XA9846722

THE CANDU 80

R.S. HART
AECL-CANDU,
Mississauga, Ontario, Canada

Abstract

AECL has completed the conceptual design of a small CANDU plant with an output in the range of 300 MWth, suitable for a variety of electrical and co-generation applications including desalination, oil sands oil extraction and processing, and the provision of electricity and heat to areas with low demand.

The design of this plant, called the CANDU 80, builds on AECL's extensive experience with small nuclear power plants, including NPD (22 MW(e)), KANUPP (125 MW(e)), Douglas Point (220 MW(e)) and Gentilly-1 (250 MW(e)), while taking advantage of the technological advances made by the latest large CANDU plants in the areas of design technology, construction methods, control and instrumentation, materials, and chemistry.

The "economy of scale" disadvantage is partly overcome through simplification, exploitation of the inherent characteristics of small reactor size, and incorporation of relatively low peak bundle powers (about 60% of those for large CANDU plants). For example the small core is stable, requiring no spatial control, and the limiting transients are relatively slow.

The station and plant layouts for the a CANDU 80, dedicated to electricity production and located at a coastal site are shown in Figures 1 and 2 respectively. These layouts are readily adapted to suit various co-generation and site conditions. Section and plan views of the containment system, showing the location of major components, are presented in Figures 3 and 4 respectively.

The CANDU 80 makes extensive use of component designs available from larger CANDU plants; these include two Pickering steam generators, two Pickering HTS pumps, the Gentilly-1 fuelling machine, and the same pressure tubes as Wolsong 3 and 4 (length reduced from 6 m to 5 m). Proven designs and operating parameters are used throughout (for example, heat transport system conditions are essentially the same as Pickering), while a limited number of new features serve to simplify operation, increase operating margins, and to enhance safety are incorporated.

Safety features include: low power density; stability and slow transients provided by the small core; two independent shutdown systems; double containment; fully capable emergency core cooling; low man-rem maintenance capability; passive decay heat removal via steam generators; passive moderator heat removal; passive shield cooling; and passive primary containment cooling.

This paper provides a brief overview of the CANDU 80, and discusses key features contributing to safety and operational margins.

1. INTRODUCTION

1.1 Background

The CANDU 80 is ideally suited to a variety of electricity and co-generation applications, including desalination, oil sands oil extraction and processing, and the provision of electricity and heat to areas with a relatively small demand. CANDU 80 can also fill a valuable role in the economic development of infrastructure in countries planning a large nuclear program, effectively bridging the gap between research reactors and the large (500 MW(e) to 1500 MW(e)) nuclear power plants currently available.

The CANDU 80 features low power density and large operating margins, thereby facilitating many simplifications and providing highly tolerant operating characteristics relative to large nuclear power plants. CANDU 80 takes advantage of the small CANDU reactor experience gained with early plants such as NPD, KANUPP, and Douglas Point, and the equipment, materials and chemistry advances made in the latest large CANDU reactors, while introducing a limited number of advanced features that enhance safety and reduce operation and maintenance costs.

Proven technology is used throughout the CANDU 80, updated with relevant features resulting from ongoing Canadian research and development. The CANDU 80 builds on the reactor and process system designs of the established CANDU plants, and incorporates advanced construction methods and operational features. The fuel and fuel channel technology and thermohydraulic and neutronic operating characteristics are the same as those of operating CANDU plants, and have been confirmed by extensive materials and full-scale fuel channel tests.

A high level of standardization has always been a feature of CANDU reactors. This theme is emphasized in the CANDU 80; all key components (for example, steam generators, coolant pumps, and pressure tubes) are of the same design as those proven in service in operating CANDU power stations.

1.2 CANDU 80 Accomplishments

A number of significant accomplishments are evident in the CANDU 80 design. These include:

1) The development of an economic small nuclear power plant (in the range of 300 MW(th)/100 MW(e)) thereby providing a nuclear power option for meeting many relatively small energy demands.
2) The maintenance of all traditional CANDU features including horizontal fuel channels, heavy water moderator and coolant, on power refuelling, and the ability to operate on a variety of low fissile content fuels including natural uranium.
3) The use of many proven component designs from previous CANDU plants without any significant design changes. These include steam generators and heat transport pumps from Pickering, pressure tubes from Wolsong 3 and 4, and the Gentilly 1 fuelling machine.
4) The use of proven system concepts and operating conditions. For example, the heat transport system conditions are essentially the same as those in Pickering.
5) The incorporation of large operating and safety margins, and ease of operation. The peak fuel bundle power for example is only 60% of that of CANDU 6.
6) The inclusion of a number of passive heat rejection systems to enhance safety, increase simplicity of operation, and reduce testing requirements.
7) A relatively short 24 month construction schedule.
8) The allocation of space within the containment structures for isotope production and/or test loop facilities.

1.3 CANDU 80 Safety

The CANDU 80 provides an extremely high level of safety through the provision of large operating margins and the incorporation of both traditional and advanced safety and safety support features. These include:

1) Two independent, fully capable safety shutdown systems. Both systems are passive, using gravity to inject neutron absorbing liquid into incore tubes.
2) A fully capable (pumped) emergency core cooling system to assure fuel cooling following a loss of coolant accident (LOCA). This system is backed up by two independent, passive decay heat removal systems (the moderator system and the shield cooling system).
3) A double containment system including a steel primary containment and a reinforced concrete secondary containment. The primary containment is passive, with passive post accident (LOCA or steam line failure) cooling.
4) Reject condensers to remove decay heat from the steam generators in the event of a loss of feedwater; this system is completely passive, requiring no valve or operator action to initiate operation.
5) A passive backup moderator cooling system capable of removing decay heat from the fuel via the moderator immediately after reactor shutdown.
6) The Reserve Water System, which can remove decay heat via the steam generators, the moderator system or the shield cooling system, and provide cooling of the primary containment for a minimum of 3 days without external cooling or power, or water makeup.

2. DESIGN SUMMARY

2.1 Layout

The principal structures of the CANDU 80 Nuclear Generating Station include the secondary containment building, the reactor auxiliary building, the maintenance building and a heat utilization building. The turbine building shown in the station layout, Figure 1, is typical of a heat utilization building for a CANDU 80 dedicated to electricity production and located at a coastal site; this facility can be modified as required to comply with specific co-generation or heat application requirements. Auxiliary structures include the administration building, and depending on site conditions and application, a pumphouse and/or cooling tower.

