IMPROVEMENTS IN NUCLEAR PLANT STAFFING RESULTING FROM THE AP600 DESIGN PROGRAMME

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Abstract

The staffing for a single-unit, AP600 is estimated to require a staff for operation and maintenance about 32% smaller than current generation power plants of similar size. These staffing reductions are driven primarily by various features incorporated into the AP600 plant design.

1. INTRODUCTION

The Westinghouse AP600 reactor has been designed as part of the advanced light water reactor (ALWR) programme sponsored by the U.S. DOE, EPRI and U.S. and international utilities. Following an extensive design review, the AP600 received final design approval on September 3, 1998 from the U.S. NRC. A detailed design programme (FOAKE-First of a kind engineering) has been completed under the sponsorship of DOE, the Advanced Reactor Corporation (ARC), and EPRI.

Electric Power Research Institute (EPRI) has, with a broad participation of numerous countries, developed a utility requirements document (URD) for ALWRs, taking into account the wealth of information related to nuclear power plant safety and operations that has been generated worldwide with commercial nuclear power. The purpose of the URD is to delineate 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.

Incorporation of the URD has been a design goal for the AP600 from the design inception, and has continued to be so during the FOAKE programme. The AP600 has a well-defined design basis that is confirmed through proven systems and equipment, engineering analyses and testing and is in conformance with the URD.

The AP600 FOAKE programme has had extensive utility involvement in the detailed design process. It included participation of 16 utilities in the U.S. Experts from these utilities were located on-site at Westinghouse (20 man–a) in the ARC project office and provided oversight for the detailed engineering. Approximately 20 formal utility steering group meetings and bi-monthly ARC utility sponsor group meetings were held to review detailed aspects for the design. In addition, monthly project meetings were held, and in-depth task teams were created for significant or key issues including maintainability guidelines and allocation, refuelling outage plan, valve standardization guidelines, maintenance isolation valve design criteria, and constructability plan. A detailed review of the AP50 in-service testing (IST) plan was conducted by the utilities, and detailed procedures and scenarios were analysed to verify that the proposed IST could be conducted with the plant as designed.

Another area of significant utility involvement was in the area of plant layout focusing on such features as containment access, laydown space, special platforms for improved maintenance inside containment, other repair and maintenance provisions using cranes and lifting devices, and use of standard service modules throughout the plant. With the use of the AP600 3D model, utility personnel have been able to perform simulated walkdowns of the plant to improve potential maintenance problems.

As part of the FOAKE programme, the utilities provided detailed review, comment and approval of AP600 deliverables including:

- system specification documents;
- piping and instrumentation diagrams;
- general arrangement drawings;
- plant 3D model;
- pipe routing drawings;
- control logic diagrams;
- one-line diagrams;
- concrete outline/structural steel drawings.

2. AP600 DESIGN FEATURES

Simplification

The AP600 uses passive safety systems to enhance the safety of the plant and to satisfy NRC safety criteria. These passive safety systems result in increased safety and also significantly simplify pant systems, equipment, and operation. The systems use only natural forces, such as gravity, natural circulation, and compressed gas. No pumps, fans, diesels, chillers, or other rotating machinery are used for supporting safe shutdown of the plant. A few simple valves are used to align the passive safety systems when they are automatically actuated. The passive safety systems are significantly simpler than typical PWR safety systems. Simplified safety systems reduce surveillance requirements by enabling significantly simplified technical specifications.

In addition to being simpler, the passive safety systems do not require the large network of safety support systems needed in typical nuclear plants, such as AC power, HVAC, and cooling water systems and seismic buildings to house their network of support systems (e.g. air start, fuel storage tanks and transfer pumps, and the air intake/exhausted system). As a result, the fuel storage tanks and transferpumps, and the air intake/exhaust system). As a result, the support systems no longer need to be safety grade and can be simplified or eliminated. Elimination of technical specifications from those systems remaining simplifies maintenance.

The simplifications in the AP600 dramatically reduce the amount of equipment to be maintained and inspected while improving plant operability. These equipment reductions, as indicated in Table 1, result in direct reductions in required inspection and maintenance activities.

