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## SUPERCRITICAL WATER COOLED REACTORS

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### 1. Introduction:

As the demand for electric power is increasing as well as the issues related to climate change, there's a need to develop new sustainable environmentally friendly energy systems. Research activities are currently underway worldwide to develop Generation IV nuclear reactor concepts with the objective of improving thermal efficiency and increasing economic competitiveness of (NPPs) compared to modern thermal power plants. There is a great interest in many countries in the research and development (R&D) and conceptual design of SCWRs (one of the six reactor technologies selected for research and development under the Generation IV program). The supercritical water cooled reactor (SCWR) uses supercritical water as the working fluid. SCWRs resemble light water reactors (LWRs) but operate above the thermodynamic critical point of water (374C, 22.1MPa), with a direct once-through cycle like a supercritical boiler. This helps improve the thermal efficiencies (i.e., about 45% vs. about 33% efficiency for current LWRs) and a simplified reactor system (i.e., the need for a pressurizer, steam generators, steam separators, and dryers is eliminated), and is hence expected to help improve its economic competitiveness as the main mission of the SCWR is generation of low-cost electricity. [1][2]

### 2.Supercritical operation and general considerations:

The feedwater is pressurized to a pressure beyond its critical pressure. The change in the thermo-physical properties of water at critical and supercritical pressures is dramatic, but continuous (As shown in Fig-2). [3] **.** Such heating can be made to be closer to the heat source temperature than a subcritical cycle with the same steam temperature that shows an abrupt change in temperature within the two phase region, so the cycle receives more of its heat at higher temperatures than a subcritical cycle with the same turbine inlet steam temperature resulting in decreasing the external irreversibilities of the cycle. A disadvantage of the supercritical-pressure cycle, however is that expansion from point 1 to the condenser pressure would result in very wet vapor in the latter stages of the turbine which decreases the turbine efficiency ,hence, supercritical pressure cycles invariably use reheat and often double reheat with separators.

• At supercritical pressures, there's no liquid-vapor phase transition (Boiling), so the coolant remains single-phase throughout the system, therefore, there's no such a thing as Critical Heat Flux or burn out, only in a certain range of operation a Deteriorated Heat Transfer may occur. (Pioro and Duffy 2003).

• Working near the pseudo critical point allows working with higher rates of enthalpy content which results in significant decrease in the mass flow rate of the coolant and thus a reduction in the size of the system and the reactor coolant pumping power.

•The large temperature difference inside the core leads to a significant density decrease and poor moderation in the upper part of the core, this can be eliminated by the use of water rods in which the cold coolant flows down or a solid moderator (as shown in Fig-3) [4].

•Conventional fuels like UO2 are not suitable for supercritical operation, due to the decrease in their thermal conductivity at high temperatures, which leads to a rise in their centerline temperature above the industry accepted limit affecting the fuel integrity (1850ºC).

•The SCWR structural and cladding systems are challenging aspects, as water properties change rapidly around the pseudo-critical point and the effects on materials are less known. However, recent studies showed that Zirconium-based alloys, common in water-cooled reactors, may not be a viable as zirconium would corrode rapidly at very high temperatures, and hence the enrichment of the fuel will have to be higher to compensate for the neutron absorption by the cladding, which can't be made from the zirconium customary in LWRs. Stainless steel or nickel alloys may be used.

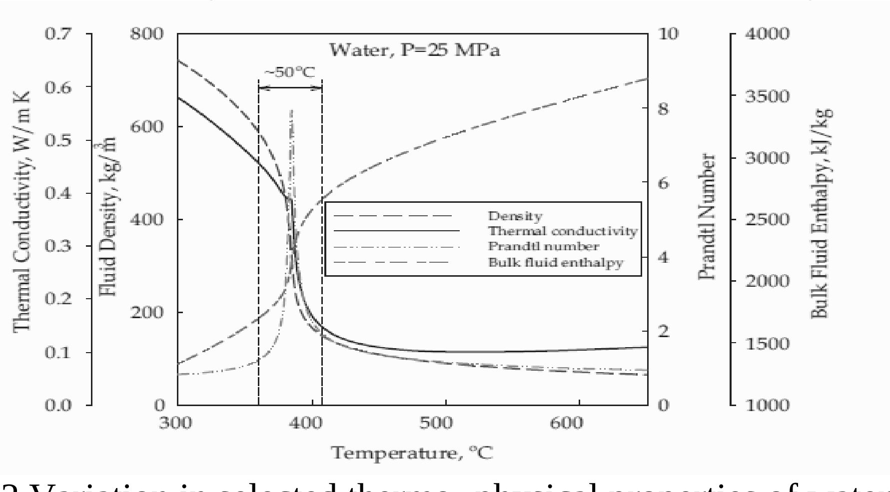


Fig.2.Variation in selected thermo- physical properties of water near the Pseudo-critical point.