The distribution of equipment and services among the buildings is primarily by function. To the maximum extent possible, the structures are self-contained units with a minimum number of connections to other structures. The plant layout is presemted in Figure 2.

The layout provides for a short construction schedule by simplifying, minimizing and localizing interfaces, by allowing the parallel fabrication of equipment modules and civil construction, by reducing construction congestion, by the provision of construction access to all areas, by providing flexible equipment installation sequences, and by reducing material handling requirements. The layout also benefits from the application of modern human factors design practices, including a plant-wide "Link Analysis"; this serves to improve operations and maintenance efficiency, and to minimize the potential for human error.

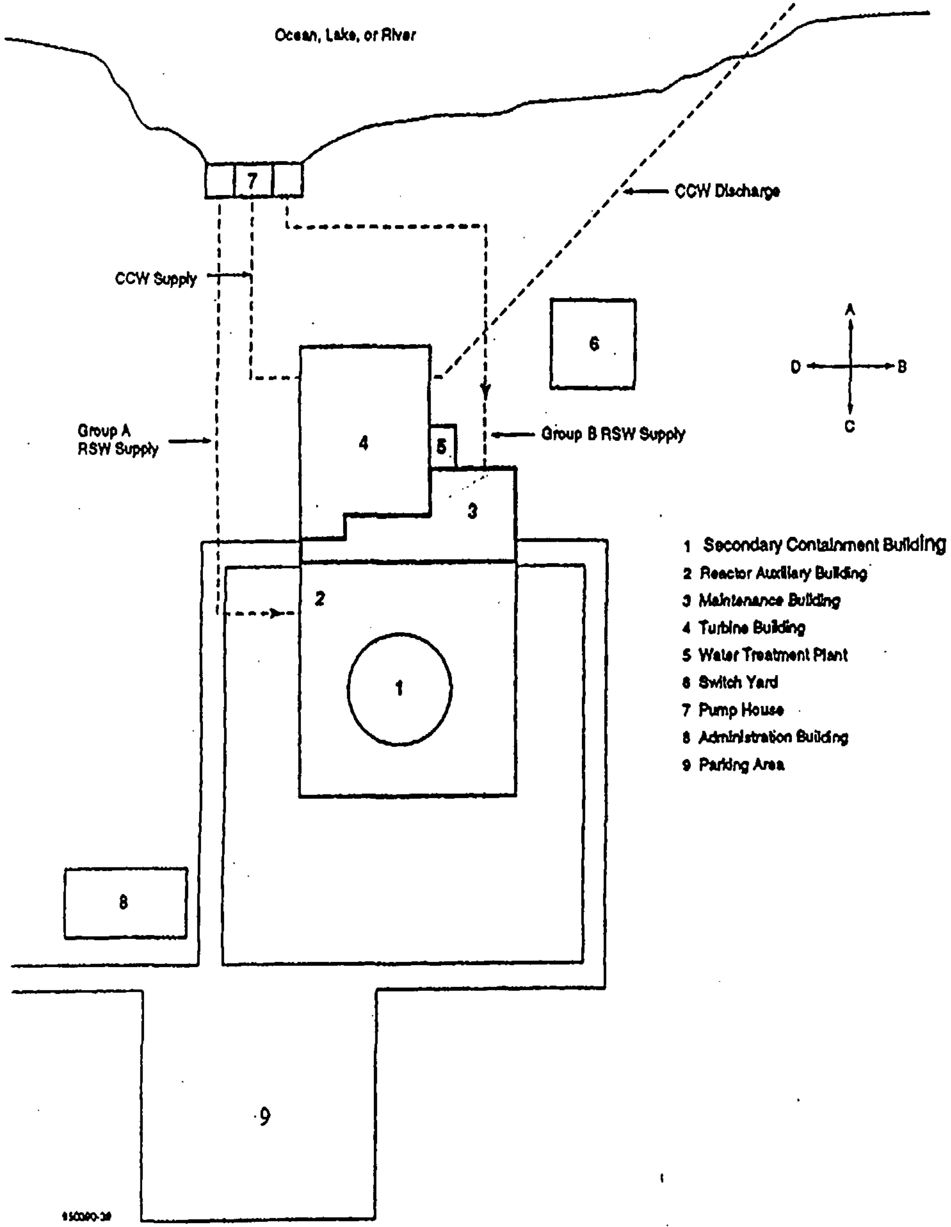


Figure 1 Station Layout

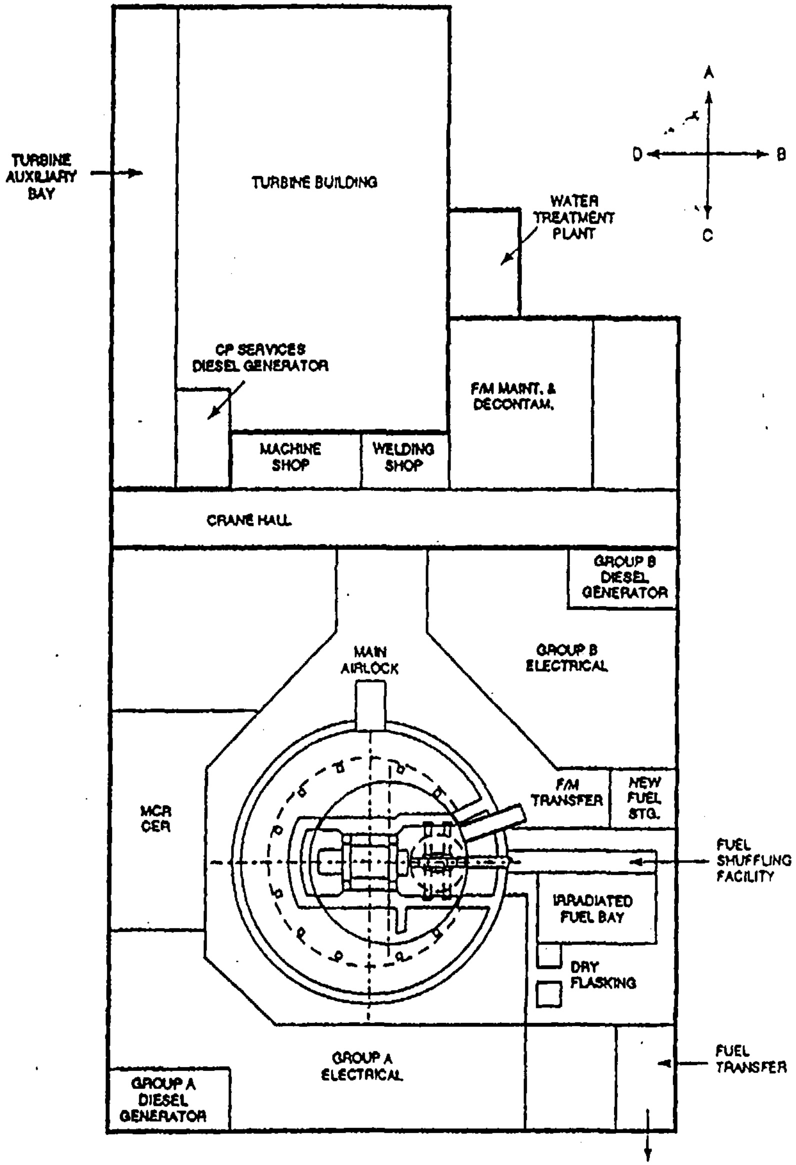


Figure 2 Plant Layout

The CANDU 80 incorporates a double containment system that builds on the operational features proven in-service at the Ontario Hydro Bruce and Darlington stations. Specifically, the high energy nuclear systems are housed within a compact Primary Containment, while key nuclear steam plant services are accommodated within confinements adjacent to the primary containment. In CANDU 80, the primary containment and the confinements are housed within a robust Secondary Containment. The CANDU 80 containment system is illustrated in Figures 3 and 4. The principal advantages of the CANDU 80 containment system include enhanced safety, reduced exclusion radius, ease of maintenance, and reduced capital and operating costs.

2.1.1 Grouping and Separation

All process systems and services in CANDU 80 are assigned to one of three groups (Group A, Group B, or Conventional Plant (CP) Services). Group A and Group B systems are primarily located in the Nuclear Steam Plant portion of the station, while CP Services are primarily located in the Conventional Plant portion of the station.

