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REACTOR CORE AND PLANT DESIGN CONCEPTS OF THE CANADIAN SUPERCRITICAL WATER-COOLED REACTOR

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Abstract

Canada is developing a 1200 MWe supercritical water-cooled reactor (SCWR), which has evolved from the well-established pressure-tube type CANDU®[1] reactor. This SCWR reactor concept, which is often referred to as the Canadian SCWR, uses supercritical water as a coolant, has a low-pressure heavy water moderator and a direct cycle for power production. The reactor concept incorporates advanced safety features, such as passive emergency core cooling, long-term decay heat rejection to the environment and fuel melt prevention via passive moderator cooling. These features significantly reduce the core damage frequency beyond existing nuclear reactors.

This paper presents a description of the Canadian SCWR core design concept, the integration of in-core and out-of-core components and the mechanical plant design concept. Supporting systems for reactor safety, reactor control and moderator cooling are also described.

Introduction

The supercritical water-cooled reactor (SCWR) is one of the six reactor concepts selected by the Generation IV International Forum (GIF). Canada is a member of GIF and has been developing a channel-type SCWR concept, known as the Canadian SCWR. This reactor concept targets to meet the GIF goals of enhanced safety features (inherent safe operation and deploying passive safety features), improved economics, improved resource utilization, sustainable fuel cycle, and greater proliferation resistance than the existing nuclear reactors.

The Canadian SCWR reactor consists of a high-pressure inlet plenum, a separate low-pressure heavy water moderator contained in a calandria vessel, and more than 300 pressure tubes surrounded by the moderator, forming the core. The reactor uses supercritical water (SCW) as the coolant, and a direct steam power cycle to generate electricity [1].

1. Background

The Canadian SCWR uses water at supercritical pressures and temperatures to take advantage of the higher thermodynamic efficiencies that can be achieved at higher temperatures. Typical pressures in traditional water-cooled reactors range from about 7 MPa for boiling water reactors (BWRs) to about

[1] CANDU – Canada Deuterium Uranium, a registered trademark of Atomic Energy of Canada Limited (AECL).

15 MPa in pressurised water reactors (PWRs). Heavy-water cooled CANDU reactors operate at about 10 MPa pressure. The highest operating temperatures in water-cooled reactors are about 340 ºC (in PWRs). In comparison, the various SCWR concepts that have been proposed recently [1], [2], [3] operate at pressures close to 25 MPa and outlet temperatures in the range from 500 ºC to 625 ºC. At supercritical conditions, SCW behaves like a single phase fluid. Hence, although higher operating pressures and temperatures introduce challenges in material selection, the use of SCW as a coolant simplifies the mechanical design by eliminating some of the major components in the reactor core or in the containment building, i.e.:

- Neither steam generators nor steam separators are needed: existing SCW turbine generators make it possible to adopt a direct cycle power generation (as in BWRs) eliminating the need for steam generators. Because SCW behaves like a single phase fluid, no steam separators are needed either.

The Canadian SCWR design is further simplified through the use of following design decisions:

- Batch fuelling and vertical orientation are adopted. This allows the use of a simpler overhead-crane fuelling machine with a robotic arm and eliminates the on-line fuelling machine typical in pressure-tube type reactors.
- Passive safety systems are used. These systems have very few or no moving components. Hence, they are more reliable and simpler to maintain.
- Inlet feeders, outlet feeders and fuel channel sealing components typically used in pressure-tube type reactors are eliminated which significantly reduces the number of components in the plant.

2. Reactor Core Concept

The reactor core design concept is illustrated in Figure 1. It consists of a pressurized inlet plenum, a low-pressure calandria vessel that contains heavy water moderator and pressure-tube fuel channels that are attached to the common inlet plenum. A counter-flow fuel channel is adopted to position the inlet and outlet piping above the reactor core so that a complete break of either an inlet pipe or an outlet pipe will not result in an immediate loss of coolant at the reactor core. A flow tube, with no fuel elements in it, is located at the center of the fuel channel to increase neutron moderation close to the inner fuel rings. This design feature results in reasonably uniform radial power distributions across the fuel channel as well as a much-desired negative coefficient of void reactivity throughout the cycle.

The reactor is oriented vertically for ease of batch refuelling. As illustrated in Figure 1, the primary coolant flows into the inlet plenum, around the outside of the outlet header and then enters the fuel channels through several slots, into the cross-over piece (top right figure), down through a flow tube in the centre of the fuel assembly, back up through the fuel assembly (bottom right and center right figures) and then out through the outlet header.

