ACR-1000® Technical Summary

AECL

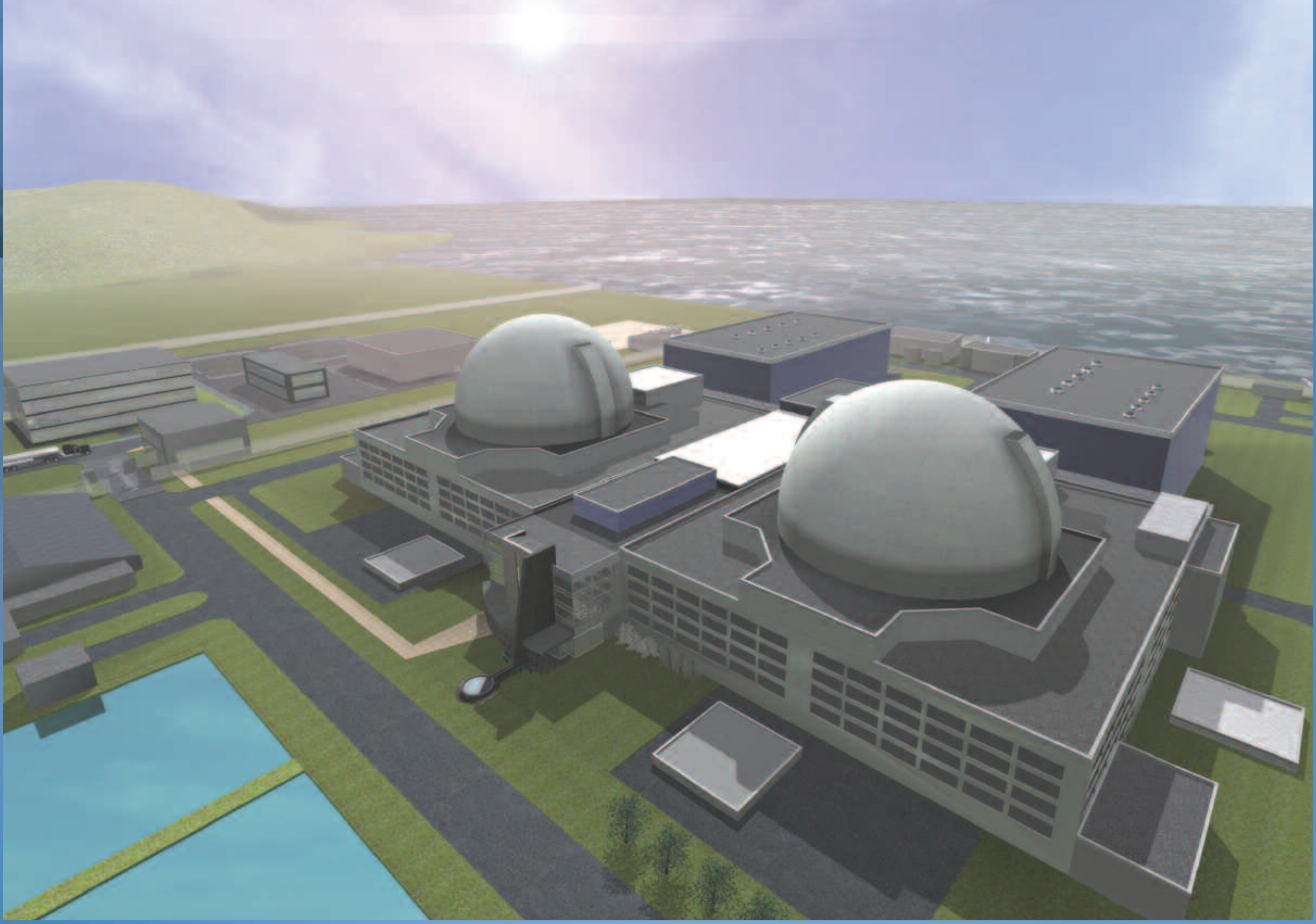


Figure S-1 Pictorial View of Two-Unit ACR-1000 Plant

Summary

The ACR-1000®* is an evolutionary, Gen III+**, 1200 MWe class pressure tube reactor, designed to meet industry and public expectations for safe, reliable, environmentally friendly, low-cost nuclear power generation.

The reactor core consists of fuel and light-water coolant in pressure tubes with a heavy water moderator. Derived from the well-established CANDU*** line of reactors, the ACR-1000 was developed from valuable project-based experience in the design, construction and operation of CANDU plants for utilities around the globe.

The ACR-1000 retains basic CANDU design features such as: modular, horizontal fuel channel core, low-temperature heavy water moderator, water-filled vault, two diverse shutdown systems, on-power fuelling and an accessible reactor building for on-power maintenance.

To achieve outstanding safety, operation, performance and economics, the ACR-1000 incorporates a specific set of innovative features and state-of-the-art technologies.

Enhanced Safety

- A small, negative coolant void reactivity offers a good balance of nuclear protection between loss-of-coolant accidents and fast cool-down accidents
- Enhanced prevention and mitigating measures for severe accident management, based on insight gained from Probabilistic Safety Analysis (PSA) during the design process
- A strengthened calandria tube providing additional assurance that it will contain a pressure tube failure
- New and improved passive designs for emergency core cooling (ECC), moderator cooling, reactor vault cooling and containment cooling. Design simplifications include sharing of long-term emergency cooling and shutdown safety functions
- Reduced operator decision-making and action workload through state-of-the-art automation and human/machine interface

Improved operation, performance and economics

- Reduction in heavy water inventory by approximately 60% over traditional CANDU reactors, cutting capital costs and improving environmental performance and occupational safety
- Ability to burn alternate fuels such as mixed oxides (MOX) and thorium
- Less refuelling and lower spent fuel volume per MWh, through use of low enriched uranium (LEU) in a CANFLEX®[****]-ACR fuel bundle, as a result of increased fuel burn-up
- Simplified reactor control resulting from reduced pressure tube lattice pitch and use of LEU fuel for a highly stable, more compact core. Further simplification achieved with mechanical zonal control rods and eliminating the liquid zone control system
- Improved on-power maintenance and testing, additional redundancy in actuating signals for trip channels, reduced risk of spurious trips and overall increased reliability, through use of quadrant-based layout for safety and heat sink systems
- Enhanced power manoeuvring ability due to a lower xenon load after shutdown than in traditional CANDU plants
- Higher overall thermal cycle efficiency, resulting from increased coolant and steam supply pressure and temperature

This document provides a brief description of the main features of an ACR-1000 two-unit plant, including overall plant design, major systems and their key components, and the plans to complete construction of an ACR-1000 within 42 months for the first unit of the nth integrated two-unit plant. AECL experience and services in support of regulatory approvals, operations and final decommissioning are also described.

[*] ACR-1000® (Advanced CANDU Reactor®) is a registered trademark of Atomic Energy of Canada Limited (AECL).

[**] Gen III+ is the classification given to nuclear technologies by an international team, including Canada, that is collaborating on the research to develop the next generation, Gen IV reactors. ACR-1000 is one of the technologies that are considered as a generation III+ design.

[***] CANDU® (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL).

[****] CANFLEX® is a registered trademark of AECL and the Korea Atomic Energy Research Institute (KAERI).

CANDU®: The Evolution

ZEEP
research reactor
10 Watts
Criticality: 1945

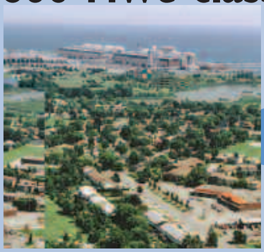
NRX
research reactor
42 MW
Criticality: 1947

NRU
research reactor
200 MW
Criticality: 1957

NPD
CANDU
demonstration reactor
24 MWe
In-service: 1962

Douglas Point
CANDU commercial
prototype
220 MWe
In-service: 1968

CANDU
600 MWe class



Pickering A
4 units, 542 MWe
In-service: 1971-73

Pickering B
4 units, 540 MWe
In-service: 1983-86

All figures for operating commercial units indicate gross output.
Source: Nuclear Engineering International (NEI)

CANDU®, CANDU 6® (CANada Deuterium Uranium) and ACR-1000® (Advanced CANDU Reactor) are registered trademarks of Atomic Energy of Canada Limited (AECL).

www.aecl.ca *2007 June PP&I 1383*

CANDU 6® 700 MWe class

Pt. Lepreau 680 MWe
In-service: 1983

Embalse 648 MWe
In-service: 1984

Wolsong Unit 1 679 MWe
In-service: 1983

Wolsong Unit 2 715 MWe
In-service: 1997

Wolsong Unit 3 715 MWe
In-service: 1998

Wolsong Unit 4 715 MWe
In-service: 1999

Gentilly 2 675 MWe
In-service: 1983

Cernavoda Unit 1 708 MWe
In-service: 1996

Cernavoda Unit 2 708 MWe
Projected in-service date: 2007

CANDU 900 MWe class

Bruce A 4 units 900 MWe
In-service: 1977-79

Bruce B 4 units 915 MWe
In-service: 1984-87

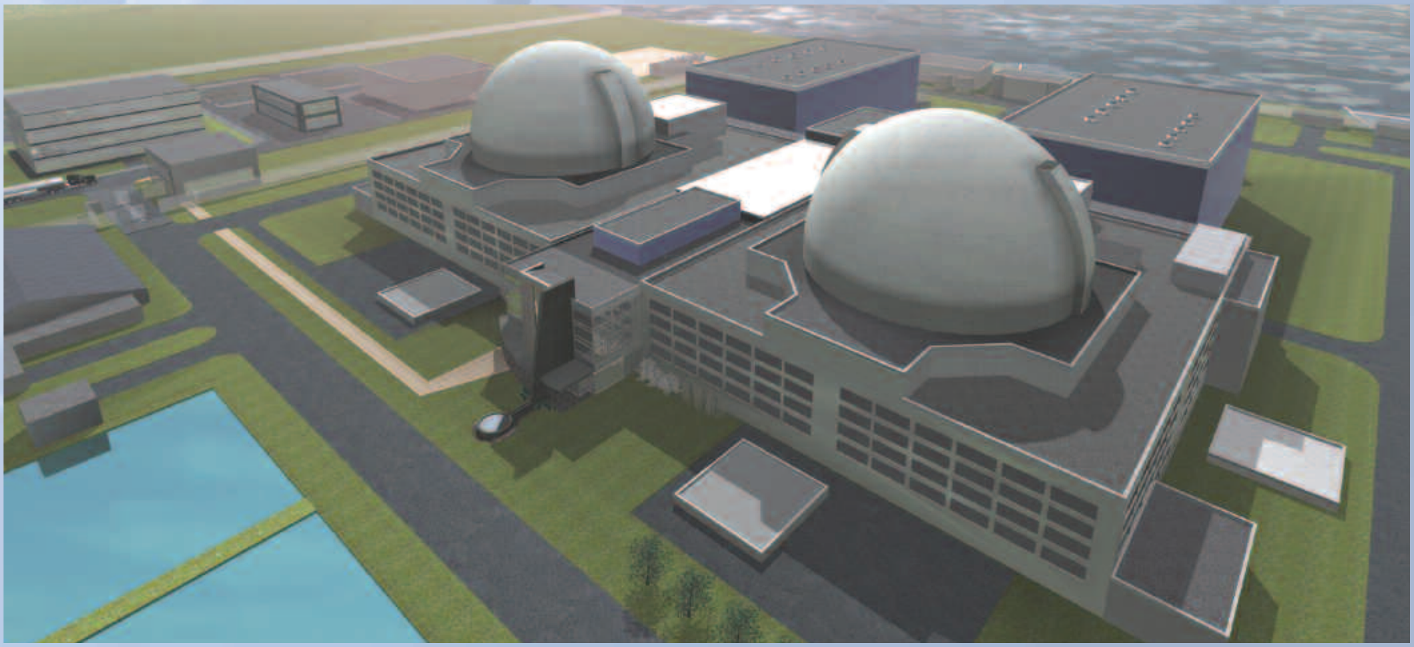
Darlington 4 units 935 MWe
In-service: 1990-93

Figure S-2 Evolution of ACR-1000

Qinshan Phase III Unit 1 728 MWe
In-service: 2002

Qinshan Phase III Unit 2 728 MWe
In-service: 2003

ACR-1000® 1200 MWe class



Artist's impression of a 2-unit ACR-1000 Nuclear Power Plant:
1200 MWe class Gen III+

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1. An Introduction to ACR-1000 Evolution

1.1 The ACR-1000

The ACR-1000 is built to meet industry and public expectations for safe, reliable, environmentally friendly, low-cost nuclear power generation. It has been developed by AECL from experience and feedback gained in the design, construction and operation of CANDU plants operated by ten utilities around the world.

With a 60-year design life, the ACR-1000 is a light-water-cooled, heavy-water-moderated pressure-tube reactor derived from the well-established CANDU line. It retains basic CANDU design features while incorporating a specific set of innovative features and state-of-the-art technologies to ensure its safety, operation, performance and economics are second to none.

Enhanced safety features include a core design with a small negative coolant void reactivity, larger thermal margins due to the use of CANFLEX®**** fuel, and design improvements based on insights gained from Probabilistic Safety Analysis (PSA) performed during the design process.

The latest design tools (CADDS) linking material management, documentation, safety analysis and project execution databases are used to ensure that accurate and complete configuration management can be readily maintained by the plant Owner.

1.2 Design Features

The ACR-1000 benefits from the proven principles and characteristics of CANDU design and the extensive knowledge base of CANDU technology gained over many decades of operation.

Proven CANDU strengths

- Modular, horizontal fuel channel core
- Separate low-temperature and pressure moderator
- Reactor vault filled with light water surrounding the core
- On-power refuelling
- Two independent passively driven, safety shutdown systems
- Reactor building access for on-power maintenance

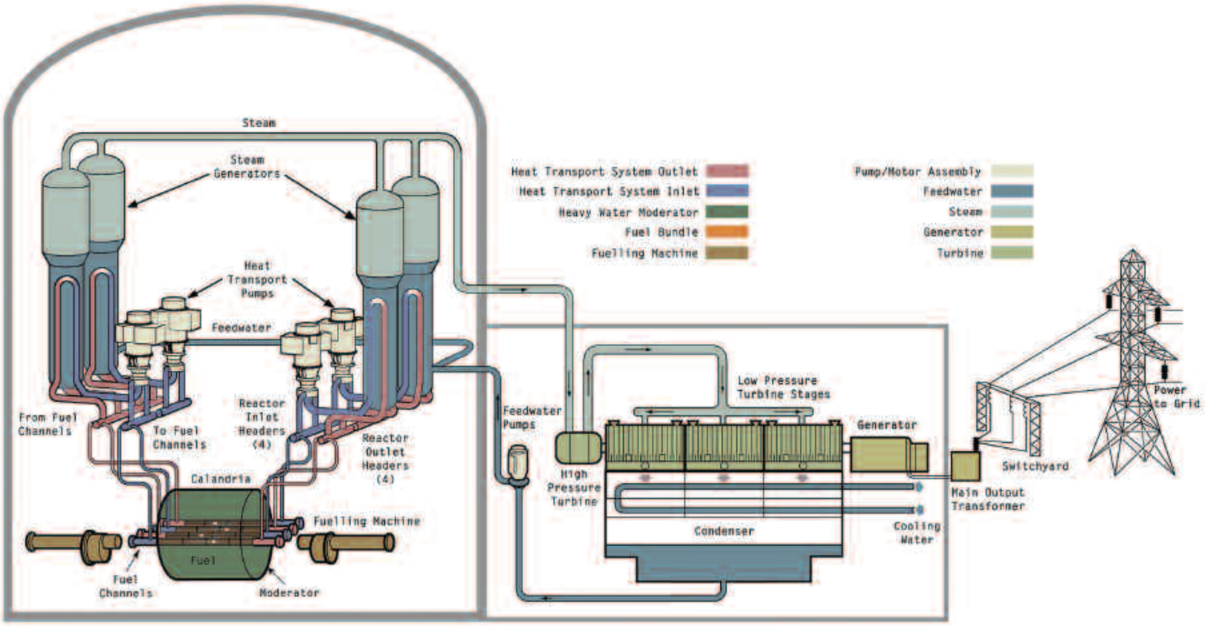


Figure 1-1 Overall ACR-1000 Plant Flow Diagram

ACR innovations

- A more compact core design, which reduces heavy water inventory and results in lower costs and reduced emissions
- Use of light water as reactor coolant, resulting in reduction of systems for heavy water coolant cleanup and recovery and simplification of containment atmosphere cleanup systems
- Improved fuel burn-up through the use of low enriched uranium (LEU) fuel, contained in advanced CANFLEX®-ACR fuel bundles
- Efficient means for burning other fuel types such as mixed oxides (MOX) and thorium fuels
- Increased fuel safety margins
- Improved plant thermal efficiency through use of higher pressures and higher temperatures in the coolant and steam supply systems
- Enhanced accident resistance and core damage prevention features
- Improved performance through use of SMART CANDU™ advanced operational and maintenance information systems and provision of designed-in maintenance features such as lifting devices, platforms and laydown areas
- Approximately 60% reduction in spent fuel quantities compared to current operating CANDU plants

Significant design simplifications

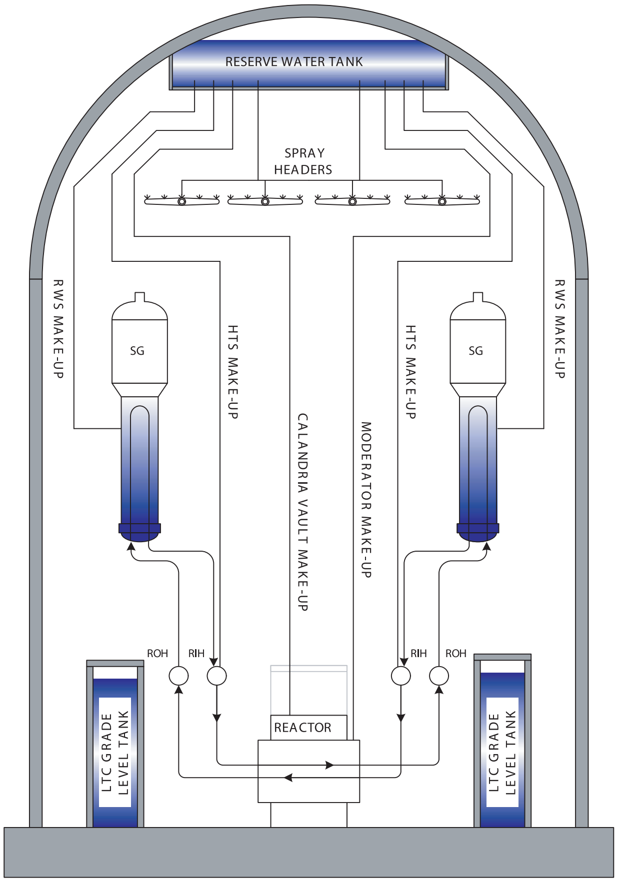
- Steel-lined containment designed for all design basis events
- Sharing of long-term emergency cooling and shutdown cooling safety functions
- Use of light water coolant enabling a simplified Emergency Coolant Injection (ECI) system, which replaces large motor-operated, safety-qualified injection valves with passive check valves
- Reduced inspections through selection of feeder materials for increasing resistance to flow-assisted corrosion (FAC) and robust fuel channel design margins
- Reduced on-line and start-up time with computerized testing of major safety systems and automatic calibration of in-core detector control signals
- Fuelling machine simplification with electric drives eliminating complex pneumatic systems. This accelerates the on-line fuelling process, reduces maintenance and speeds pressure tube in-service inspection
- Faster movement of personnel, without risk of airborne contamination spread, through use of ventilation systems that allow main airlock doors to be open during an outage
- Maintenance-based design providing required space allocation, reduction in temporary scaffolds and hoists, and provision for built-in electrical, water and air supplies for on-power and normal shutdown maintenance
- Reduction in number of sensors due to permitted sharing between systems

These technical improvements, along with advancements in project engineering, manufacturing, and construction, result in significantly reduced capital cost and construction schedule, while enhancing the inherent safety of the ACR-1000 design.

1.3 Passive Safety Features

The ACR-1000 design includes a number of "passive" safety features, some of which are design improvements over the already robust systems in existing CANDU plants. Examples of optimized features include:

- Two independent passively driven shutdown systems, each of which is capable of safely shutting down the reactor
- Increased safety margins with negative reactivity coefficients
- Passive emergency coolant injection operation
- Cool, low-pressure moderator serving as a passive heat sink for decay heat from fuel channels in severe accident situations
- Large concrete reactor vault, surrounding the core in the calandria vessel and containing a large volume of light water to further slow down or arrest severe core damage progression by providing a second, passive, core heat sink
- Elevated reserve water tank (RWT) in upper level of the containment building to deliver passive make-up cooling water by gravity to heat transport system, steam generators, moderator and the calandria vault. This delays progression of severe accidents and provides even more time for mitigating actions by the operator
- Passive, robust, seismically-qualified containment consisting of:
    - Thickened pre-stressed concrete structure designed to withstand aircraft crashes
    - Leak-tight inner steel liner to reduce potential leakages
    - Passive spray system from elevated reserve water tank to reduce reactor building pressures in the event of a severe accident
    - Passive Hydrogen Recombiner



ONLY ONE LOOP OF HTS IS SHOWN

Figure 1-2 Reserve Water System

2. Plant Design

2.1 Layout: Inherently Safer and Faster to Build

Designed for efficient operation, increased safety and easier and faster maintenance, the plant is laid out to provide separation by distance, elevations and the use of barriers for safety-related structures, systems and components. Each corner of the reactor auxiliary building houses redundant safety equipment in a four-quadrant configuration.

