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Conceptual design of a supercritical water reactor with double-row-rod assembly

Chuanqi Zhao [a], Liangzhi Cao [a,*], Hongchun Wu [a], Jue Yang [b], Yong Zhang [b]

[a] *School of Nuclear Science and Technology, Xi'an JiaoTong University, Xi'an Shaanxi 710049, China*
[b] *China Nuclear Power Technology Research Institute, Guangdong Shenzhen 518026, China*

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ABSTRACT

A novel type of fuel assemblies with double rows of fuel rods between water rods is proposed and optimized for a supercritical light water reactor design. It brings improved neutron moderation and lower local power peak. Gadolinium is introduced as burnable poison to reduce excess reactivity at the beginning of the fuel cycle. The optimizations for the fuel rods with gadolinium are performed in the present paper. SS316L is used for fuel rod cladding and structural material. In order to reduce the amount of SS316L because of its high thermal neutron absorption, honeycomb structure filled with thermal isolation is introduced to replace the solid stainless steel. The two-pass water flow scheme is chosen with more fuel assemblies for downward flow. Fuel in-core loading pattern and control rod clusters pattern are designed to flatten power distribution at inner regions to enhance coolant outlet temperature. Axial fuel enrichment is zoned into three regions to control axial power peak, which might affect maximum cladding surface temperature. An equilibrium core is then analyzed based on neutronics/thermal-hydraulics coupling model. The numerical results indicate that a high average coolant outlet temperature of 500 °C is achieved with a maximum cladding surface temperature less than 650 °C. The void reactivity effects of moderator and coolant are negative throughout the cycle.

1. Introduction

Supercritical light water reactor (SCWR) is a thermal reactor cooled and moderated by supercritical water. Water does not exhibit a phase change from liquid to gas above 22.1 MPa. Therefore, the plant system is simpler and more compact than PWRs and BWRs without a dryer, water-steam separators and recirculation pumps. The coolant outlet temperature is high because there is no limitation of saturation temperature at supercritical pressure. This results in high thermal efficiency, which is good not only for producing electricity but also for reducing the amount of spent fuel per generated watt of electricity.

As supercritical water doesn't undergo a change of phase, the Maximum Cladding Surface Temperature (MCST) is taken as design criterion for SCWR. Average coolant outlet temperature is also an important parameter, because it directly affects the thermal efficiency. The closed channel is designed to avoid coolant mixing between fuel assemblies. Thus, a uniform power distribution within an assembly is very important for increasing the outlet temperature while keeping a low MCST. This is paid attention to in previous studies, but there is still room for improvements. In SCWR of Japan (JSCWR) (Yamaji et al., 2005a, 2005b; Kamei et al., 2006), assemblies with single row of fuel rods between water rods are used in core design. Fuel rods in the periphery of the assembly and the corner of water rods have lower power than others. In order to provide uniform neutron moderation, peripheral water rods are used which increase the complexity of the assembly. Another promising design is the European High Performance Light Water Reactor (HPLWR) (Schulenberg et al., 2011; Maráczy et al., 2011). A small, square, 7 by 7 fuel pin lattices with a water rod occupying 9 lattices in the center has been designed for the HPLWR fuel assembly. An assembly cluster consists of 3 by 3 assemblies. There is gap between assemblies filled with moderator. In this assembly, 4 corner pins have better moderation than the remaining ones. Thus, two different enrichments are used to flatten local radial power distribution, which makes the assembly complex. In this study, assemblies with dual rows of fuel rods between water rods is chosen, which results in improved uniformity of neutron moderation and coolant temperature (Liu and Cheng, 2010a). This assembly has been used in a mixed spectrum core (Liu and Cheng, 2010b, 2010c). However, some optimizations should be made to satisfy the thermal core. The thickness of water rods wall and assembly box is larger than that of assemblies in previous studies (Yamaji et al., 2005a, 2005b; Kamei et al., 2006) for engineering

* Corresponding author. Tel.: +86 29 8266 3285; fax: +86 29 8266 7802.
E-mail address: caolz@mail.xjtu.edu.cn (L. Cao).

