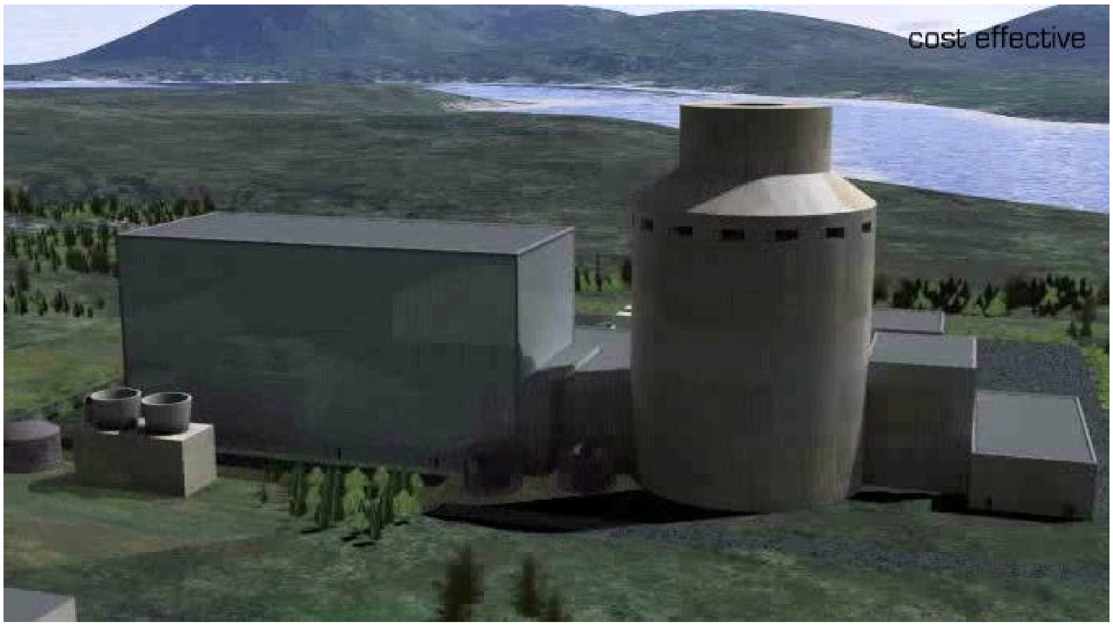
The Westinghouse AP1000 Advanced Nuclear Plant



Plant description

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1 Introduction

The Westinghouse Advanced Passive PWR AP1000 is a 1117 MWe pressurized water reactor (PWR) based closely on the AP600 design. The AP1000 maintains the AP600 design configuration, use of proven components and licensing basis by limiting the changes to the AP600 design to as few as possible. The AP1000 design includes advanced passive safety features and extensive plant simplifications to enhance the safety, construction, operation, and maintenance of the plant. The plant design utilizes proven technology, which builds on over 35 years of operating PWR experience. PWRs represent 76 percent of all Light Water Reactors around the world, and 67 percent of the PWRs are based on Westinghouse PWR technology.

The AP1000 is designed to achieve a high safety and performance record. It is conservatively based on proven PWR technology, but with an emphasis on safety features that rely on natural forces. Safety systems use natural driving forces such as pressurized gas, gravity flow, natural circulation flow, and convection. Safety systems do not use active components (such as pumps, fans or diesel generators) and are designed to function without safety-grade support systems (such as AC power, component cooling water, service water, HVAC). The number and complexity of operator actions required to control the safety systems are minimized; the approach is to eliminate operator action rather than automate it.

The AP1000 is designed to meet U.S. NRC deterministic safety criteria and probabilistic risk criteria with large margins. Safety analysis has been completed and documented in the Design Control Document (DCD) and Probabilistic Risk Analysis (PRA). The extensive AP600 testing program, which is applicable to the AP1000, verifies that the innovative plant features will perform as designed and analyzed. PRA results show a very low core damage frequency, which meets the goals established for advanced reactor designs and a low frequency of release due to improved containment isolation and cooling.

An important aspect of the AP1000 design philosophy focuses on plant operability and maintainability. The AP1000 design includes features such as simplified system design to improve operability while reducing the number of components and associated maintenance requirements. In particular, simplified safety systems reduce surveillance requirements by enabling significantly simplified technical specifications.

Selection of proven components has been emphasized to ensure a high degree of reliability with a low maintenance requirement. Component standardization reduces spare parts, minimizes maintenance, training requirements, and allows shorter maintenance durations. Built-in testing capability is provided for critical components.

Plant layout ensures adequate access for inspection and maintenance. Laydown space provides for staging of equipment and personnel, equipment removal paths, and space to accommodate remotely operated service equipment and mobile units. Access platforms and lifting devices are provided at key locations, as are service provisions such as electrical power, demineralized water, breathing and service air, ventilation and lighting.

The AP1000 design also incorporates radiation exposure reduction principles to keep worker dose as low as reasonably achievable (ALARA). Exposure length, distance, shielding and source reduction are fundamental criteria that are incorporated into the design.

Various features have been incorporated in the design to minimize construction time and total cost by eliminating components and reducing bulk quantities and building volumes. Some of these features include the following:

- Flat, common Nuclear Island basemat design minimizes construction cost and schedule.
- Integrated protection system, advanced control room, distributed logic cabinets, multiplexing, and fiber optics, significantly reduce the quantity of cables, cable trays, and conduits.

- Stacked arrangement of the Class 1E battery, dc switchgear, integrated protection system, and the main control rooms eliminate the need for the upper and lower cable spreading rooms that are required in current generation PWR plants.
- Application of the passive safeguards systems replaces and/or eliminates many of the conventional mechanical safeguards systems typically located in Seismic Category I buildings in current generation PWR plants.

The AP1000 is designed with environmental consideration as a priority. The safety of the public, the power plant workers, and the impact to the environment have been addressed as follows:

- Operational releases have been minimized by design features.
- Aggressive goals for worker radiation exposure have been set and satisfied.
- Total radwaste volumes have been minimized.
- Other hazardous waste (non-radioactive) have been minimized.

The AP1000 has a well-defined design basis that has been confirmed through thorough engineering analyses and testing. Some of the high-level design characteristics of the plant are:

- Net electrical power of at least 1117 MWe; and a thermal power of 3415 MWt.
- Rated performance is achieved with up to 10% of the steam generator tubes plugged and with a maximum hot leg temperature of 610°F (321°C).
- Core design is robust with at least a 15% operating margin on core power parameters.
- Short lead time (five years from owner's commitment to commercial operation) and construction schedule (3 years).
- No plant prototype is needed since proven power generating system components are used.
- Major safety systems are passive; they require no operator action for 72 hours after an accident, and maintain core and containment cooling for a protracted time without ac power.
- Predicted core damage frequency of 2.4E-07/yr is well below the 1E-05/yr requirement, and frequency of significant release of 1.95E-08/yr is well below the 1E-06/yr requirement.
- Standard design is applicable to anticipated US and international sites.
- Occupational radiation exposure expected to be below 0.7 man-Sv/yr (70 man-rem/yr).
- Core is designed for a 18-month fuel cycle.
- Refueling outages can be conducted in 17 days or less.
- Plant design life of 60 years without replacement of the reactor vessel.
- Overall plant availability greater than 93%, including forced and planned outages; the goal for unplanned reactor trips is less than one per year.
- Leak-before-break on primary lines > 6-inches and on main steam lines.
- Seismic based on 0.3g ground acceleration.
- Security enhanced with all safe shutdown equipment located in safety reinforced concrete Nuclear Island buildings.
- Meets URD and EUR requirements.
- Invessel retention of core debris following core melt which significantly reduces the uncertainty in the assessment of containment failure and radioactive release to the environment due to ex-vessel severe accident phenomena.
- No reactor pressure vessel penetrations below the top of the core. This eliminates the possibility of a loss of coolant accident by leakage from the reactor vessel, which could lead to core uncovery.

2 Description of the nuclear systems

2.1 Primary circuit and its main characterisitcs

The primary circuit of the AP1000 reactor retains most of the general design features of current designs, with added evolutionary features to enhance the safety and maintainability of the system. The system consists of two heat transfer circuits (Figure 1) each with a single hot leg and two cold legs, a steam generator, and two reactor coolant pumps installed directly onto the steam generator; eliminating the primary piping between pumps and steam generator. A simplified support structure for the primary systems reduces in-service inspections and improves accessibility for maintenance.

The reactor coolant system pressure boundary provides a barrier against the release of radioactivity generated within the reactor and is designed to provide a high degree of integrity throughout operation of the plant

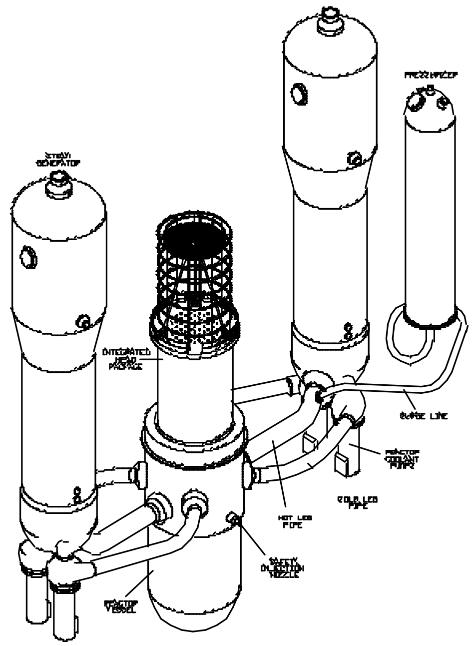

Figure 1 Isometric view of AP1000 NSSS

2.2 Reactor core and fuel design

The core, reactor vessel, and reactor internals of the AP1000 are similar to those of conventional Westinghouse PWR designs. Several important enhancements, all based on existing technology, have been used to improve the performance characteristics of the design. The AP1000 incorporates a low boron core design to increase safety margins for accident scenarios such as Anticipated Transients Without Scram. Fuel performance improvements include ZIRLO™ grids, removable top nozzles, and longer burnup features. The AP1000 core incorporates the Westinghouse ROBUST fuel assembly design compared to the Vantage 5-H design of the AP600. The reactor core is comprised of 157, 14 foot (426.7 mm), 17×17 fuel assemblies. The AP1000 core design provides a robust design with at least 15 percent in departure from nucleate boiling (DNB) margin.