Security and physical protection have been addressed to ensure that the response to potential common and abnormal events, such as fires, aircraft crashes and malevolent acts meets latest criteria.

The plant layout is also designed to achieve the shortest practical construction schedule while supporting easier maintenance practices. Buildings are arranged to minimize interferences during construction, with allowance for on-site fabrication of module assemblies. Through the use of open-top construction, provisions exist for flexible equipment installation sequences.

The footprint of the two-unit plant has been minimized with the adoption of common areas for the main control room, service and maintenance buildings. A single-unit plant can be adapted from the two-unit layout with no significant changes to the reference design. The plant is designed for an exclusion zone of 500 metre radius. The size of the power block for a 2-unit ACR-1000 station is 48,700 m^2* (actual area).

** Power block consists of 2 reactor buildings, 2 reactor auxiliary buildings, 2 turbine buildings, 1 service building, 1 main control building, 1 maintenance building, 1 crane hall, 2 secondary control buildings and four diesel generator buildings.*

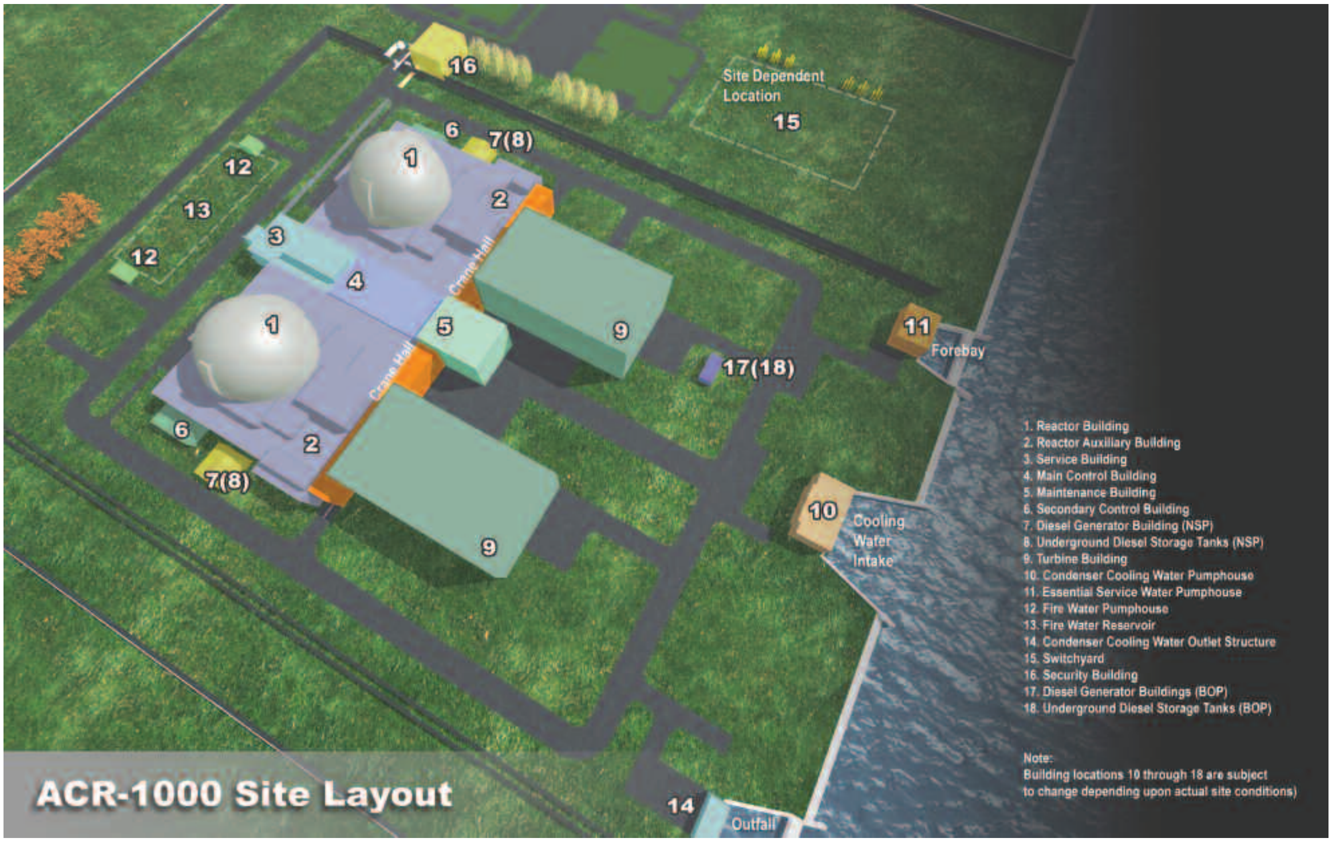


Figure 2-1 Two-Unit Plant Layout of Major Structures

Major buildings and structures of two-unit plant

- Reactor Buildings (2)
- Reactor Auxiliary Buildings (2)
- Turbine Buildings (2)
- Main Control Building
- Secondary Control Buildings (2)
- Maintenance and Service Buildings
- Condenser Cooling Water Pumphouse
- Essential Service Water Pumphouse
- Main Switchyard

Reactor Building

Strengthened over previous CANDU designs, the pre-stressed concrete reactor building is seismically-qualified and tornado-proofed. The concrete outer wall has an inner steel liner that will achieve significantly reduced leak rates in the event of an accident.

An isolation system ensures “button-up” in case of accidents.

The entire structure, including concrete internal structures, is supported on a reinforced concrete base slab to ensure a fully enclosed boundary for environmental protection and biological shielding.

During reactor operation, internal shielding permits personnel access to an environment that is temperature-controlled for personal comfort. Airlocks are designed as routine entry/exit doors.

Containment structure perimeter walls are separate from internal structures, so as to eliminate any interdependence and to provide flexibility in construction.

The reactor building is the principal component of the containment system.

	CANDU 6	**ACR-1000**
Containment Structure		
Type	Pre-stressed concrete / epoxy liner	Pre-stressed concrete / steel liner
RB inside diameter	41.4 m	56.5 m
RB containment wall thickness	1.07 m	1.8 m
Building height (base slab to top of dome)	51.2 m	74.0 m

Reactor Auxiliary Building

The reactor auxiliary building is a multi-level, reinforced concrete and steel structure that is seismically-qualified and tornado protected. It surrounds the reactor building and accommodates the umbilicals that run between the principal structures, the electrical systems, and the spent fuel bay and associated fuel-handling facilities. It also houses the long-term cooling (LTC) pumps and heat exchangers, the spent fuel bay cooling and purification system pumps and heat exchangers, the essential cooling water pumps, heat exchangers and valve stations, and the essential service water valve stations. Safety and isolation valves for the main steam lines are housed in a seismically-qualified concrete structure on top of the building.

Turbine Building

The turbine building is located to one side of the reactor auxiliary building, so that turbine shaft alignment is perpendicular to the reactor building. This is also an optimum location for access to the main control room, the piping and cable tray runs to and from the reactor auxiliary building, and the condenser cooling water ducts to and from the main pumphouse. Access routes are provided between the turbine building and the reactor auxiliary building.

The turbine building houses the turbine generator and its auxiliary systems: condenser, condensate and feedwater systems, the building heating plant, and any compressed gas required for the balance of plant (BOP). Blow-out panels in the walls and roof serve to relieve internal pressure in the event of a steam-line break.

Figure 2-2 Reactor Building

Main Control Building

Seismically-qualified and tornado-protected, the main control building is a multi-level structure located between the two units. It has a superstructure of steel and reinforced concrete and reinforced concrete substructure. It contains the main control room (MCR) and associated control and electrical equipment for the two units. Each side of the MCR has dedicated panels, computers, displays and operator consoles with separation of cabling and equipment for each unit.

Secondary Control Building

Each unit has a completely separate secondary control building (SCB) with sufficient control and monitoring equipment to shut down the unit, initiate required cooling and ensure a safe, maintained shutdown state should the MCR become uninhabitable or non-functional. The SCB is located so that the MCR and SCB cannot be simultaneously rendered inoperable due to any design basis event. SCB human-system interface components are similar to those in the MCR so as to minimize human error should the operator relocate from one area to the other.

Maintenance and Service Buildings

The seismically-qualified maintenance and service buildings are located between the two-unit ACR-1000 plant. They house all conventional plant services, including radioactive waste handling facilities, heavy water management systems, common services, central stores, central active/non-active maintenance shops, and change rooms for staff. They are multi-level structures with a reinforced concrete substructure and braced steel-frame superstructure.

Condenser Cooling Water Pumphouse

The condenser cooling water (CCW) pumphouse has a reinforced concrete substructure and braced steel-frame superstructure. It contains the CCW pumps, plant water system pumps, screen wash pumps, trash racks, screens, and chlorination equipment, if required. Together with related intake and outfall structures, the pumphouse serves the two-unit ACR-1000 plant, housing separate CCW and plant water systems with adequate separation for each unit. Sites with limited cooling water availability can use cooling towers instead of the conventional CCW system.

Essential Service Water (ESW) Pumphouse

The essential service water (ESW) pumphouse contains the ESW pumps. It has a reinforced concrete substructure, braced steel-frame superstructure and is seismically and tornado-qualified.

Main Switchyard

The switchyard is designed to allow flexible operation for power output, switching and maintenance. A breaker-and-a-half design with single voltage is proposed for high reliability. Each ACR-1000 unit will have at least four bays of power inputs/outputs from the main transformers and grid system, with options to add more as future plant and grid requirements may dictate.

2.2 Plant Siting

2.2.1 Unit Output

Each unit of the ACR-1000 two-unit integrated plant design has a nominal gross electrical output of 1165 MWe. Output can be optimized by adjusting the turbine/condenser design to suit any site cooling water conditions.

2.2.2 Adaptation to Site Requirements

The ACR-1000 can accommodate a wide range of geotechnical and meteorological data and conditions. Some of these flexible design features include:

- Cooling water systems for all nuclear steam requirements, saltwater or freshwater. Conventional cooling towers can also be used
- Cooling water temperatures from typical cold to typical warm sites. A generic set of reference conditions has been developed for potential ACR-1000 sites
- Tornado protection as required. The design basis tornado (DBT) is defined by a maximum wind speed of 483 km/h. DBT for the ACR-1000 is selected to satisfy tornado design requirements for North American sites and potential sites overseas

- Plant exclusion zone capability of only 500 m radius. All unauthorized persons are restricted from this zone. Larger zones may be selected where desired
- Design basis earthquake (DBE) protection of up to 0.3 g acceleration. This is the maximum ground motion of potentially severe quakes, with low probability of being exceeded during the life of the plant

2.3 Nuclear Systems

ACR-1000 nuclear systems are located in the reactor building and the reactor auxiliary building. These buildings are robust and shielded where necessary to ensure all radioactive substances are always secure. Systems include:

- Heat transport system with light water coolant in a two-loop, figure-eight configuration with four steam generators, four heat transport pumps, four reactor outlet headers and four reactor inlet headers. This configuration is standard on all CANDU 6 reactors and the larger 935 MWe Darlington Nuclear Generating Station (NGS) CANDU design
- Heavy water moderator system
- Reactor assembly consisting of calandria vessel installed in concrete vault
- Fuel handling system consisting of two fuelling machine heads, each mounted on a fuelling machine bridge and supported by columns, located at each end of the reactor. The fuelling machines have been simplified to enhance maintainability and accelerate pressure tube in-service inspection
- Two independent shutdown systems, emergency core cooling (ECC) system, containment system and associated safety support systems

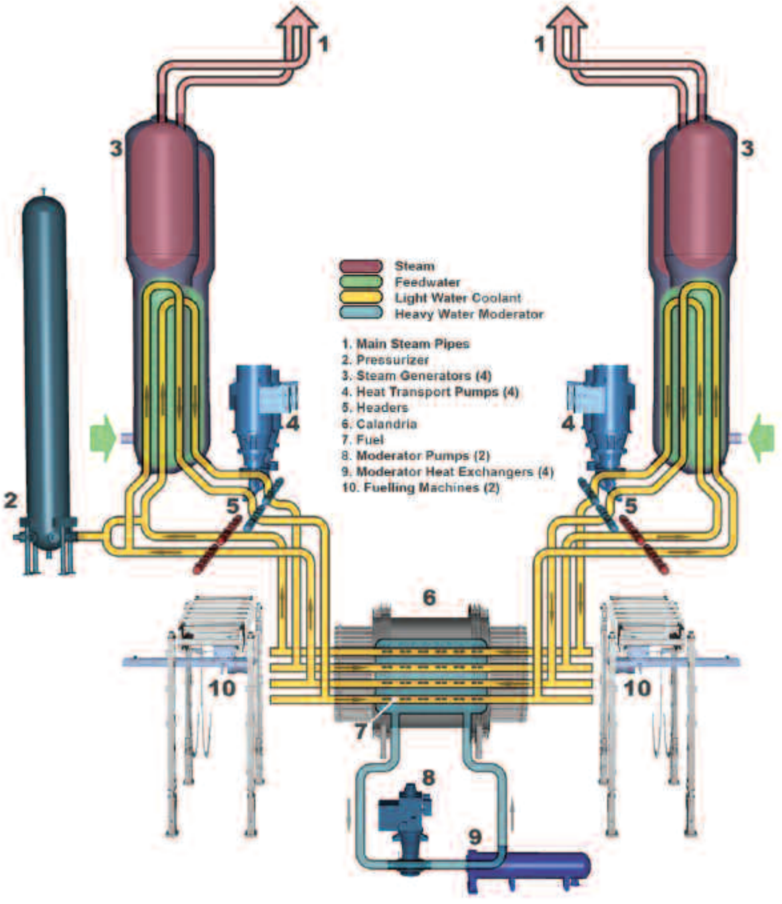


Figure 2-3 Nuclear Systems Schematic

2.4 Heat Transport System and Auxiliary Systems

The ACR-1000 heat transport system (HTS) circulates pressurized light water coolant through the reactor fuel channels to remove heat produced by nuclear fission in the core. The use of light water coolant is a design simplification allowing for the reduction of systems for cleanup and recovery. It also simplifies containment atmosphere cleanup systems.

The ACR-1000 HTS consists of 520 reactor fuel channels with associated corrosion-resistant stainless steel feeders, four inlet headers, four outlet headers and interconnecting piping. The system includes four steam generators and four electrically-driven heat transport pumps in a two-loop, figure-eight configuration. Headers, steam generators and pumps are all located above the reactor.

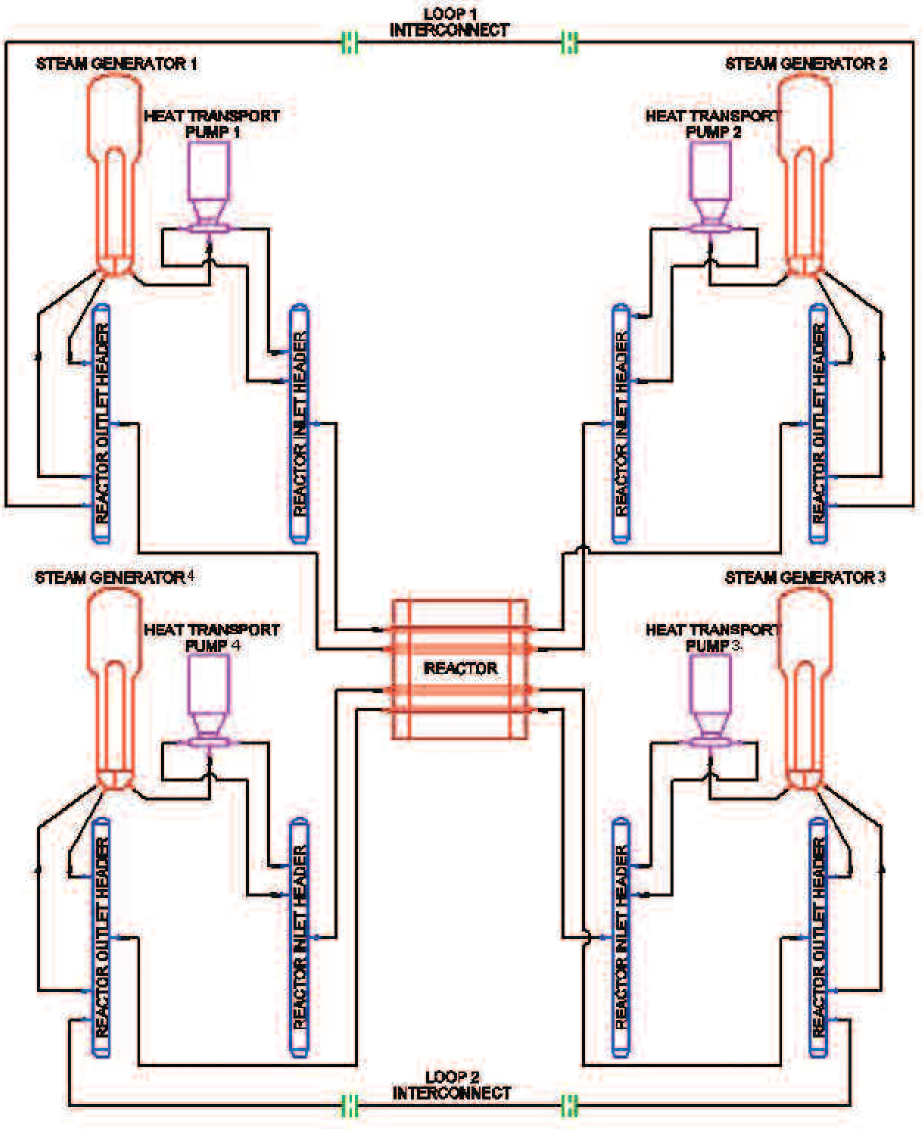


Figure 2-4 Heat Transport System Flow Diagram

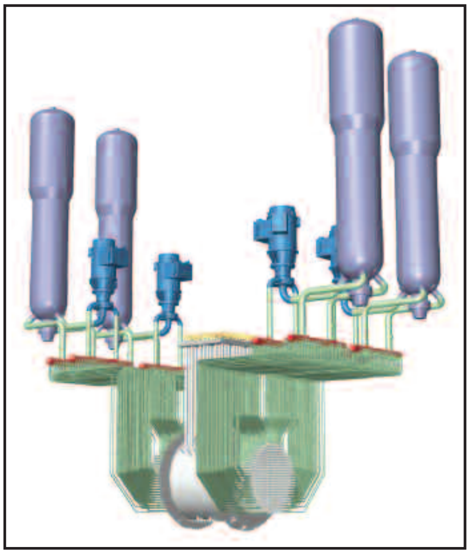


Figure 2-5 3D View of Heat Transport System Layout

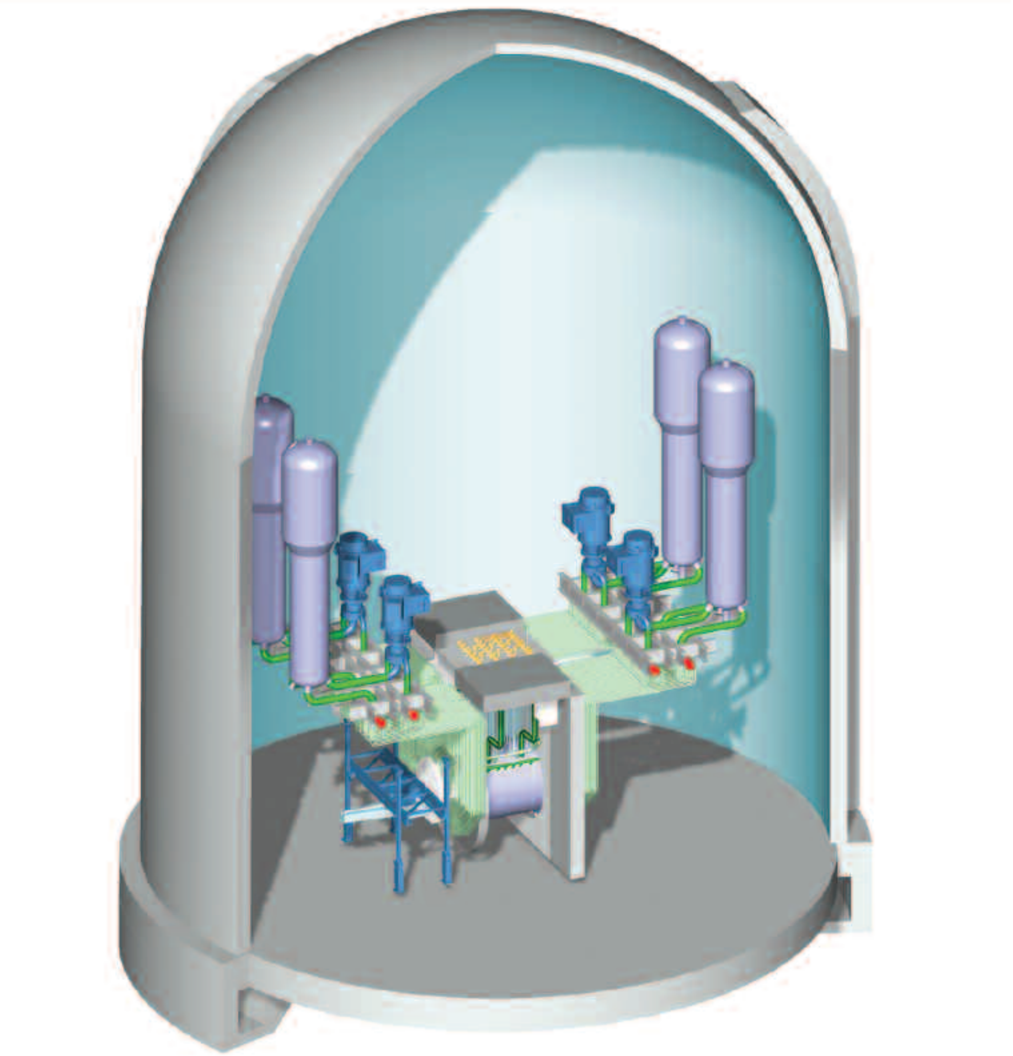


Figure 2-6 3D View of Heat Transport System in Reactor Building

Table 2-1 Heat Transport System Design Data

	CANDU 6	Darlington	ACR-1000
Reactor outlet header pressure [MPa (g)]	9.9	9.9	11.1
Reactor outlet header temperature [°C]	310	310	319
Reactor inlet header pressure [MPa (g)]	11.2	11.3	12.5
Reactor inlet header temperature [°C]	260	267	275
Single channel flow (maximum) [kg/s]	28	27.4	28

Pressure and Inventory Control System

The ACR-1000 heat transport pressure and inventory control system consists of pressurizer, pumps, feed and bleed valves and a coolant storage tank. This system provides:

- Pressure and inventory control for each heat transport system loop
- Overpressure protection
- Controlled degassing flow

Light water in the pressurizer is heated electrically to pressurize the vapour space above the liquid. The volume of the vapour space is designed to cushion pressure transients, without allowing excessively high or low pressures in the heat transport system.