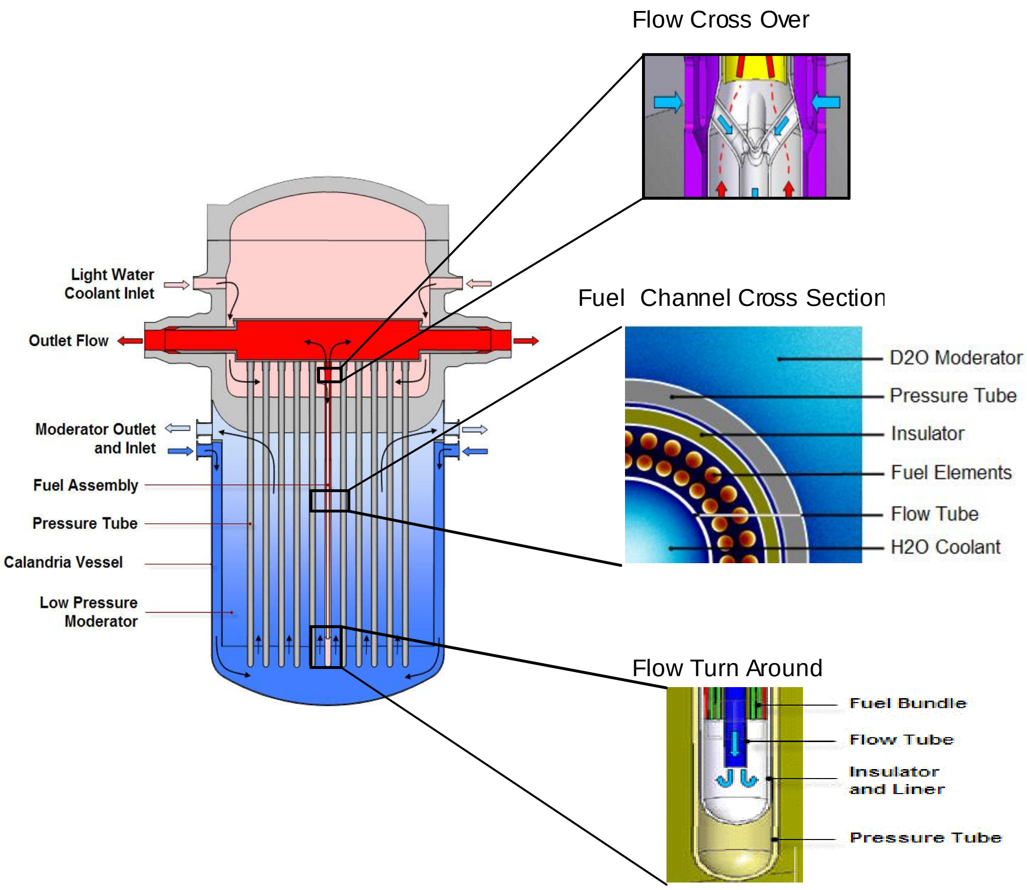


Figure 1 Canadian SCWR Core Schematic

2.1 Inlet Plenum and Outlet Header

The inlet plenum is designed as two forged steel pieces joined together at a bolted flange. The flange connects the domed top with the rest of the inlet plenum, which is manufactured from a single piece of forged material to avoid welds, and seals the high pressure inlet fluid with a series of concentric metallic O-rings. Penetrations in this vessel exist for four inlet pipes and four outlet pipes. The inlet and outlet pipes, shown in Figure 2, are sized such that the inlet and outlet flow velocities are less than 7 m/s and 20 m/s, respectively. These velocities are selected to avoid excessive flow accelerated corrosion of these components.

The outlet header is situated completely inside the inlet plenum with outlet pipes sealed externally where they penetrate the inlet plenum. A sliding seal between the outlet header and the thermal sleeve inside the outlet nozzle allows the outlet header to expand with respect to the cooler inlet plenum. The coolant flows through the inlet pipes into the large cavity of the inlet plenum above the outlet header and then down past the outlet header to the fuel channel array below as illustrated by the arrows in Figure 1. The inlet pipe is situated as high in the inlet plenum as possible so that, in the case of an inlet line break and depressurisation, some coolant will remain in the inlet plenum providing cooling to the fuel channels. It is recognised that the temperature difference between inlet and outlet streams is large and, hence, the resultant thermal stresses can be high in some components. Inlet plenum and inlet/outlet piping are insulated to reduce heat losses to the environment. Numerical analyses are being conducted to evaluate heat transfer, thermal stresses and the structural integrity.

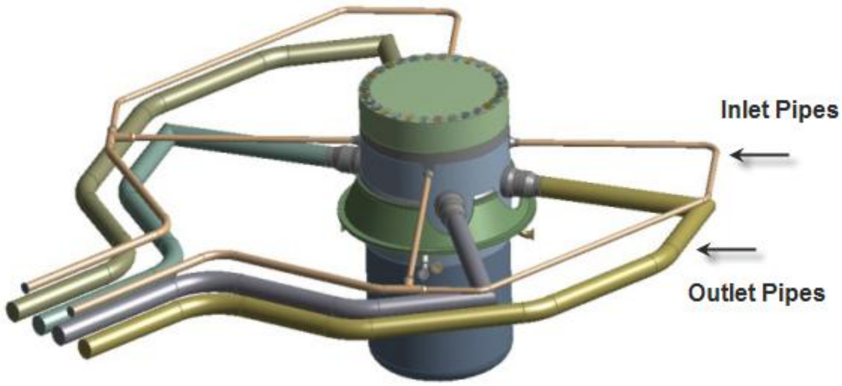


Figure 2 A 3D model of the Canadian SCWR core concept showing the core, inlet plenum, inlet piping and outlet piping

