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The Westinghouse AP1000® : Passive, Proven Technology to Meet European Energy Demands*

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Abstract. Even though several years ago nuclear power was merely considered to be an "optimistic future assessment", the world-wide renaissance of nuclear power has become reality!

The economical and climate-friendly nuclear power generation is internationally regarded to be in an evident upturn. The 435 nuclear power plants in operation worldwide are being modernized and the capacity is increased continuously. Furthermore, to date, 42 power plants are under construction, another 81 are already being applied for and or definitely planned. The global total net capacity out of nuclear power will increase accordingly in the upcoming years from currently 372 to more than 500 GWe, which presents an increase of more than one third.

Westinghouse's contribution hereto is considerable: At the present time, 4 power plants of the series AP1000® are under construction. To begin with, 2 units each are under construction at the Chinese sites Sanmen and Haiyang, another 4 per site are being planned. In the USA, Westinghouse has been contracted with a Engineering, Procurement and Construction (EPC) project for a total of 4 power plant units at the Vogtle and V.C. Summer.

Also in Europe, the plans to construct new plants are meanwhile very specific and many countries have formally established the marginal conditions for new nuclear projects. The AP1000®, with its medium output capacity, is ideally positioned for many markets and can – as a twin unit – also cover large capacity demands.

At the present time, Westinghouse, with its AP1000®, participates in the so-called GDA (Generic Design Assessment) process in Great Britain, where the British regulatory authorities conduct an assessment and evaluation of the safety aspects of this plant design in a defined multilevel process. The successful conclusion of this process ultimately leads to a "Design Acceptance Confirmation", which will basically make the construction of the plant in Great Britain possible.

1 Introduction

Both the Utility Requirements Document (URD) and the European Utility Requirements (EUR) have the general approach of preserving the virtues of the operating plants when it comes to the power producing systems. But there is also a requirement for a simpler plant that is safer and costs less to construct.

Both the EUR and URD anticipate and address specifically the advantages of passive safety features for reducing both construction cost and reliance on operator actions for the mitigation of design basis events. In fact, the expectation for a passive plant is to achieve and maintain safe shutdown in case of an accident for 72 hours without operator action. This is substantially different than the 30 minute period for operator action specified for an "evolutionary" plant that uses active safety systems. The URD also expects that new plant designs offered to utilities will be complete plants, encompassing the entire plant up to its connection to the grid.

In line with the URD and EUR requirements, the AP1000® passive design represents a significant improvement over conventional PWRs, and is developed around the fundamental design principles of increased safety, simplification and standardization [1-4].

2 AP1000® Overview

2.1 Retaining the virtues of current operating plants

The AP1000® plant is designed around a primary system configuration with the reactor pressure vessel, two steam generators and four reactor coolant pumps directly mounted in the steam generator lower head.

The power producing primary system is a familiar one based on proven and reliable Westinghouse PWR features but with evolutionary improvements. The combination of decades of operating experience and the development of improved materials and better manufacturing techniques are expected to result in significant benefit with respect to plant safety, reliability and lifetime. Examples of these improvements are:

- The AP1000® reactor vessel is ring-forged, eliminating longitudinal welds and there are no circumferential welds in the high flux core region. These features combined with improved materials allow for a 60 year vessel life. The fuel design is closely based on the XL Robust Fuel Assembly design that has been operating in Doel, Tihange and South Texas;

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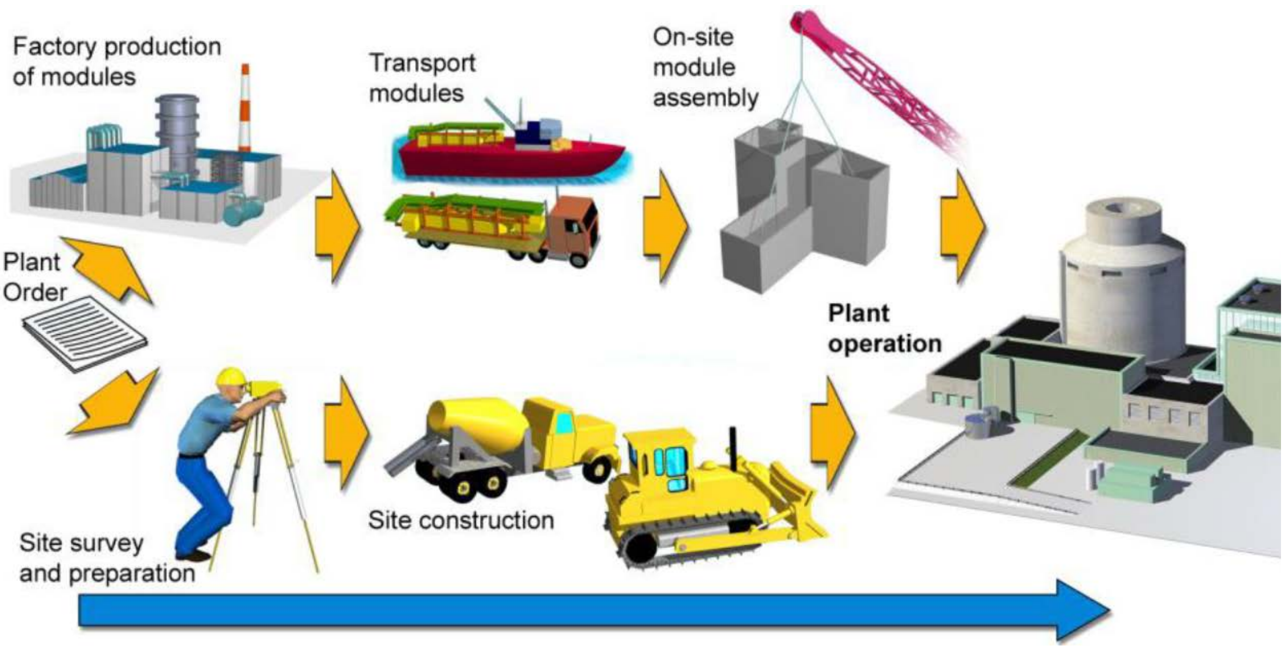