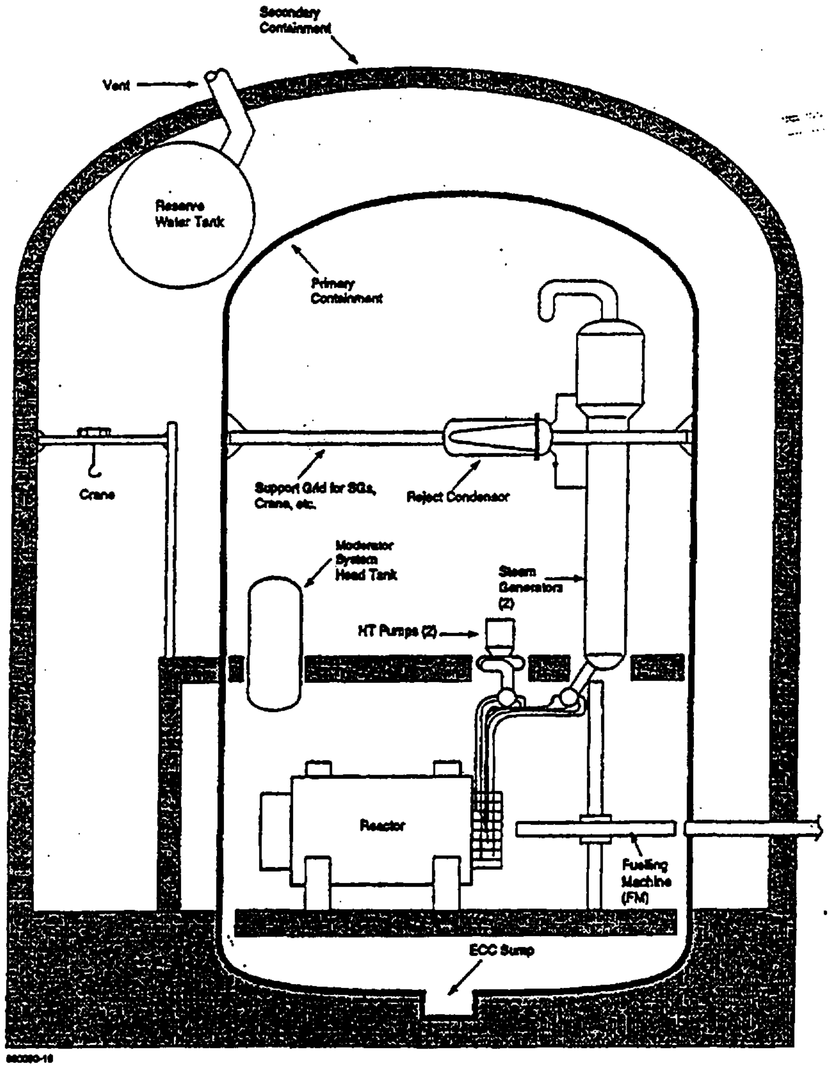


Figure 3 Containment System, Section View

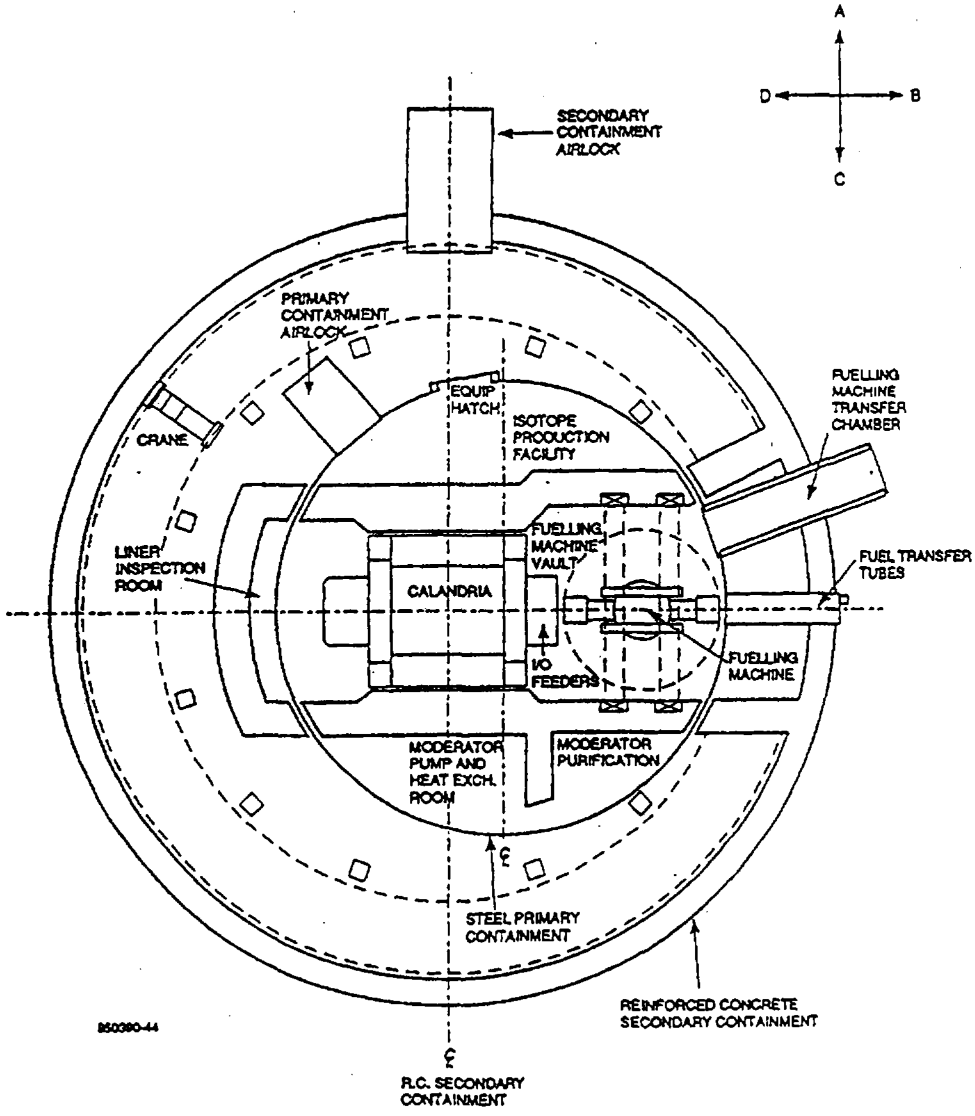


Figure 4 Containment System, Plan View

Group A and Group B systems each serve about half of the Nuclear Steam Plant (NSP) loads, and each include two of the four special safety systems; shutdown system No. 1 and the emergency core cooling system are assigned to Group A, while shutdown system No. 2 and the containment system are assigned to Group B. The control room is located in Group A; the secondary shutdown area is located in Group B. Group A and Group B services are provided to most of the principal nuclear steam plant systems; for example, the equipment served by the Group A recirculated cooling water system includes one moderator heat exchanger, one emergency core cooling system heat exchanger, and one primary containment cooling system heat exchanger, while the second heat exchanger in each system is served by the Group B recirculated cooling water system. In general, both Group A and Group B services are required for plant operation at full power, while safety requirements can be supplied by either Group A or Group B services, or in some cases, without the need for either Group A or Group B services. Group A and Group B systems are seismically and environmentally qualified, and tornado protected consistent with site requirements.

The CP Services are generally dedicated to normal power production, and are seismically qualified to local building code requirements.

To guard against cross-linked and common mode events, the Group A systems, Group B systems, and CP Services are, to the greatest extent possible, located in separate areas of the station, as shown in Figure 5. This approach to the grouping and separation of systems, an extension of current CANDU practice, results from studies that considered safety, operability, human factors, and cost.

3. SAFETY AND OPERATIONAL MARGINS

3.1 Overview

The CANDU 80 incorporates many features that enhance safety and increase operational margins. These include the approach to grouping and separation and the double containment system discussed in the previous section. Other features, including low power density and the incorporation of several passive heat removal systems, are discussed in the following sub-sections.