The pressurizer also accommodates change in reactor coolant volume from zero power to full power. This permits reactor power to be increased or decreased rapidly, without imposing severe demand on the coolant feed and bleed components of the system.

When the reactor is at power, pressure is controlled by the pressurizer; heat is added with the electric heaters to increase pressure, and removed by spraying cold water via the reactor inlet headers to reduce pressure. The coolant inventory is adjusted by the feed-and-bleed circuit. Pressure can also be controlled by the feed-and-bleed circuit with the pressurizer isolated at low reactor power and when the reactor is shut down. The feed-and-bleed circuit is designed to accommodate the changes in coolant volume that take place during heat-up and cool-down.

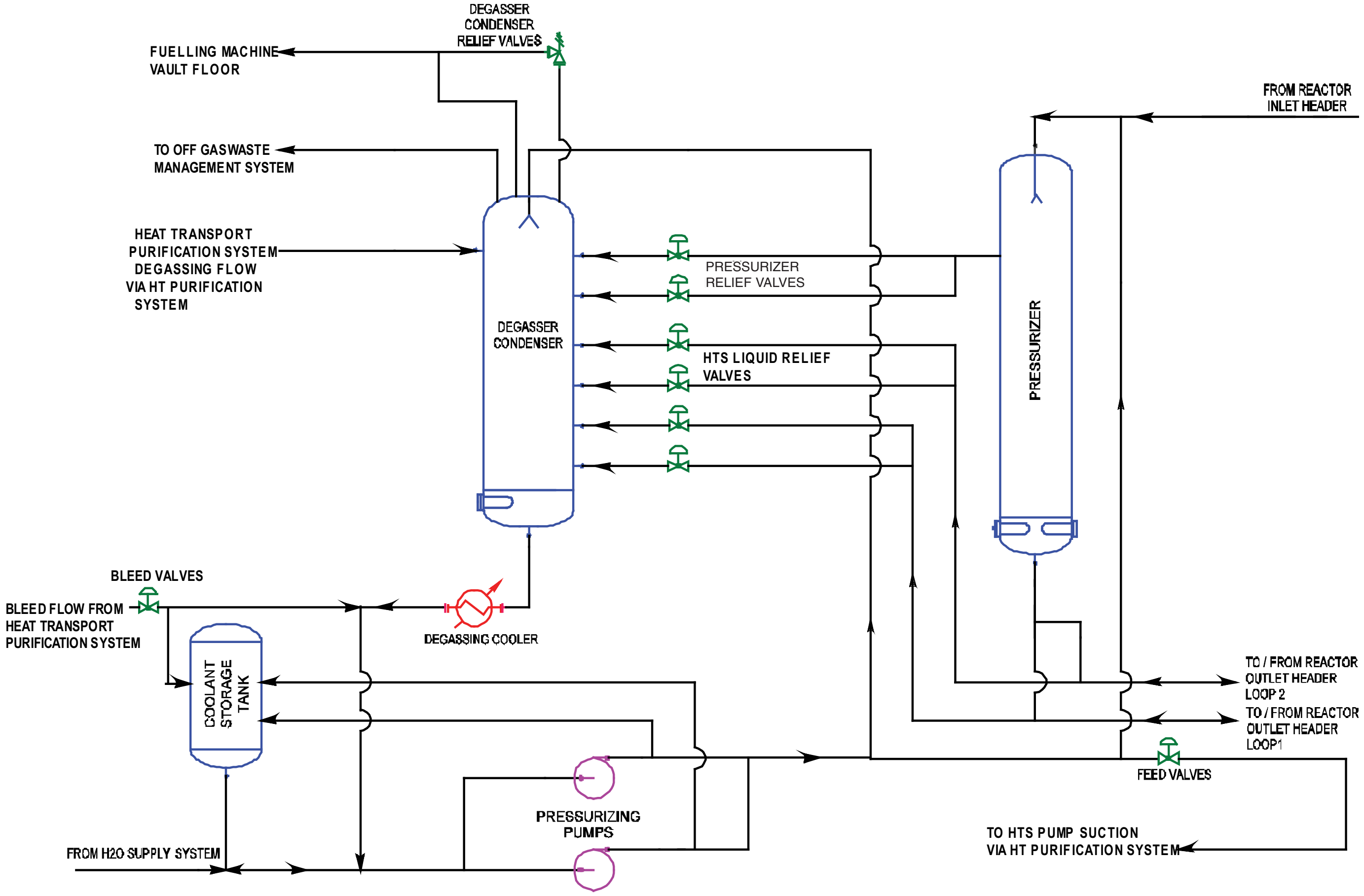


Figure 2-7 Pressure and Inventory Control Flow Diagram

2.4.1 Heat Transport Pumps

The ACR-1000 heat transport pumps are an enhanced, larger version of the double-discharge design used in the CANDU 6 and Darlington reactors.

The ACR-1000 retains the CANDU mechanical multi-seal design, which allows for easy replacement. Backup seal cooling extends pump survivability, even during accident conditions, if service water is lost.

Table 2-2 Heat Transport Pump Data

	CANDU 6	Darlington	ACR-1000
Number	4	4	4
Rated flow [L/s]	2228	3240	4300
Motor rating [MWe]	6.7	9.6	10.0

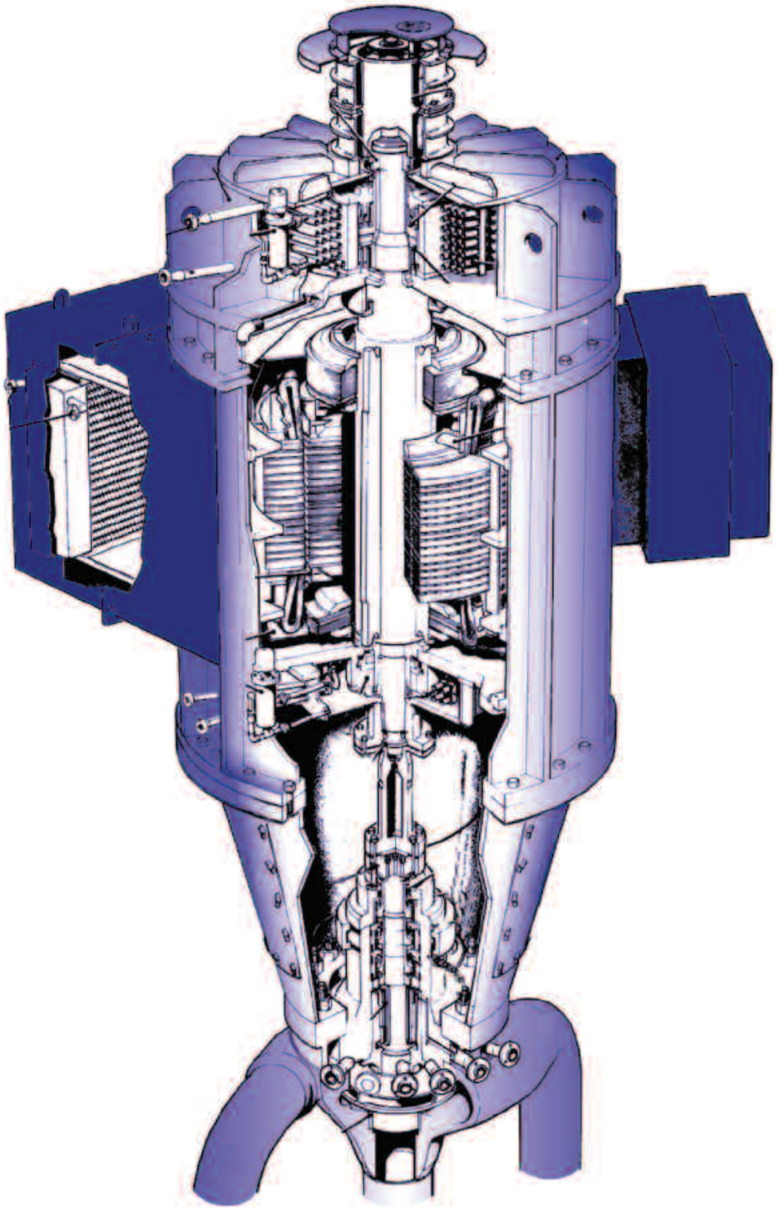


Figure 2-8 Heat Transport System Pump

2.4.2 Steam Generators

The ACR-1000 steam generators are similar to the CANDU 6 and Darlington designs, except for the larger physical size. For the ACR-1000, steam generator tubing diameter is increased to take advantage of the change to light water coolant.

ACR-1000 tubing is made of Incoloy-800, a material with proven operating performance and service at CANDU 6 and Darlington stations. Steam wetness at the steam nozzle has been reduced to 0.1%, based on latest steam separator technology, leading to improved turbine cycle economics.

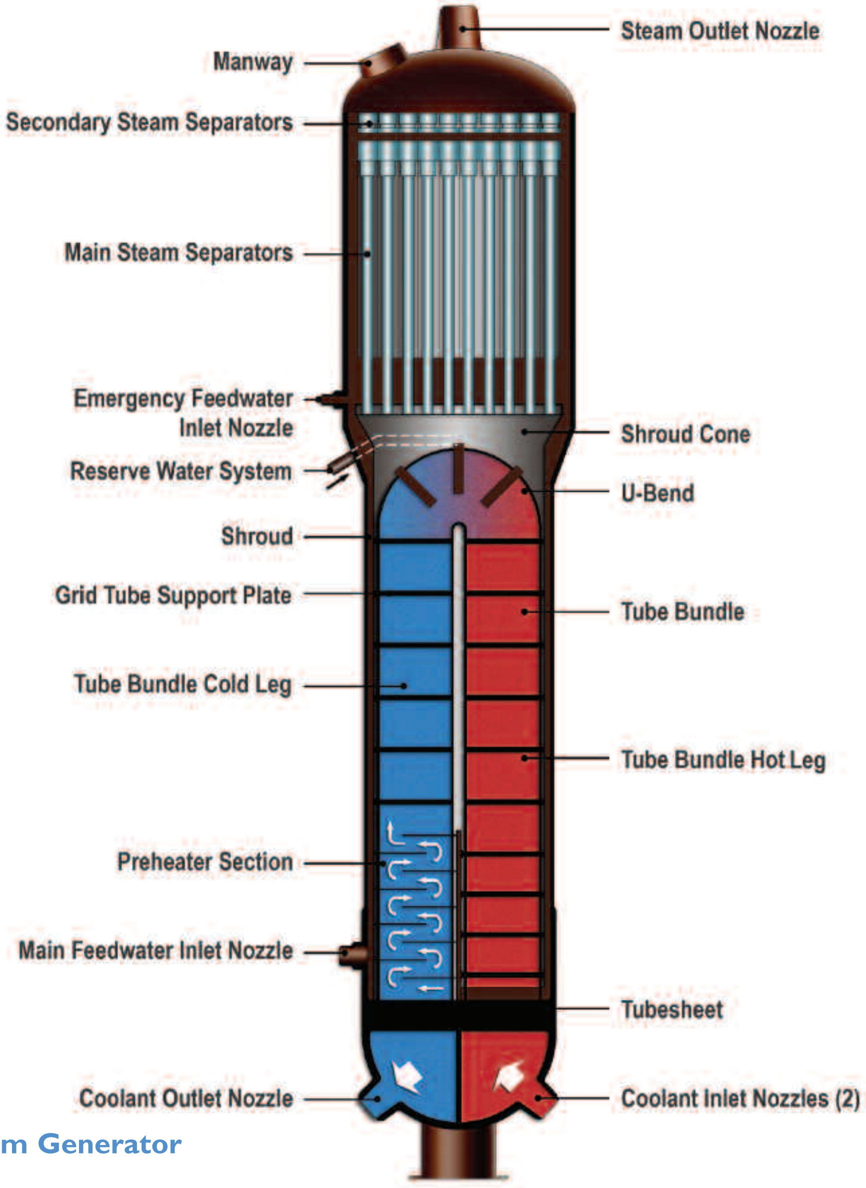


Figure 2-9 Steam Generator

Table 2-3 Steam Generator Design Data

Steam Generators	**CANDU 6**	**Darlington**	**ACR-1000**
Number	4	4	4
Type	Vertical U-tube / integral pre-heater	Vertical U-tube / integral pre-heater	Vertical U-tube / integral pre-heater
Nominal tube diameter [mm]	15.9 (5/8”)	15.9 (5/8”)	17.5 (11/16”)
Steam temperature (nominal) [°C]	260	265	275.5
Steam quality	0.9975	0.9975	0.999
Steam pressure [MPa (g)]	4.6	5.0	5.9

2.5 Moderator System

The ACR-1000 moderator is a low-pressure, low-temperature system that is fully independent of the heat transport system. It consists of pumps and heat exchangers that circulate heavy water moderator (D_2O) through the calandria vessel and remove heat generated within the moderator during reactor operation. Heavy water acts as both moderator and reflector for the neutron flux in the core.

Inlet and outlet nozzles are located at the top of the calandria vessel to prevent inadvertent draining and are oriented to ensure uniform moderator temperature distribution inside the calandria.

The ACR-1000 moderator system also fulfills a safety function that is unique to ACR/CANDU. It serves as a backup heat sink in the event of loss of fuel cooling via the heat transport system, thereby mitigating core damage consequences. Heat exchangers are provided with seismically-qualified cooling water and standby power.

Another safety improvement in the ACR-1000 is the connection to the reserve water tank. It provides additional passive gravity-fed inventory to the calandria vessel, extends core cooling and delays severe accident event progression.

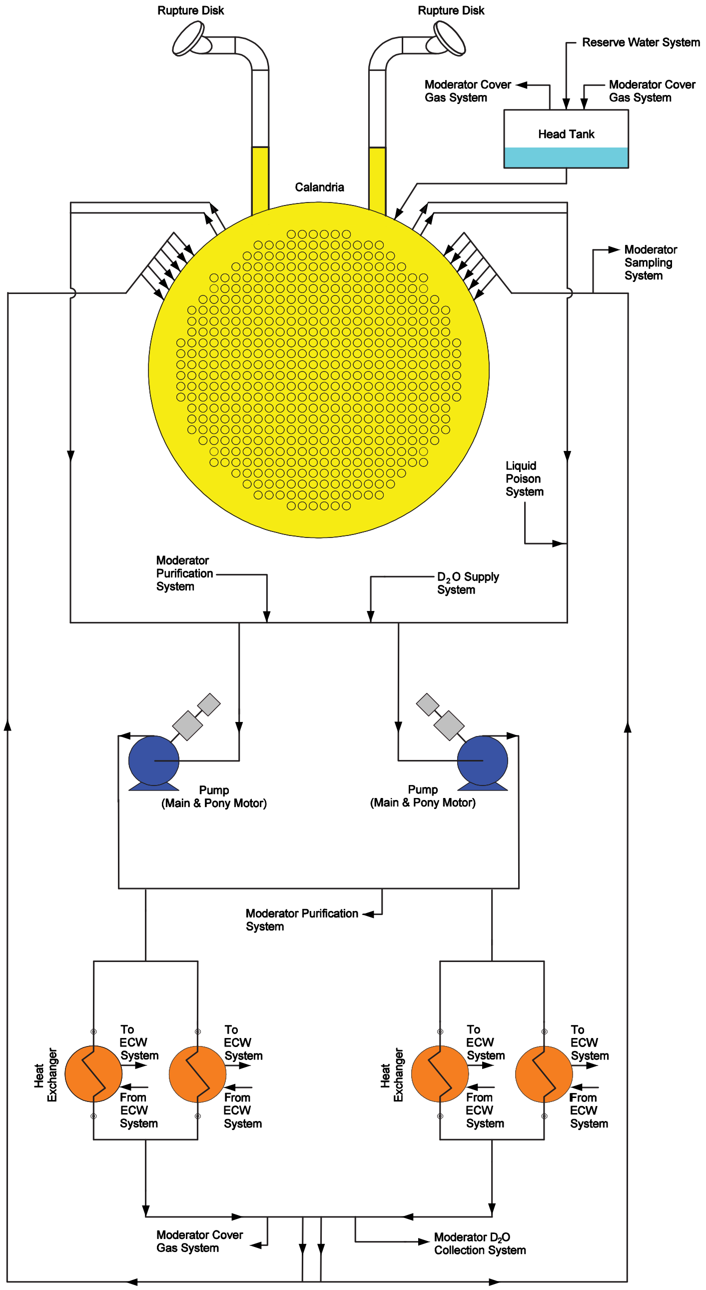


Figure 2-10 Moderator System Flow Diagram

Table 2–4 Heavy Water Inventory Design Data

	CANDU 6	Darlington	ACR-1000
Moderator System			
[Mg D_2O]	265	312	250
Heat Transport System			
[Mg D_2O]	192	280	0
Total [Mg D_2O]	457	592	250

2.6 Reactor Assembly

The ACR-1000 reactor assembly consists of the horizontal, cylindrical, low-pressure calandria and end-shield assembly. This enclosed assembly contains the heavy water moderator and the 520 fuel channel assemblies. The reactor is supported within a concrete, light-water-filled calandria vault. Fuel is enclosed in the fuel channels that pass through the end shields. Each fuel channel permits access for on-line fuelling operation while the reactor is at power.

The ability to replace fuel as required for maintaining power means minimal "excess" reactivity in the core at all times, an inherent safety feature. This feature also contributes to operational flexibility for improved outage planning, since fixed cycle times are not required and prompt removal of defect bundles can be accomplished without shutdown.

2.6.1 Reactor Core Characteristics

The ACR-1000 reactor core offers the following distinctive advantages:

- Compact size due to smaller fuel channel lattice pitch than CANDU, resulting in reduced heavy water requirements
- Use of light water as coolant
- Negative coolant void reactivity
- Simplified reactor control through negative feedback in reactor power
- Flattened axial and radial profiles to optimize channel thermal power output

The physical size of the ACR-1000 core, while producing greater power output, is similar to that of the CANDU 6.