Figure 1. Modular construction allows activities in parallel – standardization.

- The AP1000® primary system design makes use of seal-less reactor coolant pumps, eliminating the need for shaft seals and their complex support systems. The sealless RCPs require no oil lubrication system and are designed to be maintenance-free. Sealless motor pumps were used in the first generation of Westinghouse PWRs but, as the plants became larger with the second generation designs, they out-grew the capacity of that type of pump available at the time. Since then, sealless pump sizes have increased, enabling their application to power reactors once again.
- The quantity of Stellite®has been minimized to reduce cobalt-60 production thus reducing plant dose rates.
- Multiple levels of defense-in-depth are aimed at accident mitigation resulting in a low core damage frequency.

2.2 Safety

The over-arching design principle of the AP1000® with respect to nuclear safety is the use of simple, passive safety systems. These safety systems are dedicated to the mitigation of safety issues and are not required for normal operation. This approach is applicable to core cooling, containment cooling, spent fuel cooling, control room habitability, and the electrical power supply for I&C.

The AP1000® passive safety systems use natural driving forces such as gravity and natural convection to address abnormal and/or accident conditions. These passive safety systems require no external or on-site AC power sources to function, and once actuated require no support systems to maintain their functionality for at least 72 hours. The passive systems require no pumps or other "active" component responses to perform functions after their initiation. They automatically establish and maintain reactor safe shutdown conditions.

Limited operator actions are required to maintain safe conditions in the spent fuel pool via passive means. This provides the benefit of greatly reducing the dependency on operator actions to respond to an event. The AP1000® utilizes the inherent reliability of natural phenomena to simplify safety systems while enhancing safety. In addition to redundancy, the passive safety features also incorporate functional diversity based on Probabilistic Risk Assessment (PRA) insights [2].

Structures, systems and components critical to placing the reactor in a safe shutdown condition are protected within the steel containment vessel which is further surrounded by a substantial "steel and concrete" composite shield building.

When AC power is available, the AP1000® passive systems can be supplemented with simple, active defense-in-depth systems and equipment. The active defense-in-depth systems use reliable and redundant active equipment, supported by the use of defense-in-depth standby diesels to facilitate their functions when offsite AC power is available or not. These simple, active structures, systems and components are optimized for their normal operating functions.

The active systems provide investment protection and reduce the overall risk to the plant owner and the public by minimizing the demand on the passive safety features. While important to the safe normal operation of the plant, the active systems are not necessary for the safe shutdown of the reactor following a design basis accident.

The multiple levels of defense provided by the active defense-in-depth systems and passive safety systems result in very low core damage and large release frequencies as calculated by the PRA [2].

In addition, the AP1000® design has carefully evaluated and addressed severe accident phenomenon. A key AP1000® feature in dealing with a severe accident is in-vessel retention of a molten core. This feature provides a robust, reliable, simple means of preventing a molten core from breeching the reactor vessel, eliminating ex-vessel phenomena that could cause containment failure. References 2, 3 provide additional information on severe accident design features.

2.3 Simplification

The principle of simplification is applied throughout the lifecycle of the AP1000® plant:

- Simpler design: The elimination or simplification of active systems as a result of the reliable passive safety systems and the evolutionary improvements included in the AP1000® design allows an overall simplification of the plant, a reduction of equipment and structures, and maximizes the certainty of delivery and schedule.
- Simpler construction: AP1000® has a highly developed construction plan to minimize the time and cost of construction. It is designed from the outset for modular and "open top" construction techniques. Modular construction allows activities to be run in parallel and it allows more activities to be performed in a controlled factory environment instead of in the field (Figure 1).
- Fewer safety related components: The passive safety systems result in fewer components which contribute to considerable savings in maintenance, testing & operation costs.

