

# 基于 RMC/Fluent 的高参数堆组件核-热-燃耗耦合特性分析

## 摘要

高保真、高分辨率模拟让堆芯挖掘裕量成为可能。高功率密度压水堆在传统压水堆基础上提高堆芯功率密度，堆芯内可能出现泡状流甚至弹状流。功率分布、热工参数分布的不均匀性增加，给堆芯寿命设计带来挑战。本文基于 RMC、Fluent 开发了一套核-热-燃耗耦合工具，对功率映射方法进行改进，最终用于不同功率水平下组件的多场耦合特性分析。结果表明本文提出的功率映射算法能兼容板、帮的计算需求，具有较好的网格兼容性和几何兼容性。核-热-燃耗耦合程序通过单棒的验证，得到  $^{235}\text{U}$ 、 $^{241}\text{Pu}$  的相对偏差小于 1%。Fluent 两相流模型也通过 Martin 实验的验证。从不同功率水平组件的耦合结果来看， $k_{\text{eff}}$ 、功率峰因子、 $^{235}\text{U}$  等重要核素浓度、燃料温度、冷却剂温度等参数变化趋势一致，但两相流的引入导致功率峰因子显著增大、寿期燃料最高温度变化幅度增大，同时会导致计算时间增加约 1.7 倍。

## 关键词

蒙卡；CFD；高参数堆；核-热-燃耗耦合

## Abstract

High-fidelity, high-resolution simulation enables nuclear reactor margin exploration. High-Power-Density Pressurized Water Reactors (PWRs) increase power density compared to conventional PWRs, potentially leading to bubbly or even slug flow in the core. The increased non-uniformity of power and thermal-hydraulic parameter distributions poses challenges to core lifetime design. In this paper, a neutronics-thermal-hydraulic-burnup coupling tool is developed based on RMC and Fluent, with an improved power mapping method, and is subsequently applied to the multi-field coupling analysis of fuel assemblies under various power levels. Results show that the proposed power mapping algorithm can accommodate both rod-type and plate-type computational requirements, exhibiting good mesh and geometric compatibility. The coupled neutronics/thermal-hydraulic/burnup code is validated against a single-pin cell, yielding relative deviations for  $^{235}\text{U}$  and  $^{241}\text{Pu}$  density of less than 1%. The Fluent two-phase flow model is also validated against the Martin experiment. From the coupling results for assemblies at different power levels, the trends of key parameters such as  $k_{\text{eff}}$ , power peaking factor, concentrations of important nuclides (e.g.,  $^{235}\text{U}$ ), fuel temperature, and coolant temperature are consistent. However, the introduction of two-phase flow leads to a significant increase in the power peaking factor and a larger variation in the maximum fuel temperature over the fuel lifetime, while also increasing the computational time by approximately 1.7 times.

## Keywords

Monte Carlo; CFD; High power density PWR; neutronics/thermal-hydraulics/burnup coupling

**Author:** 颖, 何 (清华大学)

**Co-authors:** Mr 国栋, 刘 (清华大学); Mr 星宇, 赵 (清华大学); Mr 海升, 陈 (清华大学); Mr 郡任, 侯 (清华大学); Ms 美铭, 邱 (清华大学); Mr 善仿, 黄 (清华大学)

**Presenter:** 颖, 何 (清华大学)

**Session Classification:** 核能科学与工程

**Track Classification:** 口头报告: 核能科学与工程