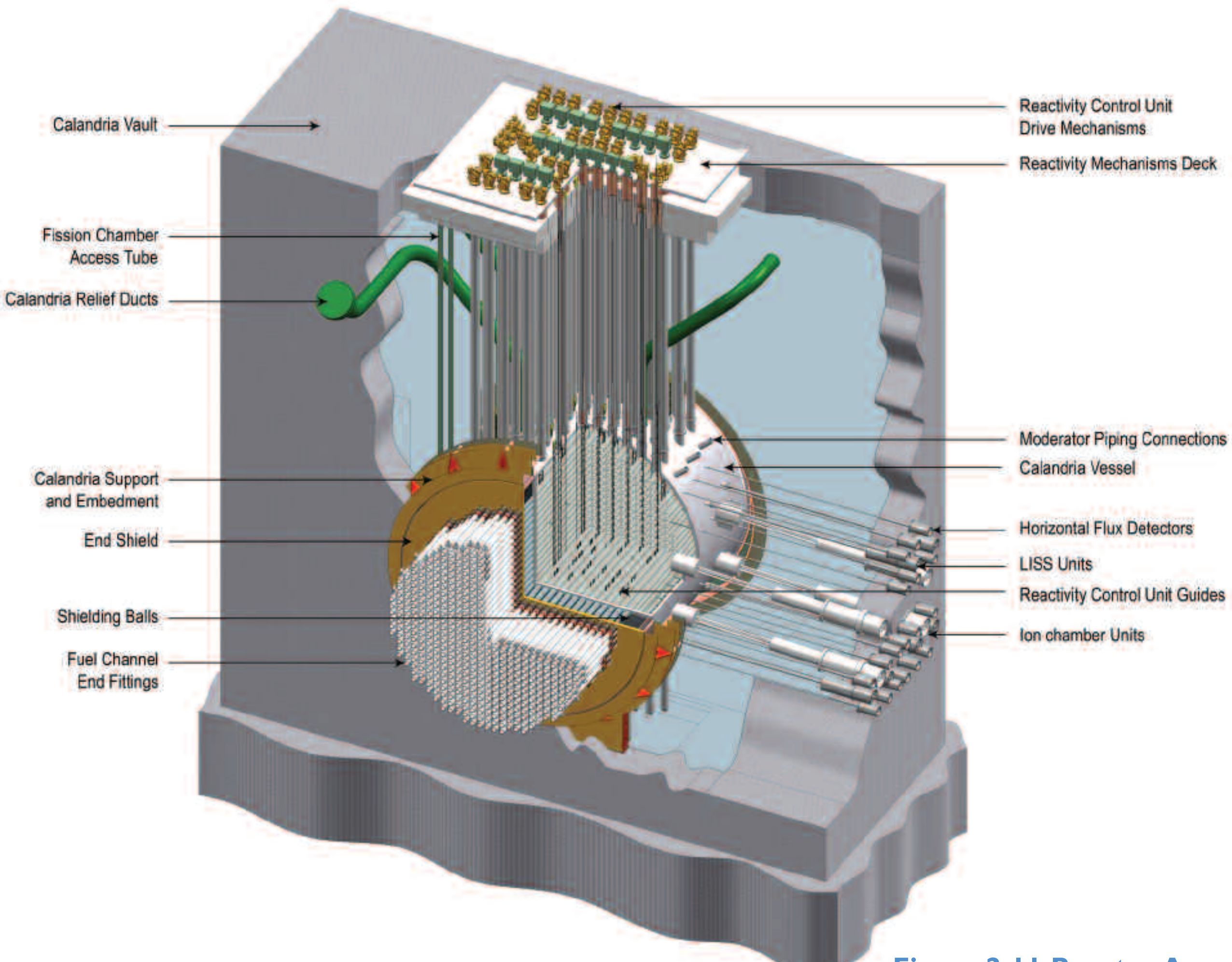


Figure 2-11 Reactor Assembly

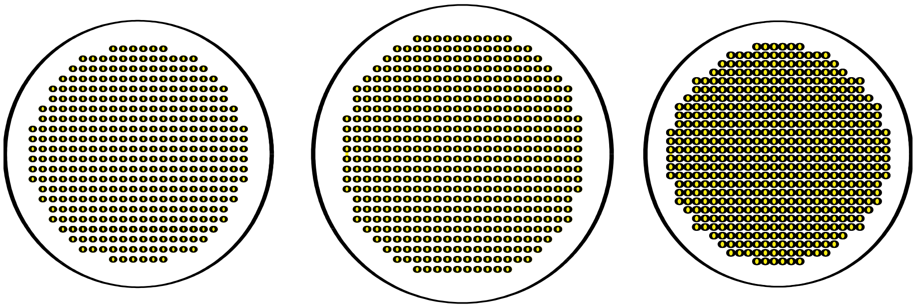
2.6.2 Reactor Control

The neutronic coupling in the compact ACR-1000 core and negative power coefficient ensure core stability. All harmonic modes, including the first axial mode, are stable at all power levels under nominal operating conditions. Stable reactor physics characteristics allow simpler control mechanism design.

Mechanical zonal control units provide primary control in the ACR-1000. Each zone control assembly consists of two independently movable segments. On-power refuelling and zone-control actions provide day-to-day reactivity control. The reactor regulating system also includes control absorber units, physically similar to the mechanical shutoff rods that can be used to reduce power if larger reductions are required.

Table 2- 5 Reactor Core Design Data

	CANDU 6	Darlington	ACR-1000
Reactor			
Output [MWth]	2064	2657	3187
Coolant	Pressurized D_2O	Pressurized D_2O	Pressurized Light Water
Moderator	D_2O	D_2O	D_2O
Calandria diameter [m]	7.6	8.5	7.5
Fuel channel	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings	Horizontal Zr 2.5wt%Nb alloy pressure tubes with modified 403 SS end-fittings
Fuel channels	380	480	520
Lattice pitch (mm)	286	286	240
Pressure tube wall thickness (mm)	4	4	6.5


CANDU - 6

Darlington

ACR-1000

Figure 2-12 Comparison of Core Sizes

2.6.3 Fuel Channel Assembly

The ACR-1000 fuel channel assembly consists of a zirconium-niobium (Zr-2.5%Nb) pressure tube, centred in a zircaloy calandria tube. The pressure tube is roll-expanded into stainless steel end fittings at each end.

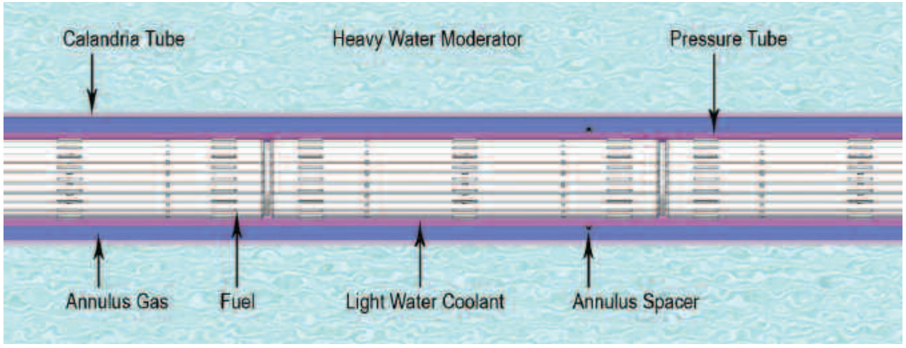


Figure 2-13 Fuel Channel

Each pressure tube is thermally insulated from the low-temperature moderator by the annulus gas between the pressure tube and the calandria tube. Fixed spacers, positioned along the length of the pressure tube, maintain annular space and prevent contact between the two tubes. Each end-fitting holds a liner tube, a fuel support plug and a channel closure. Reactor coolant flows through adjacent fuel channels in opposite directions. The ACR-1000 calandria tube has been thickened compared to the CANDU design to ensure it can withstand a pressure tube rupture.

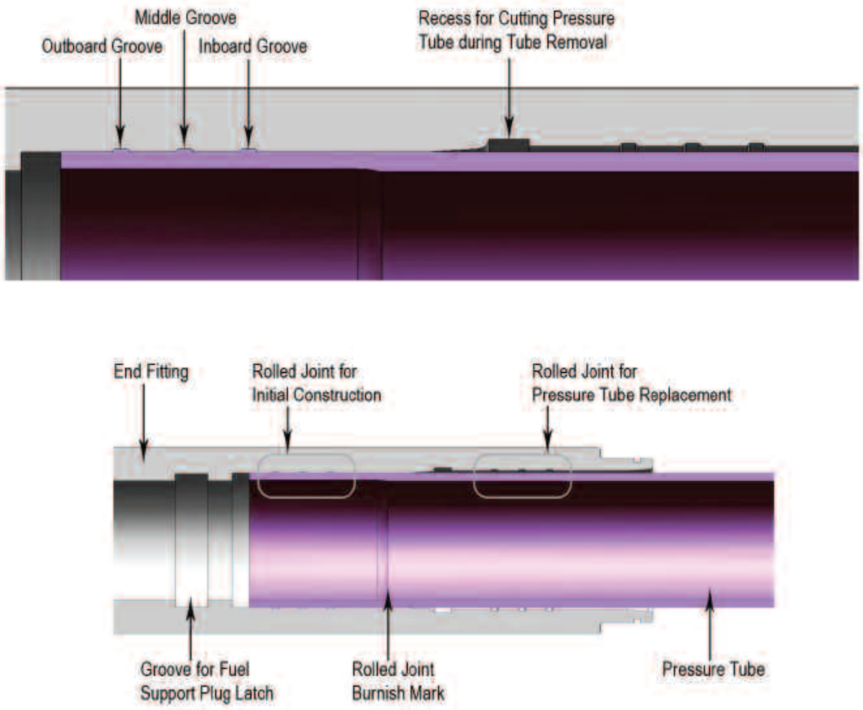


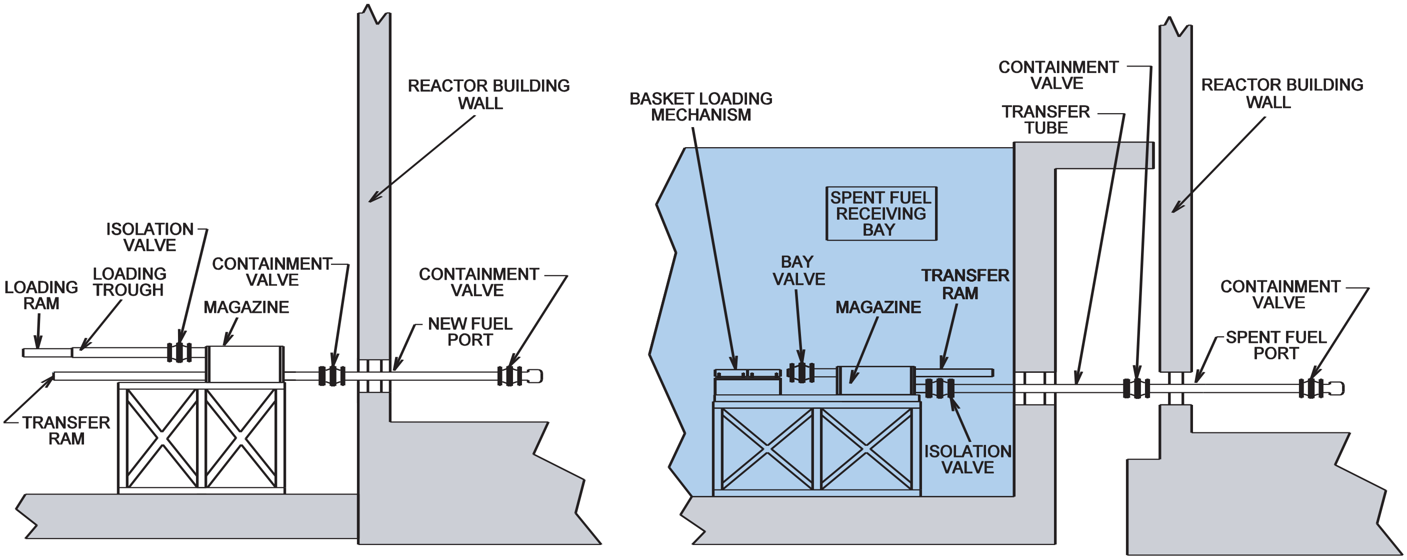
Figure 2-14 Fuel Channel Grooves

The ACR-1000 is designed for 60 years of reactor operation with provision for mid-life refurbishment, including replacement of fuel channels. Special design features, such as additional rolled joint grooves, are provided in the end-fittings to facilitate pressure tube replacement.

2.7 Fuel Handling Systems

The ACR-1000 fuel handling systems consist of:

- New fuel handling and storage system
- Fuelling machines and their supports
- Spent fuel handling and storage



NEW FUEL TRANSFER

SPENT FUEL TRANSFER

Figure 2-15 New Fuel and Spent Fuel Transfer Mechanisms

The new ACR-1000 fuel handling and storage system includes the storage of the new low enriched uranium (LEU) fuel and the supply of the two fuelling machines to maintain full-power operation. The need for operator access to the reactor building is minimized with all new fuel storage, inspection and fuelling machine loading being performed from an accessible area in the reactor auxiliary building.

Evolved from the CANDU 6 design, the simplified ACR-1000 fuel handling machines incorporate significant advances. Key design improvements include replacing water and oil hydraulic drives with electric drives, a larger capacity magazine and a mechanical ram with absolute resolvers for position feedback. Further design simplifications include change to light water operation, with heavy water eliminated from the fuel handling systems. These changes, along with built-in redundancy, will result in improved system performance, extended in-service periods and reduced maintenance requirements, including accelerated de-fuelling for pressure tube in-service inspection.

Two fuelling machines are located on opposite sides of the reactor and mounted on bridges supported by columns. The normal refuelling operation is an eight-bundle shift, in the direction of coolant flow, in which spent bundles are removed from the outlet end of a fuel channel, while fresh bundles are inserted at the inlet end.

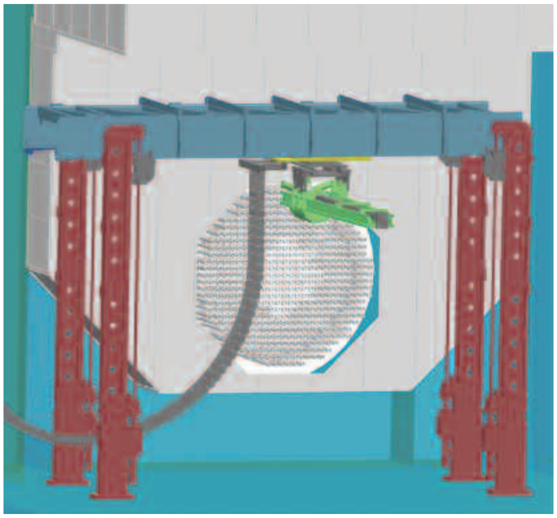


Figure 2-16 Fuelling Machine and Carriage

The ACR-1000 transfer and storage system handles spent fuel from the time it is discharged from the fuelling machine to the time it is moved to the storage bay in the reactor auxiliary building.

Once spent fuel is discharged, the transfer system uses recirculating water, which also cools the fuel, to push it through a pipe to receiving bays. The system then unloads the fuel from its magazine and moves it in baskets to the storage bay through a shielded tunnel. In the storage bay, spent fuel baskets are stacked in frames with capacity for at least 10 years operation. A storage bay bridge and handling tools permit manipulation of spent fuel and containers. Baskets are also suitable for direct transfer to dry fuel storage, which can be provided at Owner request—for an additional 50 or beyond.

The entire fuelling and spent fuel unloading process is automated and carried out from the station control room.

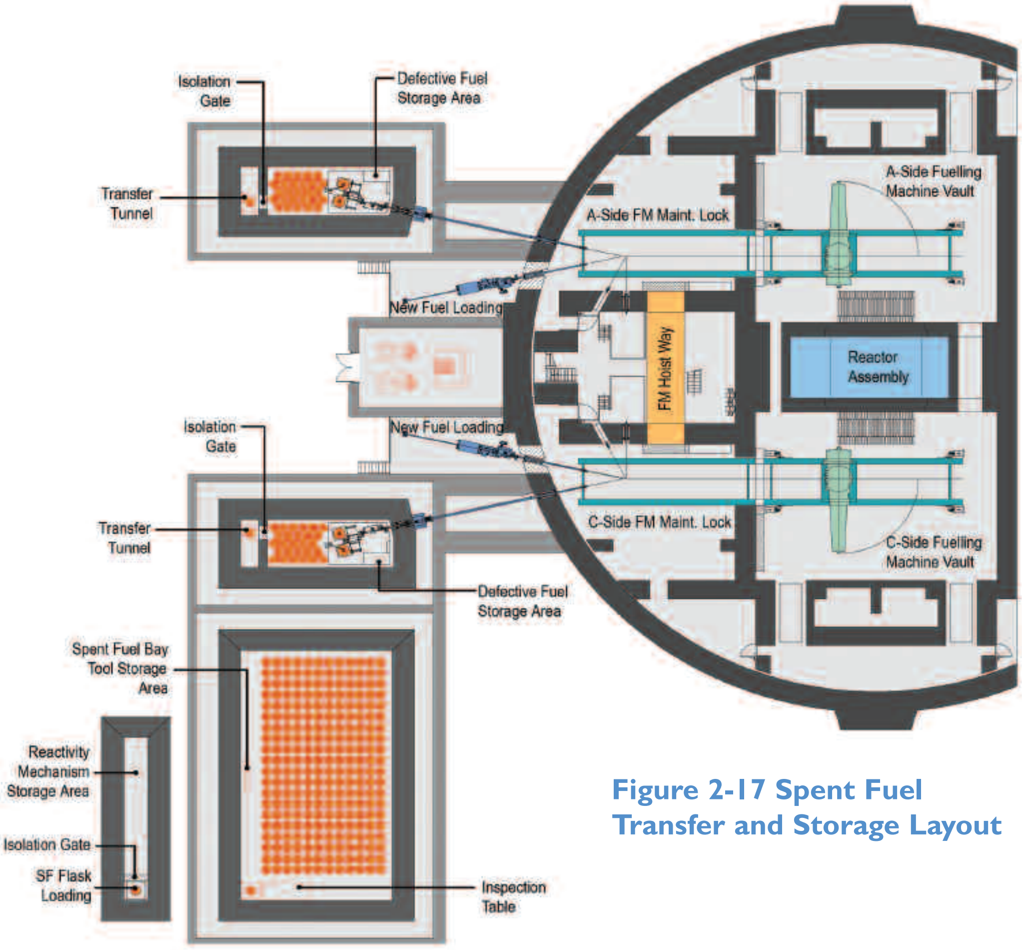


Figure 2-17 Spent Fuel Transfer and Storage Layout

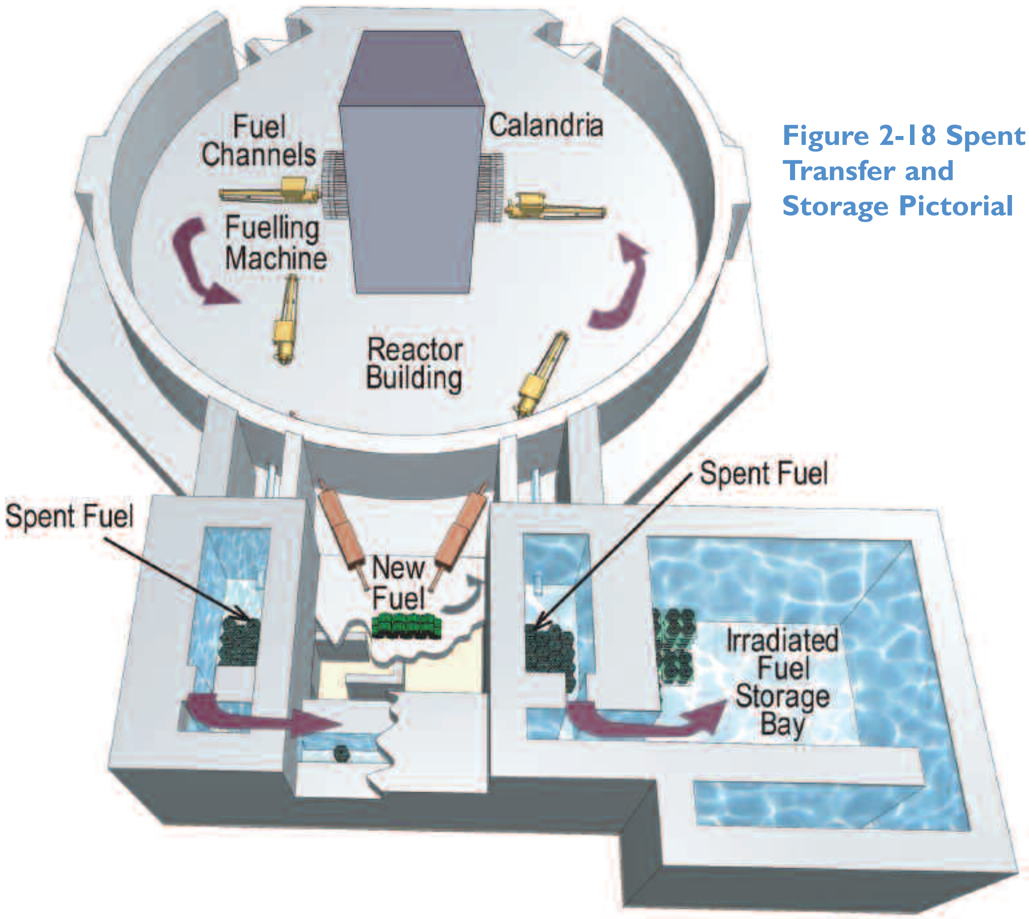


Figure 2-18 Spent Fuel Transfer and Storage Pictorial

	CANDU 6	Darlington	ACR-1000
Fuel	Natural UO_2	Natural UO_2	Low enriched UO_2
Fuel burn-up [MWd/te U]	7,500	7,791	20,000
Fuel bundle assembly	37 element	37 element	43-element CANFLEX®-ACR
Bundles per fuel channel	12	13	12

2.8 Fuel

The ACR-1000 uses the 43-element CANFLEX®-ACR fuel bundle design.

