Status Report - AP 1000 (United States of America)

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1. Overview

- [x] **In Operation**
- [ ] **Under Construction**
- [ ] **Described in**

Link to PRIS	--

- [ ] **New Concept**

Number of Units	--
Year	--

Reference Plant

Name of Site	Sanmen Units 1 & 2; Haiyang Units 1 & 2; Vogtle Units 3 & 4 (Link to PRIS)
Net Power Output (MWe)	1100
Gross Power Output (MWe)	1200

1.1 Introduction

The Westinghouse AP1000 plant is an 1100-MWe class PWR with passive safety features supplemented by simple, active systems to deliver multiple levels of defence, and extensive plant simplifications that enhance construction, operation, maintenance and safety.

The AP1000 plant design philosophy is to achieve very high levels of safety, while applying fundamental objectives of simplification and standardization to all aspects of the plant. Other key approaches implemented in the AP1000 design include: Large margin to safety limits and reduced operator actions │ Reduced components to simplify operations & maintenance │ Optimization of supply chain and localization via specification of only “form, fit, and function” requirements │ High regulatory and licensing pedigree │ Robust load follow capability │ Site parameters selected to fit a wide range of sites.

In addition to the reference configuration (electricity production), the AP1000 plant can also support other needs such as water desalinisation, district heating and hydrogen production.

The AP1000 PWR has successfully been deployed at the Sanmen and Haiyang site in China, and at the Vogtle site in the United States, with two operating AP1000 units at each site.The operating AP1000 units’ outstanding early performance has an 89% average Operation Availability Factor, with five out of six units with a Lifetime Operation Availability Factor above 91.8%.

Eight additional units are currently under construction in China, and the AP1000 plant technology has been selected for the Poland, Bulgaria and Ukraine.

1.2 Development Milestones

1999	Design Certification received from the United States Nuclear Regulatory Commission for the AP600 reactor (first Advanced Passive (AP) technology)
2009	Construction Permits issued for Haiyang Units 1 & 2 and Sanmen Units 1 & 2 (China)
2011	Design Certification received from the United States Nuclear Regulatory Commission for the AP1000 PWR amended design
2012	Combined (construction & operation) Licenses (COLs) issued for Vogtle Units 3 & 4 (United States)
2018	Commercial Operation for Sanmen Units 1 & 2 and Haiyang Unit 1 (China)
2019	Commercial Operation for Haiyang Unit 2 (China)
2023	Commercial Operation for Vogtle Unit 3 (United States)
2024	Commercial Operation for Vogtle Unit 4 (United States)

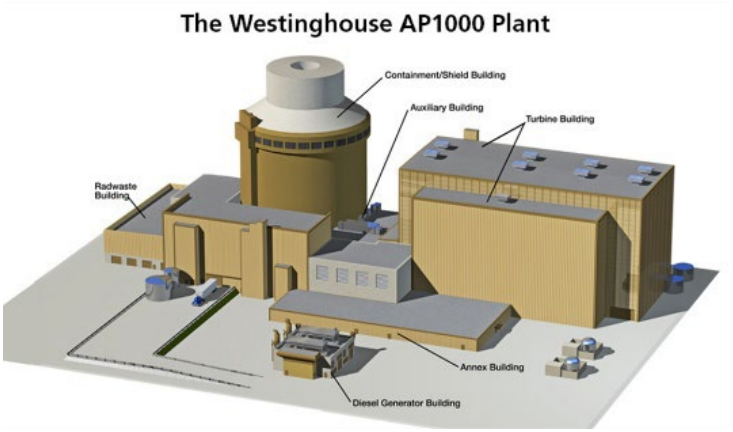
1.3 Design organization or vendor company

gorgemj@westinghouse.com

1.4 Links to designer/vendor website

https://westinghousenuclear.com/

1.5 Design Description



1.6 Licensing Application Support Documents

- AP1000 Design Control Document Revision 19 (certified by the United States Nuclear Regulatory Commission): NRC: Package ML11171A500 -Westinghouse AP1000 Design Control Document Rev. 19
- Vogtle Electric Generating Plant, Units 3 and 4, Updated Final Safety Analysis Report NRC: Package ML23165A212 - Vogtle Electric Generating Plant, Units 3 and 4, Updated Final Safety Analysis Report, Tier 1, Technical Requirements Manual and Technical Specifications Bases Annual Submittal

1.7 Reactor Unit in PRIS

China	Sanmen	2 units operating, 2 units under construction

China	Haiyang	2 units operating, 2 units under construction
China	Xudabu	2 units under construction
China	Lianjiang	2 units under construction
United States	Vogtle	2 units operating

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Dispatchable, Non-electric (for example: District heating)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	On Coast, Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)
Reference Site Design (reactor units per site)	Dual Unit	e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	H2O	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	Thermal power > 3000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	PWR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	Large	e.g. PWR, SMR
Neutron Moderator	H2O	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Loop-type (2 loop(s))	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced (4 pumps)	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H2O	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Square	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	17x17	e.g. #, n/a

Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Operational	e.g. Conceptual, Detailed, Final (with secure suppliers)
Licensing Status	In Operation	e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor	93	%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages	17 days (refuelling outage)	# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources	~550 (dependent on the number of units at site, and owner specific strategies)	# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design	Various	n Units/Modules
Capacity to Electric Grid	1100-1200 (depending on site conditions)	MWe (net to grid)
Non-electric Capacity	Water Production: 270,000 m3/day to ~ 1 million m3 /day of desalinated water using only 5% ~ 10% of generated electricity Hydrogen Production: Reference configuration uses electricity (100MWe) and steam (0.5% of Hot Reheat Steam) to produce up to 50 metric tons (115,000 lbs) of H2/day District Heating: flexible sizing for individual regional needs	e.g. MW(th) heat at x ºC, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption	~80 (partly site-specific)	MWe
Plant Footprint	56,700 for a single rectangular plant envelope. Note that the sum of the footprints of the buildings within this envelope is ~19,000 m2.	m2 (rectangular building envelope)
Site Footprint	112,000 (dependent on project specific requirements)	m2 (fenced area)
Emergency Planning Zone	8 km (site-specific)	km (radius)

Releases during Normal Operation	See Tables 11.2-7 and 11.3-3 of the AP1000 Design Control Document https://www.nrc.gov/docs/ML1117/ML11171A500.html. Note that these values have been calculated using conservative assumptions appropriate for the United States. Country-specific methodologies may yield lower values.	TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed	15% – 100%; 5% per minute	x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)
NSSS Operating Pressure (primary side)	15.4	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	5.76	MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)	~200,000 at power	kg
Nominal Coolant Flow Rate (primary)	15120	kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	280.7	ºC
Core Outlet Coolant Temperature	321.1	ºC
Available Tempeature as Process Heat Source	Up to 175	ºC
NSSS Largest Component	Reactor vessel (empty) / Steam Generator	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	RV: 13000; SG:25500	mm
- NSSS Largest Component Diameter	RV: 7000; SG:6000	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	RV: 320; SG: 695	tonne
Reactor Vessel Material	SA508	e.g. SS304, SS316, SA508, 800H, Hastelloy N

Steam Generator Design	Vertical, U-tube, Feedring -type	e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory	~75,000 (water, per SG, 2 SG per units)	kg
Pressurizer Design	Separate vessel, steam	e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume	59.5	m3 / m3 (total / liquid)
Containment Type	Steel containment	Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume	58333	m3
Spent Fuel Pool Capacity and Total Volume	17 / 721	Years of full-power operation / m3
Non Electric Application		-
Core Delta Temperature	45.3	ºC
Fuel/Core		
Single Core Thermal Power	3400	MW(th)
Refuelling Cycle	Standard design uses 18 months, but 12 or 24 months are also possible	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	4.54/4.95 for 18-month equilibrium cycle reload	%
Average Neutron Energy	Typical PWR thermal spectrum	eV
Fuel Cladding Material	ZIRLO	e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”	157 fuel assemblies	Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit	611 (UO2), 125 (Clad)	kg
Total Fissile Loading (initial)	~87000 kgU (initial core)	kg fissile material (specify isotopic and chemical composition)

% of fuel outside core during normal operation	N/A	Applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge	~75	%
Core Discharge Burnup	Fuel Assembly Avg. ~50 GWd/MTU	MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)	< 62 GWd/MTU	MWd/kgHM
Breeding/Conversion Ratio	~ 0.6	Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing	None	e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Rods supported by boron solution	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber	SS-304/Ag-In-Cd	e.g. Gd2O3
Core Volume (active)	31	m3 (used to calculate power density)
Fast Neutron Flux at Core Pressure Boundary	Typical neutron flux levels are provided in Table 4.3-6 of the AP1000 Design Control Document https://www.nrc.gov/docs/ML1117/ML11171A500.html	n/(cm²*s)
Max. Fast Neutron Flux	Typical neutron flux levels are provided in Table 4.3-6 of the AP1000 Design Control Document https://www.nrc.gov/docs/ML1117/ML11171A500.html	n/(cm²*s)
Core Control Rod Absorber		-
Core Soluble Neutron Absorber		-
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Passive	- / 100 / -
- core injection	Passive	- / 100 / -
- decay heat removal	Passive	- /100 / -
- containment isolation and cooling	Passive	- / - / -

- emergency AC supply (e.g. diesels)	N/A	- / - / -
DC Power Capacity (e.g. batteries)	72	Hours
Events in which Immediate Operator Action is required	None	e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time	72	Hours (that are assumed when following EOPs)
Severe Accident Core Provisions	IVMR	e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)	4.88E-7 (Design Certification PRA)	x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions	H2 ignitors, PARs	e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)	5.61E-8 (Design Certification PRA)	x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)	60 (first nuclear concrete to fuel load)	Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort	See Massachusetts Institute of Technology report on 2024 Total Cost Projection of Next AP1000 https://web.mit.edu/kshirvan/www/research/ANP201%20TR%20CANES.pdf	Person-years (PY) [DP&P]
Construction and Commissioning Effort	See Massachusetts Institute of Technology report on 2024 Total Cost Projection of Next AP1000 https://web.mit.edu/kshirvan/www/research/ANP201%20TR%20CANES.pdf	PY [C&C]
Material and Equipment Overnight Capital Cost	See Massachusetts Institute of Technology report on 2024 Total Cost Projection of Next AP1000 https://web.mit.edu/kshirvan/www/research/ANP201%20TR%20CANES.pdf	Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete	Not publicly available information	(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Nuclear Island (NSSS)	Not publicly available information	
- Conventional Island (Turbine and Cooling)	Not publicly available information	
- Balance of Plant (BOP)	Not publicly available information	

- Commissioning and First Fuel Loading	Not publicly available information	
Factory / On-Site split in [C&C] effort	Not publicly available information	%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate	1889	kg/s
System Steam Pressure	5.76	MPa
System Steam Temperature	272.8	ºC
System Feedwater Flow Rate	1889	kg/s
System Feedwater Temperature	226.7	ºC
Reactor Core		
Active Core Height	4.267	m
Equivalent Core Diameter	3.04	m
Average Linear Heat Rate	18.7	kW/m
Average Fuel Power Density	40.2	kW/kgU
Average Core Power Density	109.68	MW/m3
Outer Diameter Of Fuel Rods	9.5	mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The AP1000 standard plant design uses conservative, bounding site parameters (temperatures, wind velocities, soil conditions, seismic levels, etc.) to achieve a very high level of safety. As a result, the AP1000 plant design can be applied to different geographical regions around the world with varying regulatory standards and utility expectations without major changes.