The materials that serve to attenuate neutrons originating in the core and gamma rays from both the core and structural components consist of the core shroud, core barrel and associated water annuli. These are within the region between the core and the pressure vessel.

The core consists of three radial regions that have different enrichments; the enrichment of the fuel ranges from 2.35 to 4.8%. The temperature coefficient of reactivity of the core is highly negative. The core is designed for a fuel cycle of 18 months with a 93% capacity factor, region average discharge burnups as high as 60000 MWd/t.

The AP1000 uses reduced-worth control rods (termed "gray" rods) to achieve daily load follow without requiring changes in the soluble boron concentration. The use of gray rods, in conjunction with an automated load follow control strategy, eliminates the need for processing thousands of gallons of water per day to change the soluble boron concentration. As a result, systems are simplified through the elimination of boron processing equipment (such as evaporator, pumps, valves, and piping). With the exception of the neutron absorber materials used, the design of the gray rod assembly is identical to that of a normal control rod assembly.

2.3 Fuel handling and transfer systems

Refueling of the reactor is performed in the same way as for current plants. After removing the vessel head, fuel handling takes place from above, using the refueling machine to configure the core for the next cycle.

New fuel storage - New fuel is stored in a high-density rack which includes integral neutron absorbing material to maintain the required degree of subcriticality. The rack is designed to store fuel of the maximum design basis enrichment. The new fuel rack includes storage locations for 72 fuel assemblies. Minimum separation between adjacent fuel assemblies is sufficient to maintain a subcritical array even in the event the building is flooded with unborated water, fire extinguishing aerosols, or during any design basis event.

Spent fuel storage - Spent fuel is stored in high density racks which include integral neutron absorbing material to maintain the required degree of subcriticality. The racks are designed to store fuel of the maximum design basis enrichment. The spent fuel storage racks include storage locations for 619 fuel assemblies. The modified 10×7 rack module additionally contains integral storage locations for five defective fuel assemblies. The design of the rack is such that a fuel assembly can not be inserted into a location other than a location designed to receive an assembly.

2.4 Primary components

Reactor pressure vessel – The reactor vessel (Figure 2) is the high-pressure containment boundary used to support and enclose the reactor core. The vessel is cylindrical, with a hemispherical bottom head and removable flanged hemispherical upper head.

The reactor vessel is approximately 39.5 feet (12.0 m) long and has an inner diameter at the core region of 157 inches (3.988 m). Surfaces, which can become wetted during operation and refueling, are clad with stainless steel welded overlay. The AP1000 reactor vessel is designed to withstand the design environment of 2500 psia (17.1 MPa) and 650°F (343°C) for 60 years.

As a safety enhancement, there are no reactor vessel penetrations below the top of the core. This eliminates the possibility of a loss of coolant accident by leakage from the reactor vessel, which could lead to core uncovery. The core is positioned as low as

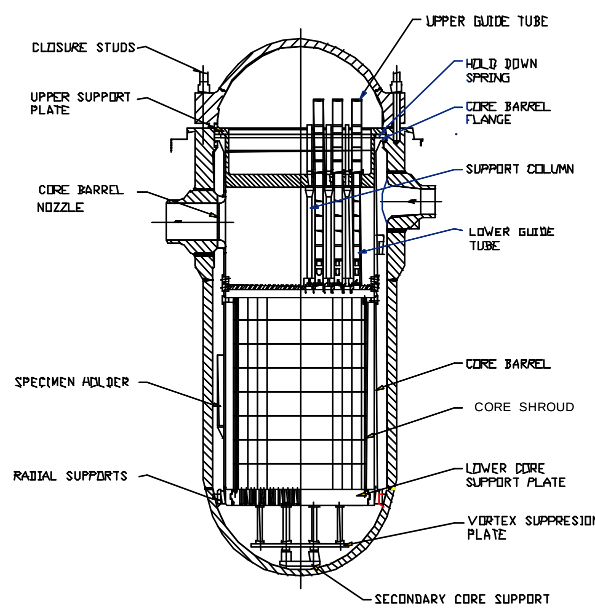

Figure 2 AP1000 Reactor pressure vessel

possible in the vessel to limit reflood time in accident situations.

Reactor internals - The reactor internals, the core support structures, the core shroud, the downcomer and flow guiding structure arrangement, and the above-core equipment and structures, are very similar to those in current plants.

The reactor internals consist of two major assemblies - the lower internals and the upper internals. The reactor internals provide the protection, alignment and support for the core, control rods, and gray rods to provide safe and reliable reactor operation.

Steam generators - Two model Delta-125 steam generators (Figure 3) are used in the AP1000 plant. The high reliability of the steam generator design is based on design enhancements and a proven design. The steam generator design is based on the following proven designs: Delta-75 replacement steam generators for V.C. Summer and other plants; Delta-94 replacement steam generator for South Texas plant; Replacement steam generators (1500 MWt per SG) for Arkansas (ANO); San Onofre and Waterford steam generator designs with capacities similar to the AP1000 steam generators. The steam generators operate on all volatile treatment secondary side water chemistry. Steam generator design enhancements include full-depth hydraulic expansion of the tubes in the tubesheets, nickel-chromium-iron Alloy 690 thermally treated tubes on a triangular pitch, broached tube support plates, improved antivibration bars, upgraded primary and secondary moisture separators, enhanced maintenance features, and a primary-side channel head design that allows for easy access and maintenance by robotic tooling. All tubes in the steam generator are accessible for sleeving, if necessary.

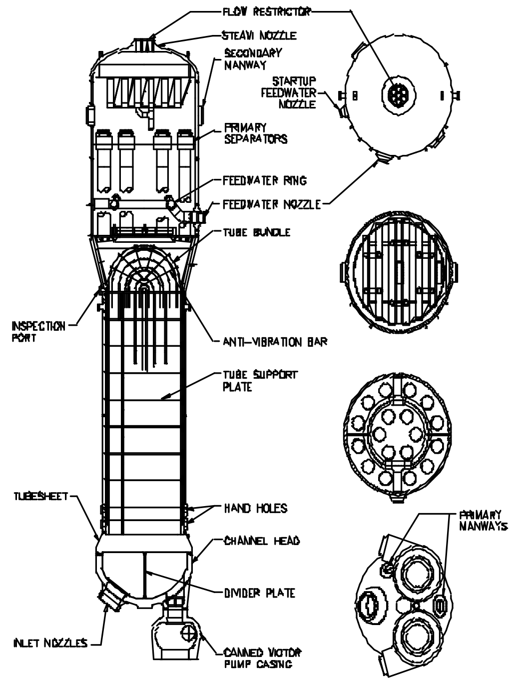

Figure 3 AP1000 Steam generator

Pressurizer - The AP1000 pressurizer is of conventional design, based on proven technology. The pressurizer volume is 2100 ft^3 (59.5 m^3). The large pressurizer avoids challenges to the plant and operator during transients, which increases transient operation margins resulting in a more reliable plant with fewer reactor trips. It also eliminates the need for fast-acting power-operated relief valves, a possible source of RCS leakage and maintenance.

Reactor coolant pumps - The reactor coolant pumps are high-inertia, highly-reliable, low-maintenance, hermetically sealed canned-motor pumps that circulate the reactor coolant through the reactor core, loop piping, and steam generators. The AP1000 pump is based on the AP600 canned-motor pump design with provisions to provide more flow and a longer flow coast down. The motor size is minimized through the use of a variable speed controller to reduce motor power requirements during cold coolant conditions. Two pumps are mounted directly in the channel head of each steam generator. This configuration eliminates the cross-over leg of coolant loop piping; reduces the loop pressure drop; simplifies the foundation and support system for the steam generator, pumps, and piping; and reduces the potential for uncovering of the core by eliminating the need to clear the loop seal during a small loss-of-coolant accident (LOCA). The reactor coolant pumps have no seals, eliminating the potential for seal failure LOCA, which significantly enhances safety and reduces pump maintenance. The pumps use a flywheel to increase the pump rotating inertia. The increased inertia provides a slower rate-of-flow coastdown to improve core thermal margins following the loss of electric power. Testing has validated the manufacturability and operability of the pump flywheel assembly.

Main coolant lines - Reactor coolant system (RCS) piping is configured with two identical main coolant loops, each employing a single 31-inch (790 mm) inside diameter hot leg pipe to transport reactor coolant to a steam generator. The two reactor coolant pump suction nozzles are welded directly to the outlet nozzles on the bottom of the steam generator channel head. Two 22-inch (560 mm) inside diameter cold leg pipes in each loop (one per pump) transport reactor coolant back to the reactor vessel to complete the circuit.