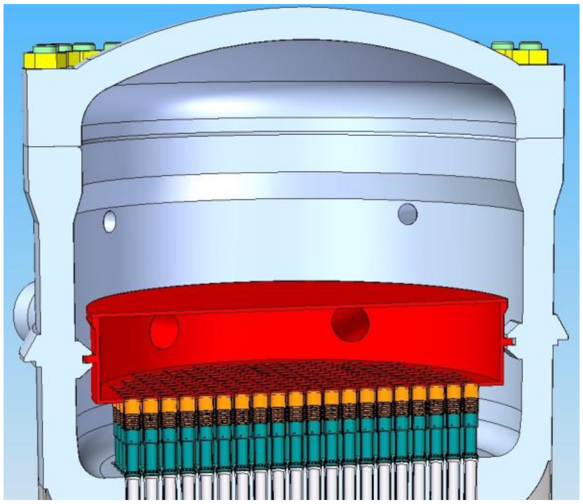
The fuel channels penetrate and are connected to the bottom of the inlet plenum, forming a tubesheet. The tubesheet is selected to have a flat geometry so that all fuel channels have the same geometry. This is desirable for manufacturing and maintenance ease even though the flat bottom is not the optimum shape for a pressure vessel from a strength point-of-view. The flat bottom has rounded edges at the periphery to minimize stress concentrations. The fluid flow within the proposed inlet plenum design with the outlet header in place can be seen in Figure 3. This geometry was analysed using the computational fluid dynamics (CFD) software ANSYS-FLUENT and no major fluid flow issues have been identified. Pressure drop at the top of the tubesheet is relatively small compared to the pressure drop in the fuel assembly. Hence, flow is reasonably uniformly distributed to individual fuel channels if the channel openings are the same in all fuel channels. CFD work is ongoing to evaluate the insulation requirements for the outlet header, which is located inside the inlet plenum, and to obtain the temperature distribution and local convective heat transfer coefficients needed for the thermal-structural analysis.

2.2 Fuel Channel and Fuel Assembly

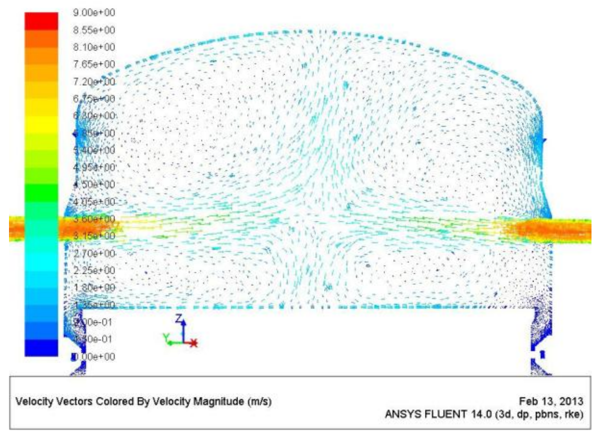
There are 336 fuel channels in the Canadian SCWR core concept. A simplified version of a fuel channel and a fuel assembly is shown in Figure 4. Note, in this figure, that the length of the channel is shortened and the gap between the pressure tube and the fuel bundle assembly is exaggerated to illustrate the details.

The fuel channel consists of a pressure tube that is connected to the tubesheet in a leak-tight fashion, a guide tube that extends the fuel channel into the inlet plenum and an expansion bellows that connects the guide tube to the outlet header.

The fuel assembly includes, from inside to outside, a central flow tube, two-rings of 31 fuel elements, an inner liner tube, a ceramic insulator and an outer liner encasing the insulator [13]. Above the core, the assembly also includes a cross-over piece that admits inlet coolant to the central flow tube. The fuel assembly, as a whole, is moved or replaced during a fuel shuffling or refuelling activities, respectively. As a result, all the components in the fuel assembly are replaced with the fuel.



(a) Outlet plenum (red) and pressure tube extensions (blue) are inside the inlet plenum.



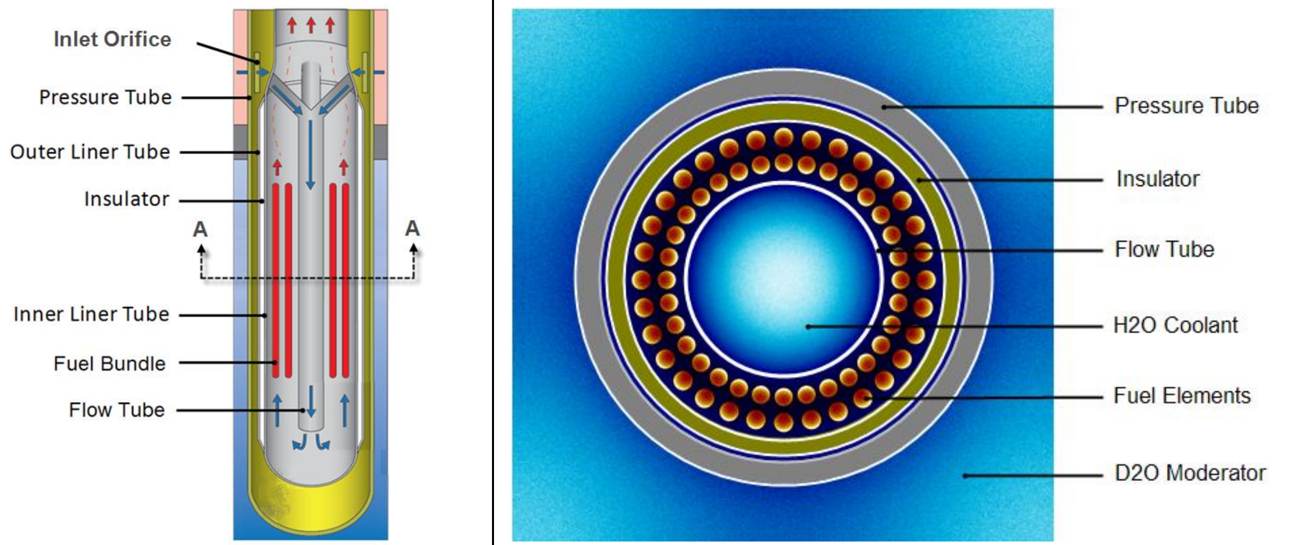
(b) CFD analysis of the inlet plenum showing velocity vectors