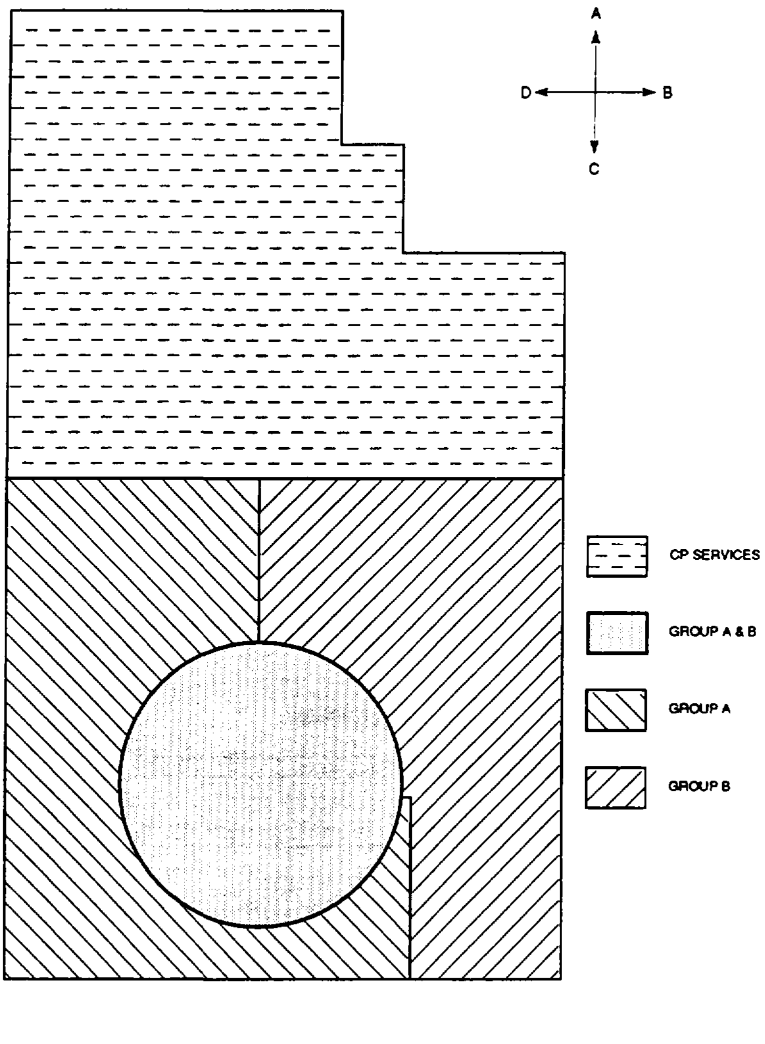


Figure 5 Area Allocation by Group

3.2 Power Density

CANDU 80 features peak fuel bundle powers that are about 60% of those of current larger CANDU plants. At the same time, heat transport system coolant conditions are about the same as those in the Pickering plants. This is accomplished by a unique fuel channel arrangement, in which the reactor coolant passes through two fuel channels, each containing 10 fuel bundles (each channel contains 12 bundles in large CANDU plants) connected in series, as shown in Figure 6. This arrangement, while making use of standard CANDU components and technology, provides the desired combination of low bundle power and Pickering HTS conditions.

3.3 Moderator System Passive Cooling

In all CANDU plants, including CANDU 80, the centre element of the fuel bundle is located less than 50 mm from the cool D_2O moderator surrounding the fuel channel. Hence, in the unlikely event of a loss of coolant from the heat transport system coincident with the failure of the emergency core cooling system, fuel can be cooled by heat rejection to the moderator. In CANDU 80 passive cooling of the moderator D_2O is provided for events that include the loss of active cooling systems.

The moderator system shown in Figure 7, circulates heavy water through the calandria to remove the nuclear heat generated in the moderator, and the heat transferred to the moderator from the fuel channels. The moderator system includes two 50% moderator pumps, two 50% plate type heat exchanger, and a head tank. The moderator pumps and heat exchangers are located in separate confinement areas, located in the interspace between the primary containment and the secondary containment. The moderator system head tank is located inside the primary containment.

During normal operation the moderator pumps draw D_2O from the top of the calandria via the moderator heat exchanger. The moderator heat exchangers are cooled by feedwater provided by the condensate extraction pumps during normal plant operation (see Section 5.4). Should feedwater flow be unavailable recirculated cooling water is directed to the secondary side of one moderator heat exchanger, to remove shutdown heat; Group A recirculating cooling water is available to one moderator heat exchanger while Group B recirculated cooling water is available to the other moderator heat exchanger.