The AP1000 plant is the most compact nuclear plant design by virtue of its passive system safety approach, and the 'Safe, Simple, Standard' approach. As such it allows for very compact size layout configurations that can minimize space utilized.

The AP1000 plant is highly capable of flexible power output (load following capabilities) providing a unique capability to stabilize modern, renewable grids. The AP1000 plant is also capable to accept full load rejection and, with its proven and reliable passive safety systems, is very resilient to the loss of offsite power.

4.1 Site Requirements during Construction

The AP1000 PWR has been and can be deployed at both inland and on-coast sites. In line with its standardization objective, the Westinghouse AP1000 PWR is designed to an enveloping set of site conditions to ensure the best suitability for a wide range of sites, including soil conditions. Specifically, six different soil profiles from soft soil to hard rock sites have been considered in the standard AP1000 plant design. The standard AP1000 site parameters are presented in detail in Chapter 2 of the AP1000 Design Control Document NRC: Package ML11171A500 -Westinghouse AP1000 Design Control Document Rev. 19.

As the atmosphere is the ultimate heat sink in the AP1000 plant passive safety approach, the key criterion for decay heat removal capability is the ambient air temperature:

Maximum Safety

- 46.1°C dry bulb/30.1°C coincident wet bulb
- 30.1°C wet bulb (noncoincident)

Minimum Safety

- -40°C

Table 1 provides indicative information on some of the major component transportation packages.

TABLE 1. Indicative information on major component transportation packages.

Component	Quantity	Length [m]	Width [m]	Height [m]	Weight [t]
Reactor vessel - body	1	13	6.5	7	320
Pressurizer	1	13.8	3.3	3.9	106.6
Steam Generator	2	25.5	6	5.7	695
Transformers	9	5.4	4.2	5.6	190

The standard AP1000 plant arrangement is comprised of five principal building structures; the nuclear island, the turbine building, the annex building, the diesel generator building, and the radwaste building (see AP1000 plant illustration in introduction).

The nuclear island is constituted of the containment building and shield building, and the auxiliary building.

The containment building is a freestanding, cylindrical, steel containment vessel with elliptical upper and lower heads. It is surrounded by a seismic Category I shield building constructed of reinforced concrete and steel concrete composite modules. 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 vessel provides the safety-related interface with the ultimate heat sink, which is the surrounding atmosphere.

The containment building is designed to house the reactor coolant system and other related systems and provides a high degree of leak tightness.

There are two floor elevations (grade access maintenance floor and operating deck) and four lower equipment compartments within the containment building. Removable hatches are provided for access to equipment at other elevations.

The principal system located within the containment building is the reactor coolant system that consists of two main coolant loops, a reactor vessel, two steam generators, four sealless reactor coolant pumps, and a pressurizer.

The passive core cooling system is also located in the containment building. The primary components of the passive core cooling system are two core makeup tanks, two accumulators, the refueling water storage tank, the passive residual heat removal heat exchanger, and two spargers.

Access to the containment is provided through a personnel airlock and the main equipment hatch located at the operating deck level and a personnel airlock and a maintenance hatch at the maintenance floor level. Access to the containment can be controlled by the health physics office in the annex building. In the event that large numbers of temporary personnel require access to the containment during a major outage, temporary personnel facilities can be provided immediately adjacent to the health physics area in the annex building.

The shield building is the structure that surrounds the containment vessel. During normal operations, a primary function of the

shield building is to provide shielding for the containment vessel and the radioactive systems and components located in the containment building. The shield building, in conjunction with the internal structures of the containment building, provides the required shielding for the reactor coolant system and the other radioactive systems and components housed in the containment.

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.

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 primary function of the auxiliary building is to provide protection and separation for the 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 auxiliary building is separated in two, non-communicating areas: the non-radiologically controlled area and the radiologically controlled area. The most significant equipment, systems, and functions contained within the auxiliary building are the following:

Non-radiologically controlled area:

- *Main control room:* The main control room provides the human system interfacesrequired to operate the plant safely under normal conditions and to maintain it in asafe condition under accident conditions.
- *Class 1E electrical system:* The Class 1E system provides 250 volts dc power forsafety-related and vital control instrumentation loads including monitoring andcontrol room emergency lighting. It is required for safe shutdown of the plant duringa loss of ac power and during a design basis accident with or without concurrentloss of offsite power.
- *The mechanical equipment areas:* these areas houses the heating, ventilating andair conditioning air handling units, associated equipment that service the maincontrol room, instrumentation and control cabinet rooms, the battery rooms, thepassive containment cooling system recirculation pumps and heating unit and theequipment associated with the air cooled chillers that are an integral part of thechilled water system.
- *Main steam and feedwater isolation valve compartment:* The main steam andfeedwater isolation valve compartment is contained within the auxiliary building.The auxiliary building provides an adequate venting area for the main steam andfeedwater isolation valve compartment in the event of a postulated leak in either amain steam line or feedwater line.
- *Containment penetration areas:* The auxiliary building contains all of thecontainment penetration areas for mechanical, electrical, and instrumentation andcontrol penetrations. The auxiliary building provides separation of the radioactivepiping penetration areas from the non-radioactive penetration areas and separationof the electrical and instrumentation and control penetration areas from themechanical penetration areas. Also provided is separation of redundant divisions ofinstrumentation and control and electrical equipment.

Radiologically controlled area:

- *Fuel handling area:* The primary function of the fuel handling area is to providefor the handling and storage of new and spent fuel. The fuel handling area inconjunction with the annex building provides the means for receiving, inspectingand storing the new fuel assemblies. It also provides for safe storage of spent fuel. Each AP1000 unit includes a spent fuel pool (located in the auxiliary building) which can safely store 889 fuel assemblies, which corresponds to approximately 17 years of operation. There is no other location for spent fuel storage in the standard AP1000 plant. However, as necessary per the local and owner requirements, a specific project may also include on site an interim spent fuel storage facility.
- *Mechanical equipment areas:* The mechanical equipment located in radiologicalcontrol areas of the auxiliary building are the normal residual heat removal pumpsand heat exchangers, the spent fuel cooling system pumps and heat exchangers, thesolid, liquid, and gaseous radwaste pumps, tanks, demineralizers and filters, thechemical and volume control pumps, and the heating, ventilating and airconditioning exhaust fans.
- *Containment penetration areas* as discussed above.

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 control support area, 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.

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.

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.

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.

4.2 Site Considerations during Operation

Water usage is highly site specific. The Circulating Water System (CWS), which cools the condenser, is by far the largest user of raw water within the AP1000 plant. The choice of a condenser cooling technology is a site-specific design choice. Mechanical draft cooling towers are used in the AP1000 standard plant CWS configuration. However, the AP1000 plants in operation use direct, once-through cooling (at the Sanmen and Haiyang sites, in China) and natural draft cooling towers (at the Vogtle site, in the United States). Less water consuming options exist and could be leveraged for sites where water availability is limited. The thermal discharges and the mode of discharge (to a water body or to the atmosphere) are highly dependent on the selection of a condenser technology, which a project-specific choice.

The AP1000 plant implements several features and strategies to minimise normal and abnormal emissions:

- The AP1000 plant is designed with fewer valves and components thanpredecessor plants which results in fewer leakage pathways and lower overallinput to the radwaste systems.
- Core reactivity is controlled by means of a chemical poison (boric acid)dissolved in the coolant, rod cluster control assemblies, gray rod clusterassemblies, and burnable absorbers. The gray rod cluster assemblies are used inload follow manoeuvring and provide a mechanical shim reactivity mechanismwhich eliminates the need for chemical shim control provided by changes to theconcentration of soluble boron. Discrete burnable absorber rods, integral fuelburnable absorber rods, or both may be used to provide partial control of theexcess reactivity available during the fuel cycle. In doing so, the burnableabsorber rods reduce the requirement for soluble boron in the moderator at thebeginning of the fuel cycle. The reactor controls provided by gray rods andburnable absorber rods reduce the requirements for varying the boronconcentrations in the primary circuit, thereby reducing the amount of liquidwaste.
- The containment is a free-standing steel pressure vessel surrounded by a steelconcrete composite shield building. The containment vessel, including all itspenetrations, is a low-leakage steel vessel designed to contain radioactivematerial that may be released from the reactor core following a design basisaccident such that offsite radiation exposures are maintained within limits. Thecontainment and shield building provide shielding from the fission products thatmay be present in the containment atmosphere following accident conditions.

The basic AP1000 PWR design principles minimize the creation of radwaste during operations and decommissioning. With fewer valves, pipes, and other components, less waste is generated during maintenance activities (repair and replacement) and decommissioning.

Waste generation is minimized in the AP1000 plant by material selection, for example, the level of cobalt in reactor internal structures, which limits the activation of the metal components. Surfaces, including steel wall and floor surfaces, are sealed to prevent penetration and to facilitate decontamination. Also, during operation and maintenance, waste is minimized by using best industry practices (for example, limiting the amount of material brought into containment).

Considering these characteristics, the decommissioning phase of the AP1000 plant is expected to be shorter. The decommissioning activities are expected to produce smaller quantities of activated or contaminated materials that need to be treated and conditioned for interim storage, and (potentially) final disposal as radioactive waste, when compared with other

nuclear power plants of similar power rating.

Westinghouse has performed a Constructability, Operability, Maintainability Inspectability, Testability (COMIT) design review for the AP1000 plant design, which included a room-by-room evaluation of components to confirm proper provisions for access and/or removal capabilities. The AP1000 plant uses proven NSSS equipment and therefore the maintenance activities to be carried on-line or during an outage can leverage the proven processes and tools developed for previous generations of nuclear power plants. The overall reduction of systems, structures and equipment achieved in the AP1000 plant also results in a lower volume of maintenance activity. As a result, the estimated duration for a refueling outage is 17 days for the AP1000 plant.

The AP1000 plant is a PWR designed for maintainability and operability. It does not require special equipment, tooling, infrastructure or systems that has not yet been already developed to support previous generations of nuclear power plants.

The manpower required during operation is highly project-specific and depends on project strategies. However, an evaluation was performed that estimated the size of the operation & maintenance staff for the operation of a single-AP1000 unit site at around 550 people.

The AP1000 plant includes features, such as a technical support center and communication system, to support the operator's emergency plans.

The emergency planning zone requirements for the AP1000 NPP reactor are broadly site-specific, with consideration for the site-specific risk profile and country-specific requirements.

4.3 Grid Integration

Westinghouse has delivered AP1000 plants in countries with both 50-Hz and 60-Hz grid. The net power output of an AP1000 unit is impacted by site-specific designs and project-specific decisions and ranges from 1100 MWe to upwards of 1200 MWe.