The RCS loop layout contains several important features that provide for a significantly simplified and safer design. The reactor coolant pumps mount directly on the channel head of each steam generator, which allows the pumps and steam generator to use the same structural support, greatly simplifying the support system and providing more space for pump and steam generator maintenance. The combined steam generator/pump vertical support is a single pinned column extending from the floor to the bottom of the channel head. The steam generator channel head is a one-piece forging with manufacturing and inspection advantages over multipiece, welded components. The integration of the pump suction into the bottom of the steam generator channel head eliminates the crossover leg of coolant loop piping, thus avoiding the potential for core uncovery due to loop seal venting during a small loss-of-coolant accident.

The simplified, compact arrangement of the RCS also provides other benefits. The two cold leg lines of the two main coolant loops are identical (except for instrumentation and small line connections) and include bends to provide a low-resistance flow path and flexibility to accommodate the expansion difference between the hot and cold leg pipes. The piping is forged and then bent, which reduces costs and in-service inspection requirements. The loop configuration and material selection yield sufficiently low pipe stresses so that the primary loop and large auxiliary lines meet leak-before-break requirements. 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. Field service experience and utility feedback have indicated the high desirability of these features.

2.5 Reactor auxiliary systems

Chemical and volume control system – The chemical and volume control system (CVS) consists of regenerative and letdown heat exchangers, demineralizers and filters, makeup pumps, tanks, and associated valves, piping, and instrumentation. The CVS is designed to perform the following major functions:

- **Purification** - maintain reactor coolant purity and activity level within acceptable limits.
- **Reactor coolant system inventory control and makeup** - maintain the required coolant inventory in the reactor coolant system; maintain the programmed pressurizer water level during normal plant operations.
- **Chemical shim and chemical control** - maintain reactor coolant chemistry during plant startups, normal dilution to compensate for fuel depletion and shutdown boration and provide the means for controlling the reactor coolant system pH by maintaining the proper level of lithium hydroxide.
- **Oxygen control** - provide the means for maintaining the proper level of dissolved hydrogen in the reactor coolant during power operation and for achieving the proper oxygen level prior to startup after each shutdown.
- **Filling and pressure testing of the reactor coolant system** - provide the means for filling and pressure testing of the reactor coolant system. The chemical and volume control system does not perform hydrostatic testing of the reactor coolant system, but provides connections for a temporary hydrostatic test pump.
- **Borated makeup to auxiliary equipment** - provide makeup water to the primary side systems, which require borated reactor grade water.

- **Pressurizer Auxiliary Spray** - provide pressurizer auxiliary spray water for depressurization.

Normal residual heat removal system - The normal residual heat removal system consists of two mechanical trains of equipment, each comprising one pump and one heat exchanger. The two trains of equipment share a common suction line from the reactor coolant system and a common discharge header. The normal residual heat removal system includes the piping, valves and instrumentation necessary for system operation. The major functions of the system are:

- **Shutdown heat removal -** remove residual and sensible heat from the core and the reactor coolant system during plant cooldown and shutdown operations. The normal residual heat removal system provides reactor coolant system cooldown from 350 to 120°F (177 to 48.9°C) within 96 hours after shutdown. The system maintains the reactor coolant temperature at or below 120°F during plant shutdown.
- **Shutdown purification -** povide reactor coolant system and refuelling cavity purification flow to the chemical and volume control system during refuelling operations.
- **In-containment refueling water storage tank cooling** – provide cooling to the IRWST to limit the IRWST water temperature to less than 212°F (100°C) during extended operation of the passive residual heat removal system and to not greater than 120°F during normal operation.
- **Low pressure reactor coolant system makeup and cooling** - provide low pressure makeup from the cask loading pit and then the IRWST to the reactor coolant system and provide additional margin for core cooling.
- **Low temperature overpressure protection** - provide low temperature overpressure protection for the reactor coolant system during refuelling, startup, and shutdown operations.
- **Long-term, post-accident containment inventory makeup flowpath** - provide a flow path for long term post-accident makeup to the reactor containment inventory, under design assumptions of containment leakage.
- **Post-accident recovery** - Remove heat from the core and the reactor coolant system following successful mitigation of an accident by the passive core cooling system
- **Spent fuel pool cooling** - Provide backup for cooling the spent fuel pool.

Spent Fuel Pool Cooling System - The spent fuel pool cooling system is designed to remove decay heat which is generated by stored fuel assemblies from the water in the spent fuel pool. This is done by pumping the high temperature water from within the fuel pool through a heat exchanger, and then returning the water to the pool. A secondary function of the spent fuel pool cooling system is clarification and purification of the water in the spent fuel pool, the transfer canal, and the refueling water. The major functions of the system are:

- **Spent fuel pool cooling** - Remove heat from the water in the spent fuel pool during operation to maintain the pool water temperature within acceptable limits.
- Spent fuel pool purification - Provide purification and clarification of the spent fuel pool water during operation.
- **Refueling cavity purification** - Provide purification of the refueling cavity during refueling operations.
- **Water transfers** - Transfer water between the in-containment refueling water storage tank (IRWST) and the refueling cavity during refueling operations.
- **In-containment refueling water storage tank purification** - Provide purification and cooling of the in-containment refueling water storage tank during normal operation.

2.6 Operating characteristics

The plant control scheme is based on the "reactor follows plant loads". A grid fluctuation can be compensated for through turbine control valves in case of a frequency drop. A decrease in pressure at the turbine would require an increase in reactor power.

The AP1000 is designed to withstand the following operational occurrences without the generation of a reactor trip or actuation of the safety related passive engineered safety systems. The logic and setpoints for the AP1000 Nuclear Steam Supply System (NSSS) control systems are developed in order to meet the following operational transients without reaching any of the protection system setpoints.

- ± 5%/minute ramp load change within 15% and 100% power
- ± 10% step load change within 15% and 100% power
- 100% generator load rejection
- 100-50-100% power level daily load follow over 90% of the fuel cycle life
- Grid frequency changes equivalent to 10% peak-to-peak power changes at 2%/minute rate
- 20% power step increase or decrease within 10 minutes
- Loss of a single feedwater pump

3 Description of turbine generator plant system

3.1 Turbine generator plant

The AP1000 turbine is a power conversion system designed to change the thermal energy of the steam flowing through the turbine into rotational mechanical work, which rotates a generator to provide electrical power. The AP1000 turbine consists of a double-flow, high-pressure cylinder and three double-flow, low-pressure cylinders that exhaust to individual condensers. It is a six flow tandem-compound, 1800 rpm machine (1500 rpm for 50 HZ applications). The turbine generator is intended for base load operation but also has load follow capability. Mechanical design of the turbine root and rotor steeple attachments uses optimized contour to significantly reduce operational stresses. Steam flow to the high-pressure turbine is controlled by two floor-mounted steam chests. Each contains two throttle/stop valve assemblies, and two load-governing valves.

The condenser and circulating water systems have been optimized. The condenser is a three-shell, multipressure unit with one double-flow, low-pressure turbine exhausting into the top of each shell.

The turbine-generator and associated piping, valves, and controls are located completely within the turbine building. There are no safety-related systems or components located within the turbine building. The probability of destructive overspeed condition and missile generation, assuming the recommended inspection frequency, is less than 1×10^{-5} per year. Turbine orientation minimizes potential interaction between turbine missiles and safety-related structures and components. The turbine-generator components and instrumentation associated with turbine-generator overspeed protection are accessible under operating conditions.

The single direct-driven generator is gas and water-cooled and rated at 1250 MVA at 24 kV, and a power factor of 0.9. Other related system components include a complete turbine-generator bearing lubrication oil system, a digital electrohydraulic (DEH) control system with supervisory instrumentation, a turbine steam sealing system, overspeed protective devices, turning gear, a generator hydrogen and seal oil system, a generator CO_2 system, an exciter cooler, a rectifier section, an exciter, and a voltage regulator.

3.2 Condensate and feedwater systems

The condensate and feedwater system supplies the steam generators with heated feedwater in a closed steam cycle using regenerative feedwater heating. The condensate and feedwater system is composed of the condensate system, the main and startup feedwater system, and portions of the steam generator system. The condensate system collects condensed steam from the condenser and pumps condensate forward to the deaerator. The feedwater system takes suction from the deaerator and pumps feedwater forward to the steam generator system utilizing high-pressure main feedwater pumps. The steam generator system contains the safety-related piping and valves that deliver feedwater to the steam generators. The condensate and feedwater systems are located within the turbine building and the steam generator system is located in the auxiliary building and containment.

The main feedwater system includes three 33-1/3% single speed motor driven feedwater pumps which operate in parallel and take suction from the associated feedwater booster pumps. The discharge from the main feedwater pumps is supplied to the high-pressure feedwater heater and then to the steam generator system.

The feedwater cycle consists of six stages of feedwater heating with three parallel string, stage 1 and 2 low-pressure feedwater heaters located in the condenser neck with the next two parallel string, stage 3 and 4 low-pressure heaters, deaerator, and the two stage 6 high-pressure heaters located within the turbine building. The condenser hotwell and deaerator storage capacity allows margin in the design. This margin, coupled with three 50 percent condensate pumps, provides greater flexibility and the ability for an operator to control feedwater and condensate transients.