The centre element contains neutron absorbers, while the remaining elements contain U-235 enriched UO_2 pellets. A burnable absorber is used in some of the elements that contain enriched pellets to optimize the power rating of the fuel. The neutron absorbers of the centre element are used for management of coolant void reactivity. A very thin layer of CANLUB covers the inside surface of the fuel cladding to enhance fuel performance.

The ACR inherent feature for operating with neutron absorbers makes it ideally suited to burn other fuel types such as mixed oxides (MOX) and thorium.

Figure 2-19
CANFLEX®-ACR Fuel Bundle

2.9 Safety Systems

ACR-1000 safety systems are designed to mitigate the consequences of plant process failures, ensuring reactor shutdown, removal of decay heat and prevention of radioactive releases.

Design follows the traditional CANDU practice of providing:

- Shutdown System 1, (SDS1)
- Shutdown System 2, (SDS2)
- Emergency Core Cooling (ECC) System
- Containment System
- Emergency Feedwater System

SDS1, SDS2, the ECC and containment systems meet high reliability requirements that have been established during system design and verified by reliability analysis.

Safety support systems are also provided to ensure reliable electrical power, cooling water and instrument air supplies to the safety systems. Eight nuclear steam plant (NSP) standby generators are provided for the two units. Four NSP standby generators are "pre-assigned" to specific distribution buses in the respective unit. Two additional BOP standby generators provide backup to the NSP for postulated station blackout events.

Safety systems and their support services are designed to perform their safety functions with a high degree of reliability. This is achieved through the use of redundancy, diversity, separation, testability, the application of appropriate quality assurance standards, and the use of stringent technical specifications, including seismic and environmental qualification for accident conditions.

2.9.1 Shutdown Systems

The ACR-1000 incorporates two passive, fast-acting, fully capable, diverse and separate shutdown systems, which are physically and functionally independent of each other.

SDS1 consists of mechanical shutoff rods that drop by gravity into the core when a trip signal de-energizes the clutches that hold the shutoff rods out of the core. The design of the shutoff rods is based on the proven CANDU 6 design. The in-core portion of the shutoff rods has been designed to accommodate the smaller ACR-1000 core lattice pitch.

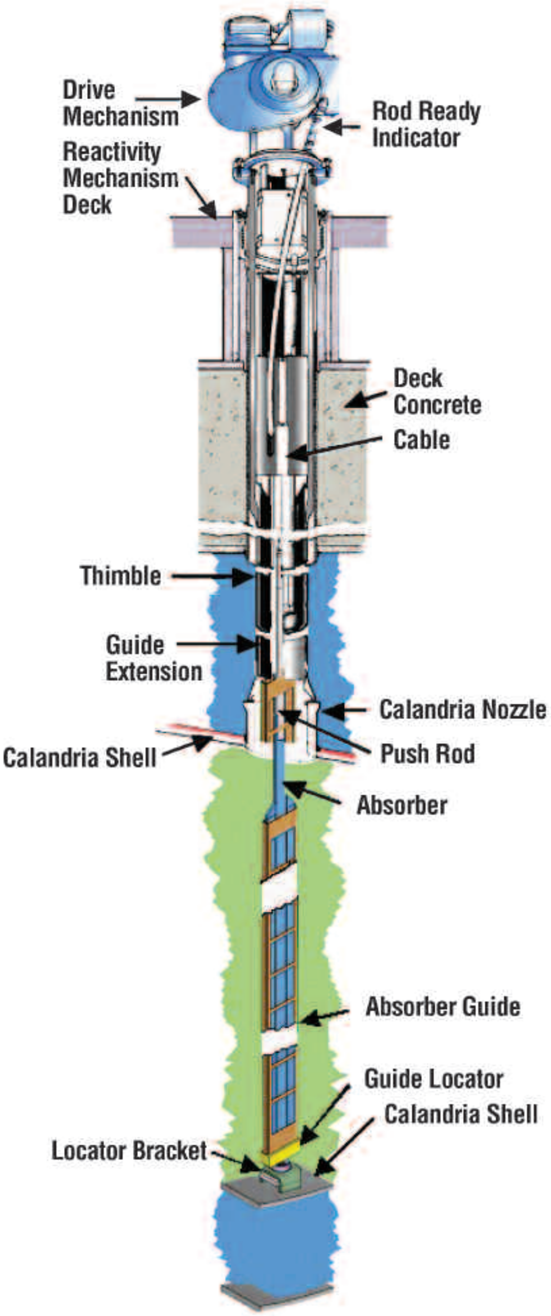


Figure 2-20 SDS1 Shutoff Rods

SDS2 injects a concentrated solution of gadolinium nitrate into the low-pressure moderator to quickly render the core sub-critical. The gadolinium nitrate solution is dispersed uniformly with pressurized gas, maximizing shutdown effectiveness.

The reactor can be put into a guaranteed shutdown state (GSS) using a rod-based system. Design simplifications have been provided to achieve this.

2.9.2 Emergency Core Cooling (ECC) System

The ACR-1000 emergency core cooling (ECC) system consists of two subsystems:

- *Passive emergency coolant injection (ECI) system:* The ECI system has accumulator tanks that will supply high-pressure water to the HTS and refill the fuel channels in the short term after a loss of coolant accident (LOCA)

  During normal operation, the ECI system is poised to detect any LOCA that results in a depletion of HTS inventory to such an extent that make-up by normal means is not assured. When the HTS pressure drops below the pressure of the ECI accumulator tanks, water is injected into the heat transport system.

  Valves on the ECI interconnect lines between the reactor outlet headers (ROH) open upon detection of a LOCA to assist in establishing a sustainable cooling flow path.

  In addition, core makeup tanks (CMTs) provide passive makeup to the intact HTS loop following a LOCA and prevent voiding for secondary side depressurization events.

- *Long-term cooling (LTC) system:*
  The LTC system provides long-term recirculation and recovery. It is used for cooling of the reactor after postulated transients, including LOCA, and during maintenance.

  LTC is initiated automatically when HTS is sufficiently depressurized, at which time the LTC system begins operation in long-term recovery mode.

2.9.3 Containment System

The ACR-1000 containment system forms a continuous, pressure-retaining envelope around the reactor core and the heat transport system. This prevents releases of radioactive material to the external environment.

The containment boundary consists of a steel-lined, pre-stressed concrete reactor building, access airlocks and a containment isolation system. The containment design ensures a low leakage rate. Hydrogen control is provided in the reactor building by passive autocatalytic recombiners and igniters to limit the hydrogen content to below deflagration limit within the containment, following a core damage accident.

Finally, the provision of a spray system connected to the elevated reserve water tank (RWT) will reduce reactor building pressures, if required, in the event of severe accidents.

Heat removal from the containment atmosphere is also normally provided by the operation of local air coolers, which are suitably located in various compartments of the reactor building, to reduce pressure and further reduce leakage over a longer period following an event.

2.9.4 Emergency Feedwater (EFW) System

The emergency heat removal function is accomplished by the EFW system. The system provides an independent supply of feedwater to the steam generators to remove decay and sensible heat to cool down the reactor following a total loss of the main and emergency feedwater systems.

The emergency feedwater system consists of emergency feedwater pumps driven by normal Class IV power and backed up by standby Class III electrical power. These pumps provide emergency feedwater to the steam generators at a rate sufficient to remove decay heat from the reactor core following a design basis event. Emergency feedwater is supplied from the reserve feedwater tank. All the components and valves of the system are seismically-qualified and are located in the seismically-qualified reactor building and reactor auxiliary building.

2.10 Essential Service Water Systems

The ACR-1000 adopts a four-division concept for essential service water systems. All divisions are physically separate, redundant and equipment in each is identical. Systems are sized to ensure that, under accident conditions, two divisions are capable of handling plant safety shutdown heat loads.

2.11 Balance of Plant (BOP)

The balance of plant (BOP) comprises the turbine building, steam turbine, generator, condenser, and the feedwater heating system with associated auxiliary and electrical equipment. The BOP also includes the water treatment facility, auxiliary steam facilities, condenser cooling water pumphouse and/or cooling towers, and associated equipment to provide all conventional services to the plant.

Turbine Generator	**CANDU 6**	**Darlington**	**ACR-1000**
Steam Turbine Type	Hitachi impulse-type, tandem-compound	Tandem-compound	Impulse-type tandem-compound
Steam Turbine Composition	One double-flow high-pressure cylinder	One double-flow high-pressure cylinder	One double-flow high-pressure cylinder
Net to turbine (MWth)	2060	2650	3180
Gross/Net electrical output* (nominal) [MWe]	728/666	935/881	1165/1085
Turbine Generator Efficiency**	35.3%	35.3%	~36.6%
Steam temperature at main stop valve [°C]	258	263	273
Final feedwater temperature [°C]	187	177	217
Condenser Vacuum [kPa (a)]	4.9	4.2	4.9

CANDU 6 data quoted is based on the Qinshan Phase III CANDU 6 design.

* Approximate values: electrical output is dependent on site conditions.

** Motor-driven feedwater pump, CANDU 6 and ACR-1000 outputs are based on reference cooling water temperature of 18.8°C. Darlington output is based on reference cooling water temperature of 11°C.

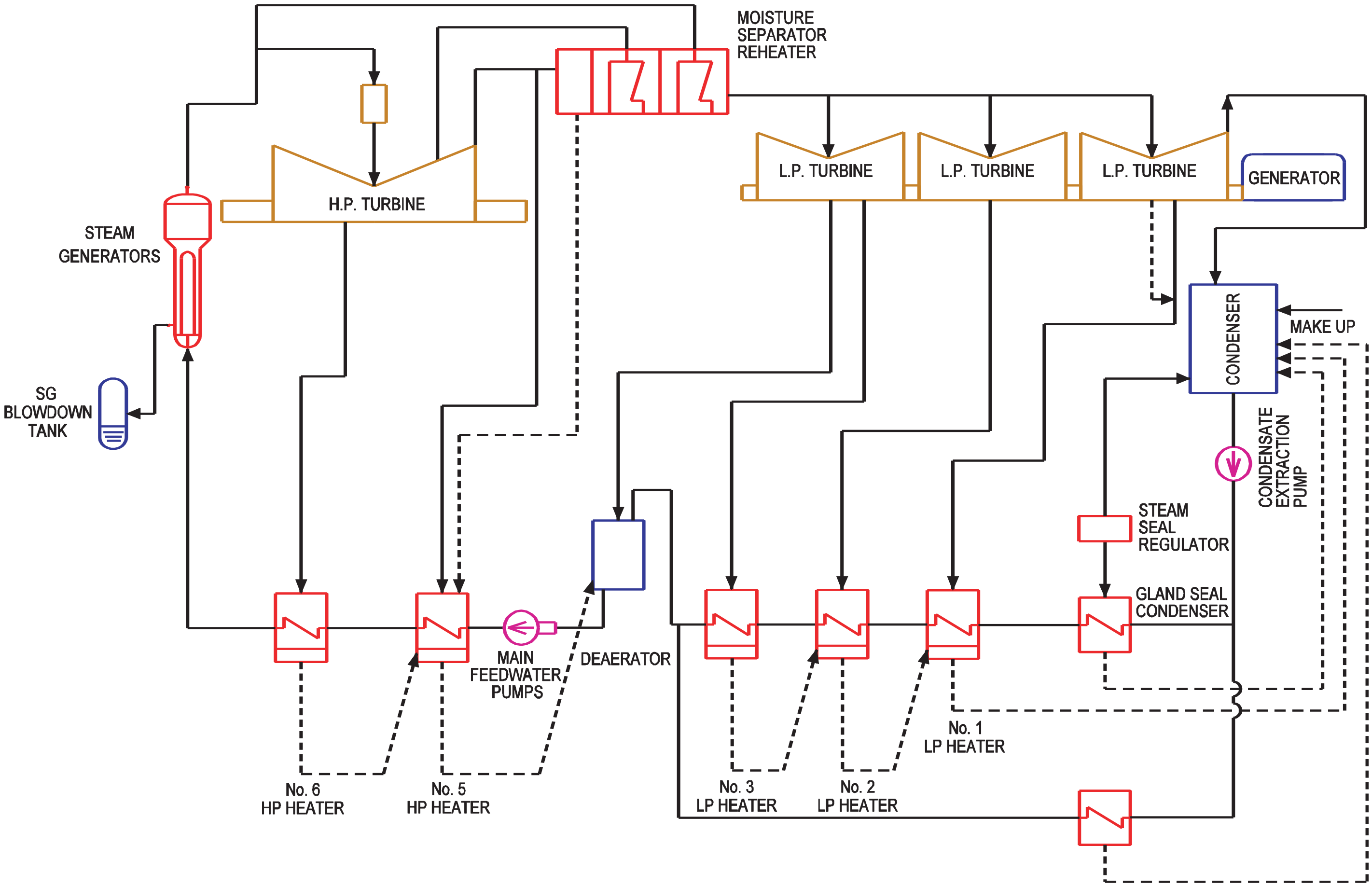


Figure 2-21 Turbine Generator and Auxiliaries Flow Diagram

2.11.1 Turbine Generator and Auxiliaries

The turbine generator system and the condensate and feedwater systems are based on conventional designs. They meet the design requirements specified by the NSP designer to assure the performance and integrity of the nuclear steam plant. These include requirements for materials (i.e., titanium condenser tubes, absence of copper alloys in the feed train), chemistry control, feed train reliability, feedwater inventory and turbine bypass capability.

In the event of station blackouts, the reactors are designed to stay at power for the duration of the event with the turbine generators disconnected from the grid. In this mode of operation, power is only supplied to internal auxiliaries as needed for the safe operation of the plant.

The BOP is capable of daily and weekly power manoeuvring to as low as 50%.

Figure 2-22 Qinshan Low-Pressure Turbine Rotor

CANDU plants have operated successfully using North American, European and Japanese turbine generators with fresh water and seawater condenser cooling water.

2.11.2 Steam and Feedwater Systems

The ACR-1000 main steam system supplies the steam from the steam generators in the reactor building to the turbine through the steam balance header. The feedwater system takes hot, pressurized feedwater from the feedwater train in the turbine building and discharges it into the pre-heater section of the steam generators. The system maintains the required steam generator level by controlling feedwater flow.

The condenser steam discharge valves (CSDVs) are designed to discharge up to 100% of steam flow directly to the condenser. This feature provides for operational flexibility in support of load following operation in conjunction with overall reactor control. It also provides a backup safety function for fuel cooling, via steam generator cooling, by making use of the large inventory in the condenser.

The safety functions of overpressure protection and cooling of the steam generator secondary side are provided by main steam safety valves (MSSVs). In addition, main steam isolation valves (MSIVs) can be used to prevent releases from containment in the event of steam generator tube leaks to the secondary side.

2.11.3 BOP Services

Conventional plant services include potable water supply, heating, ventilation, air conditioning, chlorination (if required), fire protection, compressed gases and electric power systems.

Service Water Systems

The balance of plant (BOP) water systems provide cooling water, de-mineralized water and domestic water to plant users. The systems consist of the condenser cooling water (CCW), plant water system, water treatment facility and chlorination systems.

Heating, Ventilation and Cooling Systems

Heating, ventilation, air conditioning and chilled water (from the chilled water system) are supplied to plant buildings to ensure a suitable environment for personnel and equipment during winter and summer. The building heating plant provides the steam and hot water demands of the entire plant. Steam extracted from the turbine is used as the normal building heating source. Dedicated, separate ventilation systems are provided for the main control building and secondary control building.

Fire Protection System

Water supply for the main fire protection system comes from a fresh water source via a buried pipe circuit. The main system provides fire protection for the entire station (i.e., both NSP and BOP).

The fire protection system also includes standpipe and fire hose systems, portable fire extinguishers for fire suppression, and a fire detection and alarm system covering all plant buildings and areas.

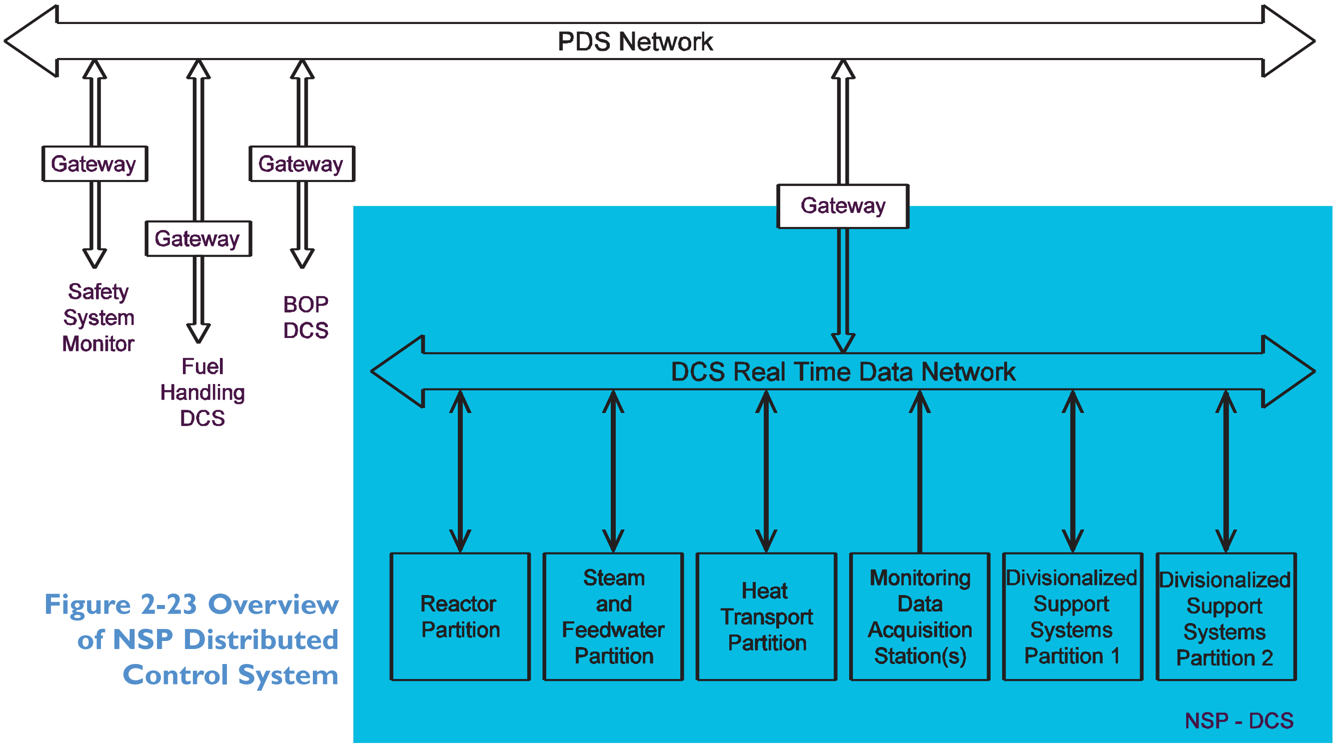


Figure 2-23 Overview of NSP Distributed Control System

Fire-resistant barriers are provided for mitigation purposes, where necessary, to isolate and localize fire hazards and to prevent spread of fire to other equipment and areas. The four-quadrant layout in the reactor auxiliary building provides maximum separation of redundant safety equipment for added fire protection.

2.12 Instrumentation and Control

The ACR-1000 unit control and monitoring systems apply modern distributed control, display and network communication technologies. Safety system logic and control are based on four-channel architecture to provide fault tolerance protection and to minimize spurious reactor trips. This results in enhanced monitoring capability and contributes to lower operating and capital costs due to:

- Reduction in the number of instrumentation and control components, leading to improved reliability and reduced maintenance and construction costs
- Design simplification through permitted sharing of systems, enabling the reduction in the number of sensors
- Increased automation, thus reducing frequency of operator error
- Improved information and data communications systems that provide detailed information on unit operational state, enabling early detection and diagnosis of faults and improving timely preventive equipment maintenance, thereby reducing unplanned plant outages

Most control functions are performed by a state-of-the art distributed control system (DCS) that uses small, programmable digital controller modules in place of a single central computer. The controllers communicate with one another by means of data highways, which use reliable, high-security data transmission methods. Manual control commands to be executed by the DCS are entered by the operators via the plant display system.

Control Centre

The ACR-1000 plant control centre enables operating staff to monitor, control and effectively operate the units in both normal and abnormal modes.

A computerized plant display system (PDS) is used for all plant control and monitoring. Integrated computer technology is used throughout the controls, displays, panels and consoles. These link operating procedures, testing requirements and configuration management to achieve high plant performance and enhanced operator effectiveness.