A defined design basis (reference) daily load following operation profile has been established for the AP1000 plant. It is used as the design basis profile for analyses impacted by load following operation, such as the equipment design transients. It does not limit operational capability to this reference profile. The reference load follow profile is:

- Linear power ramp from 100% to 50% in 2 hours
- Remain at 50% power for 2 to 10 hours
- Linear power ramp from 50% to 100% in 2 hours
- Remainder of 24 hours at 100% power

Using this profile, the AP1000 plant is designed for load follow operation for up to 90% of the fuel cycle using the mechanical shim (MSHIM) mode of operation. The benefit of this mode of operation is that the critical boron concentration remains constant during load follow, significantly reducing the generation of wastewater. The axial power shape can be maintained throughout the load follow sequence while simultaneously maintaining a constant boron concentration. As a result, MSHIM operation does not generate severe axial xenon oscillations and radial power distributions that would lead to violations of maximum heat flux hot channel factor and departure from nucleate boiling ratio limits. Operation at the reference load follow profile is within the NSSS design basis for component design.

In addition to the design basis capability, the AP1000 plant has the capability for variation in scheduled and unscheduled load follow operations during 90% of the fuel cycle. The AP1000 plant is capable of load following operation over the range of 100% power to 15% power.

The AP1000 plant capability for load follow operations includes such variations as:

- Any load follow pattern that changes power by less than 50% and is slower thanthe reference load follow can be performed daily for the first 90% of the cycle.
- Load follow maneuvers to 30% power (at approximately 85% of cycle).
- Weekend load follow to 50% power (down power that lasts for 2 days).
- Daily load follow operations between 100% and 50%, at ramp rates and plateausother than the reference load follow profile.

The NSSS control system is designed to perform power maneuvers anywhere between 15% and 100% power and can accommodate ramp rates up to 5% per minute, with the average coolant temperature as the primary control parameter.

The plant is designed to accept a 100 percent load rejection from full power to house loads without reactor trip or operation of the pressurizer or steam generator safety valves. The design provides for a turbine capable of continued stable operation at house loads.

In terms of importance of the grid reliability for off-normal operation, the use of passive safety systems combined with active defence-in-depth systems powered by redundant onsite standby diesel generators make the AP1000 plant very resilient to loss of offsite power events. This category of events only represents 0.4% of the AP1000 plant core damage frequency (in the standard plant design certification probabilistic risk assessment), while it usually represents 25% of the core damage frequency for Generation II, active nuclear power plants.

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

The AP1000 plant is designed around a 2 loop, 2 steam generator primary system configuration with two hot legs, four reactor coolant pumps directly mounted in the steam generator lower head and four cold legs. The power producing primary system is a familiar one based on proven and reliable Westinghouse PWR features, but with evolutionary improvements to be expected with the benefit of decades of operating experience, development of improved materials and better manufacturing techniques.
The core, reactor vessel, and reactor internals of the AP1000 plant are similar to those of conventional Westinghouse PWR designs. The reactor core is comprised of 157, 426.7 cm (14 feet) long, 17x17 UO2 fuel assemblies and has several important enhancements, all based on existing technology, that improve the performance characteristics of the design.

Fuel is handled in two areas of the plant: the Containment Building and the Fuel Handling Area of the Auxiliary Building. The fuel handling equipment and fuel movement with the AP1000 plant are similar to those implemented in previous PWRs.

During normal operation, the reactivity control of the core depends on control rods, which are moved by the plant control system using the control rod drive mechanisms, dissolved boron in the coolant, and other poisons. The normal control of the boron concentration is one of the functions of the chemical and volume control system. The AP1000 plant provides instrumentation and controls to sense accident situations and initiate engineered safety features. 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.
The condensate and feedwater system supplies the steam generators with heated feedwater in a closed steam cycle using regenerative feedwater heating. The AP1000 turbine generator 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 containment vessel is a free-standing, cylindrical steel vessel with ellipsoidal upper and lower heads. The AP1000 containment isolation is significantly improved over that of conventional PWRs. The Containment Leak Rate Test System (VUS) provides a vehicle for confirming that the containment vessel leak rate is less than the value used in design analysis. The AP1000 containment is capable of providing an effective barrier to the release of fission products to the environment and includes effective hydrogen control measures.

The AP1000 plant safety and operation is supported by the AP1000 instrumentation and control architecture which is arranged in a hierarchical manner to provide a simplified structured design that is horizontally and vertically integrated, and an advanced main control room.

The AP1000 plant is the only operating nuclear power plant with safety-related passive safety systems. Another unique technical design feature is the adoption of modular construction for the AP1000 plant. Modular construction allows activities to be run in parallel and it also allows more activities to be performed in a controlled factory environment instead of in the field.

5.1 Primary Circuit

The primary circuit of the AP1000 reactor retains most of the general design features of Generation II PWRs, with added evolutionary features to enhance the safety and maintainability of the system. The Reactor Coolant System (RCS) 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 release of radioactivity and is designed to provide a high degree of integrity throughout operation of the plant.

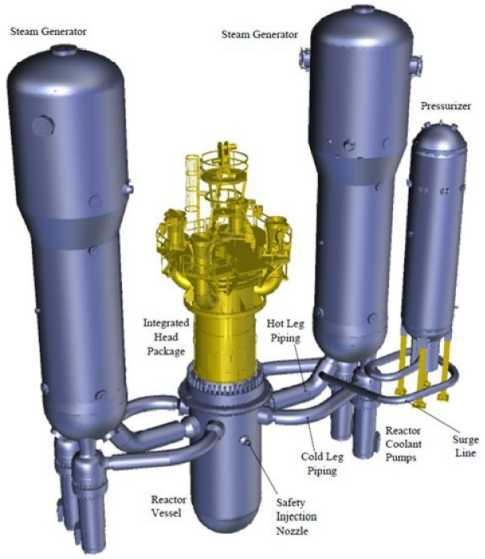


Figure 1. AP1000 Reactor Coolant System.

The reactor vessel 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 12.0 m (39.5 feet) long and has an inner diameter at the core region of approximately 4.039 m (159 inches). Surfaces which can become wetted during operation and refueling are clad with stainless steel welded overlay. The AP1000 plant reactor vessel design pressure and temperature are 17.1 MPa (2500 psia) and 343°C (650°F) respectively and has a 60 year design life. As a safety enhancement, there are no reactor vessel penetrations below the top of the core. This feature is part of the AP1000 plant severe accident strategy to retain core debris inside the reactor vessel following postulated scenarios that result in core melt. The core is positioned low in the vessel to minimize reflood time following postulated large LOCAs and also supports in-vessel retention of core debris following core melt.

The AP1000 plant reactor coolant pumps are high-inertia, high-reliability, low-maintenance, hermetically sealed pumps that circulate the reactor coolant through the reactor core, loop piping, and steam generators. The motor size is minimized through the use of a variable speed controller to reduce motor power requirements during cold coolant conditions, and to allow the use of identical pumps in countries with either 50Hz or 60Hz electrical grids. Two pumps are mounted directly in the channel head of each steam generator. This configuration eliminates the crossover leg of coolant loop piping between the steam generator and the pump, thereby reducing the loop pressure drop and simplifying the foundation and support system for the steam generator, pumps, and loop piping. The elimination of the cross-over piping also reduces the potential for uncovering of the core by eliminating the need to clear the loop seal during a small 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 an internal flywheel to increase the pump rotating inertia and thereby providing a slower rate-of-flow coastdown to improve core thermal margins following the loss of electric power.

Two model Delta-125 steam generators are used in the AP1000 plant. The steam generators operate on all volatile treatment secondary side water chemistry. The AP1000 plant steam generator design includes enhancements such as 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 anti-vibration bars, upgraded primary and secondary moisture separators, enhanced maintenance features, and a primary-side channel head design that allows easy access and maintenance by robotic tooling. All tubes in the

steam generator are accessible for sleeving, if necessary.

The AP1000 plant pressurizer is of conventional design, based on proven technology. The pressurizer volume is approximately 59.5 m3 (2100 ft3). The large pressurizer minimizes challenges to the plant and operator during transients by providing increased operating margins resulting in a more reliable plant with fewer reactor trips. The large pressurizer size also eliminates the need for fast-acting power-operated relief valves, which are a possible source of RCS leakage and maintenance.

The RCS piping is configured with two identical main coolant loops, each employing a single 790 mm (31-inch) inside diameter hot leg pipe to transport reactor coolant to a steam generator and two 560 mm (22-inch) inside diameter cold leg pipes (one per pump) to transport reactor coolant back to the reactor vessel to complete the circuit. The two reactor coolant pump suction nozzles are welded directly to the outlet nozzles on the bottom of the steam generator channel head. 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 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 multi-piece, 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 postulated small cold leg break LOCA event.

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 whip 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 and supports.

The reactor coolant system is also served by a number of auxiliary systems, including the chemical and volume control system and the normal residual heat removal system described hereafter, the primary sampling system that allows adequate sampling of the RCS, the liquid radwaste system which collects leakage and let downs from the RCS and the component cooling water system which cools the external heat exchanger of the reactor coolant pumps.

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

- Purification - maintains reactor coolant purity and activity level within acceptablelimits.
- Reactor coolant system inventory control and makeup - maintains the requiredcoolant inventory in the reactor coolant system; maintain the programmedpressurizer water level during normal plant operations.
- Chemical shim and chemical control - maintains reactor coolant chemistry duringplant start-ups, normal boron dilution for plant start-up and to compensate for fueldepletion, shutdown boration, and controls the reactor coolant system pH bymaintaining the proper level of lithium hydroxide.
- Oxygen control - provides the means for maintaining the proper level of dissolvedhydrogen in the reactor coolant during power operation and for achieving theproper oxygen level prior to plant start-up after each shutdown.
- Filling and pressure testing of the reactor coolant system – provides the means forfilling and pressure testing of the reactor coolant system. The chemical and volumecontrol system does not perform hydrostatic testing of the reactor coolant systembut provides connections for a temporary hydrostatic test pump.
- Borated makeup to auxiliary equipment - provides makeup water to the primaryside systems, which requires borated reactor grade water.
- Pressurizer Auxiliary Spray - provides pressurizer auxiliary spray water fordepressurization.

The normal residual heat removal system consists of two mechanical trains of equipment, each comprising one pump and one heat exchanger. The system also includes the piping, valves and instrumentation necessary for system operation. The major functions are:

- Shutdown heat removal - removes residual and sensible heat from the core and thereactor coolant system during plant cooldown and shutdown operations. Thesystem provides reactor coolant system cooldown from 177 to 48.9°C (350

to120°F) within 96 hours after shutdown and maintains the reactor coolanttemperature at or below 48.9°C (120°F).
- Shutdown purification - provides reactor coolant system and refuelling cavitypurification flow to the chemical and volume control system during refuellingoperations.
- In-containment refuelling water storage tank (IRWST) cooling– provides coolingto the IRWST to limit the IRWST water temperature to less than 100°C (212°F) during extended operation of the passive residual heat removal system and to not greater than 48.9°C (120°F) during normal operation.
- Low pressure reactor coolant system makeup and cooling - provides low pressuremakeup to the reactor coolant system from the cask loading pit and then from the IRWST thus providing additional margin for core cooling.
- Low temperature overpressure protection - provides low temperature overpressureprotection for the reactor coolant system during refuelling, start-up, and shutdownoperations.
- Long-term, post-accident containment inventory makeup flow path - provides aflow path for long term post-accident makeup to the reactor containment waterinventory to make up for containment leakage.
- Post-accident recovery - removes heat from the core and the reactor coolant systemfollowing successful mitigation of an accident by the passive core cooling system.
- Spent fuel pool cooling - provides backup cooling of the spent fuel pool.