Figure 3 CFD Analysis of the Inlet Plenum (a) a 3D model of the inlet plenum and internals, (b) CFD predictions of flow velocities

Due to manufacturing tolerances and to ease fuelling and reshuffling activities, there are gaps between these components. These gaps are a critical part of the no-core-melt argument and are currently being optimized to minimize heat transfer resistance during accident conditions so that core decay heat can be transferred to the moderator more effectively.

2.2.1 Pressure Tube

The pressure tube forms the fuel channel pressure boundary and is in direct contact with the heavy water moderator. The pressure tube is sized to maintain the internal coolant pressure at 25 MPa. Currently, the moderator temperature is targeted to be 100 ºC in order to maintain the pressure tube temperature between 120 ºC and 150 ºC with the calandria vessel operating at 0.35 MPa (absolute). The candidate pressure tube material is Excel, a zirconium alloy, developed by AECL in the 1970s, that has high strength and high creep resistance at this operating temperature [5]. The pressure tube is connected to the tubesheet above the reactor core with a welded connection to ensure leak-tightness. Above the tubesheet, a guide tube and an expansion bellows (together they are called “the pressure tube extension”) extends from the tubesheet to the outlet header and guide the fuel assembly into the pressure tube. The pressure tube extension has perforations that admit flow into the fuel assembly. The perforations on the fuel channel extension are sized to match the flow rate with the channel power for a close-to-uniform outlet temperature across the reactor core.



(a) Fuel Channel and Fuel Assembly | (b) Section AA of Fuel Channel and Fuel Assembly

Figure 4 Canadian SCWR fuel channel concept (a) A simplified CAD model of the Fuel Channel and Fuel Assembly (for clarity, the length of the fuel channel is shown much shorter than it is in relation to the channel diameter), (b) A Section of Fuel Assembly

2.2.2 Fuel Elements

Sixty two fuel elements in a two-ring configuration of 31 fuel elements each [6] are arranged circumferentially around the central flow channel. The size of the flow channel, ring and fuel element diameters are determined through an iterative solution process that couples the physics and thermalhydraulics analyses. The cross section of this fuel and other fuel channel components are shown in Figure 4(b). This configuration is currently being optimised and may be modified slightly, but the main concept will remain as described above.

The high outlet temperatures of the Canadian SCWR combined with the reduced heat-transfer coefficient of SCW (compared to water) result in high fuel cladding temperatures compared with current typical reactor fuels. Fuel cladding temperatures close to 800 ºC are predicted for the proposed assembly without considering any heat-transfer enhancements, such as wire-wrapped spacers [6]. At this temperature, material strengths of most candidate materials are significantly less than at the typical cladding temperatures of 400 ºC found in existing water-cooled rectors. Hence, internally pressurised fuel cladding is not a feasible option without a very thick cladding material. However, collapsible fuel cladding, as used in CANDU reactors, is a viable option. Numerical models developed to model the thermal-structural behaviour of Canadian SCWR fuel indicate that cladding thickness as small as 0.4 mm is feasible at the Canadian SCWR operating conditions if a Ni-based cladding material is used [7]. Work is ongoing in this area that will identify the most appropriate cladding material and cladding thickness.

2.2.3 Insulator

The Canadian SCWR fuel channel differs from the typical CANDU fuel channel in one significant way: the SCWR fuel channel doesn’t have a calandria tube and insulating gas annulus separating the hot pressure tube and the calandria tube. Instead, an yttria-stabilized zirconia (YSZ) insulator is used inside the pressure tube for the purposes of shielding the pressure tube from the high-temperature coolant and reducing heat loss to the moderator. The insulator is mounted in the fuel assembly and is separated from the fuel by the inner liner and encapsulated by the outer liner, as shown in Figure 4. Because the fuel elements, liner tubes and the insulator are all part of the fuel assembly, they are all replaced or shuffled as a whole during refuelling activities.

2.3 Calandria Vessel

The calandria is a low-pressure vessel that contains the heavy water moderator, fuel channels, reactivity control mechanisms, and emergency shutdown devices. Heavy water at low pressure and low temperature is chosen for the moderator because of its superior neutron moderation properties. The moderator operates at sub-cooled temperatures using a pumped recirculation system. In case of a station blackout, the moderator heats up to the saturation temperature, making it possible to use a flashing-driven natural circulation loop to passively remove core decay heat. The operating pressure of the moderator will be optimized to ensure that “no-core-melt” requirements are satisfied. Currently, the calandria vessel pressure is set to 0.35 MPa and the operating temperature is close to 100 ºC (about 40 ºC subcooled).