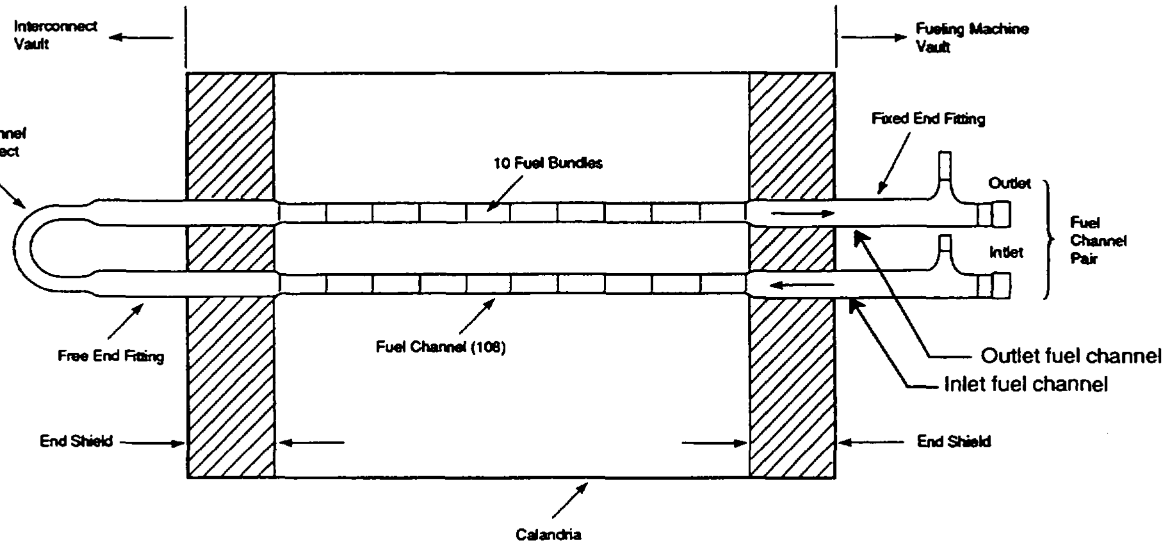


Figure 6 Arrangement of Fuel Channel Pairs

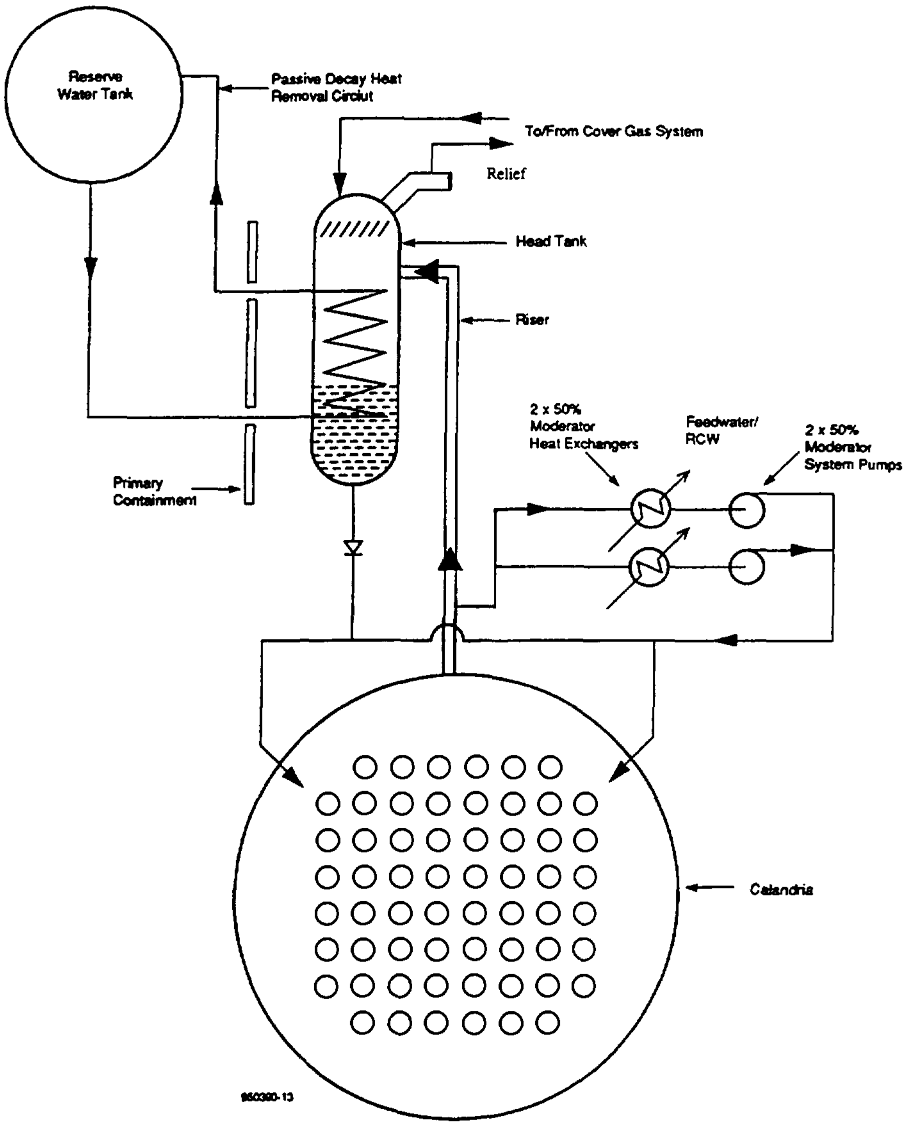


Figure 7 Moderator System Flowsheet

In the event that the moderator system pumps and/or heat exchangers are lost, the reactor is shut down, and flashing in the riser initiates natural convection circulation of the moderator. In this mode, heat is rejected to the water in the reserve water tank via a cooling coil located in the moderator system head tank, utilizing natural convection. The capacity of this mode of moderator cooling is sufficient to remove decay power under conditions of coincident loss of coolant and loss of emergency core cooling, without makeup water or cooling being provided to the reserve water tank, for a period of 72 hours. The reserve water tank includes four sub-sections; one sub-section is devoted to moderator system cooling (see Section 3.4).

Initiation of moderator cooling via the head tank cooling coil/reserve water tank is totally passive. No operator or control action is required.

3.4 The Reserve Water System

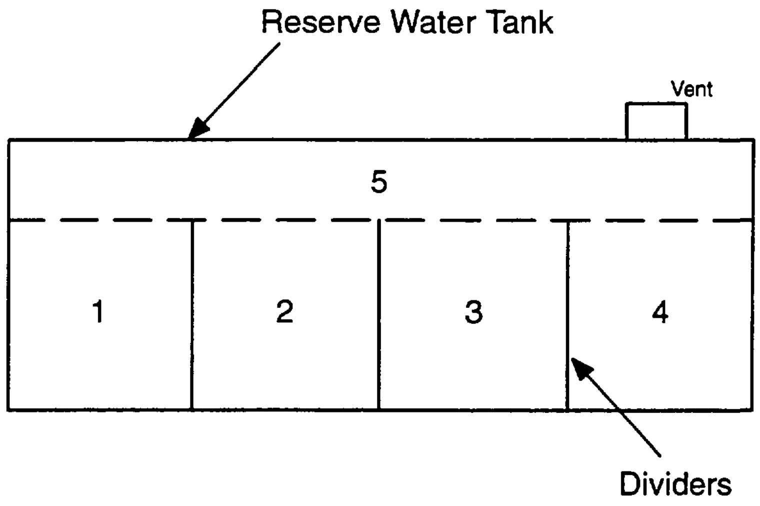
The Reserve Water System provides passive decay heat removal from the steam generators (via the reject condenser), the moderator system, the shield cooling system, and the primary containment internal environment. The principal component of the reserve water system is a large water storage tank (the reserve water tank) located at a high elevation in the interspace between the secondary and primary containment structures (see Figure 8). The lower portion of the reserve water tank is divided four compartments, each of which is open to the common upper portion of the reserve water tank. This arrangement is conceptually illustrated in Figure 8. Each compartment is dedicated to heat removal from one of the four associated systems (reject condensers, moderator system, shield cooling system, and primary containment). Each compartment contains sufficient water to remove decay heat for 24 hours following reactor shutdown. The common (upper) portion of the tank contains water for an additional 48 hours of decay heat removal. Hence, 72 hours of decay heat removal are available via any one of the associated systems. The section of the reserve water tank dedicated to primary containment cooling contains two cooling coils, one cooled by the Group A recirculated cooling water system and one cooled by the Group B recirculated cooling water system, each capable of removing decay heat. The water from the shield cooling system passes through the shield cooling system heat exchanger, cooled by Group B recirculated cooling water, before returning to the reserve water tank.

A vent line from the reserve water tank allows any steam produced in the reserve water tank to discharge to the atmosphere.

A purification system, consisting of a small pump, filter, ion exchange column, and sampling and chemical addition facilities maintains the chemistry and purity of the reserve water tank water within the design limits.

3.5 The Steam Reject System

The steam reject system, shown in Figure 9, includes a reject condenser, connected to each steam generator.