5.2 Reactor Core and Fuel

The core, reactor vessel, and reactor internals of the AP1000 plant are similar to those of conventional Westinghouse PWR designs. The reactor core is comprised of 157, 426.7 cm (14 feet) tall fuel assemblies based on the Westinghouse 17x17 Robust Fuel Assembly (RFA) design, which has been utilized extensively in more than 50 plants worldwide, exhibiting excellent performance in over 20 years of reliable and cost-effective operation. Based on a long history of experience gained from earlier Westinghouse fuel designs, the RFA fuel design was first introduced in 1997. Since then, it has undergone numerous design enhancements and evolutions to further improve fuel and plant performance and reliability. Thanks to the Westinghouse state-of-the-art fuel design and fuel management strategies, the AP1000 core achieves more than 15% margin to departure from nucleate boiling (DNB), featuring ZIRLOTM grids, removable top nozzles, and providing excellent performance and reliability. The AP1000 plant core design and gravity driven boron addition from the core makeup tanks increase safety margins for accident scenarios such as Anticipated Transients Without Scram (ATWS).

The materials between the core and the pressure vessel 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 the associated reactor vessel downcomer water annuli.

The AP1000 features an 18-month low-leakage advanced first core with five fuel regions spanning enrichments from natural U to 4.8 w/o U-235. The placement of natural U on some of the peripheral assemblies helps achieving a low leakage design, which improves fuel cycle economics, while the checkerboard of lower and higher enriched fuel in the inner part of the core mimics the conditions of subsequent reloads, containing fresh and burned fuel assemblies. This state-of-the-art fuel management strategy allows to quickly converge subsequent fuel reloads on the behavior at the equilibrium cycle, minimizing the impact of transition cycles and allowing significant operational and fuel economics improvements compared to traditional first core designs. The equilibrium cycle consists of split-feed ~2.5-batch fuel reloads with average U-235 enrichment of ~4.5 w/o U-235 achieving an assembly-average discharge burnup in excess of 50000 MWd/tU, with peak pin BU within current licensed limit of 62000 MWd/tU and fissile use well in excess of 1.10 GWd/kgU-235.

The AP1000 plant incorporates both reduced-worth (“gray”) rod cluster control assemblies (RCCAs) and heavy-worth (“black”) RCCAs to implement the mechanical shim (MSHIM) operational strategy. The MSHIM operation and control strategy greatly simplifies reactor operations by automatically moving certain banks to compensate reactivity changes as the core depletes throughout the cycle, thereby requiring the operator to make changes to the soluble boron concentration only every few weeks instead of multiple times a day. Additionally, the MSHIM strategy allows to perform load following manoeuvres without changes to the soluble boron concentration during the manoeuvre. This eliminates the need for processing thousands of liters of water per day to change the reactor coolant soluble boron concentration. As a result, there is no need for a boron processing/recycle system and the waste liquid system is simplified since letdown flow and processing are greatly decreased. Other than for containing a lighter (and slow depleting) neutron absorber, which allows for their insertion at power with minimal perturbation to power distribution and loss in negative reactivity worth from absorber depletion, the design of the gray RCCAs is identical to that of the heavy (standard) RCCAs.

Westinghouse is the largest supplier of nuclear fuel world-wide and has an extensive experience and three world-class facilities that fabricate our fuel. Westinghouse provides security and diversity of supply, currently supporting 145 nuclear plants

worldwide. A benefit of operating a global manufacturing system is the resiliency it provides. Cross-qualification of manufacturing fuel designs at multiple facilities adds to the depth of manufacturing experience and broadens the ability for sites to support one other (including the ability to shift load from one Westinghouse plant to the next to navigate market fluctuations and preclude any interruption in fuel supply). This reliable, robust, redundant network is a key strategic factor in Westinghouse's ability to guarantee a secure supply of state-of-the-art fuel products for AP1000 customers worldwide.

5.3 Fuel Handling

Fuel is handled in two areas of the plant: the Containment Building and the Fuel Handling Area of the Auxiliary Building. The refueling cavity inside Containment is flooded only during plant shutdown for refueling. The Fuel Handling Area provides for transferring new fuel assemblies from the Auxiliary Building rail car bay to and 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 pool within the Auxiliary Building. The Fuel Handling Area provides the means for removing the spent fuel assemblies from the spent fuel storage pool 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.

New fuel is stored in a high-density rack which includes integral neutron absorbing material to maintain sub-criticality. 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 sub-critical array even in the event the building is flooded with unborated water, fire extinguishing aerosols, or during any design basis event.

Spent fuel is stored in high density racks which include integral neutron absorbing material to maintain subcriticality. The racks are designed to store fuel of the maximum design basis enrichment. The spent fuel storage racks include storage locations for 884 fuel assemblies and five defective fuel assemblies. The design of the racks is such that a fuel assembly cannot be inserted into a location other than a location designed to receive an assembly.

The Spent Fuel Pool Cooling System is designed to remove decay heat from the stored fuel assemblies by removing heat 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 cooler water to the pool. A secondary function of this system is clarification and purification of the water in the spent fuel pool, the transfer canal, and the refuelling water. The major functions of the system are:

- Spent fuel pool cooling - removes heat from the water in the spent fuel pool duringall plant operations to maintain the pool water temperature within acceptable limits.
- Spent fuel pool purification - provides purification and clarification of the spentfuel pool water during operation.
- Refuelling cavity purification - provides purification of the refuelling cavity duringrefuelling operations.
- Water transfers - transfers water between the in-containment refuelling waterstorage tank (IRWST) and the refuelling cavity during refuelling operations.
- In-containment refuelling water storage tank purification - provides purificationand cooling of the IRWST during normal operation.

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

5.4 Reactor Protection

During normal operation, the reactivity control of the core depends on control rods, which are moved by the plant control system using the control rod drive mechanisms, dissolved boron in the coolant, and other poisons. The normal control of the boron concentration is one of the functions of the chemical and volume control system.
The AP1000 plant provides instrumentation and controls to sense accident situations and initiate engineered safety 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 safety features. This combination of events prevents or mitigates damage to the core and RCS components and provides containment integrity.

The engineered safety features of the AP1000 plant include the passive core cooling system and the passive containment cooling system.

The Passive Core Cooling System (PXS), shown below, protects the plant against all postulated events from transients to Reactor Coolant System (RCS) 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 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, 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 they are injected.

There are two CMTs located inside the containment at an elevation above the reactor coolant loops. During normal operation, the CMTs are completely full of 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 valves that are located in parallel in the tank discharge lines.

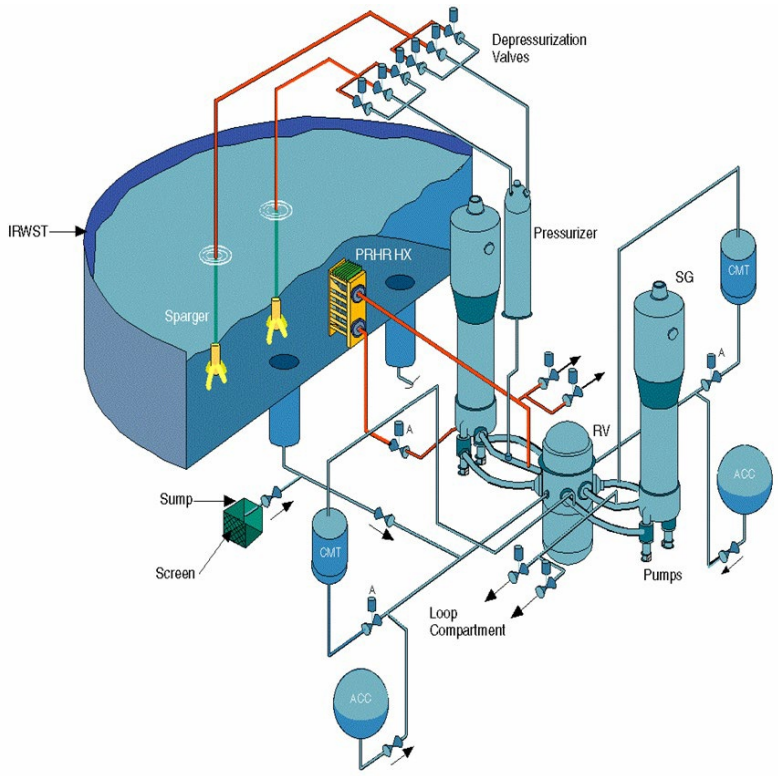


Figure 2. AP1000 Passive Core Cooling System.

The two accumulators contain borated water and a compressed nitrogen cover gas 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, so that they 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.

The PXS includes one passive residual heat removal heat exchanger (PRHR HX). 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 in-containment refueling water storage tank (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 valves that are located in parallel in the HX outlet (return) line. Following PRHR HX actuation the IRWST water can absorb the core decay heat and RCS sensible heat for almost two hours before the IRWST water begins to boil. Once boiling starts, steam is vented to the containment and is condensed on the steel containment vessel and, after collection, drains by gravity back into the IRWST. The PRHR HX, the IRWST water inventory, and the passive containment cooling system (described below) provide decay heat removal capability for an extended time with no operator action or AC power required.

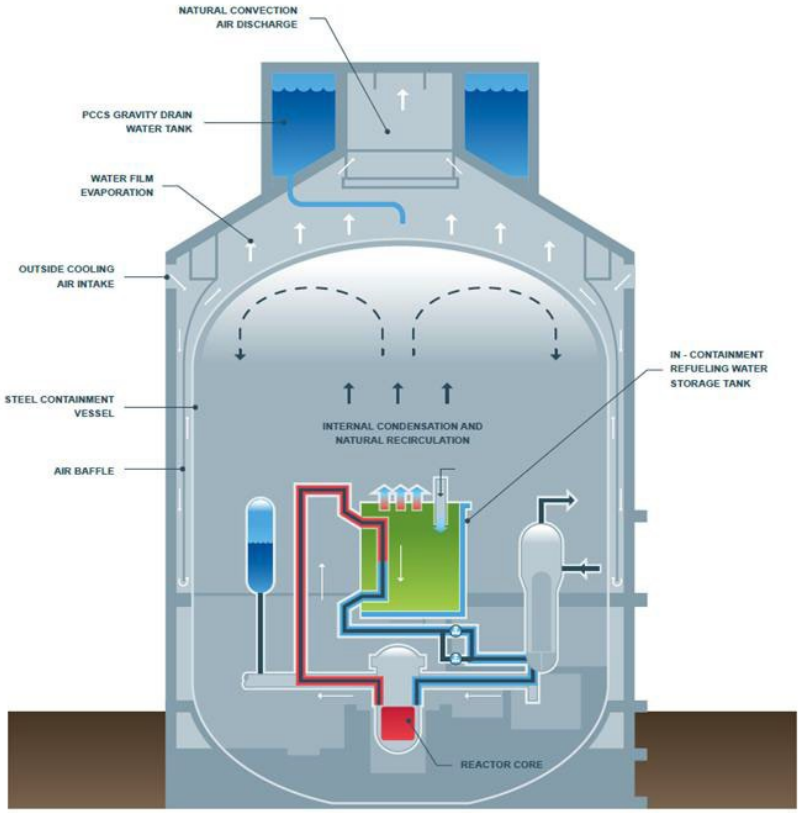


Figure 3. AP1000 Passive Residual Heat Removal and Passive Containment Cooling.