3. Reactor Buildings

The primary objective of a reactor containment building is to contain radioactivity within the building during an accident. The reactor containment building also provides radiation shielding during normal and accident conditions, minimizes releases of radioactivity during normal operations and protects the reactor against external events i.e., severe weather, air-plane crash, or external explosion. The IAEA safety guide “Design of Reactor Containment Systems for Nuclear Power Plants” [18] provides guidance for nuclear reactor containment systems.

Based on the current IAEA design requirements and the design guides, a double-wall reactor building is adopted for the Canadian SCWR. A cutaway view of the reactor building is shown in Figure 5 together with major systems and components located inside the reactor building. The inner reactor building is the primary containment building, which is simply referred as *the containment building* in this paper. The containment building is leak-tight to internal pressures up to 0.5 MPa(g) and also carries thermal and mechanically induced loads and environmental conditions in case of a design-basis event. It contains all safety-related pressure boundary components and is the second last level of protection against the unintentional release of radioactive materials to the environment. Inlet and outlet pipes penetrating the containment building are equipped with isolation valves so that the radiation release to environment can be isolated and confined inside the containment building. Because a suppression pool is used to limit containment pressure, the containment building has a reasonably small volume as compared to PWRs and CANDUs.

The containment building is enveloped by *the shield building*. The main purpose of the shield building is to protect against external missiles, airplane crashes and natural hazards such as tornados, tsunamis and floods. It also functions as a secondary containment barrier and the last level of protection against the release of radioactive materials to the environment. The shield building cannot sustain high pressures, but is equipped with means for the collection and filtration of leaks of fission products from the containment building in the event of a beyond-design-basis accident. This arrangement is in compliance with the IAEA safety guide, which recommends a secondary confinement for new plants [18].

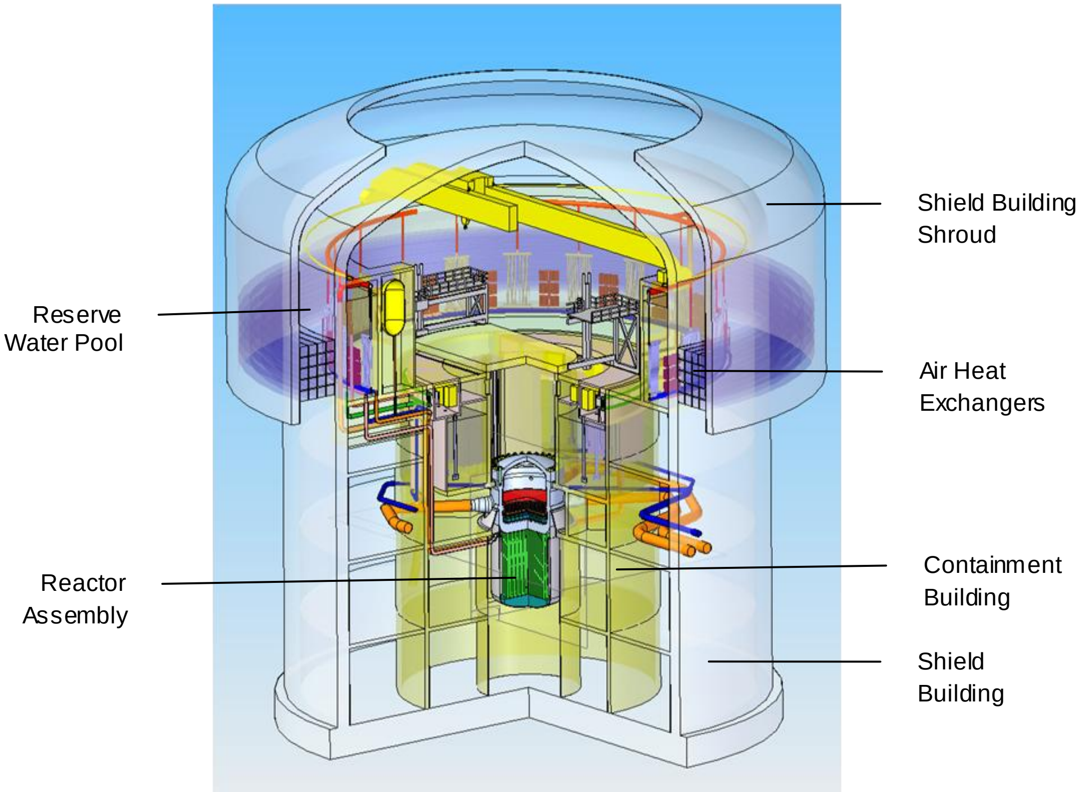


Figure 5 Cutaway View of Reactor Building

Both the containment building and the shield building are to be built on the same base slab, but they are structurally decoupled except at the base in order to reduce loads induced by an external missile or an aircraft crash on the shield building. The physical separation of the two reactor buildings also simplifies construction and limits the detrimental effects that might occur from deformations resulting from design loads, temperature variations and differential settlement.