3.3 Auxiliary systems

Radioactive waste management

The radioactive waste management systems include systems, which deal with liquid, gaseous and solid waste, which may contain radioactive material. The systems for liquid wastes include:

- Steam generator blowdown processing system
- Radioactive waste drain system
- Liquid radwaste system

The waste processing systems are closely integrated with the chemical and volume control system (CVS). The steam generator blowdown processing system controls and maintains the steam generator secondary cycle water chemistry. The blowdown is normally recycled to the condenser via an electronic ion exchange system, but in the case of high radiation the blowdown would be directed to the liquid radwaste system (WLS). This allows a large simplification in the blowdown system without an increase in the amount of WLS equipment.

The liquid radwaste system (WLS) uses ion exchangers to process and discharge all wastes from the reactor coolant system. To enhance ion exchange performance, the WLS is divided into two reprocessing trains to separate borated reactor coolant from mixed liquid waste. Based on conservative fuel defect levels and ion exchange performance consistent with the Utility Requirements Document, no evaporators are required.

A simple, vacuum-type degasifier is used to remove radioactive gases in the liquid discharge from the RCS to the WLS. The degasifier eliminates the need for cover gases or a diaphragm in the waste holdup tanks.

The gaseous radwaste system is a once-through, ambient-temperature, charcoal delay system. The system consists of a drain pot, a gas cooler, a moisture separator, an activated charcoal-filled guard bed, and two activated charcoal-filled delay beds. Also included in the system are an oxygen analyzer subsystem and a gas sampling subsystem.The radioactive fission gases entering the system are carried by hydrogen and nitrogen gas. The primary influent source is the liquid radwaste system degasifier. The degasifier extracts both hydrogen and fission gases from the chemical and volume control system letdown flow.

The solid waste management system is designed to collect and accumulate spent ion exchange resins and deep bed filtration media, spent filter cartridges, dry active wastes, and mixed wastes generated as a result of normal plant operation, including anticipated operational occurrences. The system is located in the auxiliary and radwaste buildings. Processing and packaging of wastes are by mobile systems in the auxiliary building loading bay and the mobile systems facility which is a part of the radwaste building. The packaged waste is stored in the annex, auxiliary and radwaste buildings until it is shipped offsite to a licensed disposal facility.

4 Instrumentation and control systems

The I&C system design for AP1000 integrates individual systems using similar technology. The heart of the system is the portion used for plant protection and for operation of the plant.

The integrated AP1000 I&C system provides the following benefits:

- Control wiring is reduced by 80 percent compared to equivalent hard wired plants without passive safety features
- Cable spreading rooms are eliminated
- Maintenance is simplified
- Plant design changes have little impact on I&C design
- Accurate, drift-free calibration is maintained
- Operating margins are improved

The AP1000 man-machine interfaces have been simplified compared to existing plants. The probability of operator error is reduced and operations, testing, and maintenance are simplified. An automatic signal selector in the control system selects from a redundant sensor for control inputs in lieu of requiring manual selection by the control board operator. Accident monitoring and safety parameters are displayed on safety qualified displays with a coordinated set of graphics generated by the qualified data processor. The major benefits of the improved man-machine interfaces are:

- Reduced quantity of manual actions is required
- Reduced quantity of data is presented to operator
- Number of alarms is reduced
- Improved quality of data is presented to operator
- Data is interpreted for the operator by system computer
- Maintenance is simplified

4.1 Design concept, including control room

The AP1000 instrumentation and control architecture is arranged in a hierarchical manner to provide a simplified structured design that is horizontally and vertically integrated.

Above the monitor bus are the systems that facilitate the interaction between the plant operators and the I&C. These are the operations and control centers system (OCS) and the data display and monitoring system (DDS). Below the monitor bus are the systems and functions that perform the protective, control, and data monitoring functions. These are the protection and safety monitoring system (PMS) (Section 4.2) the plant control system (PLS), the special monitoring system (SMS), and the in-core instrumentation system (IIS).

The plant control system (PLS) has the function of establishing and maintaining the plant operating conditions within prescribed limits. The control system improves plant safety by minimizing the number of situations for which protective response is initiated and it relieves the operator from routine tasks.

The purpose of the diverse actuation system (DAS) is to provide alternative means of initiating the reactor trip and emergency safeguards features. The hardware and software used to implement the DAS are different from the hardware and software used to implement the protection and safety monitoring system. The DAS is included to meet the anticipated transient without (reactor) trip (ATWT) rule and to reduce the probability of a severe accident resulting from the unlikely coincidence of a transient and common mode failure of the protection and safety monitoring. The protection and safety monitoring system is designed to prevent common mode failures; however, in the low-probability case where a common mode failure could occur, the DAS provides diverse protection.

Main control room - The operations and control centers system includes the complete operational scope of the main control room, the remote shutdown workstation, the waste processing control room, and partial scope for the technical support center. With the exception of the control console structures, the equipment in the control room is part of the other systems (for example, protection and safety monitoring system, plant control system, data and display processing system). The conceptual arrangement of the main control room is shown in Figure 4.

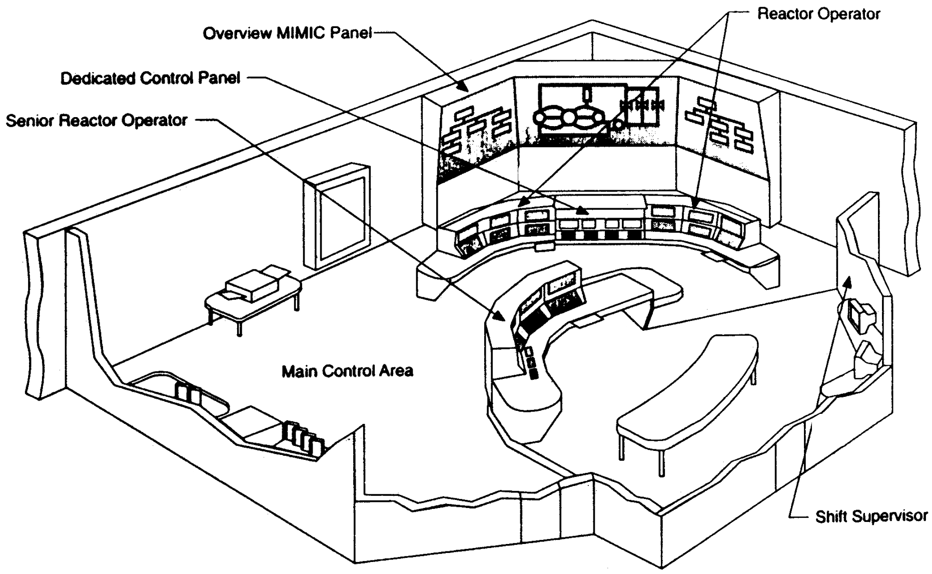

Figure 4 AP1000 Main control room

The boundaries of the operations and control center system for the main control room and the remote shutdown workstation are the signal interfaces with the plant components. These interfaces are via the plant protection and safety monitoring system processor and logic circuits, which interface with the reactor trip and engineered safety features plant components; the plant control system processor and logic circuits, which interface with the nonsafety-related plant components; and the plant monitor bus, which provides plant parameters, plant component status, and alarms.

4.2 Reactor protection system and other safety systems

The AP1000 provides instrumentation and controls to sense accident situations and initiate engineered safeguards features. The occurrence of a limiting fault, such as a loss-of-coolant accident or a secondary system break, requires a reactor trip plus actuation of one or more of the engineered safeguards features. This combination of events prevents or mitigates damage to the core and reactor coolant system components, and provides containment integrity.

The protection and safety monitoring system (PMS) provides the safety-related functions necessary to shut down the plant, and to maintain the plant in a safe shutdown condition. The protection and safety monitoring system controls safety-related components in the plant that may be operated from the main control room or remote shutdown workstation.

5 Electrical systems

The AP1000 on-site power system includes the main AC power system and the DC power system. The main AC power is a non-Class 1E system. The DC power system consists of two independent systems, one Class 1E and one non-Class 1E. The on-site power system is designed to provide reliable electric power to the plant safety and non-safety equipment for normal plant operation, startup, normal shutdown, accident mitigation, and emergency shutdown.

The main generator is connected to the off-site power system via three single-phase main step-up transformers. The normal power source for the plant auxiliary AC loads is provided from the 24 kV isophase generator buses through the two unit auxiliary transformers of identical ratings. In the event of a loss of the main generator, the power is maintained without interruption from the preferred power supply by an auto-trip of the main generator breaker. Power then flows from the main transformer to the auxiliary loads through the unit auxiliary transformers.

Off-site power has no safety-related function due to the passive safety features incorporated in the AP1000 design. Therefore, redundant off-site power supplies are not required. The design provides a reliable offsite power system that minimizes challenges to the passive safety system.

5.1 Operational power supply systems

The main AC power system is a non-Class 1E system that does not perform any safety functions. The standby power supply is included in the on-site standby power system.

The power to the main AC power system normally comes from the station main generator through unit auxiliary transformers. The plant is designed to sustain a load rejection from 100 percent power with the turbine generator continuing stable operation while supplying the plant house loads. The load rejection feature does not perform any safety function

The on-site standby AC power system is powered by the two on-site standby diesel generators and supplies power to selected loads in the event of loss of normal, and preferred AC power supplies.

The plant DC power system comprises two independent Class 1E and non-Class 1E DC power systems. Each system consists of ungrounded stationary batteries, DC distribution equipment, and uninterruptible power supplies.