The passive containment cooling system (PCS) 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 the continuous, natural circulation of air. If required, the normally operating 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 flowpath. The water is provided from a tank located on top of the containment shield building and drains by gravity by opening either one of two, normally closed, fail-open valves in parallel lines, or by opening 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 includes additional on-site water storage and equipment to continue water application for an additional four days. After this time period air-cooling alone is sufficient to prevent containment over pressurization.

5.5 Secondary Side

The condensate and feedwater system supplies the steam generators with heated feedwater in a closed steam cycle using regenerative feedwater heating. 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 within the auxiliary building and containment. The main feedwater system includes three single speed motor driven feedwater pumps which operate in parallel and take suction from their associated feedwater booster pump. The discharge from the main feedwater pumps is supplied to the high-pressure feedwater heater and then to the steam generator system.

The AP1000 turbine generator 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 turbine is a 1,800 rpm (1,500 rpm for 50 HZ applications) turbine. The high-pressure turbine element includes one double-flow, high-pressure turbine. The low-pressure turbine elements include three double-flow, low-pressure turbines and two external moisture separator/reheaters (MSRs) with two stages of reheating. The turbine generator is intended for base load operation but also has load follow capability.

The condenser and circulating water systems have been optimized. For sites using cooling towers, the condenser is a three-shell, multi-pressure unit with one double-flow, low-pressure turbine exhausting into the top of each shell. For sites with direct cooling, the condenser is a single pressure, single pass unit.

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. 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.

5.6 Containment/Confinement

The AP1000 containment vessel is a free-standing, cylindrical steel vessel with ellipsoidal upper and lower heads:

- A cylindrical diameter of 39.624 m (130 ft).
- An overall height of 65.634 m (215 ft, 4 in).
- Shell wall thickness of 44.45mm (13/4"), plus corrosion tolerance forembedments.
- A design pressure of 4.07 barg (59 psig).
- A design temperature of 148.9°C (300°F).
- ASME Section III Class MC Component.
- An inorganic zinc coating on the inside and outside containment surfaces. Theinorganic coating protects the containment shell from corrosion and promotessurface wettability.
- An epoxy coating is used to overcoat part of the inside containment surface.

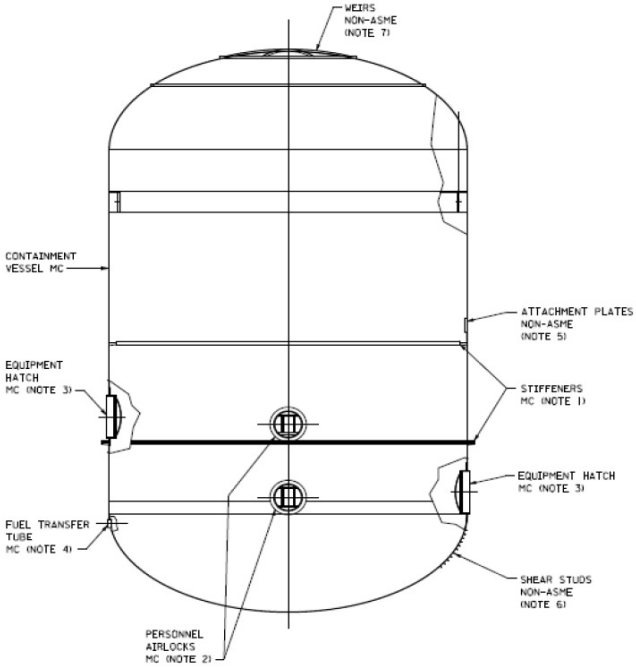


Figure 4. AP1000 Containment Vessel.

The 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, the passive residual heat removal and passive safety injection features are located entirely inside containment, and the passive containment cooling system operates outside the containment).

The AP1000 containment contains a 4.9 m (16 ft) diameter main equipment hatch and a personnel airlock at the operating deck level, and a 4.9 m (16 ft) 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.

The Containment Leak Rate Test System (VUS) provides a vehicle for confirming that the containment vessel leak rate is less than the value used in design analysis. The VUS is used to leak test the containment system, its isolation valves, hatches, penetrations and air locks. The containment system consists of the containment vessel, and its isolation features.

The containment leak rate test system contains the testing requirements such as, location, method and its technique, frequency, media, pressure, acceptance limits for testing the containment, its penetrations, and their isolation barriers. Additionally, the VUS has containment humidity sensors and transmitters that can be employed to detect Reactor Coolant System (RCS) leakage inside containment.

The AP1000 containment is capable of providing an effective barrier to the release of fission products to the environment and includes effective hydrogen control measures.

5.7 Electrical, I&C and Human Interface

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 center 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), the plant control system (PLS), the special monitoring system (SMS), and the in-core instrumentation system (IIS). The 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 a diverse means of initiating the reactor trip and emergency safety 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 of a common mode failure, the DAS provides diverse protection.

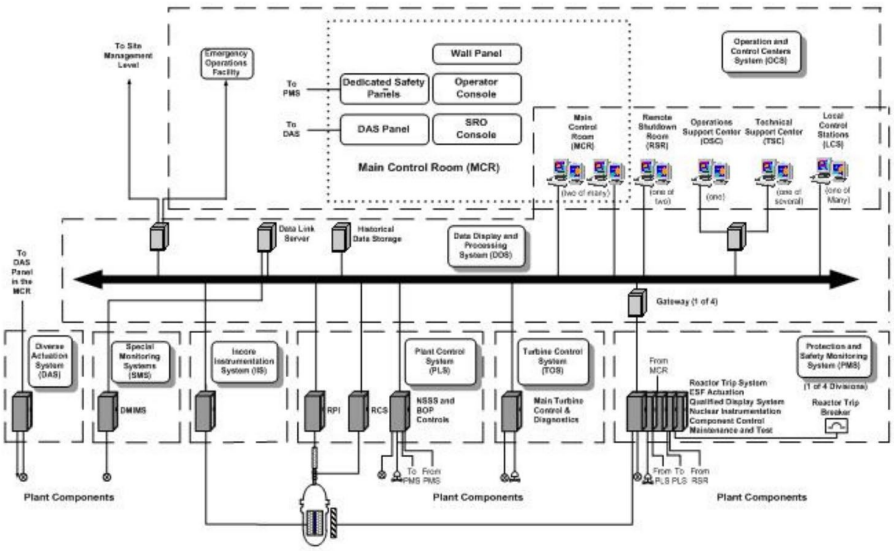


Figure 5. AP1000 Instrumentation & Control Architecture.

The operations and control center 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 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 non-safety-related plant components; and the plant monitor bus, which provides plant parameters, plant component status, and alarms. alarms.



Figure 6. AP1000 Main Control Room.

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, start-up, 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.

5.8 Unique Technical Design Features (if any)

The AP1000 plant is the only operating nuclear power plant with safety-related passive safety systems.

Another unique technical design features is the adoption of modular construction for the AP1000 plant. The AP1000 plant 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 also allows more activities to be performed in a controlled factory environment instead of in the field. The whole process of construction and construction planning is further abetted by the lower appetite of the AP1000 plant for construction commodities afforded by the passive design’s more compact dimensions and greatly reduced areas requiring safety-related, seismic construction.

6. Technology Readiness

SUMMARY FOR BOOKLET

The AP1000 Nuclear Power Plant has a highly-advanced and proven design. The Westinghouse unit has a high level of design completion, based on standardized nuclear island design and worldwide experience.

The AP1000 PWR has successfully been deployed at the Sanmen and Haiyang site in China, and at the Vogtle site in the United States, with two operating AP1000 units at each site. The operating AP1000 units’ outstanding early performance has an 89% average Operation Availability Factor with five out of six units with a Lifetime Operation Availability Factor above 91.9%.

Eight additional units are currently under construction in China. The AP1000 plant technology has been selected for Poland, Bulgaria and Ukraine.

The AP1000 reactor is the only operating Generation III+ reactor with fully passive safety systems, modular construction design and the smallest footprint per MWe on the market.

6.1 Deployed Reactors

Existing and operating units are listed in the table below, together with the units currently under construction. The AP1000 PWR has successfully been deployed at the Sanmen and Haiyang site in China, and at the Vogtle site in the United States, with two operating AP1000 units at each site. Eight additional units are currently under construction in China.

Country	Site Name	No. of Units (operating / under construction
China	Sanmen	2 units operating, 2 units under construction
China	Haiyang	2 units operating, 2 units under construction
China	Xudabu	2 units under construction
China	Lianjiang	2 units under construction
United States	Vogtle	2 units operating

The six currently operating AP1000 units demonstrate outstanding early performance:

- Expedient, predictable and consistent outage performance.
- 89% average Operation Availability Factor. Excluding the extended outage thatSanmen Unit 2 had to undergo in 2019 to address an infantile component issue that ledto the replacement on a reactor coolant pump, the average operation availability factorsdemonstrated by the operating AP1000 units is 92.9%.
- Excellent response to low follow operation and shutdown/down-powers to adapt to griddemand (e.g. during Holiday periods).
- Exceptional response to grid issues (e.g. load rejections), without leading to a reactorshutdown which is highly beneficial for the grid maintenance and rapid load recovery.
- Unprecedented low reactor trip rate for first implementation of new technology.

In addition to the licenses issued in China and the United States for the operating AP1000 units, the AP1000 plant has also been reviewed through the following programs:

- Westinghouse was among the first vendors to participate in the Generic DesignAssessment process in the United Kingdom. From 2007 to 2011, Westinghouse, theUnited Kingdom Office for Nuclear Regulation (ONR), and the Environment Agency(EA) completed GDA Steps 1 through 4 for the AP1000 plant. In December 2011, theONR and EA issued an interim Design Acceptance Confirmation (iDAC) and interimStatement of Design Acceptability (iSODA). The AP1000 plant resumed in 2015 andresulted in the issuance of a Design Acceptance Confirmation (DAC) and Statement ofDesign Acceptability (SoDA) for the AP1000 plant design in 2017.
- IAEA experts performed a limited review of the AP1000 Design Control Document(DCD)in 2008-2009. The following statement is extracted from the IAEA review report:“The AP1000 Licensing Document addresses the IAEA Fundamental Safety Principlesand a majority of the Draft Safety Assessment for Facilities and Activities Requirements(DS348) as well as Design Safety Requirements (NS-R-1), demonstrating a consistentsafety approach at the basic levels sought by the IAEA Safety Requirements.”

6.2 Reactors under Licensing Review

The AP1000 plant technology has been selected for Poland, Bulgaria and Ukraine. Future AP1000 reactors in these countries are currently in the pre-licensing stage.

