 10 hours each day, and then take 4 days off while another crew works 4 days. Using 2 shifts per day, the jobsite is fully manned 20 hours per day the week around. This type of effort has been found to reduce elapsed construction time by 25% from that required with conventional manpower scheduling, and in addition leads to high morale and good productivity.

ARTIFICIAL INTELLIGENCE IN MAINTENANCE

A new field of computer application is developing in what is called Artificial Intelligence (AI). Computers, often small stand-alone types, are used to query the plant equipment and analyze the data. Then the AI portion of the system applies logical rules to signal trends, provide warnings, and suggest probable causes of trouble. This tool will work hand in hand with the operator to identify problems and schedule maintenance or repair at a convenient time. A schematic for a system for the Hydrogen Generator portion of the BOP was contained in Reference 5 and is shown in Figure 6.

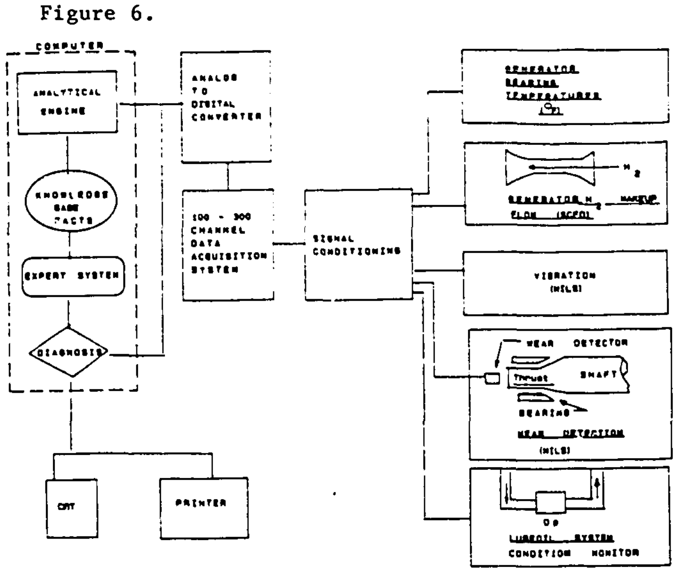

Fig. 6. AI System Designed and Programmed to Monitor and Evaluate Rate of System/Equipment Deterioration and Make Recommendations.

Bechtel has developed a system called SCOPE (System Component Performance Evaluation) which it is proposing for both nuclear and fossil-fired power plants[5]. The system, once modeled for a plant, will operate continuously and unattended, repeatedly analyzing the plant's performance. The system can also be used to train new operators as to how the plant will react to any variation in performance.

Future reactors should utilize this new and impressive tool to increase availability of plants.

SUMMARY

Regardless of the type of reactors used to fuel future generations of nuclear power plants, the BOP will play an important role both in the initial capital cost and in the availability of the power plant to produce electricity and thus generate dollars for its owners.

An early appreciation of this importance is crucial from the initial concept employing standardization, a simplified design, and computer aided design; through to the construction phase; and finally during the operating life of the plant with Artificial Intelligence systems.

We expect to see the fruits of these improvements in the next generation of reactors.

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