5.2 Safety-related systems

The Class 1E DC power system includes four independent divisions of battery systems. Any three of the four divisions can shut down the plant safely and maintain it in a safe shutdown condition. Divisions B and C have two battery banks. One of these battery banks is sized to supply power to selected safety-related loads for at least 24 hours, and the other battery bank is sized to supply power to another smaller set of selected safety-related loads for at least 72 hours following a design basis event (including the loss of all AC power).

For supplying power during the post-72 hour period following a design basis accident, provisions are made to connect an ancillary ac generator to the Class 1E voltage regulating transformers (Divisions B and C only). This powers the Class 1E post-accident monitoring systems, the lighting in the main control room, and ventilation in the main control room and Divisions B and C instrumentation and control rooms.

6 Safety concept

6.1 Safety requirements and design philosophy

The AP1000 design provides for multiple levels of defense for accident mitigation (defense-in-depth), resulting in extremely low core damage probabilities while minimizing the occurrences of containment flooding, pressurization, and heat-up. Defense-in-depth is integral to the AP1000 design, with a multitude of individual plant features capable of providing some degree of defense of plant safety. Six aspects of the AP1000 design contribute to defense-in-depth:

Stable Operation. In normal operation, the most fundamental level of defense-in-depth ensures that the plant can be operated stably and reliably. This is achieved by the selection of materials, by quality assurance during design and construction, by well-trained operators, and by an advanced control system and plant design that provide substantial margins for plant operation before approaching safety limits.

Physical Plant Boundaries. One of the most recognizable aspects of defense-in-depth is the protection of public safety through the physical plant boundaries. Releases of radiation are directly prevented by the fuel cladding, the reactor pressure boundary, and the containment pressure boundary.

Passive Safety-Related Systems. The AP1000 safety-related passive systems and equipment are sufficient to automatically establish and maintain core cooling and containment integrity for an indefinite period of time following design basis events assuming the most limiting single failure, no operator action and no onsite and offsite ac power sources.

Diversity within the Safety-Related Systems. An additional level of defense is provided through the diverse mitigation functions within the passive safety-related systems. This diversity exists, for example, in the residual heat removal function. The PRHR HX is the passive safety-related feature for removing decay heat during a transient. In case of multiple failures in the PRHR HX, defense-in-depth is provided by the passive safety injection and automatic depressurization (passive feed and bleed) functions of the passive core cooling system.

Non-safety Systems. The next level of defense-in-depth is the availability of certain non-safety systems for reducing the potential for events leading to core damage. For more probable events, these highly reliable non-safety systems automatically actuate to provide a first level of defense to reduce the likelihood of unnecessary actuation and operation of the safety-related systems.

Containing Core Damage. The AP1000 design provides the operators with the ability to drain the IRWST water into the reactor cavity in the event that the core has uncovered and is melting. This prevents reactor vessel failure and subsequent relocation of molten core debris into the containment. Retention of the debris in the vessel significantly reduces the uncertainty in the assessment of containment failure and radioactive release to the environment due to ex-vessel severe accident phenomena. (See Section 6.3 for additional discussion regarding in-vessel retention of molten core debris.)

AP1000 defense-in-depth features enhance safety such that no severe release of fission products is predicted to occur from an initially intact containment for more than 100 hours after the onset of core damage, assuming no actions for recovery. This amount of time provides for performance of accident management actions to mitigate the accident and prevent containment failure. The frequency of severe release as predicted by PRA is 1.95×10^{-8} per reactor year, which is much lower than for conventional plants.

6.2 Safety systems and features (active, passive, and inherent)

The AP1000 uses passive safety systems to improve the safety of the plant and to satisfy safety criteria of regulatory authorities. The use of passive safety systems provides superiority over conventional plant designs through significant and measurable improvements in plant simplification, safety, reliability, and investment protection. The passive safety systems require no operator actions to mitigate design basis accidents. These systems use only natural forces such as gravity, natural circulation, and compressed gas to make the systems work. No pumps, fans, diesels, chillers, or other active machinery are used. A few simple valves align and automatically actuate the passive safety systems. To provide high reliability, these valves are designed to actuate to their safeguards positions upon loss of power or upon receipt of a safeguards actuation signal. They are supported by multiple, reliable power sources to avoid unnecessary actuations.

The passive safety systems do not require the large network of active safety support systems (ac power, HVAC, cooling water, and the associated seismic buildings to house these components) that are needed in typical nuclear plants. As a result, support systems no longer must be safety class, and they are simplified or eliminated.

The AP1000 passive safety-related systems include:

- The passive core cooling system (PXS)
- The passive containment cooling system (PCS)
- The main control room emergency habitability system (VES)
- Containment isolation

These passive safety systems provide a major enhancement in plant safety and investment protection as compared with conventional plants. They establish and maintain core cooling and containment integrity indefinitely, with no operator or ac power support requirements. The passive systems are designed to meet the single-failure criteria, and probabilistic risk assessments (PRAs) are used to verify their reliability.

The AP1000 passive safety systems are significantly simpler than typical PWR safety systems since they contain significantly fewer components, reducing the required tests, inspections, and maintenance. They require no active support systems, and their readiness is easily monitored.

Emergency core cooling system- The passive core cooling system (PXS) (Figure 5) protects the plant against reactor coolant system (RCS) leaks and ruptures of various sizes and locations. The PXS provides the safety functions of core residual heat removal, safety injection, and depressurization. Safety analyses (using US NRC-approved codes) demonstrate the effectiveness of the PXS in protecting the core following various RCS break events, even for breaks as severe as the 8-inch (200 mm) vessel injection lines. The PXS provides approximately a 76°F (42.2°C) margin to the maximum peak clad temperature limit for the double-ended rupture of a main reactor coolant pipe.

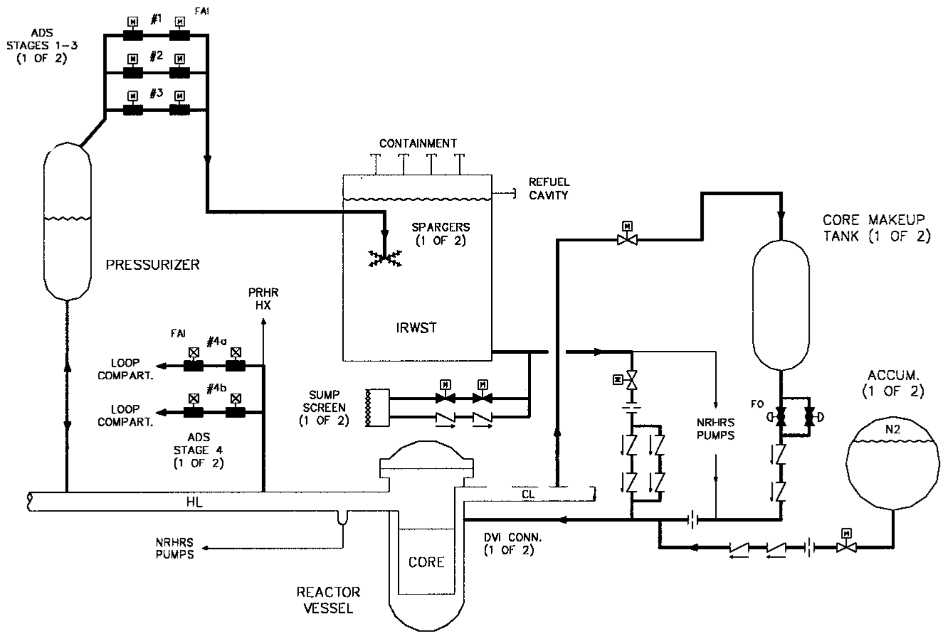

Figure 5 AP1000 Passive core cooling system

Safety injection and depressurization - The PXS uses three passive sources of water to maintain core cooling through safety injection. These injection sources include the core makeup tanks (CMTs), the accumulators, and the IRWST. These injection sources are directly connected to two nozzles on the reactor vessel so that no injection flow can be spilled for the main reactor coolant pipe break cases.

Long-term injection water is provided by gravity from the IRWST, which is located in the containment just above the RCS loops. Normally, the IRWST is isolated from the RCS by squib valves. The tank is designed for atmospheric pressure, and therefore, the RCS must be depressurized before injection can occur.

The depressurization of the RCS is automatically controlled to reduce pressure to about 12 psig (0.18 MPa) which allows IRWST injection. The PXS provides for depressurization using the four stages of the ADS to permit a relatively slow, controlled RCS pressure reduction.

Passive residual heat removal - The PXS includes a 100% capacity passive residual heat removal heat exchanger (PRHR HX). The PRHR HX is connected through inlet and outlet lines to RCS loop 1. The PRHR HX protects the plant against transients that upset the normal steam generator feedwater and steam systems. The PRHR HX satisfies the safety criteria for loss of feedwater, feedwater line breaks, and steam line breaks.

The IRWST provides the heat sink for the PRHR HX. The IRWST water volume is sufficient to absorb decay heat for more than 1 hour before the water begins to boil. Once boiling starts, steam passes to the containment. This steam condenses on the steel containment vessel and, after collection, drains by gravity back into the IRWST. The PRHR HX and the passive containment cooling system provide indefinite decay heat removal capability with no operator action required.

Passive containment cooling - The passive containment cooling system (PCS) (Figure 6) provides the safety-related ultimate heat sink for the plant. As demonstrated by computer analyses and extensive test programs, the PCS effectively cools the containment following an accident such that the pressure is rapidly reduced and the design pressure is not exceeded.