6.3 Reactors in the Design Stage

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.

Therefore, current and future AP1000 projects do not require any extensive design to be completed, beyond those necessary adaptations to the site.

Nevertheless, reviewing and addressing lessons learned is a hallmark of the nuclear industry. Feedback acquired during the execution of new build AP1000 units in China and in the United States allowed to identify design optimizations to ease the construction of future AP1000 units. These enhancements span across multiple functional areas and include concepts like the reduction of reinforcing bar, minimizing full penetration welds, simplification of attachment plates, reduction in cable sizing, raceway simplifications, and the further leveraging of digitalization and use of building information management (BIM) techniques in the 3D modeling environment.

7. Safety Concepts

SUMMARY FOR BOOKLET

The over-arching AP1000 plant principle with respect to nuclear safety is the use of simple, passive safety systems dedicated to the mitigation of safety issues. The passive systems harness the inherent reliability of natural driving forces (for example gravity and natural convection). Their design and operation have been demonstrated by an extensive testing program. These passive safety systems require no external or internal alternating current (ac) power sources to function, and no operator action, and once actuated require no support systems to maintain their functionality for a minimum of 72 hours.

When ac power is available, the AP1000 plant passive systems can be supplemented with simple, active defense-in-depth systems and equipment. These systems use reliable and redundant active equipment, supported by the use of redundant diesels to facilitate their functions when offsite ac power is not available. 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 operation of the plant, the active systems are not necessary for the safe shutdown of the reactor following a design basis event.

Another contributor to plant safety is the diverse actuation system which provides a diverse backup to the protection and safety monitoring system in case of a common cause failures (CCF) in the protection and safety monitoring system when the first line of defence offered by the active systems is unavailable. The AP1000 plant approach considers the CCF or multiple failures that are determined to be risk important in the probabilistic safety assessment, and the passive safety systems include diversity to address these situations.
Finally, the AP1000 plant design includes mitigation features to protect the containment in case of a core melt event. These include hydrogen mitigation features and in-vessel retention of molten core debris via water cooling of the external surface of the reactor vessel.

7.1 Safety Philosophy and Implementation

The AP1000 plant approach to nuclear safety is fundamental to the overall design concept of the plant. The over-arching AP1000 plant principle with respect to nuclear safety is the use of simple, passive safety systems. These safety-related systems are dedicated to the mitigation of safety issues and are not required for normal operation. This approach is applicable to core cooling, core reactivity control, containment cooling, spent fuel cooling, direct current (dc) power and control room habitability. The passive systems harness the inherent reliability of natural phenomena to enhance safety; they use natural driving forces such as gravity and natural convection to mitigate abnormal and/or accident conditions. The design and operation of the AP1000 plant passive safety features have been demonstrated by an extensive testing program.

These passive safety systems (see Section 2.4) require no external or internal alternating current (ac) power sources to function, and once actuated require no support systems to maintain their functionality for an extended period of time. The passive systems require no pumps or other “active” components in order to perform their safety-related functions after their initiation. This significant simplification provides the benefit of greatly reducing the dependency on operator actions to respond to an event. The design and operation of the AP1000 passive safety features has been demonstrated by an extensive testing program, together with the startup testing programs of the six AP1000 units currently in operation.

When ac power is available, the AP1000 plant passive systems can be supplemented with simple, active defence-in-depth systems and equipment. The active defence-in-depth systems use reliable and redundant active equipment, supported by the use of redundant, defence-in-depth diesels to facilitate their functions when offsite ac power is not available. These simple, active systems, structures and components (SSCs) 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 operation of the plant, the active systems are not necessary for the safe shutdown of the reactor following a design basis event.
In other words, typical PWR safety-related systems and safety-related support systems exist as simplified, yet redundant, defence-in-depth systems. The defence-in-depth system design includes sufficient redundancy so that the most probable single failures cannot result in the loss of the defence-in-depth functions, for example by including two 100 percent capacity trains. The defence-in-depth SSCs are controlled by the plant control system, while the passive safety-related systems are actuated by the protection and safety monitoring system.

Another contributor to plant safety is the diverse actuation system. The diverse actuation system provides a diverse backup to the protection and safety monitoring system in case of a common cause failures (CCF) in the protection and safety monitoring system when the first line of defence offered by the defence-in-depth SSCs is unavailable.

The AP1000 plant approach considers the CCF or multiple failures that are determined to be risk important in the PRA. More specifically, the requirements for diversity were derived from the aggressive AP1000 plant PRA goals: the higher the frequency of the event, the more reliable the mitigation means must be in order to bring the corresponding core damage frequency and large release frequency to the targeted order of magnitude. Thus the design includes more of levels of defense and significant diversity for the more frequent initiating events. The passive features provide diversity in addition to redundancy; for example, passive feed and bleed cooling provides a backup diverse means to the passive residual heat removal heat exchanger of removing decay heat from the reactor coolant system. In addition to the use of diverse mechanical components, these diverse decay heat removal features are both actuated by the protection and safety monitoring system as well as by the diverse actuation system. Furthermore, the electrical power requirements for these features are also diverse. The passive residual heat removal heat exchanger is self-actuating and does not require electrical power (loss of ac power results in the initiation of natural circulation through the heat exchanger). The passive feed and bleed capability uses dc power from safety batteries.

The effectiveness of the AP1000 plant features to both prevent core damage and to also mitigate the consequences of core damage is verified in the PRA. Level 1 of the PRA determines the combinations of failures that can result in core damage. These failures are passed on to the Level 2 PRA, which evaluates the challenges to the containment integrity, so that the systems and actions necessary to mitigate the severe accident within a specific plant damage state do not credit the features that have failed and caused the core damage. This process ensures that sufficient redundancy and diversity are incorporated into the AP1000 plant systems to provide low core damage frequency as well as low large release frequency.

PRA results show that the AP1000 design achieves both a very low core damage frequency and a low large release frequency, which far exceed the goals established for advanced reactor designs. The CDF, considering random internal events as well as fire and flood events during at-power and shutdown operations is 4.88x1E-7/yr. The LRF for these same events is about 5.61x1E-8/yr. This very low risk is a result of the AP1000 safety design features (simple passive safety features and active defence in depth features) as well as the use of PRA throughout the design process starting from the initial design phase.
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.

In summary, robust protection for multiple failures and CCFs is provided by the multiple levels of defence. This approach can be summarized as follows:

- Redundancy exists within the active systems.
- Diversity and redundancy exists within the passive systems.
- Diversity exists between the passive and active systems.
- Severe accident phenomena are addressed in the design

Safety-related equipment are environmentally qualified. Environmentally qualified equipment exposed to a harsh environment has a qualified life goal of 60 years. Demonstration of qualified life by test or test and analysis is provided to address applicable aging effects. For critical components susceptible to aging, a qualified life is established that includes the effects of the total integrated radiation dose experienced at their respective locations within the plant. When a 60-year qualified life is not achievable, a shorter qualified life is established, and a replacement program is implemented. For equipment located in a mild environment, a design life goal is established by using known significant aging mechanisms and reliability data.

ALARA is a very important aspect for the nuclear industry and much has been learned through the operation of the current nuclear power plant fleet that would reduce the radiation exposure of power plant workers. Many of these methods have been incorporated into the design of the AP1000 which has allowed it to have an estimated annual dose much lower than currently operating power plants. One major method for the reduction in dose has been accomplished through the reduction of crud deposits. Low cobalt limits have been set for stainless steel and nickel-alloys, and the use of stellite in valves has been minimized. Crud traps have also been minimized, and, in some areas, cleanouts have been added that allows an operator to clear out a crud trap from adjacent low-dose areas. Electro-polishing and chrome plating of materials is also used to reduce local dose rates. Chemistry control is also a large contributor to reducing total dose. Zinc addition is used to control crud levels, a high pH is maintained in order to reduce corrosion rates, and hydrogen peroxide is used during shutdown to control oxygenation.

Other technologies that have been included are the use of reach rods for valve operation, Closed Circuit Televisions which allow for remote viewing, and robotics for use of reactor vessel head In-Service Inspection and for steam generator eddy current and tube plugging inspections. The use of these methods, in addition to many others, has allowed the AP1000 to have an estimated annual occupational dose of less than 0.25 man-Sv (25 man-rem).

7.2 Transient/Accident Behaviour

The AP1000 plant response to a station black-out is described in the following brochure:
https://westinghousenuclear.com/media/3pipeoof/ap1000-station-blackout.pdf

The AP1000 plant response to a loss of coolant accident is illustrated in https://www.youtube.com/watch?v=wPboRuuNCAE.

The AP1000 plant is designed to mitigate the consequences of extreme external hazards such as beyond design basis seismic and flooding events. This significant increase in plant safety can be summarized by the following three key safety advancements:

1. The AP1000 plant “fails safe.” Even with a loss of all electrical power, I&C controls,and instrument air, the AP1000 passively aligns crucial safety related systems to a safestate which protects the reactor core and the spent fuel pool.
2. The AP1000 plant is self-reliant. The AP1000 passive safety systems reduce theimportance of AC electrical power or heat sinks such as the service water coolinginterface with nearby bodies of water. AP1000 plants ultimately use ambient air as aheat sink.
3. The AP1000 plant is self-contained. All SSCs required to maintain AP1000 in a safeshutdown are located within the steel containment vessel and surrounded by the robuststeel-concrete-steel shield building. The shield building and the containment protect thesafe shutdown systems and equipment from external events

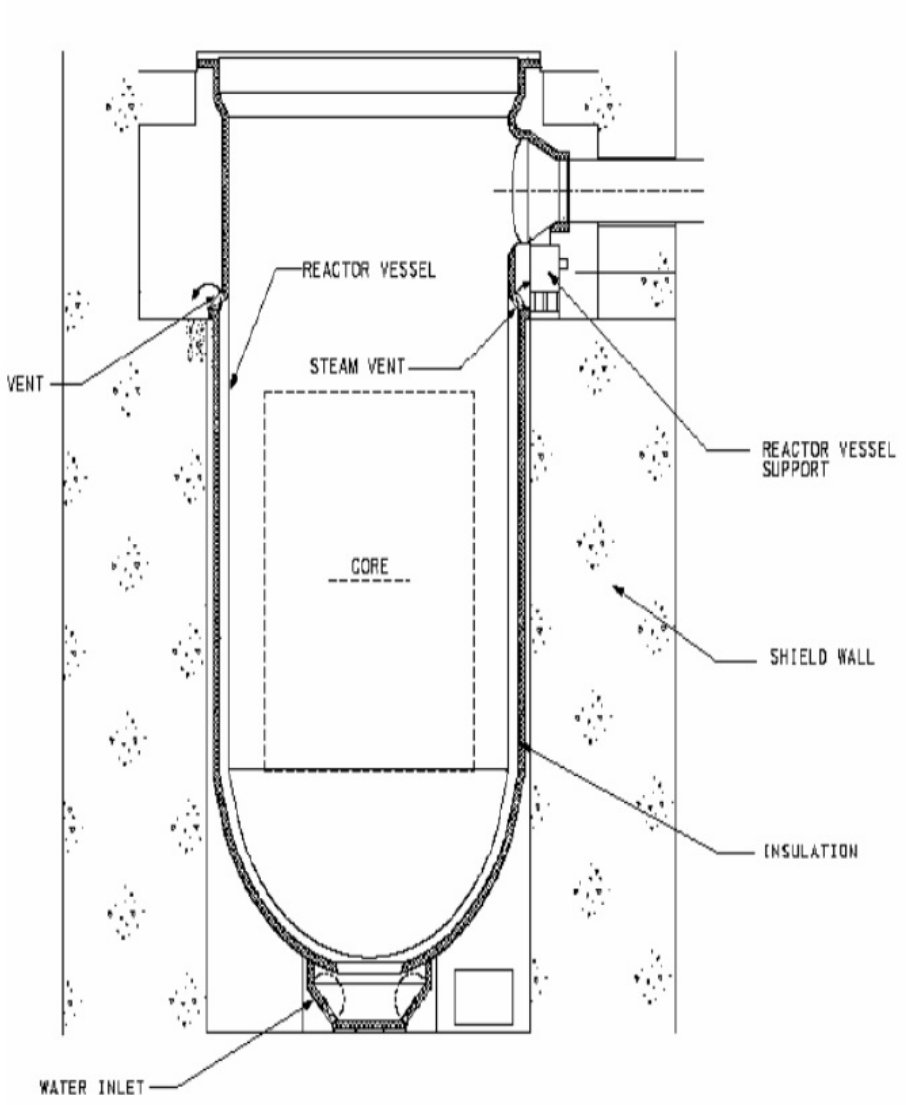


Figure 7. AP1000 Features supporting In-Vessel Retention.