Table 1. AP600 Equipment, Component and Building Reductions
(compared to a conventional, 2-loop 600MWe plant)

Category	Reduction
Valves	50%
Pumps	35%
Safety class pipe	80%
Seismic building volume	45%
Cable	70%

Other aspects of the design also contribute to direct reductions in required inspection and maintenance activities. The cold leg lines of the reactor coolants loops are forged and then

bent by a hot induction forming process. The use of a pipe bend reduces in-service inspection requirements by eliminating welds. The steam generator channel head is a one-piece forging with manufacturing and inspection advantages over multi-piece, welded components.

Use of canned motor reactor coolant pumps allows elimination of RCP seal injection and leakoff pipe and valves. Since the pumps have no seals, they cannot cause a seal failure LOCA and seal replacement activities are eliminated.

Use of reduced-worth control rods to achieve load follow without requiring changes in soluble boron concentration allows elimination of the boron recycle system and the rector makeup water system. Liquid radwaste is simplified by the use of modern resin types — processes, thereby eliminating a large, complicated and troublesome evaporator. Gas radwaste is simplified by use of charcoal bed and has no compressors or storage tanks. Solid radwaste is greatly simplified by use of portable de-watering equipment instead of onsite solidification equipment.

Standardization

Early design work intentionally provided for the selection of equipment such as pumps, valves, and motors, and commodities such as pipe, cable and structural steel, on a consistent and standard basis throughout the plant to minimise spare parts inventory, training costs, maintenance procedures, and human error in servicing multiple similar components, for example, standardisation of air handling units (AHU) has reduced the number of unique designs from 44 to 16. Within each AHU design, standization is being applied to unit layout, component standardization, and electrical interface connections. As a major activity in valve standardization, 24 standard valves account for over 60 percent of non-packaged valves.

Plant layout

Plant layout ensures adequate access for inspection and maintenance. Laydown space for staging of equipment and personnel, equipment removal paths, and space to accommodate remotely operated service equipment and mobile units have been considered as part of the plant design.

As an example, accessibility to the containment during an outage is extremely important to those maintenance activities that can be performed only during to the outage. A conventional containment may have only one large equipment hatch, a personnel airlock, and an emergency escape hatch. The AP600 containment contains a 22-foot (6.7m) diameter main equipment hatch and personnel airlock at the operating deck level, and a 16-foot (4.9 m) diameter maintenance hatch with truck access and personnel airlock at grade level. These large hatches significantly enhance accessibility to the containment during outages and, consequently, reduce the potential for congestion at the containment entrances. These containment hatches, located at two different levels, allow activities occurring about the operating deck to be unaffected by activities occurring below. The containment arrangement also provides significantly larger laydown areas inside containment than most conventional plants at both the operating deck level and maintenance floor level. Additionally, the auxiliary building and the adjacent annex building provide large staging and laydown areas immediately outside of both large equipment hatches.

Accessibility to equipment and components is also enhanced by aspects of the plant design. The reactor coolant pumps mount directly on the channel head of each steam generator. This allows the pumps and steam generator to use the same structural support, greatly simpfliying the support system and providing more space for pump and steam

generator maintenance. The reactor coolant loop configuration and material selection yield sufficiently low pipe stresses so that the primary loop configuration and material selection yield sufficiently low pipe stresses so that the primarily loop and most of the high energy auxiliary lines larger than 4^{th} are qualified to demonstrate leak-before-break. Thus, pipe rupture restraints are not required, greatly simplifying the design and providing enhanced access for maintenance. The simplified RCS loop configuration also allows for a significant reduction in the number of snubbers, whip restraints, and supports.

Access platforms and lifting devices are provided at equipment locations requiring periodic inspections, testing, or maintenance. Standard plant services such as electrical power, demineralized water, breathing and service air,, ventilation and lighting are provided in all buildings at strategic locations to facilitate maintenance activities.

Instrumentation and control

The AP600 instrumentation and control has been designed as an integrated system with consistent and efficient interfaces, improved availability and operability, reduced spare parts requirements, and considerable design flexibility. The I&C design includes equipment for control tasks in both the nuclear and turbine islands, thereby extending plant I&C uniformity and further reducing spare parts requirements.

The I&C system also contains a number of features resulting in improved maintenance. More accurate and stable calibrations result from entering setpoints in engineering units. A printout of these data may be requested for verification. No scaling manuals are required, and because values are stored in digital memory, they do not drift. Semi-automatic test subsytems are implemented in the equipment design. This feature allows maintenance personnel to perform periodic functional checks in an efficient manner. Since testing time is reduced, both plant safety and availability are improved. Improved failure diagnosis allows troubleshooting down the circuit card or input — output module, reducing repair time for a given fault. Availability is improved because when one protection channel is undergoing maintenance or test, two out of four logic will automatically change to two out of three when a channel is bypassed. Modular design of the protection and safety monitoring system electronics aids in identifying and repairing equipment failures.