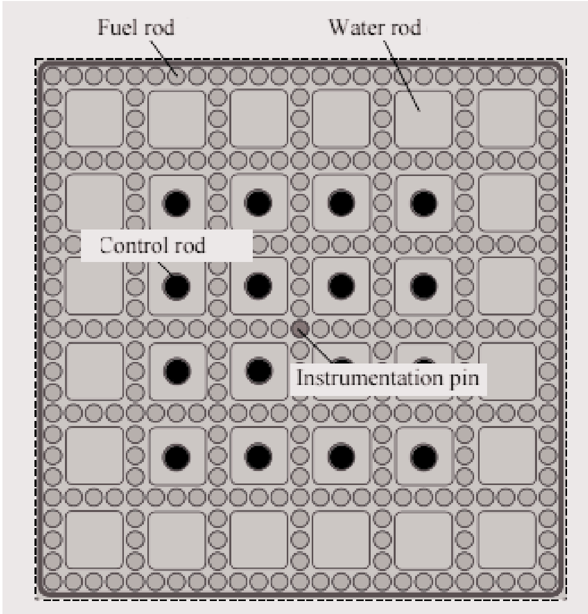

Fig.3. Typical reference core design with water rods

**3.Typical supercritical water reactor design:** Different design concepts are under study but they are divided into two main groups:

- Pressure Tube system (Derived by the CANDU experience)
- Pressure Vessel system (Derived by LWRs experience)

A typical design of a PV-SCWR (is shown in Fig-12) is a direct cycle, thermal neutrons, ordinary water cooled and moderated with an operating pressure of 25MPa and inlet/outlet coolant temperature of 280/500 C, low enriched fuel with a thermal efficiency of about 45%.[4]

A typical SCWR design parameters are contained in Table4.1

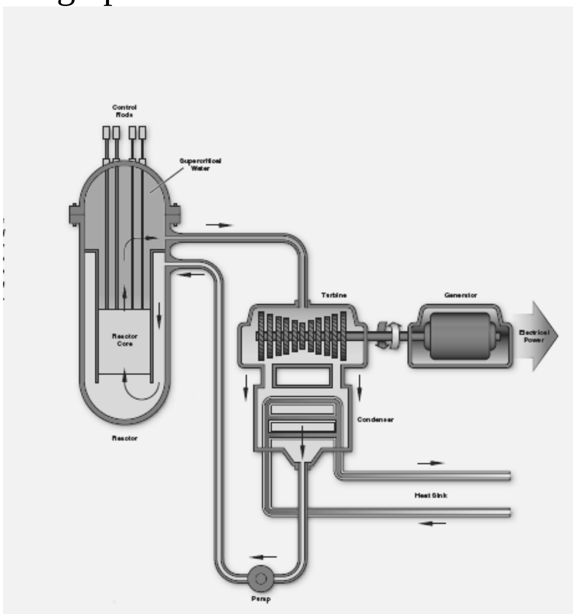

Fig.12. Pressure Vessel SCWR schematic (Courtesy of USDOE)

| Parameter | Value |
|---|---|
| Thermal power | 3575 MWt |
| Net electric power | 1600 MWe |
| Net thermal efficiency | 44.8% |
| Operating pressure | 25 MPa |
| Reactor inlet temperature | 280°C |
| Reactor outlet temperature | 500°C |
| Reactor flow rate | 1843 kg/s |
| Plant lifetime | 60 years |

Table4.1 Typical SCWR Design Parameters

Summary:

•Using NPPs with supercritical water reactors can lead to considerable economic advantages such as:

-Increase in the efficiency up to 44 -45%,

-Decrease in the metal intensity of equipment and reduction of construction and assembling

•We still need to develop suitable materials for structures and cladding that can withstand high pressures and temperatures in a severe aggressive medium like supercritical water along with heat transfer correlations at supercritical flow conditions.

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