Severe accident management capabilities have been integrated into the AP1000 plant design from the beginning of the design process. Probabilistic risk assessment (PRA) and associated analyses were used to identify scenarios, boundary conditions and postulated severe accident phenomena that must be mitigated to ensure containment integrity in the event of core damage. Symptom based emergency operating procedures (EOPs) and severe accident management guidelines (SAMGs) have been developed to assist the operators in properly managing the event progression.

The AP1000 plant maintains one consistent philosophy for the operator to mitigate any loss of core cooling scenario: depressurize the reactor coolant system (RCS) and send coolant, by whatever means available, as close to the core as possible to protect all fission product barriers from failure. The design features facilitate a single approach for recovery and operator actions, if needed, to mitigate the event by ensuring that heat removal is provided through active defense-in-depth or passive safety-related sources of water inventory designed to remove heat from the core, the containment and the spent fuel pool.

The AP1000 design provides flexible, consistent, diverse and redundant levels of defense (passive and active) against release of radioactivity to the environment following core damage. Severe accident phenomena are addressed with engineered design features to reduce the impact of phenomenological uncertainties. The AP1000 plant severe accident features promote RCS depressurization and in-vessel retention of molten core debris and recovery of the damaged core within the reactor vessel. Hydrogen that may be produced by cladding oxidation during the core melting and relocation is managed by providing engineered release locations, passive mixing into a large containment volume, intentional ignition at low concentrations and passive recombination.

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

The AP1000 core features 157 fuel assemblies of the Westinghouse 17x17 Robust Fuel Assembly (RFA) design, with an active fuel length of 14 ft (46.72 cm). RFA fuel has been utilized extensively in more than 50 plants worldwide exhibiting excellent performance over 20 years of reliable and cost-effective operation. Fuel rods feature ZIRLO cladding material with UO2 pellets. The Westinghouse Integral Fuel Burnable Absorber (IFBA), a ZrB2 coating applied on the fuel pellet, is employed in selected fuel rods. Reduced-worth (“gray”) rod cluster control assemblies (RCCAs) and heavy-worth (“black”) RCCAs provide rapid shutdown capability for the reactor core and are utilized for reactivity and power distribution control to implement the mechanical shim (MSHIM) operational strategy.

The MSHIM operation and control strategy greatly simplifies reactor operations by automatically compensating reactivity changes from fuel depletion by movement of selected control banks, thereby minimizing changes to the coolant soluble boron concentration from multiple times a day in standard plants operation to only every few weeks in the AP1000. Additionally, the MSHIM strategy allows to perform load following manoeuvres without changes to the soluble boron concentration during the manoeuvre, which greatly reduces water effluents generated at the plant and the burden on the chemical and volume control system. The AP1000 features an advanced first core with an innovative loading pattern mimicking the behavior at the equilibrium cycle already from the startup core, which allows to achieve efficient fuel use and minimize transition cycles impacts, thereby offering significant operational fuel cycle economics advantages compared to traditional first core designs.

The standard AP1000 fuel cycle is 18 months, but shorter (12 months) or longer (24 months) fuel cycles are also possible. Assembly-average discharge burnup in excess of 50000 MWd/tU, with peak pin BU within current licensed limit of 62000 MWd/tU, is achieved at the equilibrium cycle for the baseline 18-month core design, using UO2 fuel at less than 5% U-235 enrichment. While the standard fuel product for the AP1000 plant is U-235 enriched UO2 fuel, use of MOX fuel has also been evaluated and proved feasible for up to a 50%MOX core design without requiring any modification to the NSSS design, or the MSHIM operational strategy.



Figure 8. AP1000 Fuel Assemblies and Shipping Canisters.

8.1 Fuel Cycle Options

The AP1000 plant fuel rods consist of cylindrical, ceramic pellets of slightly enriched uranium dioxide (UO2). These pellets are contained in cold-worked and stress-relieved ZIRLO tubing, which is plugged and seal-welded at the ends to encapsulate the fuel. Sintered, high-density UO2 fuel reacts only slightly with the cladding at core operating temperatures and pressures. In the event of cladding defects, the high UO2 resistance to attack by water protects against fuel deterioration, although limited fuel erosion can occur. The consequences of defects in the cladding are greatly reduced by the ability of UO2 to retain fission products, including those which are gaseous or highly volatile. ZIRLO is an advanced zirconium-based alloy which has a high corrosion resistance to coolant, fuel, and fission products, and high strength and ductility at operating temperatures. Selection of ZIRLO cladding materials minimises the formation of defects that can result in radioactive releases to the reactor coolant.

The AP1000 core features 157 fuel assemblies of the Westinghouse 17x17 Robust Fuel Assembly (RFA) design, with an active fuel length of 14 ft (46.72 cm). RFA fuel has been utilized extensively in more than 50 plants worldwide exhibiting excellent performance over 20 years of reliable and cost-effective operation.

The AP1000 features an advanced first core with an innovative fuel loading pattern which mimics the behavior at the equilibrium cycle already from the startup core. This allows to achieve efficient fuel use and minimize transition cycles impacts thereby offering significant operational and fuel cycle economics advantages compared to traditional first core designs. The Westinghouse Integral Fuel Burnable Absorber (IFBA), a ZrB2 coating applied on the fuel pellet, is employed in selected fuel rods for reactivity hold-down and power shaping. Unlike other fuel burnable absorbers such as Gadolinia (Gd2O3), IFBA avoids uranium displacement from the fuel matrix and allows complete absorber consumption over the fuel irradiation cycle, thereby offering potential for best fuel use and associated fuel economics performance.

The standard AP1000 fuel cycle is 18 months, but shorter (12 months) or longer (24 months) fuel cycles are also possible within the current fuel licensing envelope. Equilibrium cycle reloads for the baseline 18-month cycle consist of 64 feed assemblies (out of 157 core fuel assemblies) with average U-235 enrichment of ~4.5 w/o, and assembly-average discharge burnup in excess of 50000 MWd/tU (with peak pin BU within current licensed limit of 62000 MWd/tU) and fissile use is in excess of 1.10 GWd/kgU-235.

While the standard fuel product for the AP1000 plant is U-235 enriched UO2 fuel, use of MOX fuel has also been evaluated and proved feasible for up to a 50% MOX core design without requiring any modification to the NSSS design, or the MSHIM operational strategy.

8.2 Resource Use Optimization

As discussed in the previous section, the AP1000 incorporates state-of-the-art Westinghouse fuel products and innovative fuel management solutions, including optimal burnable absorbers, that allow best fuel utilization (and fuel economics) without challenging the fuel operational envelope and licensed limits.

8.3 Unique Fuel/Fuel Cycle Design Features

As previously discussed, the AP1000 plant uses proven Westinghouse 17x17 Robust Fuel Assembly (RFA) design, which has been utilized extensively in more than 50 plants worldwide, exhibiting excellent performance in over 20 years of reliable and cost-effective operation. RFA fuel design was first introduced in 1997, and since then, it has undergone numerous design enhancements and evolutions that further improve fuel and plant performance and reliability, and that are incorporated in the AP1000 fuel.

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

Westinghouse together with the world's leading civilian nuclear power plant vendors have adopted a common set of principles that reflect global best practices in connection with the export of nuclear power plants. Known as the Nuclear Power Plant Exporters' (NPPE) Principles of Conduct, the principles articulate the nuclear power plant industry's shared high standards in the areas of safety, security, environmental protection and spent fuel management, compensation in the unlikely event of nuclear-related damage, non-proliferation, and ethics. Westinghouse is committed to the peaceful use of nuclear energy and the promotion of proliferation-resistant designs and the AP1000 plant design addresses the IAEA

safeguards requirements. The AP1000 PWR is also designed to the highest criteria to provide assurance for the protection of the health and safety of the public against radiological sabotage.

9.1 Safeguards

The AP1000 plant does not present any unique issues relative to other light water reactors with regards to proliferation and commercial nuclear power plants. Principal materials of concern in the nuclear weapons production cycle include highly enriched uranium (HEU) and plutonium. Uranium as mined from the earth poses no risk of proliferation. Before its use in reactors, mined uranium must undergo an enrichment process that concentrates isotopes necessary for power production. This process creates low enriched uranium (LEU) through a lengthy, complex and expensive process. It is impossible to create a nuclear weapon from LEU.

However, analysts are mindful that the same enrichment facilities used to create LEU may have the capability to convert natural uranium into highly enriched uranium. Nuclear reactors, once in operation, produce plutonium as a by product. However, the separation of plutonium contained in used fuel pellets requires complex chemical reprocessing. Like enrichment, reprocessing calls for a highly sophisticated infrastructure.

To further demonstrate its commitment to the peaceful use of nuclear energy, Westinghouse developed a partnership with the International Atomic Energy Agency (IAEA) and the U.S. Nuclear Regulatory Commission to a establish a voluntary safeguards transparency program at the AP1000 plants in the United States. As part of this effort, Westinghouse engineers received training from the U.S. National Laboratories on the technical requirements and generalized approaches to IAEA safeguards technical systems utilized for nuclear reactor systems. One major objective of this program included the design of a generalized safeguards approach to AP designed nuclear reactors and developing the design information questionnaire for a customer as part of a regulatory requirement for international safeguards compliance.

9.2 Security

The AP1000 plant design and layout has taken security design considerations into account throughout the plant's detailed design development. The design and configuration inherently protect the plant against human induced malevolent external impacts and insider action.

Access control capability for the plant protected and vital areas is provided by limiting entry to authorized personnel, vehicles, and material only. The plant is constantly under video surveillance, the adequate lighting and power supply is provided, as necessary, for essential elements of the surveillance and assessment security systems and to allow effective response by the plant security response force.