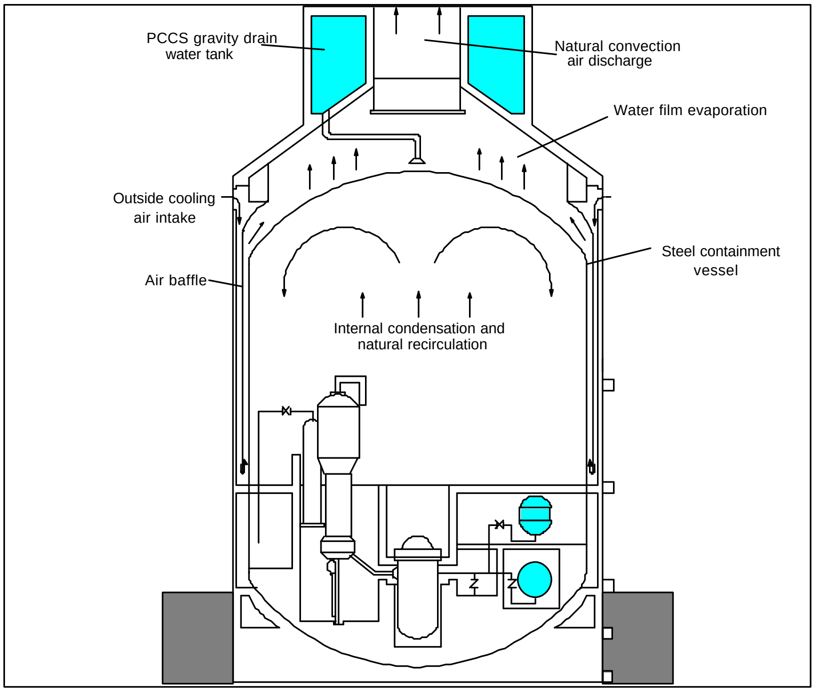

Figure 6 AP1000 Passive containment cooling system

The steel containment vessel provides the heat transfer surface that removes heat from inside the containment and rejects it to the atmosphere. Heat is removed from the containment vessel by continuous natural circulation flow of air. During an accident, the air cooling is supplemented by evaporation of water. The water drains by gravity from a tank located on top of the containment shield building.

Calculations have shown the AP1000 to have a significantly reduced large release frequency following a severe accident core damage scenario. With only the normal PCS air cooling, the containment stays well below the predicted failure pressure for at least 24 hours. Other factors include improved containment isolation and reduced potential for LOCAs outside of containment. This improved containment performance supports the technical basis for simplification of offsite emergency planning.

Main control room emergency habitability - The main control room emergency habitability system (VES) provides fresh air, cooling, and pressurization to the main control room (MCR) following a plant accident. Operation of the VES is automatically initiated upon receipt of a high MCR radiation signal, which isolates the normal control room ventilation path and initiates pressurization. Following system actuation, all functions are completely passive. The VES air supply is contained in a set of compressed air storage tanks. The VES also maintains the MCR at a slight positive pressure, to minimize the infiltration of airborne contaminants from the surrounding areas.

Containment isolation - AP1000 containment isolation is significantly improved over that of conventional PWRs. One major improvement is the large reduction in the number of penetrations. Furthermore, the number of normally open penetrations is reduced by 60 percent. There are no penetrations required to support post-accident mitigation functions (the canned motor reactor coolant pumps do not require seal injection, and the passive residual heat removal and passive safety injection features are located entirely inside containment).

Long-term accident mitigation - A major safety advantage of the AP1000 versus current-day PWRs is that long-term accident mitigation is maintained by the passive safety systems without operator action and without reliance on offsite or onsite ac power sources. For the limiting design basis accidents, the core coolant inventory in the containment for recirculation cooling and boration of the core is sufficient to last for at least 30 days, even if inventory is lost at the design basis containment leak rate.

6.3 Severe accidents (Beyond design basis accidents)

In-vessel retention of molten core debris - In-vessel retention (IVR) of molten core debris via water cooling of the external surface of the reactor vessel is an inherent severe accident management feature of the AP1000 passive plant. During postulated severe accidents, the accident management strategy to flood the reactor cavity with in-containment refueling water storage tank (IRWST) water and submerge the reactor vessel is credited with preventing vessel failure in the AP1000 probabilistic risk assessment (PRA). The water cools the external surface of the vessel and prevents molten debris in the lower head from failing the vessel wall and relocating into the containment. Retaining the debris in the reactor vessel protects the containment integrity by preventing ex-vessel severe accident phenomena, such as ex-vessel steam explosion and core-concrete interaction, which have large uncertainties with respect to containment integrity.

The passive plant is uniquely suited to in-vessel retention because it contains features that promote external cooling of the reactor vessel. Figure 7 provides a schematic of the AP1000 reactor vessel, vessel cavity, vessel insulation and vents configuration that promotes IVR of molten core debris.

- The reliable multi-stage reactor coolant system (RCS) depressurization system results in low stresses on the vessel wall after the pressure is reduced.
- The vessel lower head has no vessel penetrations to provide a failure mode for the vessel other than creep failure of the wall itself.
- The reactor cavity can be flooded to submerge the vessel above the coolant loop elevation with water intentionally drained from the in-containment refueling water storage tank.
- The reactor vessel insulation design concept provides an engineered pathway for water-cooling the vessel and for venting steam from the reactor cavity.

The results of the AP1000 IVR analysis show that, with the AP1000 insulation designed to increase the cooling limitation at the lower head surface and the cavity adequately flooded, the AP1000 provides significant margin-to-failure for IVR via external reactor vessel cooling.

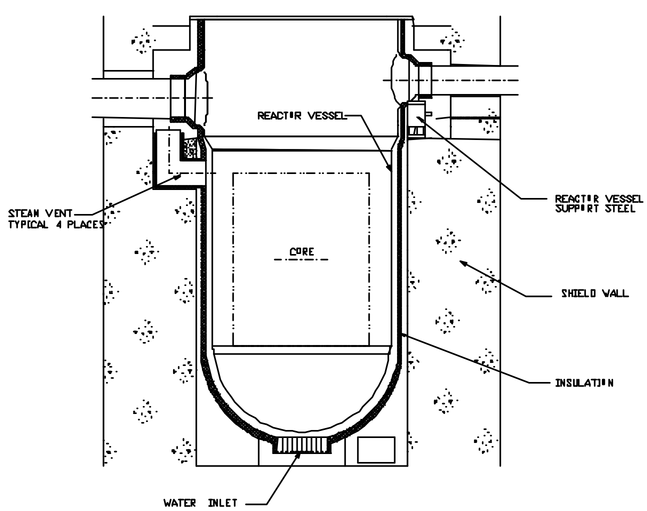

Figure 7 AP1000 Configuration to Promote IVR of Molten Core Debris

7 Plant layout

7.1 Buildings and structures, including plot plan

A typical site plan for a single unit AP1000 is shown on Figure 8. The power block complex consists of five principal building structures; the nuclear island, the turbine building, the annex building, the diesel generator building and the radwaste building. Each of these building structures are constructed on individual basemats. The nuclear island consists of the containment building, the shield building, and the auxiliary building, all of which are constructed on a common basemat.

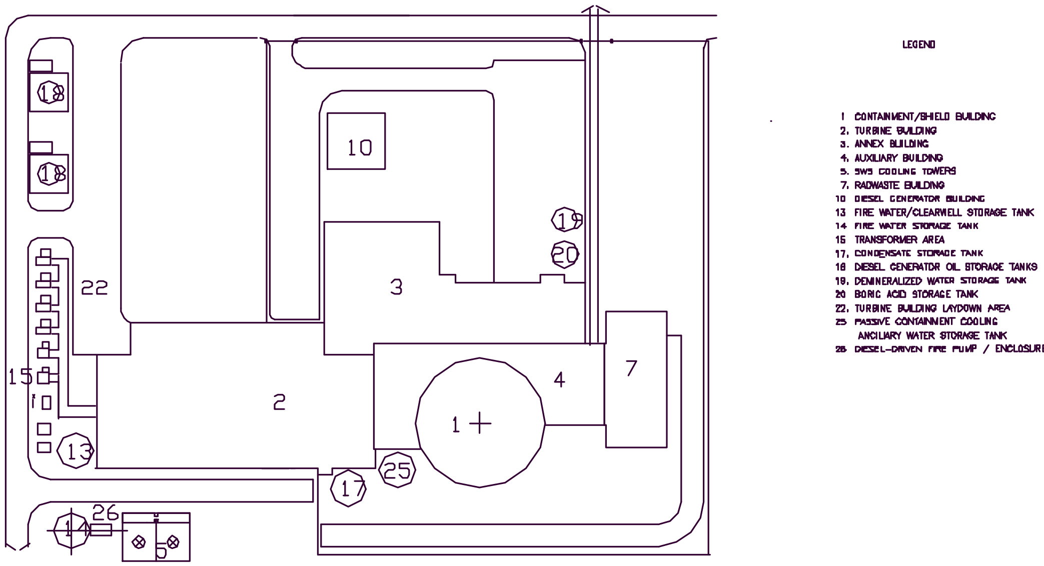

Figure 8 AP1000 - Site layout

Plant arrangement - The AP1000 containment contains a 16-foot (4.9 m) diameter main equipment hatch and a personnel airlock at the operating deck level, and a 16-foot (4.9 m) diameter maintenance hatch and a 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 the two different levels, allow activities occurring above the operating deck to be unaffected by activities occurring below the operating deck.