The AP1000® standard plant design uses conservative, bounding site parameters (temperatures, wind velocities and seismic levels), achieves a very high level of safety and incorporates utility operational desires. As a result, it is a plant design that can be applied to different geographical regions around the world with varying regulatory standards and utility expectations without major changes which simplifies and standardizes construction, procurement, installation, testing, operator training, licensing and operation.

3 AP1000® Passive Safety Systems

3.1 Emergency core cooling system

The Passive Core Cooling System (PXS), shown in Figure 2, protects the plant against all postulated events in the Reactor Coolant System (RCS) like leaks and ruptures of various sizes and locations. The PXS provides core residual heat removal, core reactivity control, safety injection and depressurization. Safety analyses (using U.S. Nuclear Regulatory Commission-approved codes) demonstrate the effectiveness of the PXS in protecting the core following all postulated design basis events. Even for breaks in the RCS as severe as one of the 20.0 cm (8 in) vessel injection lines,

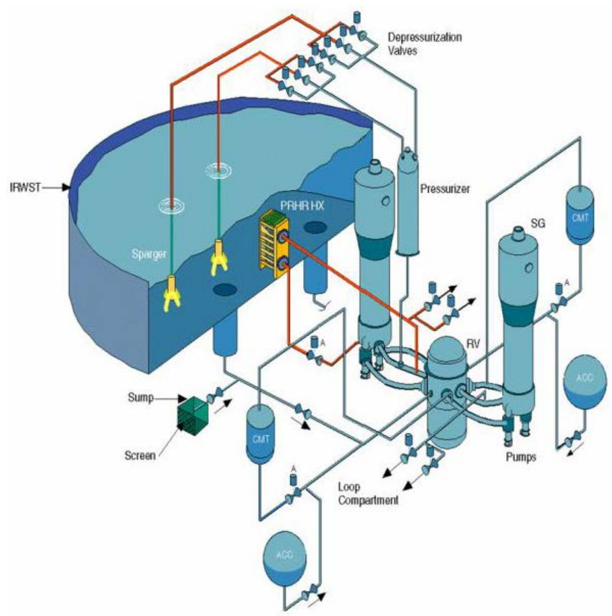

Figure 2. Passive core cooling system.

there is no core uncovery. Following a double ended rupture of a main reactor coolant pipe, the PXS cools the reactor with ample margin to the peak clad temperature limit thus minimizing core damage and clad/steam reaction.

The PXS uses three sources of water to ensure boration and maintain core cooling through safety injection. These injection sources include the core makeup tanks (CMTs), the accumulators, and the in-containment refueling water storage tank (IRWST). These injection sources, together with the containment recirculation flow paths, are directly connected to two nozzles on the reactor vessel so that no injection flow is spilled in case of larger breaks in the loop piping. They contain borated water which ensures RCS boration when the water is injected.

There are two CMTs located inside the containment at an elevation above the reactor coolant loops. During normal operation, the CMTs are completely filled with cold borated water.

The boron concentration of this water is somewhat higher than that of the water in the accumulators and the IRWST. The boration capability of these tanks provides adequate core shutdown margin following a steam line break and for all safe shutdown events. Each CMT is connected to the RCS by a normally closed discharge line which injects directly into the reactor vessel downcomer, and by a normally open pressure balance inlet line connected to an RCS cold leg. The CMT pressure balance lines enable the CMTs to inject borated water into the RCS at any RCS pressure. The CMTs are actuated by opening either one of two redundant, fail-open air operated valves that are located in parallel in the tank discharge lines.

The two accumulators contain borated water and a compressed nitrogen cover to provide rapid injection following postulated large breaks in the RCS. Each accumulator discharge line contains two check valves in series, which isolate the accumulators from the RCS during normal plant operation. The accumulators will inject borated water whenever the RCS pressure decreases to less than the accumulator cover gas pressure.

Long-term injection water is provided by gravity from the IRWST, which is located in the containment above the RCS loop elevation. Normally, the IRWST is isolated from the RCS by squib valves and check valves. Since this tank is designed for atmospheric pressure, the RCS must be depressurized before IRWST injection can occur. Therefore, the RCS pressure is automatically reduced so that the head of water in the IRWST is higher than the RCS pressure. The depressurization is provided using four stages of automatic depressurization to permit a relatively slow, controlled RCS pressure reduction.

The AP1000® containment is configured such that the water from the postulated break (including the PXS injection water) floods the lower portion of the containment to an elevation above the RCS loop piping. This water is returned to the reactor through two redundant and diverse containment recirculation paths. Each of the two recirculation paths contains one path with a squib valve backed up by a check valve and another path containing a different squib valve design backed up by a normally open motor-operated valve.