The difference between the design of the AP1000 plant and that of a conventional PWR represents a significant reduction in vulnerability to a wide range of security threats. The AP1000 physical design has a number of features that significantly reduce the plant's vulnerability to an attempted act of radiological sabotage. These include the following:

- The use of passive safety features that do not require ac power or cooling watersupplies inherently reduces the plant vulnerabilities. In addition the importantpassive features that provide reactor shutdown, decay heat removal andcontainment isolation are fail safe such that even the total loss of the plantprotection instrumentation system and dc power could be tolerated in a securityevent.
- All exterior and a large number of interior walls that house equipment important tosafety consist of at least 60-cm thick concrete walls. These walls offer asignificant deterrent to penetration. The design also incorporates several largestructural modules within the Auxiliary Building. The module walls are designedwith inner and outer steel plates and are filled with concrete. Such a design isinherently hardened against attempted penetration including the crash of eithercivilian or military aircraft.
- The number of entry points is minimized. The relatively small number of doors,their access paths, and their proximity to one another allow for the development ofan effective protective strategy.

9.3 Unique Safeguards and/or Security Features

None

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

Benefiting from the experience gained on previous AP1000 plant projects, Westinghouse offers the highest level of delivery certainty for future AP1000 customers. These benefits include technology maturity, licensing confidence, established and optimized design and modularization, proven construction and commissioning approaches, resolution of first-of-a kind (FOAK) challenges, and incorporation of lessons learned. All of which provide a high-level of certainty in our team's ability to achieve the overall project schedule in a safe and quality-focused manner to deliver a plant that meets all operational parameters.

As an added advantage, the AP1000 plant is positioned with a network of world-leading constructors, suppliers, and other business partners to provide a seamless and fully integrated delivery model for deploying the AP1000 PWR technology.

10.1 Project Preparation and Negotiation

Westinghouse is not an owner/operator but has experience in partnering and working with owner/operators in the deployment of new build technology. Westinghouse provides information to the ultimate owner/operator necessary to be able to operate and maintain the plant.

Westinghouse has an extensive training programme to develop employees and for training personnel who would ultimately be operating the AP1000 reactors. Westinghouse's world-class training programme has been leveraged by the global nuclear fleet to develop human capital resources. Westinghouse established training services in the early 1960's and has continued to transform its programmes to use a systematic approach to learning.

Westinghouse focuses the development of its training programmes on three main cornerstones:

- Develop long-term partnerships to grow the knowledge and skills ofnuclear professionals.
- Use of student-centred, blended learning techniques through application ofperformance-driven approaches.
- Focus on integrated plant operations to educate a nuclear workforce tomeet the unique challenges of the complexity of nuclear power planttechnology.

Westinghouse's training programmes include the use of our state-of-the-art AP1000-specific simulator facilities which have been used to train hundreds of operators on the newest digital control rooms. Additional overviews of Westinghouse's training programmes for customers and operators can be found at the following link: https://training.westinghousenuclear.com/

Westinghouse's training programmes are established within the Westinghouse Management System and governed by policies, procedures, and processes including the apprenticeship programme requirements.

The Management Systems including the training programmes have been extensively evaluated by various regulators and other accreditation bodies and have achieved praise among the stakeholders for the programmes and state of the art training facilities.

Finally, for the AP1000 projects Westinghouse have established in country training programmes to train the next nuclear workforce. Westinghouse has established internship programmes with local universities to embed university students into various Westinghouse businesses.

Westinghouse also has experience in supporting owners and operators in securing financing specifically with respect to debt financing. Westinghouse has experience working with Export Credit Agencies primarily with the Export-Import Bank of the US (EXIM).

In addition, there are options depending on the project to leverage the Engineering Multiplier Program (EMP), offered by EXIM, which could potentially provide early funding for engineering services prior to first nuclear concrete and procurement of long lead components.

In addition to ECA's, the US International Development Finance Corporation (DFC) is the US government's development finance

institution which can also support project financing. DFC was established in 2019 through the passage of the Better Utilization of Investments Leading to Development (BUILD) Act which strengthened and modernized American development finance. The BUILD Act combined the capabilities of the Overseas Private Investment Corporation and the Development Credit Authority (DCA) which had previously been housed in the US Agency for International Development (USAID). DFC advances American foreign policy and American commercial competitiveness. The investments DFC mobilizes serve as stabilizing forces in developing countries around the world. Investment in these markets also helps American businesses gain footholds in many of the world's fastest growing markets.

Project risk factors are dependent on the project structure and commercial / delivery model, site and requirements. Westinghouse generates a comprehensive site-based risk register for all projects to assess the specific risk.

Westinghouse's approach to its projects is a "buy where we build" mentality that maximizes local content bringing significant value to the local economy. Westinghouse's general localization strategy encompasses broad local benefits that include skill development, nuclear cluster and supply chain development, and climate, safety, and community engagement. Westinghouse's skills development activity supports efficient and safe operations and provides opportunities for employees where our plants are located. Westinghouse actively builds partnerships with local educational institutions to support development of a pipeline of employees. In order to support the localization of resources, Westinghouse has an extensive training program to develop employees and for training personnel that would operate an AP1000 plant.

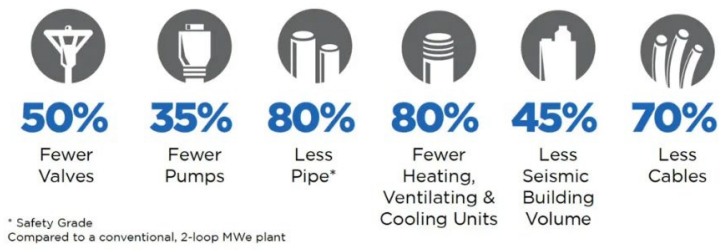
Westinghouse works closely with the customers to establish an approach to social value, human capacity development and localization that meets the needs of the project and the community.

Many factors have the potential to influence the total project costs, including climate, geology, seismicity, physical infrastructure, social factors, infrastructure bottlenecks, access to resources, etc.. As noted previously, the AP1000 plant has been designed considering bounding site parameters. As a result, the AP1000 plant design can be applied to different geographical regions around the world with varying regulatory standards and utility expectations without major changes.

10.2 Construction and Commissioning

Several of the key AP1000 reactor advantages include:

- **Compacted footprint:** The AP1000 reactor has a smaller footprint than anexisting nuclear power plant with the same generating capacity. The reactorarrangement provides separation between safety-related and non-safety-relatedsystems to preclude adverse interaction between safety-related and non-safety-related equipment. Separation between redundant, safety-related equipmenttrains and systems provides confidence that the safety design functions ofthe AP1000 PWR can be performed. In general, this separation is achieved bypartitioning an area with concrete walls.
- **Reduction in component and construction materials:** The innovativeAP1000 reactor design features: fewer safety-related valves, less safety-relatedpiping, less control cable, fewer pumps, less seismic building volume.



- Modular construction (further discussed below). Two of the drivers of plantconstruction costs are the cost of financing during the construction phase andthe substantial amount of skilled-craft-labor hours needed on site duringconstruction. The AP1000 PWR extensive use of modularization of plantconstruction mitigates both of these drivers.
- Dramatically reduced start-up test programs from 10 months to 5 monthsor less (including 1 month at full power).

The AP1000 plant contains approximately 200 structural and mechanical modules.

For the mechanical modules, the strategy consists in preassembling equipment and commodities over a structure of beam members. This eases the laborious work of on-site installation during construction and allows the civil works to progress in parallel with the mechanical, electrical and I&C assembly production, getting them ready for their scheduled installation at the right programmed moment of the construction.

Structural modules provide large, pre-fabricated, integrated structures, enabling faster construction schedules by this pre-fabrication in parallel with site preparation.



Figure 8. Placement of a structural module (CA20, in the auxiliary building).

Westinghouse leverages our comprehensive Westinghouse Management System and extensive AP1000 database for project planning and scheduling activities. Depending on the project needs, Westinghouse has extensive experience leading or supporting integrated project planning and scheduling with the Owner, constructor and other project stakeholders under a variety of project delivery models. Local labor requirements, site characteristics, climate, owner and regulatory requirements are assessed in the early stages of project planning. Standardized means of risk management, contingency planning and project controls are deployed.

Westinghouse has a mature supply chain with on-going involvement in AP1000 plant projects. In addition, Westinghouse has manufacturing facilities in the United States, Canada and Italy for the fabrication of major components. Future AP1000 projects can make direct use of this mature supply chain and internal capabilities. The current suppliers on the Westinghouse qualified suppliers list are providing Westinghouse goods and services in support of the AP1000 plant, as well as the operating fleet.

Westinghouse's buy where we build philosophy maximizes localization during construction. A comprehensive localization strategy is developed that is specific to each project as the project is being developed.

To achieve the target Overnight Capital Cost (OCC), Westinghouse adopted ambitious standardization and simplification objectives for the AP1000 plant design. The Westinghouse AP1000 PWR attenuates key cost drivers for nuclear plants by reducing the safety related footprint of the plant and optimizing the design for construction with extensive modularization. These design advantages together with Westinghouse's recent and extensive new plant delivery experience and an established and proven global nuclear supply chain achieve an OCC that is competitive economically. Refer to the Massachusetts Institute of Technology report on 2024 Total Cost Projection of Next AP1000 https://web.mit.edu/kshirvan/www/research/ANP201%20TR%20CANES.pdf.

10.3 Operation and Maintenance

The AP1000 plant uses proven Nuclear Steam Supply System (NSSS) components and the plant design life of 60 years is based on actual operating experience combined with conservative design approaches.

The calculated AP1000 plant project availability is 93%. This is supported by the actual operation availability factors reported in the IAEA PRIS database for AP1000 units, which averages at 89%. Excluding the extended outage that Sanmen Unit 2 had to

undergo in 2019 to address an infantile component issue that led to the replacement on a reactor coolant pump, the average operation availability factors demonstrated by the operating AP1000 units is 92.9%.

A big aspect of the AP1000 PWR design philosophy focuses on plant operability and maintainability. The plant includes a 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 low maintenance requirements. Component standardization reduces spare parts, minimizes maintenance, reduces training requirements, and allows shorter maintenance durations. Built-in testing capability is provided for critical components.

This is illustrated by the exceptional outage duration performance exhibited by the operating AP1000 units.

The AP1000 plant uses existing fuel technology making the costs comparable to current PWR fuel costs.

Westinghouse is a lifetime partner for owner/operators of an AP1000 plant. Offering an extensive array of experience and subject matter expertise in a variety of areas not limited to design, procurement and systems engineering and digital solutions, Westinghouse is positioned as the perfect partner for a one-stop-shop for long term, outage and maintenance operations.

The AP1000 plant design takes advantage of digital technologies to streamline day-to-day outage and maintenance operations enabling design standardization and allowing for a potential centralization of certain utility functions. The AP1000 plant design and Westinghouse overall strives to provide an integrated services model to support day-to-day operating and maintenance activities of operating plants, utilizing data, technology, standard plant design and centralizing staffing models to offer a streamlined O&M process and procedure approach.