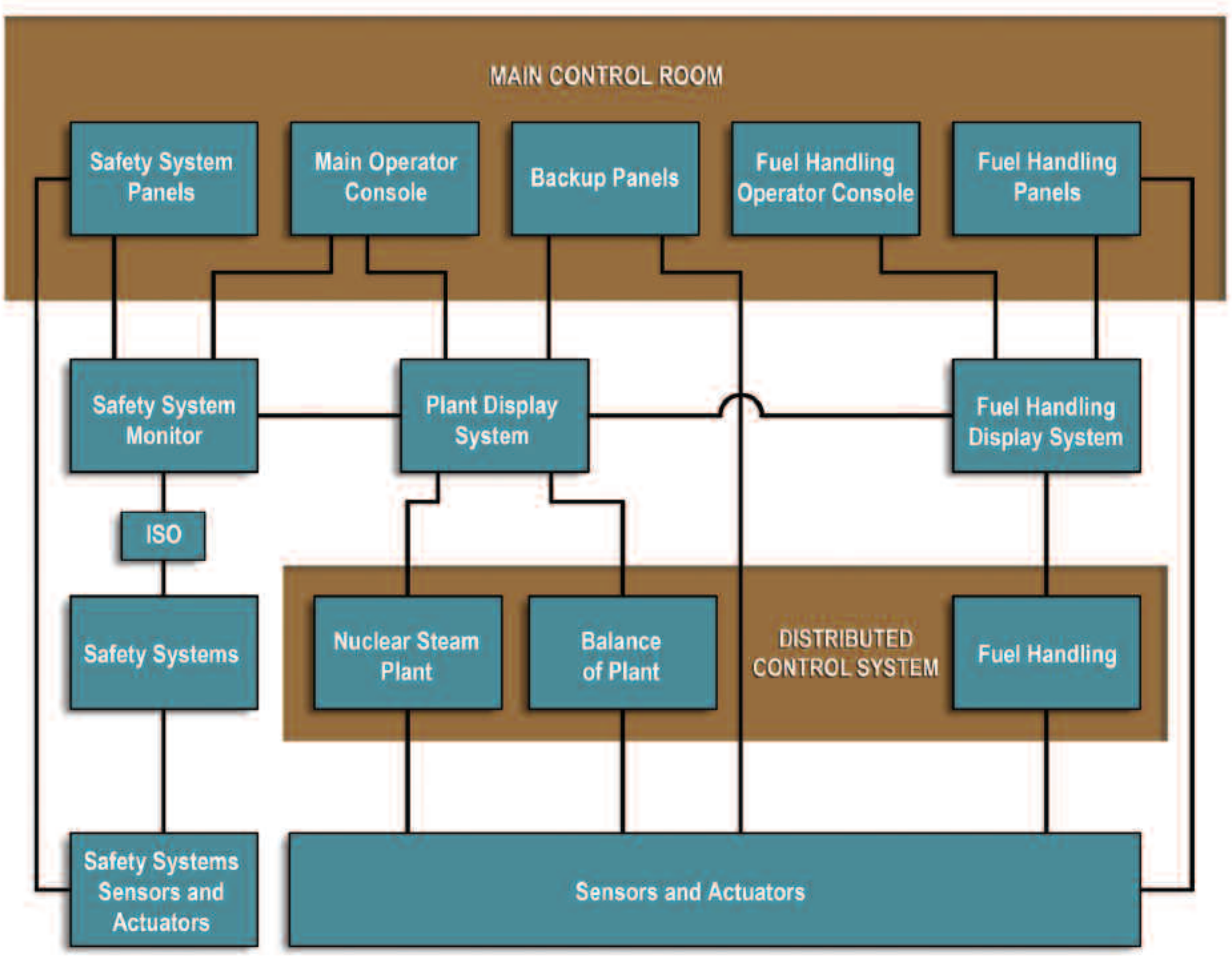
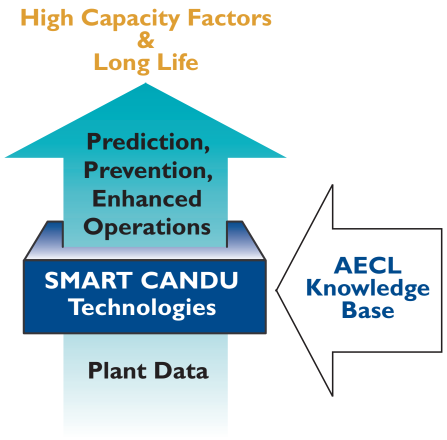


Figure 2-24 Plant Control and Monitoring Systems

The control centre information system includes an advanced alarm annunciation capability, based on the CANDU annunciation message list system (CAMLS) implemented on the Qinshan units. It conveys up-to-date unit information through fault and status displays. The control centre information system also includes an alarm interrogation application that allows operations staff to view fault and status display and to interrogate alarm history from any of the control centre panels or console workstations. The control centre information system includes on-line procedures for operator support.

Each unit has a completely separate secondary control building (SCB) to control and monitor equipment required to shut down the unit, initiate the required fuel cooling, and monitor equipment and plant state to ensure the unit remains in a safe shutdown should the main control room (MCR) become unavailable.

The ACR-1000 will also provide an integrated package of software tools and work processes aimed at plant performance optimization throughout its life cycle. SMART CANDU technologies use the AECL knowledge base and plant data to predict, prevent and enhance operations. The SMART CANDU suite of tools includes ChemAND and other superior engineering tools.



CAMLS
Intelligent Annunciation Message List System that assists operators in coping with events such as blackouts.

ChemAND
Health monitor for plant chemistry. Predicts future performance of components, determines maintenance requirements and optimal operating conditions.

ThermAND
Health monitor for heat transfer systems and components. Ensures optimal margins and maximum power output.

MIMC
Maintenance Information Management Control system that links health monitor data to the plant work management system.

Figure 2-25 SMART CANDU

2.13 Electrical Power System

The electrical power system consists of connections to the off-site grid, main turbine generator, associated main output system, on-site standby diesel generators, battery power supplies, uninterruptible power supplies (UPS) and the distribution equipment. Essential standby generators, batteries, UPS and the equipment distributing power from these sources are seismically and environmentally-qualified. This equipment is provided in a four-bus configuration, which improves reliability, allows for on-power maintenance and minimizes potential for spurious trips.

The electrical distribution system (EDS) supplies electrical power to all process and instrumentation and control loads within the unit. The EDS is divided into four classes of power based on availability: Class I is delivered from batteries, Class II from UPS, Class III from standby generators and Class IV from the main generator or grid.

In a two-unit ACR-1000 plant, each unit has a dedicated electrical distribution system with inter-unit ties only in the Class III distribution system. Four seismically-qualified, essential standby generators are provided for each unit. Two additional standby generators are provided to support station operation, including 'blackouts.'

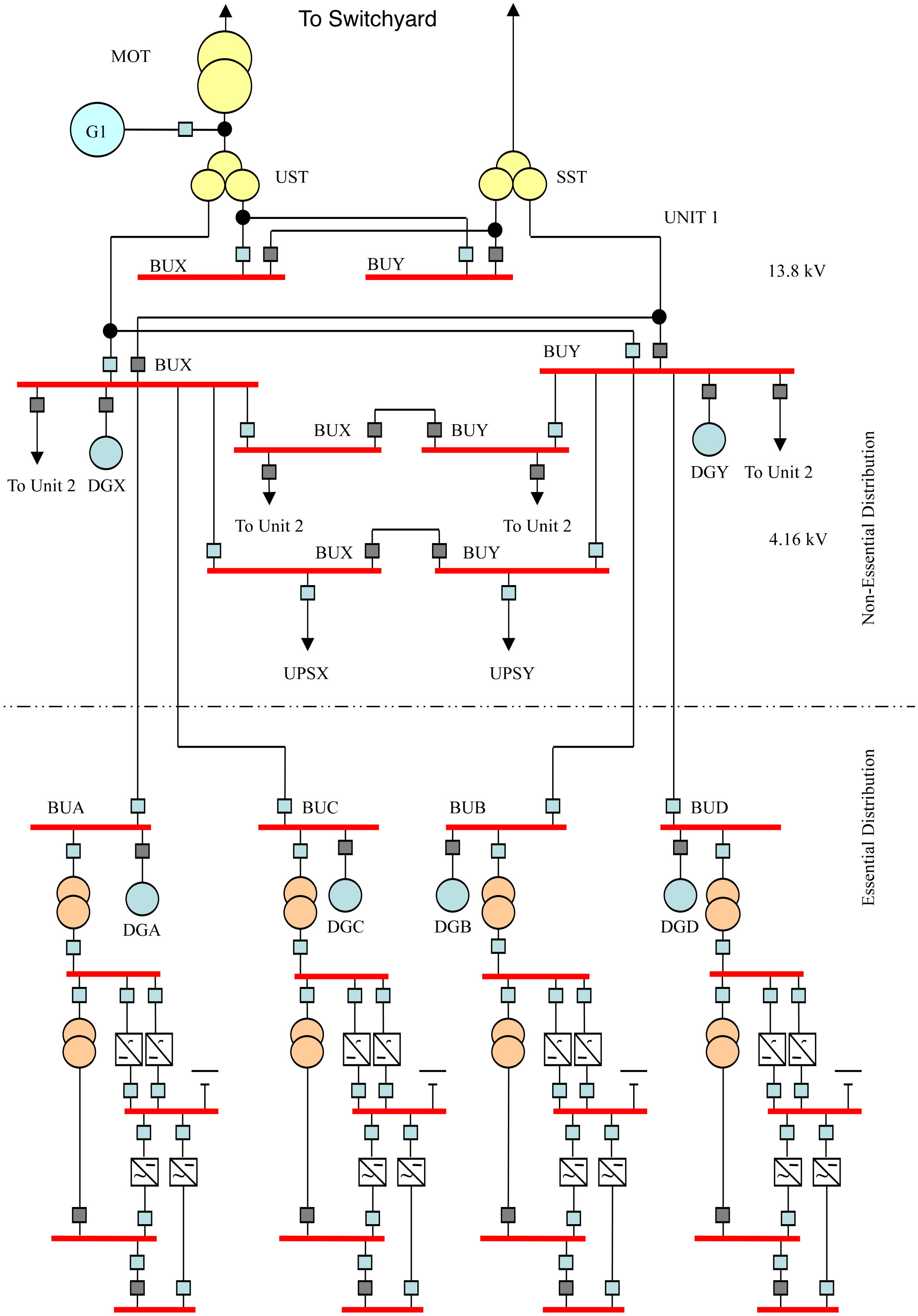


Figure 2-26 Unitized Electrical Power System

3. Nuclear Safety and Licensing

3.1 Safety Design

Nuclear safety requires that the radioactive products from the nuclear fission process be contained, both within the plant systems for worker protection and outside the plant structure to protect the public. This is achieved at all times by:

- Controlling the reactor power, and if necessary, shutting the reactor down
- Removing reactor heat, including decay heat following shutdown, in order to prevent heat up of fuel
- Containing radioactive products that are normally produced and contained within the fuel
- Monitoring the plant to ensure that the above functions are being carried out, and if not, ensuring that mitigating actions are being taken

These nuclear safety functions are carried out to a high degree of reliability by applying the following principles:

- The use of high-quality components and installations
- Maximizing the use of inherent safety features of the ACR-1000
- Implementing multiple defence-in-depth barriers for prevention of radioactive release
- Providing enhanced features to mitigate and reduce consequences of design basis events and severe accidents

The implementation of these safety measures is provided by safety systems, safety support systems, systems important to safety and robust buildings and structures that meet high standards for diversity, reliability and protection against common-mode events such as seismic occurrences, fires, flooding and unauthorized acts.

3.2 Defence-in-Depth

The ACR-1000 is based on the CANDU principle of defence-in-depth by providing the following multiple, diverse barriers for accident prevention and mitigation of consequences:

- High-quality process systems to accommodate plant transients and to minimize the likelihood of accidents
- Reliable safety systems for reactor shutdown, emergency core cooling, containment, and emergency heat removal (emergency feedwater)
- Reliable safety support systems to provide services to the safety systems and other mitigating systems
- Backup systems for heat sinks and essential controls
- Passive heat sinks to increase resistance against both design basis events and severe accidents

The ACR-1000 has at least seven barriers:

1) Fuel sheath which contains the radioactive material
2) Heat transport system, including pressure tubes
3) Calandria tubes designed to withstand a pressure tube rupture
4) Cool, low-pressure moderator
5) Cool, low-pressure reactor vault
6) Reserve water system
7) Steel-lined, concrete containment structure

The design of the safety systems follow the design principles of separation, diversity and reliability. High degrees of redundancy within systems are provided to ensure the safety functions can be carried out, even when systems or components are impaired. Protection against seismic, flooding and fire events is also provided, ensuring highly reliable and effective mitigation of postulated events, including severe accidents.

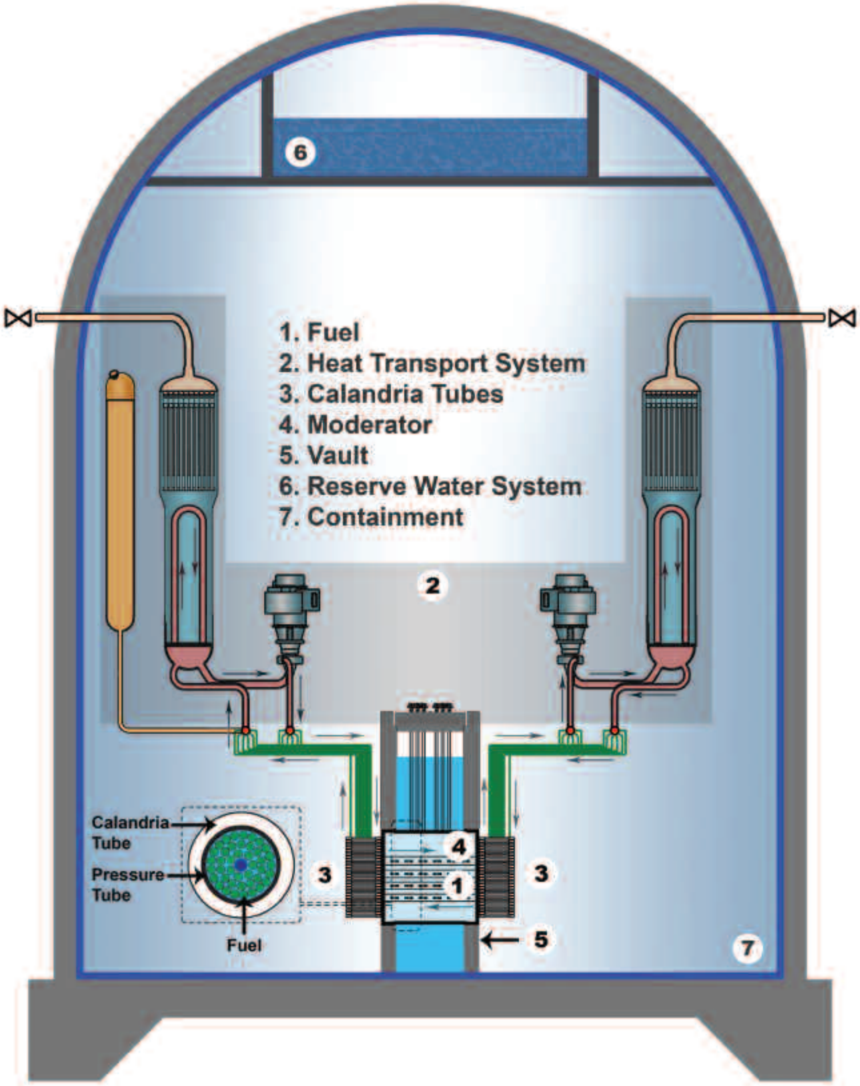


Figure 3-1 Barriers for Prevention of Releases

3.3 Inherent Safety Features

The ACR-1000 maintains the traditional CANDU inherent safety characteristics:

- Heavy water moderator, which is very efficient in slowing down neutrons, resulting in a fission process which is more than an order of magnitude slower than LWRs. Reactor control and shutdown are inherently easier to perform
- On-power refuelling, which reduces the 'excess' reactivity as required. Reactor characteristics are constant and no additional measures, such as boron addition to the coolant (and its radioactive removal), are needed
- Natural circulation capability in the reactor coolant system, which can cope with transients due to loss of forced flow
- Reactivity control devices. These are in the low-pressure moderator, do not penetrate the reactor coolant pressure boundary and therefore cannot be ejected
- Moderator backup heat sink, which maintains core coolability for loss-of-coolant accidents, even when combined with the unavailability of emergency core cooling
- Negative power reactivity coefficient, which makes reactor power more stable and easier to control
- Small negative full-core void reactivity offering a good balance of nuclear protection between loss-of-coolant accidents and fast cool-down accidents
- Very flat and stable flux across the core minimizing demand on the reactor control system
- Larger safety and operating margins due to the use of CANFLEX-ACR fuel, with lower element rating and higher critical heat flux limits

3.4 Severe Accidents

A severe accident is one in which the fuel is not cooled within the heat transport system. The ACR/CANDU design principle is to prevent severe accidents and to mitigate severe accident events, in addition to minimizing their consequences. This is achieved by providing a number of design measures:

- Normal heat removal systems
- Heat removal systems using emergency feedwater system
- Passive emergency feedwater supply from reserve water system
- Emergency core cooling
- Passive emergency heat transport system make-up from reserve water system
- Heat removal using moderator systems
- Passive thermal capacity of moderator
- Passive emergency moderator heat sink make-up from reserve water system
- Heat removal by reactor vault water
- Passive thermal capacity of reactor vault water
- Passive emergency reactor vault heat sink make-up from reserve water system
- Passive containment cooling via spray
- Severe accident management monitoring capabilities

Severe accident management, in addition to providing multiple mechanisms for fuel cooling and barriers to release, also includes mitigating measures within containment. In addition to the robust, concrete outer and inner steel liners, which by themselves can withstand the largest pipe breaks, containment is also provided by:

- Passive, hydrogen recombiners and igniters that will limit the hydrogen content to below the deflagration limit
- A spray system to reduce the build-up of containment pressure and reduce leakages
- Highly reliable local air coolers that can be used for containment heat removal

PSA studies estimate that the summed frequency of internal initiating events leading to reactor core damage during at-power operation is only 3.4 x 10^{-7} for the ACR-700 and is expected to be better for the ACR-1000. This exceeds EPRI requirements by approximately two orders of magnitude and is comparable to latest LWR designs. This marginal value is comprised of probabilities of seven dominant initiating events, all of which are relatively small.

3.5 Licensing Basis

The ACR-1000 builds on the successful CANDU track record of accommodating regulatory requirements of offshore jurisdictions in various host countries (China, South Korea, Romania, Argentina) while retaining the standard nuclear platform.

The ACR-1000 is designed to meet regulatory requirements in Canada and other countries:

- The ACR-1000 is an evolutionary, enhanced design based on current regulations. Future licensability in Canada and abroad will be based on this experience
- ACR-1000 design meets the requirements of applicable IAEA Safety Series documents for nuclear power reactors
- The design meets the Canadian and international requirements for nuclear plant siting
- International codes and standards, as they apply to the ACR-1000 design, have been incorporated. ACR-1000 has benefited from the extensive review of US NRC requirements—both its written regulations and via dialogue

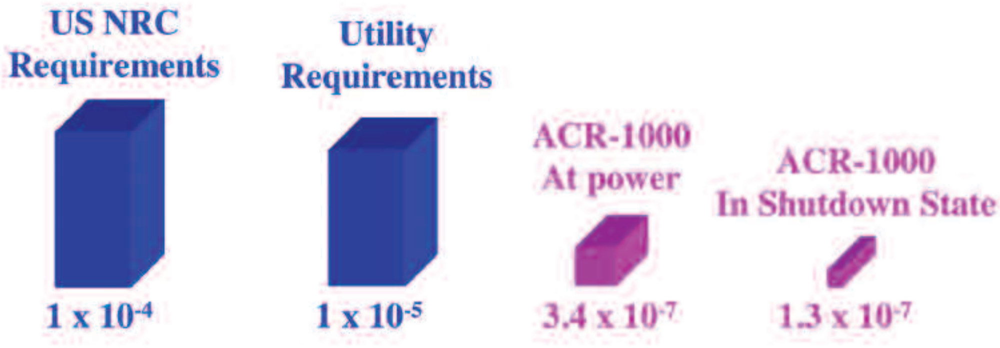


Figure 3-2 Core Damage Frequencies per Year

4. ACR-1000 Deployment

The feedback gained from AECL's past construction projects, associated with improvements and optimization of key project elements, results in an optimum 42-month schedule (nth Unit) from first Containment Concrete to fuel load. Deployment of the ACR-1000 requires the coordination and timely delivery of key project elements, including: licensing programs, environmental assessments, design engineering, procurement, construction and commissioning start-up programs.