4. Supporting Systems

The size of the reactor building is mostly determined by the reactor core and inlet/outlet piping, volume of the water pools used in safety systems, fuel handling and refuelling systems, control and startup/shutdown systems and maintenance access volumes.

4.1 Safety Systems

The Canadian SCWR safety approach and safety systems are discussed in more detail in other publications [16], [17]. In this paper, only the impact of these systems on core and plant design is discussed. The safety approach adopted for the Canadian SCWR follows those of advanced reactors in that multiple levels of independent and diverse safety systems are used as defence-in-depth and passive safety systems are adopted for increased reliability. The Canadian SCWR fuel is designed to exhibit a negative coolant void reactivity coefficient throughout its in-core residence time. Therefore, a large power pulse will not be encountered under the postulated large-break LOCA scenario.

Some of the unique safety features of the Canadian SCWR are as follows:

- **Moderator-Side Passive Cooling System and No-Core-Melt**: One of the inherent safety characteristics of the Canadian SCWR is the separation of the primary coolant from the moderator, and that the fuel channels are surrounded by heavy water moderator, which acts like a large heat sink in case of a loss-of-coolant event in fuel channels. This is achieved through radiation heat transfer from fuel elements to the liner tube and conduction-convection heat transfer to the moderator, thereby maintaining the fuel cladding below its melting point. This concept is a key feature of the Canadian SCWR concept and often referred to as the "no-core-melt" concept. The passive moderator cooling system is composed of condenser heat exchangers immersed in the reserve water pool and a head tank as described in reference [10].

- **Coolant-Side Passive Cooling System**: In case of loss of grid power, isolation condenser heat exchangers immersed in the reserve water pool are used to dump core heat to the reserve water pool in case of loss of grid power through natural circulation of the core coolant. Although such systems are employed in advanced BWRs, such as the ESBR and KARENA, it is unique in a SCWR. Preliminary analyses indicate that natural circulation cooling through isolation condensers is feasible [11] and the physical layout is described in [10].

- **Indefinite Cooling after Station Blackout:** A combination of partial water evaporation in the reserve water pool and air heat exchangers are used to remove decay heat from the reactor indefinitely. The decay power calculated for the Canadian SCWR is shown in Figure 6 as a percentage of the 2540 MWt full power. The cumulative water evaporation (at atmospheric pressure) needed to remove this decay heat is plotted on the secondary y axis in the same figure. As seen in Figure 6, about 1800 m^3 of water evaporation in the reserve water pool is sufficient to remove decay heat for 3 days. After 3 days, the decay heat reduces to 0.5% of the full power (12.5 MWt) and air exchangers alone become sufficient to remove decay heat. The reserve water pool is conservatively sized to contain 5000 m^3 of water and the air heat exchangers are also conservatively sized to remove 12.5 MWt of power.

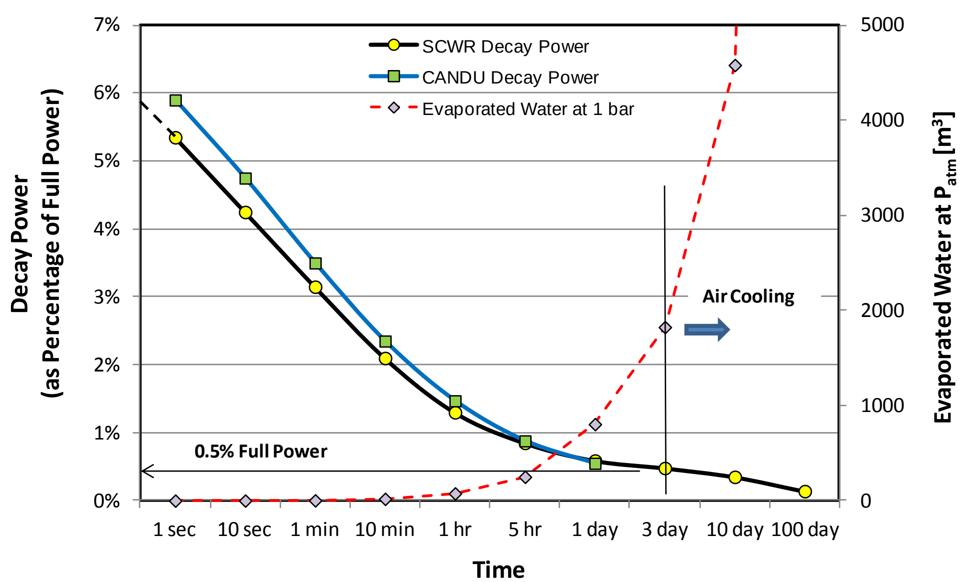


Figure 6 Calculated Decay Power for the Canadian SCWR and the Required Amount of Water Evaporation to Remove this Heat

4.2 Shutdown and Control Systems

The Canadian SCWR has two independent and diverse shutdown systems that satisfy the required negative reactivity and speed of insertion to safely shutdown the reactor. These systems are typically actuated within one second of receiving the shutdown signal and can shut down the reactor in less than two seconds.