Human systems interface

The design process for the AP600 main control room (MCR) and human system interface (HIS) follows a human factors engineering programme reviewed and approved by the U.S. NRC. A model of human decision making is mapped to the HSE resources (the alarm system, plant information system displays, computerised procedures, control, qualified data processing system, wall panel information systems, and controls). The design features of the HIS resources support the aspects of the human decision making model. A detailed operating experience review has been conducted and the design of the HIS addresses human performance issues identified by the review. Execution and completion of this design process shall result in an HIS design that manages the presentation of plant information in a much more effective manner that the control rooms of currently operating plants. Operations, testing, and maintenance are simplified. Due to features of the advance I&C systems, the number of plant transients caused by sensor failures shall be drastically reduced. Accident monitoring and safety parameters are displayed on safety qualified displays with a co-ordinated set of graphics generated by the qualified data processor. The major benefits of the improved MCR and HIS are:

- Presentation of alarms is effectively managed to avoid "alarm avalanche".
- Presentation of plant information and controls is organized in such a way as to enhance human decision making.
- Computerised emergency operating procedures reduces the operator's mental workload during high stress situations.
- Wall panel information system (wall mounted large screen displays) provides a common frame of reference tot he MCR operating crew and helps maintain overall plant situation awareness.
- Reduction in MCR hardware cost due to the compact workstation (soft control and monitoring) design.

Plant staffing study methodology

A joint utility — vendor analysis of staffing options was performed as part of the AP600 design effort. Plant staffing levels were determined by applying a series of standardization improvement factors, based on the URD and plant design data, to a current reference plant staffing level. The staffing model used is based on the application of the frequences and duration of work activity transactions within standardized work processes. A representative summary of the work processes, adapted from the NEI/EUCG standard process model, is shown in Table 3. The staffing model was benchmarked to known process staffing values of U.S. nuclear power plants of a similar size to the AP600. Using this model, and estimate of the beneficial effects of AP600 plant features compared to current generation power plants could be determined. The resulting staffing levels are based on settled in plant operation beginning about the fifth year and do not include the impact o non-process influences such as corporate culture, bargaining unit agreements, and regulatory requirements.

Staffing reductions

Staffing reductions for the AP600 compared to a current generation reference plant are shown for each of the standard work processes in the Table 2. Approximately 5% of staffing is assumed to be in training at any point in time.

Table 2.

Standard Work Process	AP600 Staffing Reduction
Station operations	50%
Configuration control	39%
Equipment reliability	36%
Materials & services	47%
Work control	34%
Waste services	25%
Waste services	25%
Training	42%
Security	17%`
Administrative support	59%
Trainees	7%
Total	**36%**

Table 3. Standard Work Process Summary

Station Operations	Work Control	Waste Services	Equipment Reliability	Configuration Control	Materials & Services	Training	Security	Administrative Support
Operate & Monitor SSCs	Monitor & Control Effluents	Planning	Long Term Maintenance Plan	Configuration Control	Inventory Management	Training Programs	Security	Information Services
Monitor & Control Plant Chemistry		Scheduling	Surveillance & Performance Tests	Design Changes	Materials & Services	Training Sessions	Safety Services	Business Services
		Preventive Maintenance	Analyse Performance & Reliability of SSCs	Design Basis Changes	Contract Services		Performance Monitoring & Improvement Services	Records Management, Document Control & Office Services
		Corrective Maintenance	Predictive Maintenance	Fuel Management Services	Warehousing		License & Permits	Personnel Services
		Non-Plant Equipment Maintenance		Decomm. Plan	Repairs, Returns & Maintenance		Emergency Operations & Preparedness	Grounds, Facilities & Vehicles Maintenance
		Plant Improvement Maintenance			Inventory Disposal & Surplussing		Fire Protection	Community & Government Relations
		Monitor & Control Radiation Exposure			Fuel Handling, Storage & Disposal			Nuclear Industry, Professional & Trade Associations
		Monitor Control Contamination			Fuel & Fuel Transport			
		Minor & Fix-it-now Maintenance						

A discussion of AP600 features resulting in the staffing reductions within each of the standard work groups follows below.