The containment arrangement provides significantly larger laydown areas than most conventional plants at both the operating deck level and the 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.

7.2 Reactor building

The reactor building of the AP1000 is a shield building surrounding the containment (Section 7.3).

7.3 Containment

Containment building - The containment building is the containment vessel and all structures contained within the containment vessel. The containment building is an integral part of the overall containment system with the functions of containing the release of airborne radioactivity following postulated design basis accidents and providing shielding for the reactor core and the reactor coolant system during normal operations.

The containment vessel is an integral part of the passive containment cooling system. The containment vessel and the passive containment cooling system are designed to remove sufficient energy from the containment to prevent the containment from exceeding its design pressure following postulated design basis accidents.

The principal systems located within the containment building are the reactor coolant system, the passive core cooling system, and the reactor coolant purification portion of the chemical and volume control system.

Shield building - The shield building is the structure and annulus area that surrounds the containment vessel. During normal operations the shield building, in conjunction with the internal structures of the containment building, provides the required shielding for the reactor coolant system and all the other radioactive systems and components housed in the containment. During accident conditions, the shield building provides the required shielding for radioactive airborne materials that may be dispersed in the containment as well as radioactive particles in the water distributed throughout the containment.

The shield building is also an integral part of the passive containment cooling system. The passive containment cooling system air baffle is located in the upper annulus area. The function of the passive containment cooling system air baffle is to provide a pathway for natural circulation of cooling air in the event that a design basis accident results in a large release of energy into the containment. In this event the outer surface of the containment vessel transfers heat to the air between the baffle and the containment shell. This heated and thus, lower density air flows up through the air baffle to the air diffuser and cooler and higher density air is drawn into the shield building through the air inlet in the upper part of the shield building.

Another function of the shield building is to protect the containment building from external events. The shield building protects the containment vessel and the reactor coolant system from the effects of tornadoes and tornado produced missiles.

7.4 Turbine building

The turbine building houses the main turbine, generator, and associated fluid and electrical systems. It provides weather protection for the laydown and maintenance of major turbine/generator components. The turbine building also houses the makeup water purification system. No safety-related equipment is located in the turbine building.

7.5 Other buildings

Auxiliary building - The primary function of the auxiliary building is to provide protection and separation for the safety-related seismic Category I mechanical and electrical equipment located outside the containment building. The auxiliary building provides protection for the safety-related equipment against the consequences of either a postulated internal or external event. The auxiliary building also provides shielding for the radioactive equipment and piping that is housed within the building. The most significant equipment, systems contained within the auxiliary building are the main control room, I&C systems, electrical power systems, fuel handling area, mechanical equipment areas, containment penetration areas, and the main steam and feedwater valve compartments.

The primary function of the auxiliary building is to provide protection and separation for the safety-related seismic Category I mechanical and electrical equipment located outside the containment building. The auxiliary building provides protection for the safety-related equipment against the consequences of either a postulated internal or external event. The auxiliary building also provides shielding for the radioactive equipment and piping that is housed within the building.
The most significant equipment, systems, and functions contained within the auxiliary building are the following:

- Main control room
- Class 1E instrumentation and control systems
- Class 1E electrical system
- Fuel handling area
- Mechanical equipment areas
- Containment penetration areas
- Main steam and feedwater isolation valve compartment

Main Control Room – The main control room provides the human system interfaces required to operate the plant safely under normal conditions and to maintain it in a safe condition under accident conditions. The main control room includes the main control area, the operations staff area, the switching and tagging room and offices for the shift supervisor and administrative support personnel.
Instrumentation and Control Systems – The protection and safety monitoring system and the plant control system provide monitoring and control of the plant during startup, ascent to power, powered operation, and shutdown. The instrumentation and control systems include the protection and safety monitoring system, the plant control system, and the data display and processing system.

Class 1E Electrical System – The Class 1E system provides 125 volts dc power for safety-related and vital control instrumentation loads including monitoring and control room emergency lighting. It is required for safe shutdown of the plant during a loss of ac power and during a design basis accident with or without concurrent loss of offsite power.

Fuel Handling Area – The primary function of the fuel handling area is to provide for the handling and storage of new and spent fuel. The fuel handling area in conjunction with the annex building provides the means for receiving, inspecting and storing the new fuel assemblies. It also provides for safe storage of spent fuel as described in DCD Section 9.1, Fuel Storage and Handling.
The fuel handling area provides for transferring new fuel assemblies from the new fuel storage area to the containment building and for transferring spent fuel assemblies from the containment building to the spent fuel storage pit within the auxiliary building.

The fuel handling area provides the means for removing the spent fuel assemblies from the spent fuel storage pit and loading the assemblies into a shipping cask for transfer from the facility. The fuel handling area is protected from external events such as tornadoes and tornado produced missiles. Protection is provided for the spent fuel assemblies, the new fuel assemblies and the associated radioactive systems from external events. The fuel handling area is constructed so that the release of airborne radiation following any postulated design basis accident that could result in damage to the fuel assemblies or associated radioactive systems does not result in unacceptable site boundary radiation levels.

Mechanical Equipment Areas – The mechanical equipment located in radiological control areas of the auxiliary building are the normal residual heat removal pumps and heat exchangers, the spent fuel cooling system pumps and heat exchangers, the solid, liquid, and gaseous radwaste pumps, tanks, demineralizers and filters, the chemical and volume control pumps, and the heating, ventilating and air conditioning exhaust fans.

The mechanical equipment located in the clean areas of the auxiliary building are the heating, ventilating and air conditioning air handling units, associated equipment that service the main control room, instrumentation and control cabinet rooms, the battery rooms, the passive containment cooling system recirculation pumps and heating unit and the equipment associated with the air cooled chillers that are an integral part of the chilled water system.

Containment Penetration Areas – The auxiliary building contains all of the containment penetration areas for mechanical, electrical, and instrumentation and control penetrations. The auxiliary building provides separation of the radioactive piping penetration areas from the non-radioactive penetration areas and separation of the electrical and instrumentation and control penetration areas from the mechanical penetration areas. Also provided is separation of redundant divisions of instrumentation and control and electrical equipment.

Main Steam and Feedwater Isolation Valve Compartment – The main steam and feedwater isolation valve compartment is contained within the auxiliary building. The auxiliary building provides an adequate venting area for the main steam and feedwater isolation valve compartment in the event of a postulated leak in either a main steam line or feedwater line.

Annex building - The annex building provides the main personnel entrance to the power generation complex. It includes accessways for personnel and equipment to the clean areas of the nuclear island in the auxiliary building and to the radiological control area. The building includes the health physics facilities for the control of entry to and exit from the radiological control area as well as personnel support facilities such as locker rooms. The building also contains the non-1E ac and dc electric power systems, the ancillary diesel generators and their fuel supply, other electrical equipment, the technical support center, and various heating, ventilating and air conditioning systems. No safety-related equipment is located in the annex building.

The annex building includes the health physics facilities and provides personnel and equipment accessways to and from the containment building and the rest of the radiological control area via the auxiliary building. Provided are large, direct accessways to the upper and lower equipment hatches of the containment building for personnel access during outages and for large equipment entry and exit. The building includes a hot machine shop for servicing radiological control area equipment. The hot machine shop includes decontamination facilities including a portable decontamination system that may be used for decontamination operations throughout the nuclear island.

Diesel generator building - The diesel generator building houses two identical slide along diesel generators separated by a three-hour fire wall. These generators provide backup power for plant operation in the event of disruption of normal power sources. No safety-related equipment is located in the diesel generator building.

Radwaste building - The radwaste building includes facilities for segregated storage of various categories of waste prior to processing, for processing by mobile systems, and for storing processed waste in shipping and disposal containers. No safety-related equipment is located in the radwaste building. Dedicated floor areas and trailer parking space for mobile processing systems is provided for the following:

- Contaminated laundry shipping for offsite processing
- Dry waste processing and packaging
- Hazardous/mixed waste shipping for offsite processing
- Chemical waste treatment
- Empty waste container receiving and storage
- Storage and loading packaged wastes for shipment

The radwaste building also provides for temporary storage of other categories of plant wastes.