Shutdown System 1 (SDS1) is the primary means of shutting down the reactor using neutron-absorbing shutoff rods. In the Canadian SCWR, gravity-driven vertical shutoff rods are not possible without penetrating the inlet plenum, which operates at 25 MPa. Instead, horizontal shutoff rods are used that penetrate the low-pressure calandria vessel. As an alternative, diagonal shut off rods that can take advantage of gravity as well as spring forces are also being considered. In both cases, the shutoff rods are spring-loaded and normally kept out of the core through electric-powered motors. They are automatically inserted in the core when the electric current is cut. The square-array fuel channel configuration is specifically selected to maximize the line-of-sight spacing between two adjacent fuel channels that is used to insert shutoff rod guide tubes.

Shutdown System No. 2 (SDS2) is a fast-acting liquid poison injection system. A liquid gadolinium nitrate solution, when injected into the moderator, absorbs neutrons to shut the reactor down.

4.3 Fuel Handling System and Refuelling Machine

A batch refuelling scheme is adopted for the Canadian SCWR. Every 425 days (~14 months), one third of the core is replaced with fresh fuel assemblies and the rest of the fuel assemblies are reshuffled in [13]. A computer-controlled refuelling machine with a telescopic robotic arm is used for refuelling. In a refuelling outage, the refuelling well above the reactor pressure vessel is flooded with water, and the reactor pressure vessel head and the top of the outlet header are removed. The fuel transfer pool, located adjacent to the refuelling well, is used to temporarily store the spent and new fuel assemblies before transferring them to the reactor vessel or the spent fuel pool. An inclined fuel transfer system connects the fuel transfer pool to the spent fuel pool in the reactor auxiliary building. The inclined fuel transfer system eliminates the space and components needed to rotate the fuel assembly to a horizontal orientation required in a horizontal fuel transfer system. The spent fuel pool can store 1344 fuel assemblies to accommodate used fuel assemblies for 10 years plus one full core (336 fuel assemblies). The spent fuel pool is cooled to remove decay heat produced by the spent fuel. In case of loss of cooling function, there is a sufficient amount of water above the fuel assemblies to provide cooling to the spent fuel for up to 72 hours without any operator intervention. The new fuel assemblies are stored dry in a rack underground in the reactor auxiliary building. The new fuel rack can store 150 fuel assemblies (more than 1/3 of the reactor core). Preventing criticality in the fuel pool is a design goal that could be managed through the use of neutron absorbers in fuel racks as well as boron addition to the pool water.

4.4 Startup System

A sliding pressure startup [14] is being considered for the Canadian SCWR that includes an incremental increase of pressure and temperature during startup. Preliminary analysis [4] indicates that the maximum fuel cladding surface temperature can be maintained well below the design limit of 800 ºC during start-up. The startup system includes a separate loop with a steam drum and a recirculation pump to bring the coolant pressure and temperature to close to supercritical conditions. Pressure, temperature and feedwater flow rate are increased in such a manner that dryout of the fuel cladding surface is avoided and the fuel cladding temperatures are kept below the design limit. A major consideration during a startup is the avoidance of channel flow instabilities that may lead to issues with reactor control. Analysis of sliding pressure schemes proposed for the Canadian SCWR indicated that hydraulic instabilities can be avoided with the appropriate selection of a startup scheme [15]. Also, the rates of temperature increases during startup should be selected to keep the thermal stresses during startup below an acceptable level to avoid metal fatigue of components.

4.5 Feedwater System

The feedwater system of the Canadian SCWR shares characteristics found in fossil-fired SCW and BWR plants, with some exceptions. Because the core inlet temperature and pressure of the Canadian SCWR is selected to match conditions used in current fossil-fired SCW plants, no significant development work is needed for the feedwater system. The main feedwater pump is typically quite massive and increases the coolant pressure to a supercritical pressure. A series of heat exchangers are used to preheat the inlet water to 350 °C. An auxiliary feedwater pump with 10% of the flow capacity is used to provide feedwater to the reactor core when the main feedwater pump is tripped. The auxiliary feedwater pump can also be run with emergency power in case of loss of grid power.

A major consideration in an SCWR is the fouling of fuel elements and transport of radioactive material (corrosion and fission products) from the core to downstream piping and the turbines. Preliminary modelling studies suggest that in-core deposition in an SCWR could be managed if the feedtrain materials and chemistry are optimized such that the dissolved iron concentration at the core inlet is kept below 0.1 µg/kg. The feedwater system is equipped with a full-flow condensate polisher to remove impurities. A key design consideration is the cascading of the feedwater heater drains back to the turbine condenser. European plants with this design have the lowest average final feedwater concentrations (0.1-0.5 µg/kg) [12]. To minimize deposit build-up during subsequent fuel cycles, fuel bundles being reloaded could be ultrasonically cleaned, as is the practice with some PWRs to address the issue of axial offset anomaly. This would also reduce activity transport due to activation and release of the deposits.

4.6 Reactor Building Size

The size of the Canadian SCWR containment building (shown with red lines in Figure 7) is comparable to that of the Japanese SCWR [3] and other advanced reactors, but significantly smaller than a typical PWR. This is mostly because of the use of suppression systems for containment cooling and containment pressure control.

5. Conclusion

The Canadian SCWR concept with passive safety systems is presented. This reactor concept has the following advantageous features that are unique amongst all SCWR concepts.