Both the IRWST injection paths and the containment recirculation paths are protected by screens that prevent debris that could interfere with core cooling from being injected to the reactor.

3.2 Passive residual heat removal

The PXS includes one passive residual heat removal heat exchanger (PRHR HX), illustrated in Figure 2 and Figure 3. The PRHR HX is able to remove core decay heat, even at full RCS pressure, and to cool the RCS to safe shutdown conditions following any event where the normal heat removal via the steam generators is unavailable; for example, a loss of feedwater event with failure to provide start-up feedwater. It satisfies the safety criteria for loss of feedwater, feedwater line breaks, and steam line breaks. The PRHR HX is submerged within the IRWST whose water inventory serves as the heat sink. The PRHR HX inlet line is connected to RCS loop 1 hot leg and the outlet line returns cooled reactor coolant to the steam generator cold side channel head which connects to the RCS cold legs. The HX is actuated by opening either one of two redundant, fail-open air operated valves that are located in parallel in the HX outlet (return) line. Following PRHR HX actuation the IRWST water absorbs the core decay heat and RCS sensible heat. After almost two hours the IRWST water will begin to boil. Once boiling starts, steam is vented to the containment and will be condensed on the steel containment vessel by the passive containment cooling system and, after collection, drains by gravity back into the IRWST. The PRHR HX, the IRWST water inventory, and the PCS provide decay heat removal capability for an extended time with no operator action or AC power required.

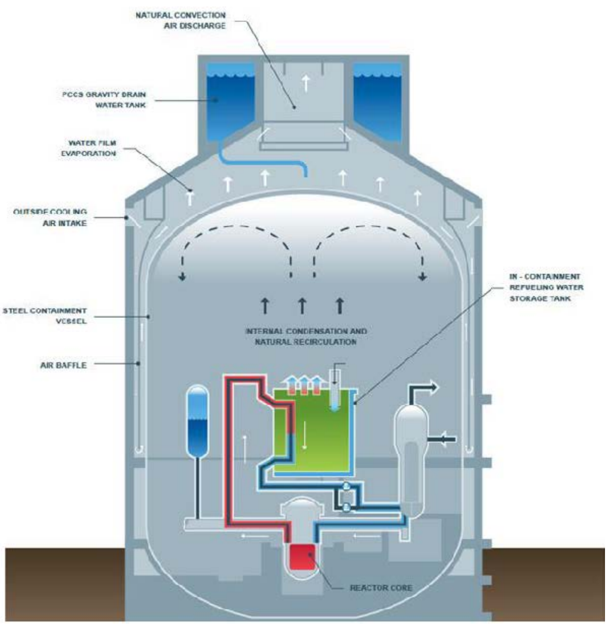

Figure 3. Passive core cooling system.

3.3 Passive containment cooling system

The PCS, also illustrated in Figure 3, provides the safety-related ultimate heat sink for the plant. The PCS cools the containment following any event which results in energy release into the containment so that containment design pressure is not exceeded and pressure inside containment is rapidly reduced. The steel containment vessel provides the heat transfer surface that removes heat from inside the containment and transfers it to the atmosphere.

Heat is removed from the containment vessel by continuous, natural circulation of air. If required, the air cooling is supplemented by applying water onto the outside of the containment steel shell, where the water is heated and evaporates into the cooling air flow path. The water is provided from a tank located on top of the containment shield building and drains by gravity after opening either one of two, normally closed, fail-open air operated valves in parallel lines or by opening a diverse, battery powered motor operated valve in a third flow path.

The PCS water storage tank located above the containment contains sufficient water for gravity draining for three days. After three days the AP1000® design includes additional onsite water storage and equipment to continue water application for additional four days. At last, after seven days air-cooling alone is sufficient to prevent containment over pressurization.

4 Conclusion

AP1000® is the safest and most economical nuclear power plant available in the worldwide commercial marketplace and offers to power generating companies an economical and climate-friendly power generation based on nuclear.

Passive safety without the direct need of operator actions leads to safety concept which is self-reliant, self-contained and fail safe. This results in a high robustness also against extreme external events with a positive contribution to public perception.

Modular and open-top construction techniques, combined to the overall simplification of the plant, results in simpler construction and shorter construction schedule.

Westinghouse has been working during the design development closely also with European utilities and organizations, mainly through the European Passive Plant (EPP) program, to ensure that European specific market needs and requirements are satisfied. These efforts culminate in a very successful EUR assessment and accounts to a licensability in European countries.

Considering these advantages the AP1000® fits perfectly to a European strategy lowering the greenhouse gas emission with ambitious reduction objectives and supporting utilities to meet the need for safe, clean and reliable energy generation.

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