Water Allocation

Volume 1 - Reject Condensers
Volume 2 - Primary Containment
Volume 3 - Moderator
Volume 4 - Shield Cooling
Volume 5 - Common

Figure 8 Reserve Water Tank Water Allocation

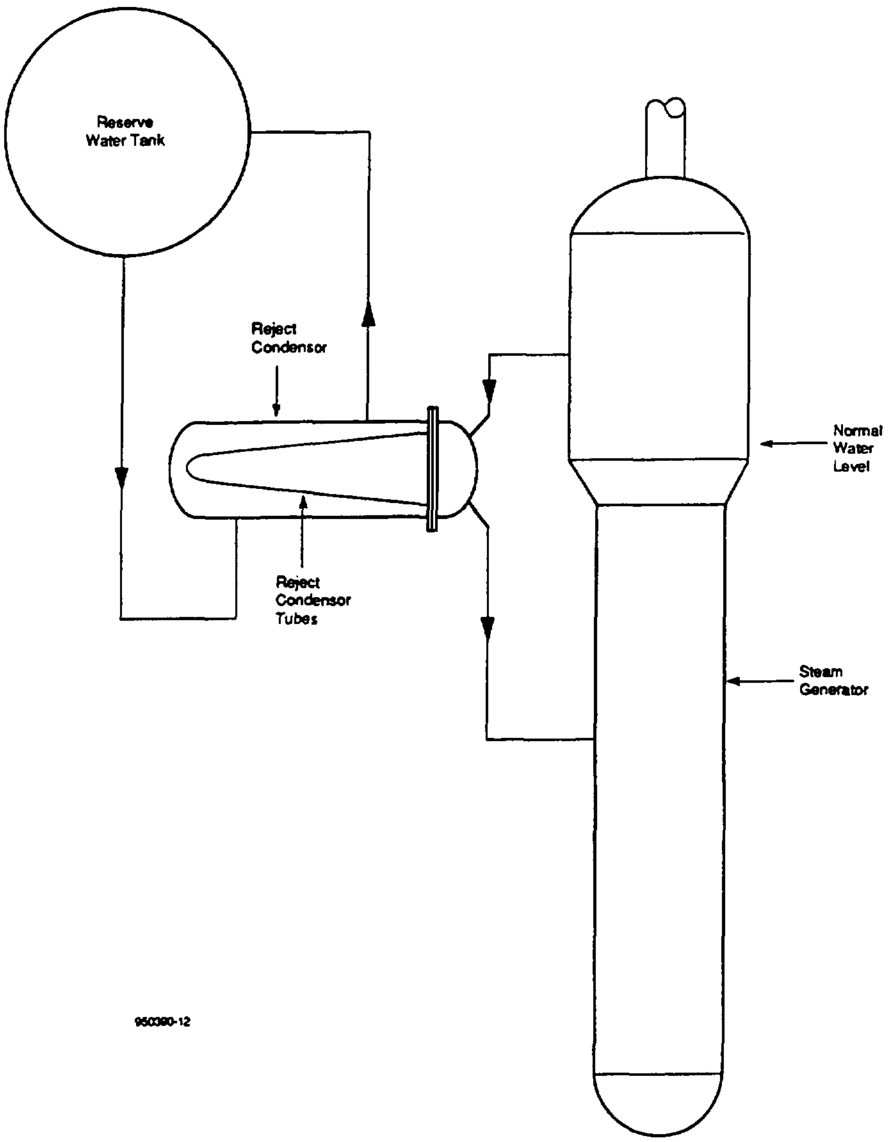


Figure 9 Reject Condenser System

When water level in the steam generator is within the specified operating range, the condensing coil in the reject condenser is filled with water, and circulation is prevented by the vapour (steam) lock in the pipe connecting the reject condenser inlet to the steam generator. In the event that feedwater flow is lost, and the water level in the steam generator drops significantly below the top reject condenser coils, steam is condensed in the reject condenser coils, and the condensate is returned to the steam generator downcomer.

The secondary side of the reject condenser is cooled by natural convection, via flow from and to the reserve water tank. The water available to the reject condensers from the reserve water tank (water in the reject condenser compartment plus the water in the common portion of the reserve water tank) is sufficient to remove decay heat, via evaporation, for a period of 72 hours without makeup or cooling to the reserve water tank.

The operation of the reject condenser system is fully passive; no valve operation or operator action is needed to initiate operation.

3.6 Shield Cooling System

The shield cooling system, shown in Figure 10 removes the nuclear heat generated in the shield water and structures and the heat transferred to the shield water, via natural circulation through the reserve water tank. During normal operation heat is removed from the shield water before returning to the reserve water tank by the shield cooling sytstem heat exchanger, which is cooled by the Group A recirculated cooling water system. The flow of cool water into the reserve water tank helps maintains the temperature of the water in the reserve water tank within the specified range. In the event that cooling water to the heat exchanger is lost, the water available to the shield cooling system (the water in the shield cooling system compartment of the reserve water tank plus the water in the common position of the reserve water tank) is sufficient to provide cooling to the end shields and shield tank for 72 hours, without makeup or cooling to the reserve water tank.

3.7 Primary Containment Cooling

The Primary Containment is inaccessible with the reactor at power. Humidity and temperature are therefore maintained at levels sufficiently low to protect the equipment located in the Primary Containment.

The Primary Containment is cooled via a water circuit, with coils located within a cooling duct inside the primary containment, which connect to the reserve water tank (see Figure 11). Two cooling coils in the reserve water tank, one provided with Group A recirculated