Design Engineering: Prior to a project contract, a series of activities are executed to ensure design readiness and a seamless transition to the procurement and construction phases. Preliminary design and research and development programs are executed in parallel with the environmental assessment and licensing programs, ensuring continuous improvement and plant configuration is maintained. The final design program ensures plant reliability, equipment and component maintainability and constructability requirements are maximized to the fullest extent.

Licensing: The ACR-1000 builds on the successful CANDU track record of accommodating requirements of offshore jurisdictions in various host countries while retaining the standard nuclear platform. Licensing programs are executed and coordinated with the engineering design programs and environmental assessment, and are structured in a manner to support regulatory process requirements.

Configuration Management: The ACR-1000 makes use of the latest computer technology for managing the complete plant configuration from design to construction and finally, turnover to the Owner. State-of-the-art electronic drafting tools are integrated with material management, wiring and device design, and other technology applications.

Project Management: The ACR-1000 project management structure provides fully integrated project management solutions. Performance management programs are executed from project concept, through a project readiness mode, and finally project closeout. The project management framework consists of three key elements:

- Total project execution planning
- Critical decision framework to control each phase of the project
- Comprehensive risk management program

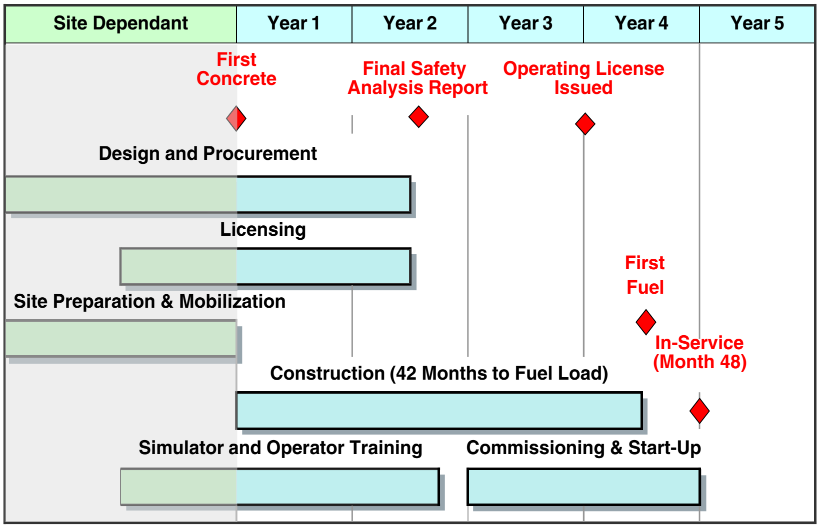


Figure 4-1 42-Month Deployment Schedule (Nominal)

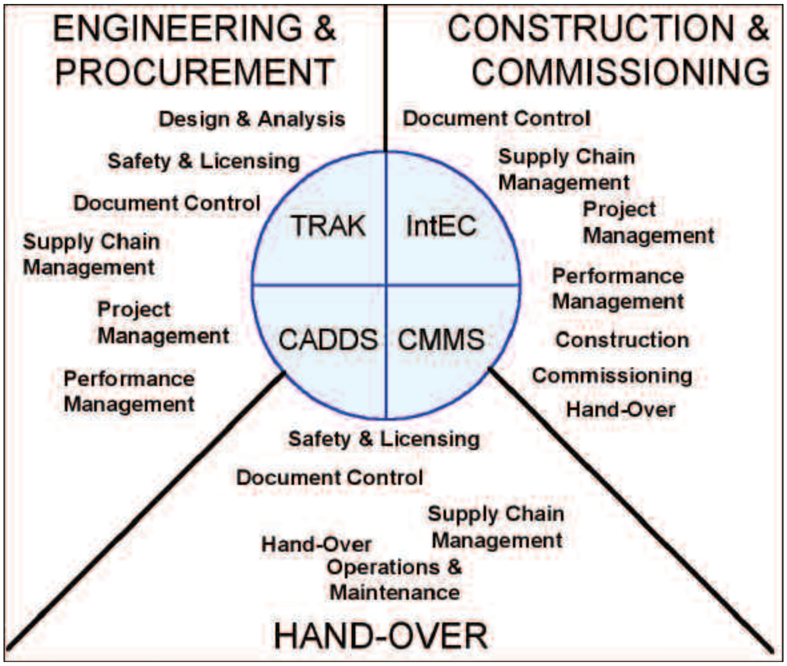


Figure 4-2 Design Engineering Applications

Procurement: Standardized procurement and supply processes are implemented to support time, cost and performance benefits to the project, including benefits such as efficiency through variety control (standardization), economy in manufacturing and servicing, and avoidance of repetitive effort in producing new specifications and processes for each procurement.

Construction Programs: Constructability programs are implemented to ensure simplification, maximized concurrent construction, increased construction productivity, minimized construction rework, decreased construction equipment costs, minimized unscheduled activities, and reduced capital costs and construction risk.

Construction Strategy: The main elements of the ACR-1000 construction strategy are:

- Open-top construction method using a very-heavy-lift crane
- Concurrent construction
- Modularization and prefabrication
- Use of advanced technologies to minimize interferences.

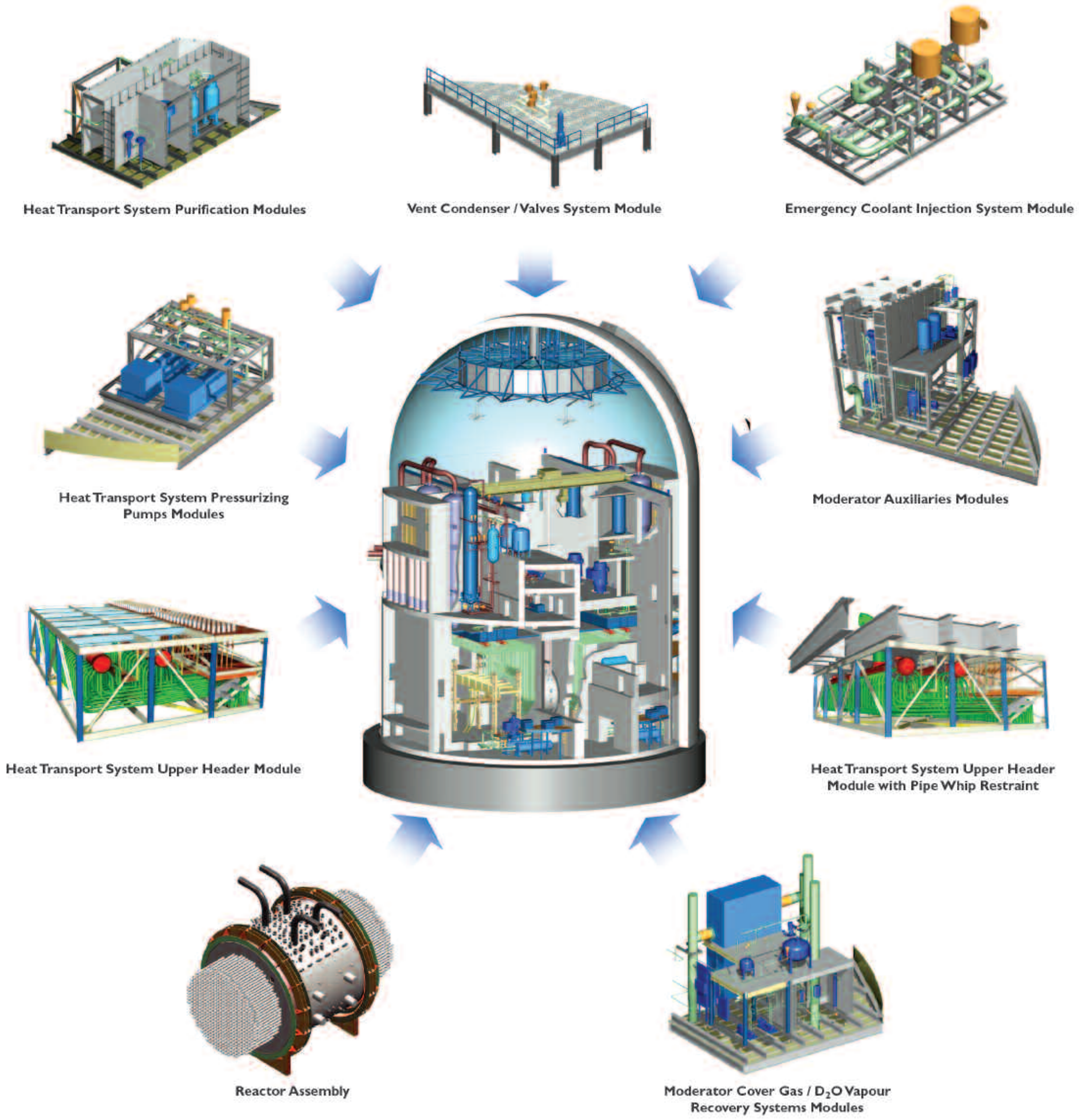
The open-top/vertical installation construction method enables an improved logic that reduces costs while reducing the schedule risk. The internal structure of the reactor building is initially built as vertical walls without floors. Major modules, including the floors, are then installed in parallel.

Commissioning: The commissioning and plant start-up programs for the ACR-1000 are being developed with input received from design staff and plant operations staff. Identification of key design parameters that require confirmation to meet overall system objectives are reviewed to ensure commissioning plans can be produced to check those identified parameters. In addition, acceptance criteria will be developed between the designer and experienced commissioning technical staff.

Test programs will be defined as part of the overall plan, including:

- Preoperational tests
- Fuel loading, initial criticality, and low power tests
- Power tests
- Test run and performance tests

Figure 4-3 Module Lift Using VHL Crane



Heat Transport System Purification Modules

Vent Condenser / Valves System Module

Emergency Coolant Injection System Module

Heat Transport System Pressurizing Pumps Modules

Moderator Auxiliaries Modules

Heat Transport System Upper Header Module

Heat Transport System Upper Header Module with Pipe Whip Restraint

Reactor Assembly

Moderator Cover Gas / D_2O Vapour Recovery Systems Modules

Figure 4-4 Typical Reactor Building Modules

5. Operation and Maintenance

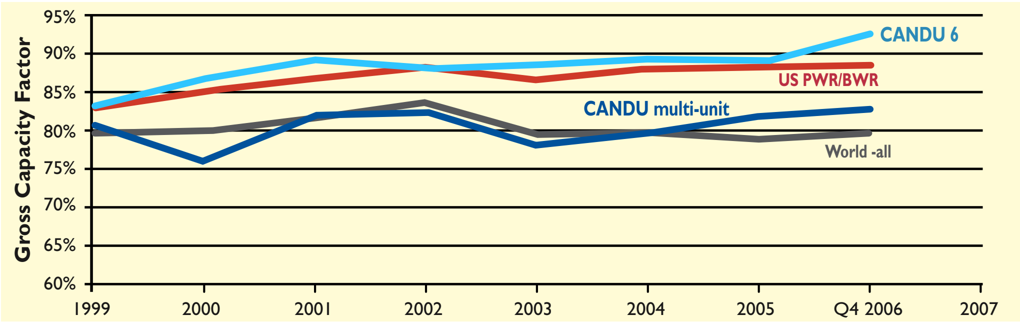
5.1 Consistently Better Performance

The lifetime capacity factor for the ACR-1000 is expected to be greater than 90% over the operating life of 60 years. The year-to-year expected capacity factor is 95%. These expectations are based on the proven track record of CANDU 6s, which have collectively surpassed the U.S. PWR/BWR Gross Capacity Factor (GCF) with a combined average of 92.4% in 2006. These results are consistently better than LWRs around the world.

The ACR-1000 has made a number of improvements to achieve these incremental performance targets.

CANDU 6/PHWR Performance Trends (1999 - 2006)

Reference: CANDU Owners Group Newsletter



COGnizant Volume 12, Issue 6, 2007, 2006 U.S. and world data based on Q4 results (courtesy of NEI)
The graph is for comparison of trends only

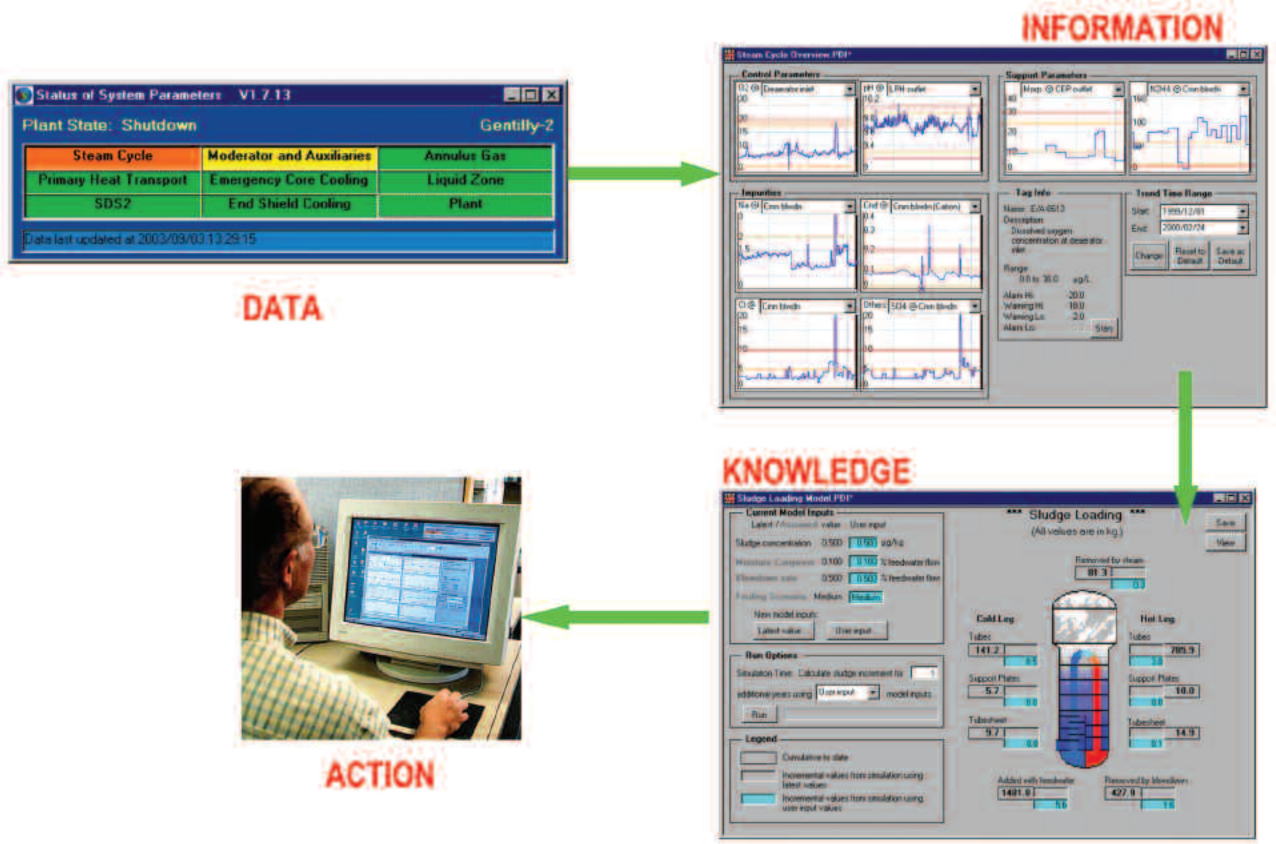
Figure 5-1 Comparison of Gross Capacity Factors

5.2 Enhanced Performance Features

Incorporation of feedback from operating reactors (both CANDU and other designs) is an integral feature of the design process. Various new features and maintenance improvement opportunities have been incorporated to enhance operating performance throughout station life.

Major enhancements include:

- Use of improved material and plant chemistry specifications, based on operating experience from CANDU plants. For example, life-limiting components such as HTS feeders and headers have been replaced with stainless steel to limit the effect of feeder corrosion
- Implementation of advanced computer control and interaction systems for monitoring, display, diagnostics and annunciation. These include ergonomic operator consoles, touch displays, large colored screens, smart communications for improved operator awareness and plant status through modern human-factors engineering
- Providing integrated SMART CANDU modules for annunciation, on-line monitoring of systems and components, and providing a predictive maintenance capability



Status of System Parameters V1.7.13

Plant State: Shutdown

Gentilly-2

Steam Cycle	Moderator and Auxiliaries	Annulus Gas
Primary Heat Transport	Emergency Core Cooling	Liquid Zone
SDS2	End Shield Cooling	Plant

Data last updated at 2003/09/03 13:29:15

Figure 5-2 ChemAND – Performance Monitor for Plant Chemistry

- Enhancing power maneuvering capability:
  - Load-following the grid provides up to 2.5% power variation, while operating at 97.5%
  - Daily load-cycling capability includes rapid load reduction from steady state 100% power operation to 75%, and periodic load reduction from 100% to 60% and as low as 50% when required (e.g. , weekends)
  - Use of LEU fuel and light water coolant has resulted in a lower xenon load following reactor power reduction compared to CANDU. This simplifies reactor operation and makes the ACR-1000 inherently more responsive
- Ensuring station blackout capability for return to full power on restoration of electrical grid. The ACR-1000 has the capability to continue operation of house load without a grid connection, enabling a rapid return to full power upon reconnection

5.3 Enhanced Maintenance Features

The lifetime capacity factor of a plant is impacted by the number and duration of maintenance outages. The traditional 'annual' outage of up to one month for currently operating CANDU plants has been improved to a 'major' outage of only 21 days every three years for the ACR-1000. A number of enhancements to achieve these objectives have been incorporated.

- A maintenance-based design strategy has been implemented. The program incorporates lessons learned and ensures maintainability of systems and components. It will define the improvements made to maintenance programs for earlier designs. The new program is based on the SMART CANDU technology. It will identify and take mitigating actions, if required, to ensure plant states are diagnosed and maintained within their design performance limits. This will lead to improved preventive maintenance and reduced forced outages at a rate of less than five days/year. Only the best available equipment for critical components will be used