1. Passive enhanced safety with a natural-convection driven coolant-based safety system through isolation condensers.
2. Multiple and diverse layers of passive safety: pressure-tubes are surrounded by heavy water moderator, which acts as a permanent standby cooling system. In case of loss of coolant in fuel channels and loss of all power, the natural-convection driven moderator-based cooling system acts as a redundant reactor cooling system and is sufficient to prevent the melting of fuel.

3. Air-coolers that extend the passive cooling capacity indefinitely beyond 72 hours in case of a total station blackout.
4. Collapsible fuel cladding that can tolerate higher operating temperatures.

The design efforts and various analyses of reactor core components are ongoing at a detailed level. Material selection, insulation needs, thermalhydraulics and thermal stresses are being investigated for design optimization. Although the basic concepts presented in this paper will remain, minor modifications to the presented concept are anticipated as the behavior of the reactor core becomes better understood through analysis.

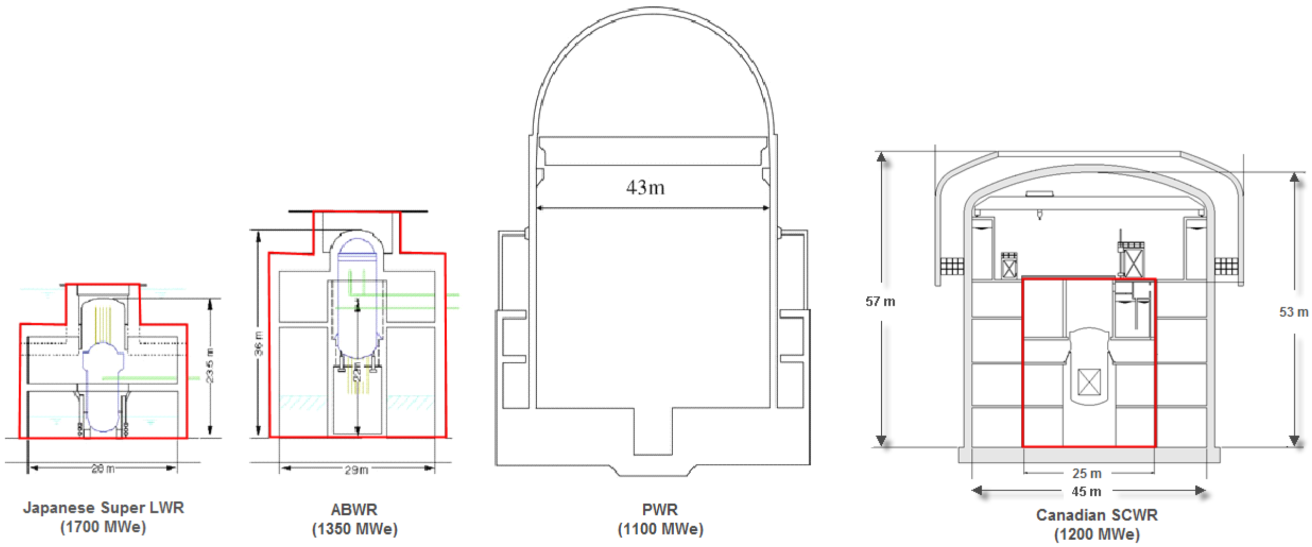


Figure 7 The size of Canadian SCWR containment building relative to those in various designs (modified from [3])

6. Acknowledgments

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Table 1
Design Summary of Canadian SCWR

Parameter	Value
General	
Power MWt/MWe	2540 MWt/1200MWe
Number of Fuel Channels	336
Steam Cycle	Direct
Coolant	Supercritical Light Water
Inlet Conditions	25.3 MPa, 350ºC
Outlet Conditions	25.0 MPa, 625ºC
Inlet Plenum	
Inside Diameter	6.25 m
Outside Diameter	7.15 m (7.4 m at flanged connection to lid)
Tubesheet Thickness	1.0 m
Candidate Material	ASME SA-508 Grade 3 Class 1
Inlet and Outlet Piping	
Inside Diameter of Inlet Piping	31 cm
Thickness of Inlet Piping	3.5 cm
Inside Diameter of Outlet Piping	56 cm
Thickness of Outlet Piping	22 cm
Fuel Channels	
Fuel Channel Configuration	Square Array
Pitch	250 mm
Pressure Tube OD and Thickness	181 mm, 12 mm
Pressure Tube Length	6.58 m
Pressure Tube Extension Length	1.0 m
Fuel Assembly	
Flow Tube OD and Thickness [mm]	91 mm, 1 mm
Inner Liner OD and Thickness [mm]	145 mm, 0.5 mm
Outer Liner ID and Thickness [mm]	157 mm, 0.5 mm
Insulator ID and Thickness [mm]	156 mm, 5.5 mm
Fuel Bundle	
Fuel Length	5 m
Inner Ring: Ring Diameter, Fuel Element OD and Fuel Sheath Thickness [mm]	106 mm, 9.5 mm, 0.6 mm
Outer Ring: Ring Diameter, Fuel Element OD and Sheath Thickness [mm]	131 mm, 10.5 mm, 0.6 mm
Fuel Sheath Type and thickness	Collapsible, 0.6 mm