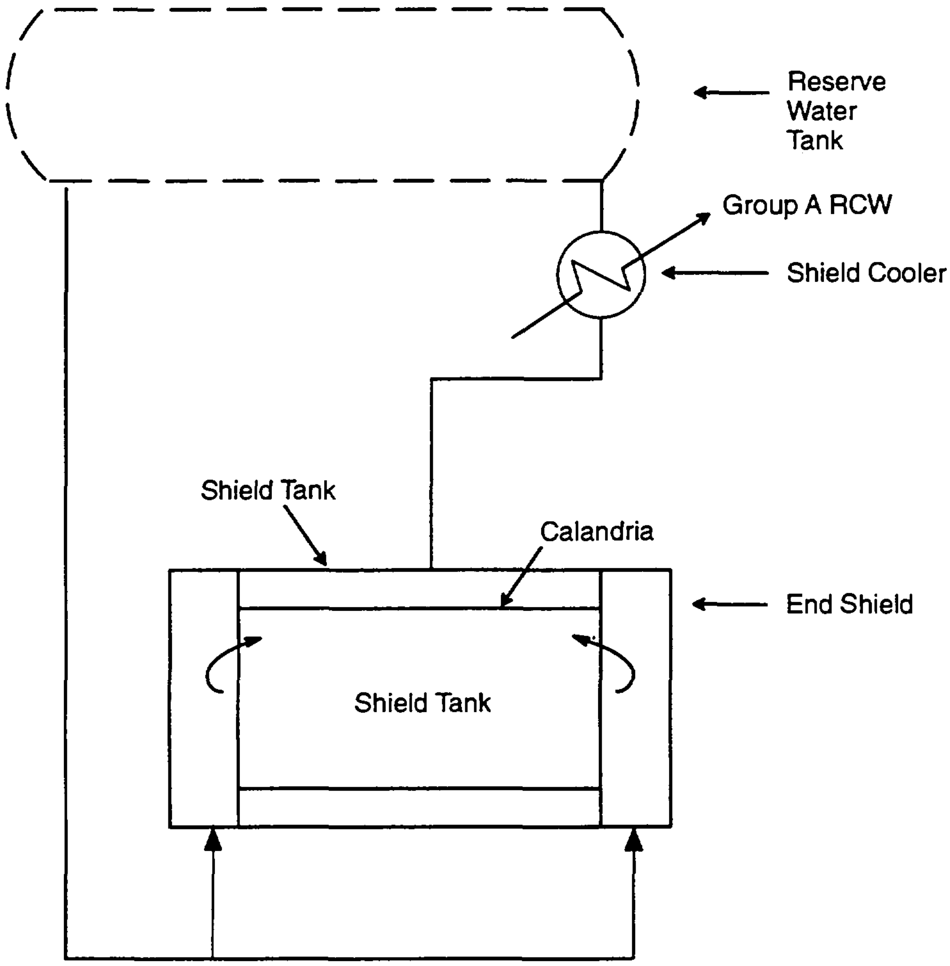


Figure 10 Shield Cooling System

cooling water and one provided with Group B recirculated cooling water maintain the temperature of the water in the reserve water tank within the design range during normal plant operations. During normal operation, 2 x 50% circulating fans located in the cooling duct and 2 x 50% pumps in the water circuit assure that temperatures in the primary containment do not exceed 50°C. One fan and one pump are provided with power from the Group A electrical distribution system while the other fan and pump are powered by the Group B electrical distribution system.

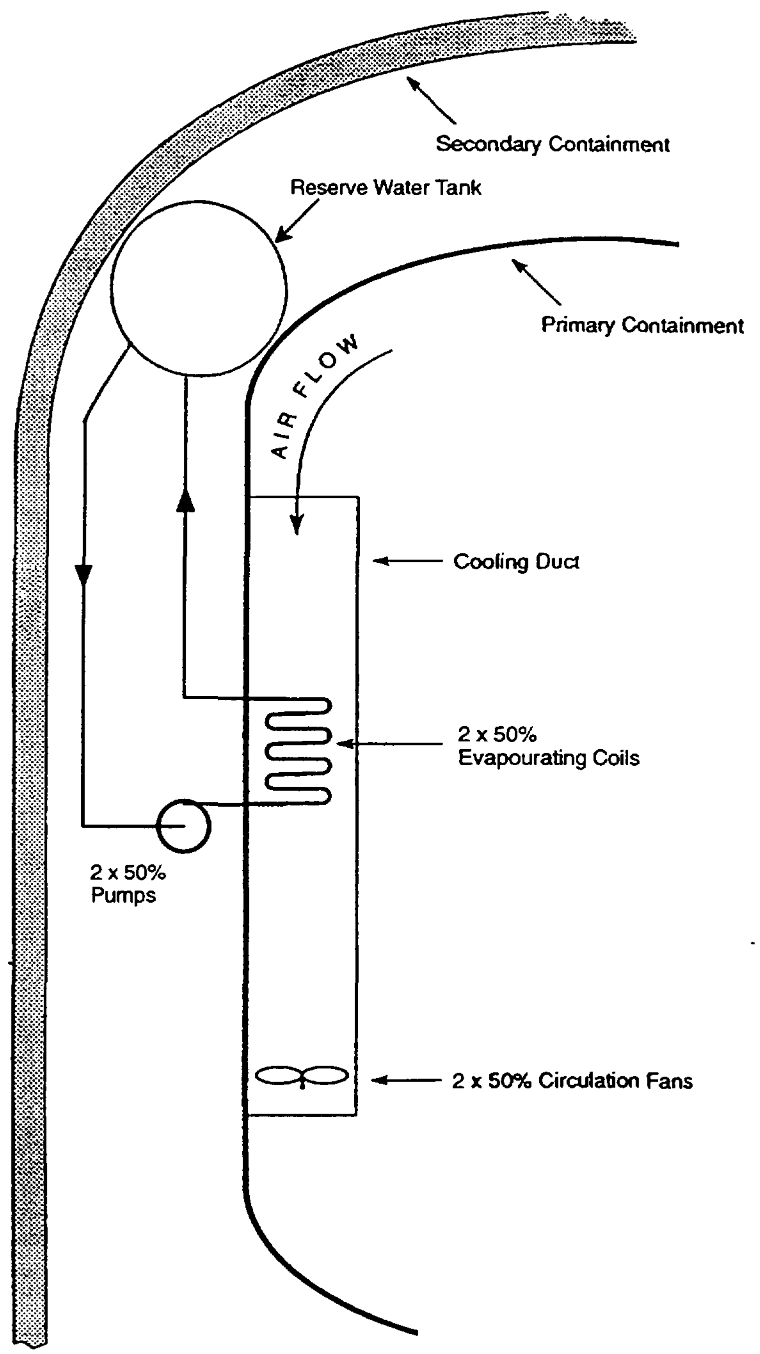


Figure 11 Primary Containment Cooling System

Following a postulated accident (Loss of Coolant Accident or a steam line failure within the primary containment), all circulation fans and pumps may be lost. Under these conditions, natural convection in the water circuit and the cooling duct maintain the primary containment temperature below 125°C (except for an initial transient period).

4. SUMMARY

The CANDU 80 is an economic nuclear plant, ideally suited for a variety of electrical production and co-generation applications, including desalination. This paper provides a brief overview of key CANDU 80 features. A CANDU 80 Technical Outline is available from the author on request.