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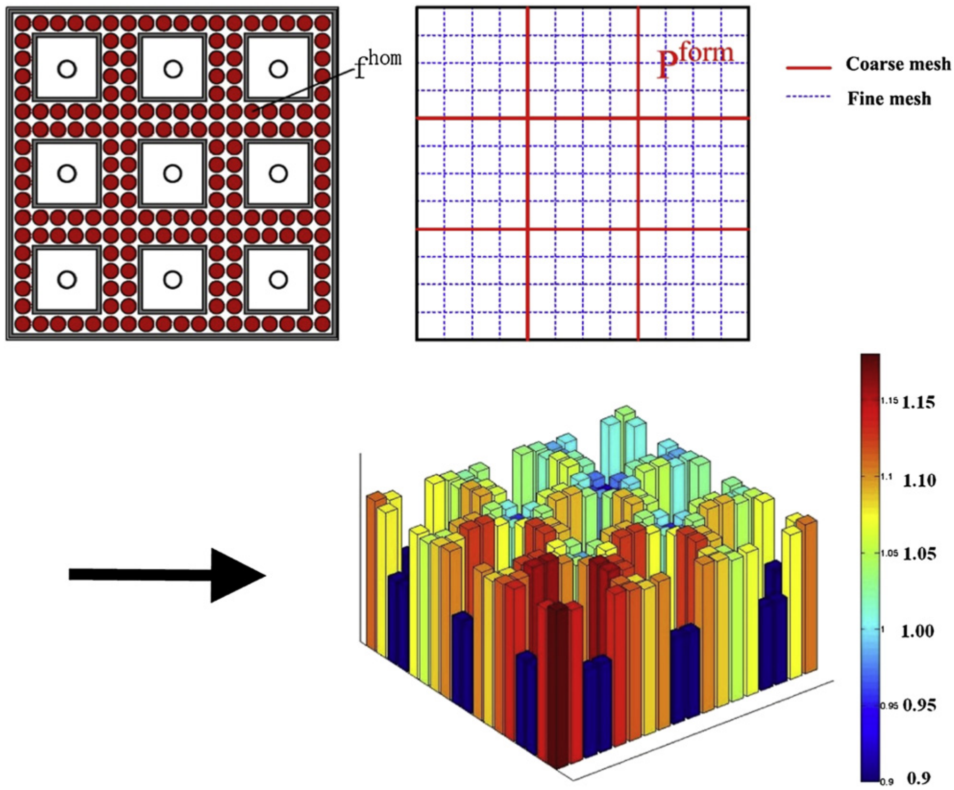

Fig. 1. Assembly power reconstruction.

feasibility, which causes higher fuel enrichment. Burnable poison is introduced to reduce the excess reactivity.

Based on this assembly, a core is designed and analyzed using coupling model of three-dimensional neutronic and thermal-hydraulic. With assembly power reconstruction, pin power distribution is obtained to improve the accuracy of coupling calculation.

This paper is organized as follows. Section 2 introduces the methods used in assembly and core design. Section 3 performs some optimizations on fuel assembly design. Section 4 studies the

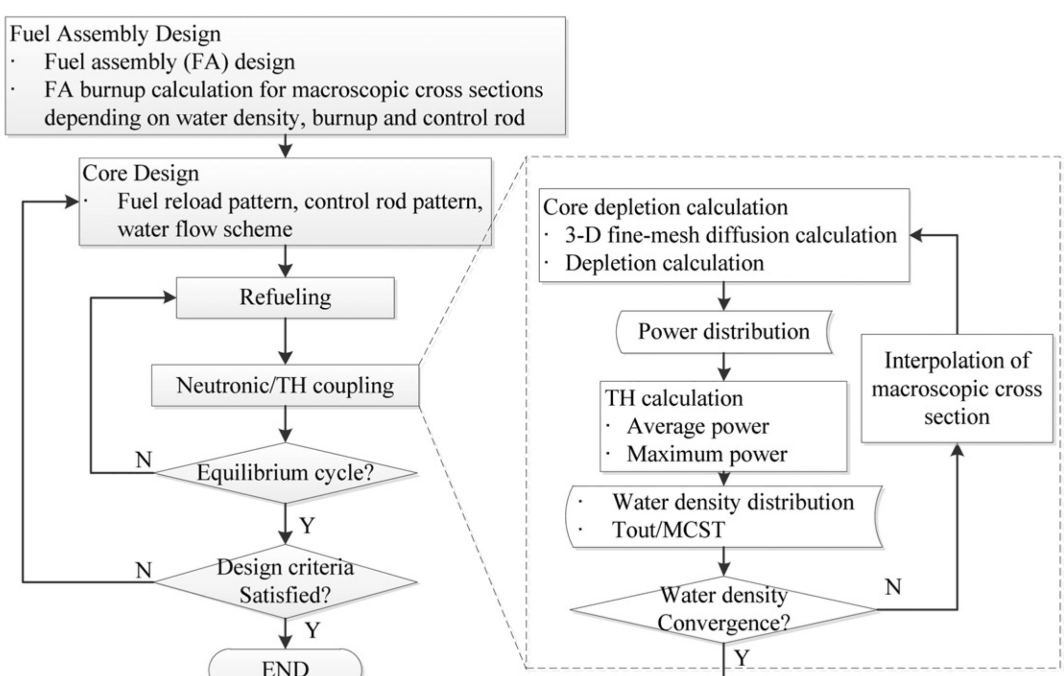

Fig. 2. Equilibrium core design method.