Station operations

This analysis conservatively assumes four operators on each shift; one operator on the control boards, a second acting as control room supervisor, a third overseeing total unit operation and a forth performing non-control room operations. The AP600 is designed to permit the plant to be operated with one operator from a single console during normal operation. Inherent accident resistance, advanced human system interface control room design, and plant simplicity reduce operator staffing requirements significantly compared to current plants.

Configuration control

The reduced numbers of components, systems, and seismic buildings in the AP600 combined with standization of components and equipment significantly reduces the number of potential plant modifications. Standardization of installed equipment allows a single change to be used repeatedly with minimal additional resources. In addition, the certified design which requires rule making to modify the design. This significantly reduces the number of items that can be changed.

Equipment reliability

The reduced number of components, systems, and seismic buildings in the AP600 directly reduces the activities required. Self-diagnostic I&C require substantially less time-consuming data evaluation. In addition, more standard uses of equipment translate into fewer types of items requiring maintenance and testing.

Materials and services

The reduced number of components, systems and seismic buildings in the AP600 directly reduces the procurements activities required. Standardisation of equipment translates into fewer spare parts, purchase orders, receipt inspections, vendor evaluations, and bids.

Work control

The reduced numbers of components, systems, and buildings in the AP600 directly reduced the activities required. Self-diagnostic I&C systems require substantially less time-hands-on testing. In addition, more standard uses of equipment translate into fewer types of items requiring maintenance and testing.

Waste services.

Fewer components and increased components reliability will significantly reduce the waste generated from maintenance. Primary plant letdown will be significantly reduced with the use of canned motor design reactor coolant pumps reducing both solid and liquid waste. Also, increased component and plant reliability and reduced outage duration will reduce both solid and liquid waste.

Training

The reduced number of systems, standardisation of components, and reduced level of immediate operator actions decreases the amount of initial operator and technician training

required. Higher entry level requirements for technicians also reduce the amount of initial training.

Security

The logical, hardened design, and small footprint of the AP600 combine to significantly reduce the estimated size of the unit security force. Additionally, provided other duties do not prevent security response capability, it is possible to assign suitable trained security personnel to other concurrent duties such as performing minor maintenance and administrative processes. Staffing of security controlled access points will occur only when access is required, otherwise, these points will be locked closed. Non-security access points will be controlled by automated means.

Administrative support

In general, administrative activity occurs as a derivative of core process activity. Therefore, reductions in administrative support staffing will result in direct proportion to the staffing reductions identified above. In addition to this, further benefits will occur from the use of advanced technology within these functions. These additional benefits of technology are discussed for each of the administrative areas. The combined effect of the core process staffing reductions discussed above with the administrative support improvements results in a 59% staff reduction.

Administrative Support Staffing (as percent of total staffing)

Admin. process	Current Reference	Single AP600	AP600 Reduction
Information services	3.0%	1.0%	67%
Financial management	1.0%	0.5%	50%
Processes & procedures	2.0%	1.0%	50%
Performance improvement & monitoring	2.8%	2.8%	0%
Total	8.8%	5.3%	40%

Information services

The information system supports online viewing of any station document at numerous locations throughout the station, therefore, minimising the need to print hard copy documents.

Financial management

The information system provides automated financial data collection and analysis. Reduced staffing results from aids such as electronic funds transfer and direct payroll deposits.

Processes and procedures

Standardization results in fewer procedures, fewer changes, and superior vendor-supplied documentation. Mandatory biennial review of procedures will be limited to normal, off-normal, and emergency operating procedures, and alarm response procedures.

Performance improvement monitoring

Evaluation of both human and process performance is considered to be a line function and, as such, is included in the staffing requirements of the core process rather than as

additional personnel. This activity, however, does include incensing activities (not including those related to the design bases or technical specification changes) and interface with outside entities related to evaluating and implementing lessons learned from internal and external experience.

3. CONCLUSION

The AP600 has been designed to provide economy of staffing during plant operation. The basic elements of the design all lead to reduced work activities required. These design elements include:

- Simplicity;
- Standardization;
- Plant layout;
- Instrumentation an control;
- Human systems interface.

A thorough staffing study was performed by utility participants to quantify the effectiveness of these elements. The result shows a reduction of 32% relative to comparable current plants.

The AP600 is in position to contribute operational economy (as well as improved safety and shorter construction) to the next generation of nuclear power plants.