8 Technical data

General plant data

Power plant output, gross	1200	MWe
Power plant output, net	1115	MWe
Reactor thermal output [core power 3400 MWt]	3415	MWt
Power plant efficiency, net	33	%
Cooling water temperature	30.5	°C

Nuclear steam supply system

Number of coolant loops	2 hot legs/4 cold legs	
Steam flow rate at nominal conditions	1886	kg/s
Feedwater flow rate at nominal conditions	1887	kg/s
Steam temperature/pressure	272.9/5.76	°C/MPa
Feedwater temperature	226.7	°C

Reactor coolant system

Primary coolant flow rate, per loop	9.94	m^3/s
Reactor operating pressure	15.5	MPa
Coolant inlet temperature, at RPV inlet	280.7	°C
Coolant outlet temperature, at RPV outlet	321.1	°C
Mean temperature rise across core	40.4	°C

Reactor core

Active core height	4.267	m
Equivalent core diameter	3.04	m
Heat transfer surface in the core	5268	m^2
Fuel inventory	84.5	t U
Average linear heat rate	18.7	kW/m
Average fuel power density	40.2	kW/kg U
Average core power density (volumetric)	109.7	kW/l
Thermal heat flux, F_q	2.60	kW/m^2
Enthalpy rise, F_H	1.65	
Fuel material	Sintered UO_2	
Fuel assembly total length	4 795	mm
Rod array	square, 17×17 (XL)	
Number of fuel assemblies	157	
Number of fuel rods/assembly	264	
Number of control rod guide tubes	24	
Number of structural spacer grids	10	
Number of intermediate flow mixing grids	4	
Enrichment (range) of first core	2.35-4.45	Wt% U-235
Enrichment of reload fuel at equilibrium core	4.8	Wt% U-235
Operating cycle length (fuel cycle length)	18	months
Average discharge burnup of fuel (nominal)	60 000	MWd/t
Cladding tube material	ZIRLO ™	
Cladding tube wall thickness	0.57	mm
Outer diameter of fuel rods	9.5	mm
Overall weight of assembly	799.7	kg
Burnable absorber, strategy/material	Discrete burnable absorber, Integral fuel burnable absorber	
Number of control rods	69 (53 black, 16 gray)	
Absorber rods per control assembly	24	
Absorber material	Ag-In-Cd (black), Ag-In-Cd/304SS (gray)	
Drive mechanism	Magnetic jack	
Positioning rate [in steps/min or mm/s]	45	steps/min
Soluble neutron absorber	Boric acid	

Reactor pressure vessel

Cylindrical shell inner diameter	3 988	mm
Wall thickness of cylindrical shell	203	mm
Total height	12056	mm
Base material: cylindrical shell	Carbon steel	
RPV head	Carbon steel	
Liner	Stainless steel	
Design pressure/temperature	17.1/ 343.3	MPa/°C

Steam generators

Type	Delta 125, vertical, U-tube	
Number	2	
Heat transfer surface	11477	m^2
Number of heat exchanger tubes	10025	
Tube dimensions	17.5/15.4	mm
Maximum outer diameter	5575.3	mm

Total height	22460	mm
Transport weight	663.7	t
Shell and tube sheet material	Carbon steel	
Tube material	Inconel 690-TT	

Reactor coolant pump

Type	Canned motor	
Number	4	
Design pressure/temperature	17.1/343.3	MPa/°C
Rated flow rate	4.97	m^3/s
Rated head	111.3	m
Pump speed (nominal)	1750	rpm

Pressurizer

Total volume	59.47	m^3
Steam volume: nominal full load	31.14	m^3
Design pressure/temperature	17.1/360	MPa/°C
Heating power of the heater rods	1600	kW
Inner diameter	2.28	m
Total height (surge nozzle safe end to spray nozzle safe end)	16.27	m

Pressurizer relief tank

Not applicable

Primary containment

Type	Dry, free standing, steel	
Overall form (spherical/cyl.)	Cylindrical	
Dimensions (diameter/height)	39.6/65.63	m
Design pressure/temperature (DBEs)	406.7/148.9	kPa-g/°C
(severe accident situations)	889.4 /204.4	kPa-g/°C
Design leakage rate	0.10	vol%/day
Is secondary containment provided?	Only around containment penetration area	
Material	SA 738, Grade B	

Safety injection

Passive residual heat removal		
Number heat exchangers	1	
Type	Vertical C-tube	
Heat transfer,design	2.01×10^8	Btu/hr
Design pressure/temperature	17.2/343.3	MPa/ °C
Core Makeup Tanks		
Number		2
Volume	70.8	m^3
Design pressure/temperature	17.2/343.3	MPa/ °C
Accumulators		
Number	2	
Volume	56.6	m^3
Design pressure/temperature	5.6/148.9	MPa/ °C
Incontainment Refueling Water Storage Tank (IRWST)		
Number	1	
Volume (minimum)	2092.6	m^3
Design pressure/temperature	0.14/65.6	MPa/ °C

Reactor auxiliary systems

Reactor water cleanup,	capacity	6.3	kg/s
(chemical volume & control)	filter type	Cartridge	
Residual heat removal,	shutdown cooling	89.3	kg/s
(normal RHR)	low pressure makeup	68.9	kg/s

Power supply systems

Main transformer, rated voltage	24 kV/site specific	
rated capacity	1250	MVA
Unit auxiliary transformers, rated voltage	24/6.9	kV
rated capacity	70	MVA
Start-up transformer, rated voltage	Site specific/6.9 kV	
rated capacity	70	MVA
Medium voltage busbars	6	
Number of low voltage busbar systems	10	
Standby diesel generating units: number	2	
rated power	4	MW
Number of diesel-backed busbar systems	2	
Voltage level of these	6900	V ac
Number of DC distributions	10	
Voltage level of these	125	V dc
Number of battery-backed busbar systems	11	
Voltage level of these	125	V ac

Turbine plant

Number of turbines per reactor	1	
Type of turbine(s)	Tandem-compound, 6-flow, 54 in. (1372 mm) last-stage blade	
Number of turbine sections per unit	1HP/ 3LP	
Turbine speed	1800	rpm
	1500	rpm (for 50 Hz)
HP inlet pressure/temperature	5.5/271	MPa/^{o}C

Generator

Type	3-phase, synchronous	
Rated power	1250	MVA
Active power	1200	MWe
Voltage	24	kV
Frequency	50 / 60	Hz

Condenser

Type	Multipressure, single pass	
Cooling water flow rate	37.85	m^3/s
Cooling water temperature	30.5	^{o}C
Condenser pressure	9.1	kPa

Condensate clean-up system

Full flow/part flow	part flow, 33%
Filter type	Deep bed

Feedwater pumps

Main Feedwater Pumps		
Number	3	
Startup Feedwater Pumps		
Number	2	
Design flow rate	0.033	m^3/s
Pump head	990.6	m
Feedwater temperature	26.7	
Pump Speed	3600	rpm

Condensate and feedwater heaters

Number of heating stages	6

9 Summary of measures taken to simplify the design, to reduce costs, construction schedule and the need for maintenance, to achieve high availability and flexibility of operation, and to improve the ability to perform maintenance

The AP1000 is a logical extension of the AP600 design. The AP1000 maintains the same design philosophy of AP600, such as use of proven components, systems simplification and state-of-the-art construction techniques. The AP1000 optimizes the power output while maintaining the AP600 NI footprint, to reduce capital and generation costs.

Simplification - AP1000 is an advance passive nuclear power plant that has been designed to meet globally recognized requirements. A concerted effort has been made to simplify systems and components, to facilitate construction, operation and maintenance and to reduce the capital and generating costs.

The use of passive systems allows the plant design to be significantly simpler than conventional pressurized water plants. In addition to being simpler, the passive safety systems do not require the large network of safety support systems found in current generation nuclear power plants (e.g., Class 1E ac power, safety HVAC, safety cooling water systems and associated seismic buildings). The AP1000 uses 50% fewer valves, 83% less pipe (safety grade), 87% less cable, 36% fewer pumps, and 56% less seismic building volumes than an equivalent conventional reactor.

Simplicity reduces the cost for reasons other than reduction of the number of items to be purchased. With a fewer number of components, installation costs are reduced, construction time is shortened and maintenance activities are minimized.

Construction Schedule- The AP1000 has been designed to make use of modern modular construction techniques. Not only does the design incorporate vendor designed skids and equipment packages, it also includes large structural modules and special equipment modules. Modularization allows construction tasks that were traditionally performed in sequence to be completed in parallel. The modules, constructed in factories, can be assembled at the site for a planned construction schedule of 3 years – from ground-breaking to fuel load. This duration has been verified by experienced construction managers through 4D (3D models plus time) reviews of the construction sequence.

Availability and O&M Costs - The AP1000 combines the best proven PWR technology with utility operating experience to enhance reliability and operability. Steam generators are similar to the recent replacement steam generators, canned motor pumps and rugged turbine generators are proven performers with outstanding operating records. The Digital on-line diagnostic instrumentation and control system features an integrated control system that avoids reactor trips due to single channel failure. In addition, the plant design provides large margins for plant operation before reaching the safety limits. This assures a stable and reliable plant operation with a reduced number of reactor trips (less than one per year). Based on the above, and considering the short planned refueling outage (17 days) and plans to use a 18 to 24-month fuel cycle, the AP1000 is expected to exceed the 93% availability goal.

For AP1000 availability is enhanced by the simplicity designed into the plant, as described above. There are fewer components which result in lower maintenance costs, both planned and unplanned. In addition, the great reduction in safety-related components results in a large reduction in inspection and tests. Simplicity is also reflected in the reduced AP1000 staffing requirements.

10 Project status and planned schedule

The AP1000 is based extensively on the AP600 passive plant design that received Final Design Approval and Design Certification from the United States Nuclear Regulatory Commission (US NRC) in September 1998 and December 1999, respectively. Westinghouse and the U.S. NRC have completed a 12-month pre-licensing review of the AP1000 that established the applicability of AP600 tests and selected safety analysis computer codes to the AP1000 design certification application. On March 28, 2002, following the pre-application review, Westinghouse submitted an Application for Final Design Approval and Design Certification for the AP1000. The U.S. NRC completed its Review for Acceptance and docketed the Application on June 25 2002. The docketing of the application signifies that its content is acceptable for review by the U.S. NRC as a complete safety case, in accordance with appropriate U.S. regulations. The U.S. NRC issued their Draft Safety Evaluation Report for AP1000 on June 16, 2003. The U.S. NRC expects to complete the review of the AP1000 and issue a Final Design Approval (FDA) in 2004.