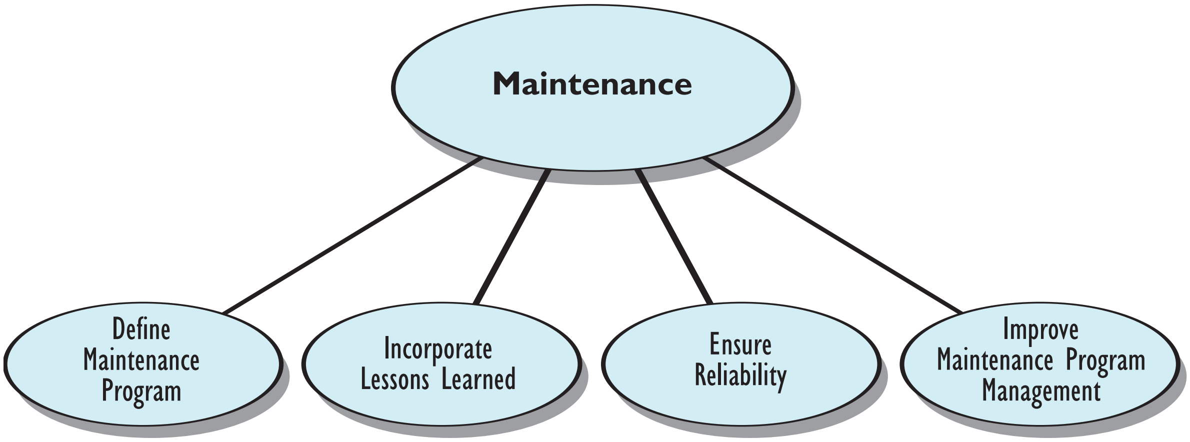


Figure 5-3 Maintenance Basis

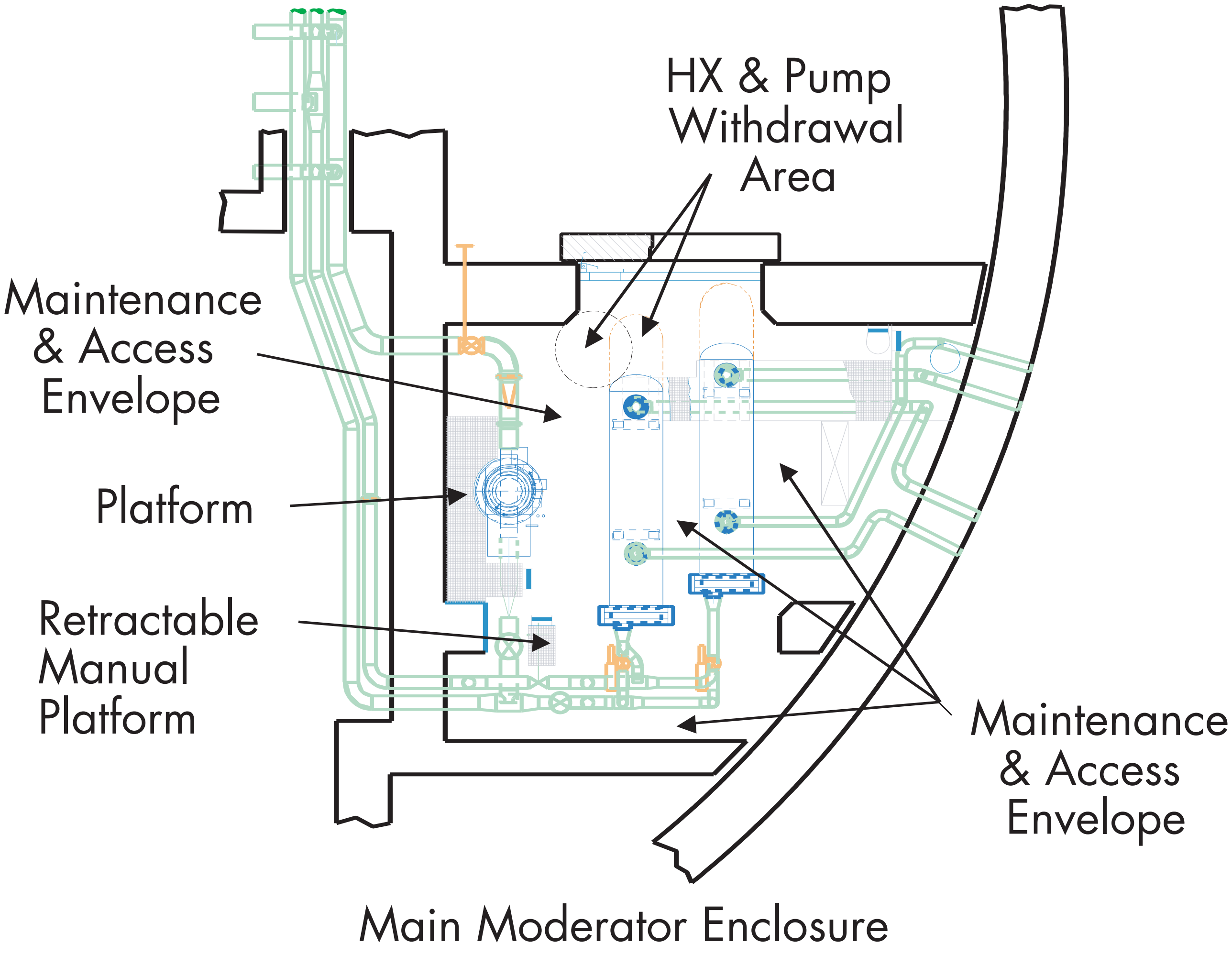
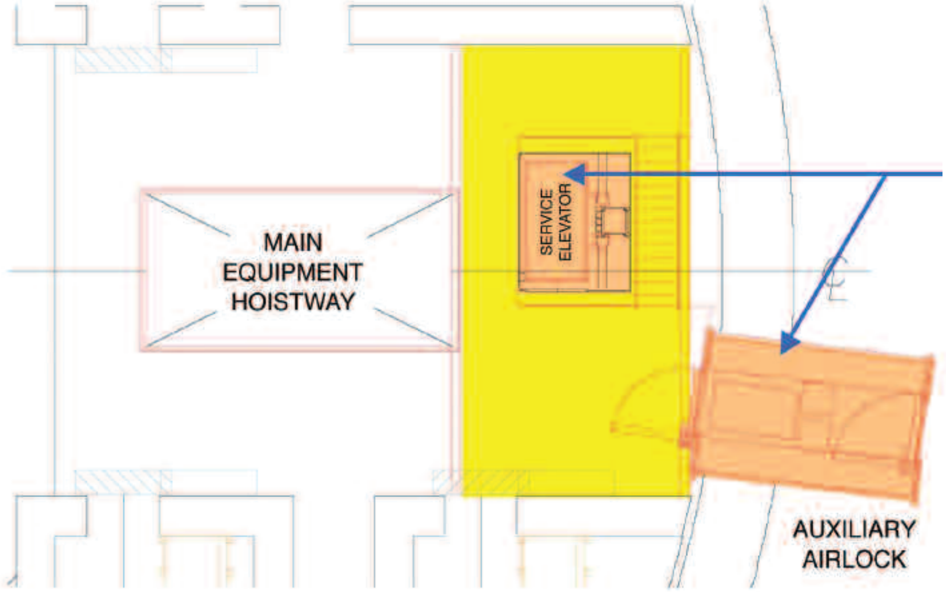


Figure 5-4 Typical System Equipment Module



Full height service elevator placed in close proximity to the auxiliary airlock, improving O&M access to all floors within the reactor building

Figure 5-5 Service Elevator

- Plant layout has been improved by providing generous space, laydown areas, good lighting, and use of permanent walkways and platforms to minimize need for temporary scaffolding. Provision for electrical, water and air supplies are built-in for on-power and normal shutdown maintenance
- Effective use of on-power reactor building accessibility and on-power maintenance of four-division design safety systems will minimize the amount of maintenance that must be performed during shutdown
- Computerized testing of major safety systems and automatic calibration of in-core detector control signals reduce both on-line testing and start-up testing time
- More durable materials and robust design margins simplify fuel channel inspections
- Shielding in radiologically-controlled areas has been increased. This feature, along with reduced tritium releases due to use of light water coolant, will result in enhanced radiological protection to further reduce worker exposure and occupational dose. Dose to an individual station staff member is expected to be less than 50 mSv in any single year
- The design for planned outages every three years is accomplished by selection of equipment and system design. It is based on probabilistic safety evaluations using three-year outage intervals

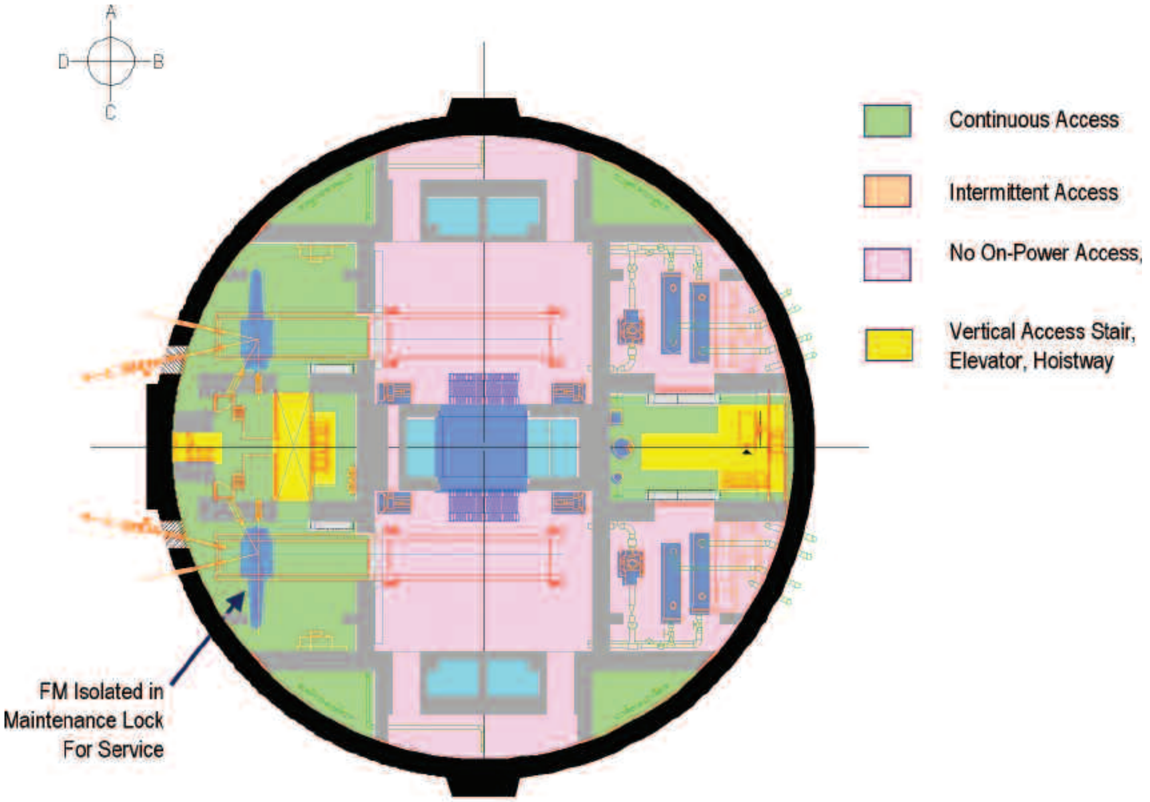


Figure 5-6 Accessible Areas in the Reactor Building – Level 100 m

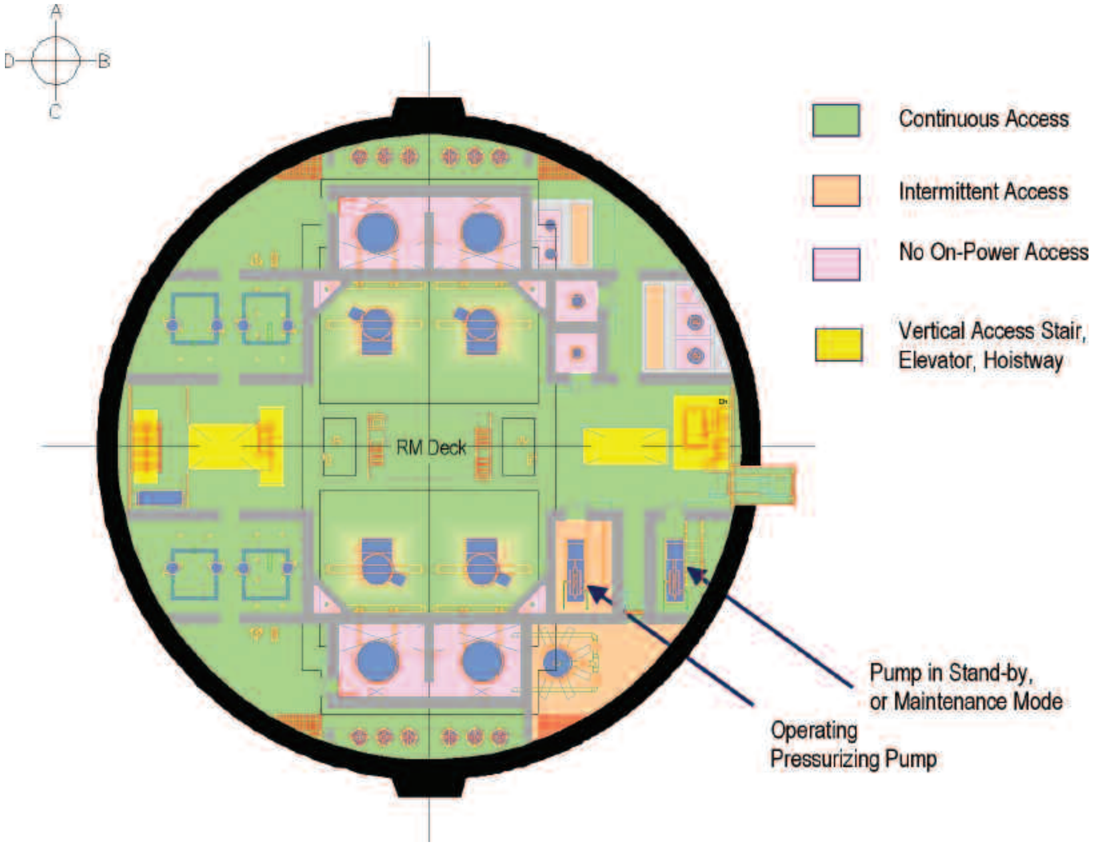


Figure 5-7 Accessible Areas in the Reactor Building – Level 125.4 m

The plant layouts above show the accessible areas in the plant, enhanced for ease of operation and maintenance.

6. Radioactive Waste Management

The waste management systems for the ACR-1000 will minimize the radiological exposure to operating staff and the public. Exposures for workers from the plant are monitored and controlled to ensure they are within the limits recommended by the International Commission on Radiological Protection. The systems for the ACR-1000 have been proven over many years at other CANDU sites. They provide for the collection, transfer and storage of all radioactive gases, liquid and solid, including spent fuel and wastes generated within the plant:

- Gaseous radioactive waste gases, vapours or airborne particulates are monitored and filtered. Active gases are treated by the off-gas management system (OGMS) with an absorber bed. Any tritium releases from isolated moderator areas are collected by a vapour recovery system and stored on site
- Liquid radioactive wastes are stored in concrete tanks located in the maintenance building. Any liquid requiring removal of radioactivity, including spills, is treated using cartridge filters and ion-exchange resins
- Solid radioactive wastes can be classified by five main groups: spent fuel, spent ion-exchange resins, spent filter cartridges, compactable and non-compactable solids. Each type is processed and moved, using specially designed transporting devices, if necessary. After processing, wastes are collected and prepared for on-site storage by the utility or for transport off-site

AECL has developed the MACSTOR®**** (Modular Air-Cooled Storage) system for safe, above-ground storage of spent fuel. MACSTOR has been developed from more than 30 years of experience.

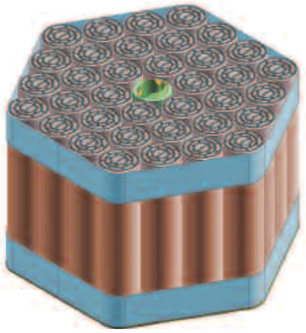


Figure 6-1 Spent Fuel Storage Basket

MACSTOR saves up to one-third of the space required for comparable systems, requires less manpower, has low operating and construction costs, and permits easy fuel retrieval.

With highly efficient heat-rejection and shielding capabilities, it is constructed using multiple barriers to provide radiation shielding for operators and the public, while being appropriately qualified and equipped with monitoring facilities.

Figure 6-2 MACSTOR Fuel Transfer

Figure 6-3 AECL's MACSTOR System

*****MACSTOR® is a registered trademark of Atomic Energy of Canada Limited (AECL).*

7. Decommissioning

AECL, through its membership in the OECD/NEA co-operative programme on decommissioning, has adopted a three-stage decommissioning strategy:

1) Placement of the station into a static state. This dormancy state is a modified IAEA Stage I concept such that:
    - Buildings around the reactor building are decommissioned for alternate use
    - The reactor building is isolated and sealed
    - The plant is monitored to ensure its dormant state

2) IAEA Stage II dormancy period, assumed to be 40 years or more, depending on the Owner's plans

3) IAEA Stage III final decommissioning to unrestricted use of the land

As an evolution of CANDU 6, the enhanced ACR-1000 design features a number of systems that have been simplified and/or optimized; some have also been eliminated. Thus, the amount of materials to be decommissioned is less than CANDU 6. Some examples are:

- Reduction of heavy water by elimination or downsizing of heavy-water-related systems
- Reactor core size reduction
- Consideration of alternative structural material yielding less cumulative radioactivity at end of life
- Civil structure size reductions

ACR-1000 design features that assist in maintenance and inspection during the lifetime of the reactor will also facilitate decommissioning. For example, the division of the reactor building into separate compartments, with proper isolation and shielding, allows the segregation of contaminated from non-contaminated systems, facilitating efficient dismantling, removal and disposal.

AECL has decommissioned three prototype Nuclear Power Plants and one research reactor to a static state. It has decommissioned at least one facility to IAEA's Stage III. AECL has also participated in decommissioning plans of facilities in Japan, the U.S. and elsewhere.

AECL has all the experience and facilities required to support Owner decommissioning plans.

8. Conclusion

Evolution

Capitalizing on the proven features of CANDU technology, AECL has designed the evolutionary ACR-1000 to be cost-competitive with all forms of energy, including other nuclear technologies, while achieving higher safety and performance standards consistent with customer expectations.

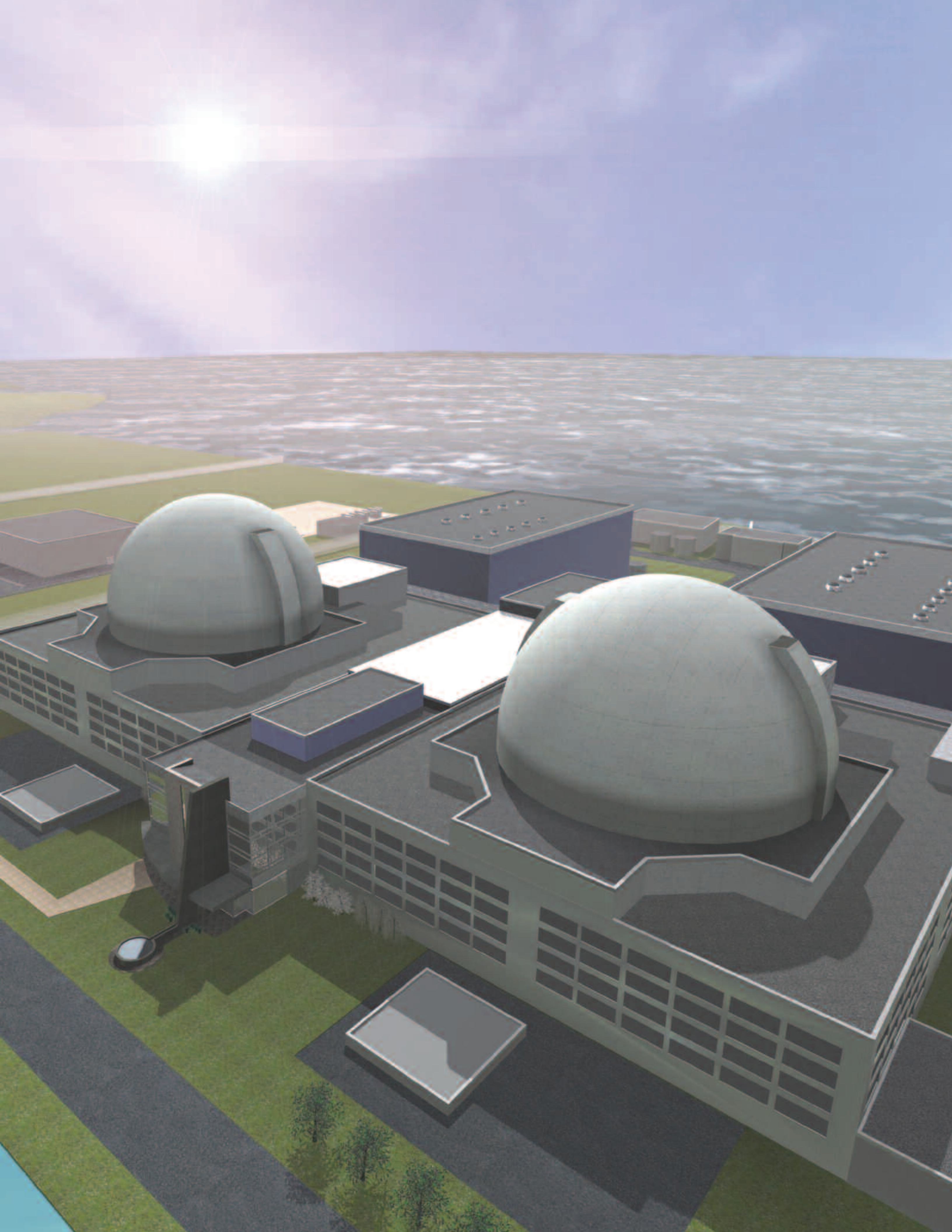
Proven CANDU Features

- Heavy water moderator and horizontal fuel channel design
- Series of parallel pressure tubes—rather than a single pressure vessel—allowing simpler manufacturing and reduced cost
- Two independent, passive, fast-acting safety shutdown systems and a unique inherent emergency cooling capability
- On-power fuelling for flexible outage planning and minimal 'excess' reactivity burden
- Multiple heat removal systems to prevent and mitigate severe accidents

ACR-1000 Innovations

- Extended fuel life through use of low enriched uranium fuel
- Reduced heavy water inventory by approximately 60% of traditional CANDU reactors, by use of light water coolant and reduced lattice
- Compact, highly stable reactor core design
- Reduced spent fuel volume
- Improved thermal efficiency through optimized, higher-pressure steam turbines
- Modular, prefabricated structures and systems
- Advanced construction techniques
- Quadrant-based safety and heat sink system layout design for improved on-power maintenance and testing, additional redundancy in actuating signals for trip channels, reduced risk of spurious trips and overall increased reliability
- Enhanced safety design including addition of reserve water system for passive accident mitigation
- Improved power manoeuvrability with lower inherent xenon load after shutdown than traditional CANDU
- Improved design for maintainability and operability
- Design validated by exhaustive proof-testing
- Comprehensive Risk Management Program

The ACR-1000 meets customer expectations for safe, reliable and economically competitive power production. It is the preferred choice… based on a wealth of experience, technical excellence and innovations in engineering.



Company Profile

AECL is an integrated nuclear technology, products and services company. Our 4,000 employees are dedicated to delivering leading edge nuclear services, R&D support, design and engineering, construction management, specialized technology, waste management and decommissioning in support of CANDU® reactor products and nuclear products from other vendors, worldwide.

AECL delivers power through partnership.

AECL

AECL

2251 Speakman Drive
Mississauga, Ontario
Canada L5K 1B2

Tel: 905-823-9060 (main)
Fax: 905-403-7565

www.aecl.ca