

Abstract

High-Temperature Gas-Cooled Reactors (HTGRs) are promising for multiple applications, including power generation, water desalination, the chemical industry, or hydrogen production. Existing safety standards in the nuclear industry require that reactor safety be maintained under all conditions.

In high-temperature reactors, the temperature of the fuel, in the form of TRI-structural ISO-tropic (TRISO) capsules is an important issue, as overheating them can risk the release of radioactive fission products from the fuel. On the other hand, these reactors have inherent safety features due to the negative temperature coefficient. This coefficient consists of phenomena that cause power to decrease with fuel temperature growth, such as the temperature Doppler effect and hardening of the neutron energy spectrum. To consider these phenomena, it is necessary to carry out coupled thermal-fluid and neutronic calculations.

A significant challenge in modeling high-temperature reactors is their complex structure, which consists of fuel elements with TRISO particles. While accounting for this dual heterogeneity is not a challenge in neutronic calculations, it is very difficult in thermal-fluid calculations, even using Computational Fluid Dynamics (CFD) calculations. It should also be noted that the aforementioned CFDs, due to their high requirements, are not suitable for modeling the entire reactor, but can be effectively used for more accurate calculations of a smaller component, such as a fuel rod.

This thesis presents the characteristics of high-temperature gas-cooled reactors, their history, and the phenomena affecting the temperature coefficient. An example of integrated calculations, which was the PUMA project using MCB and POKE software, is also presented. To demonstrate the relevance of the relationship between power distribution and temperature distribution, simulations of reactor operations with an innovative control rod structure were carried out. The result was a significant equalization of power distribution and a reduction of temperatures in the core. The purpose of this work was to demonstrate that accurate CFD calculations can support integrated thermal-fluid and neutronic calculations by more accurately representing the smaller reactor component.

A single fuel rod model in OpenFOAM was run for the previously presented calculations in MCB and POKE to more accurately represent the local temperature distribution. Temperatures lower than in POKE were obtained, nevertheless with a simplification of the homogeneous heat distribution. To

verify this simplification, the Serpent program was used, providing the ability to perform integrated calculations with OpenFOAM using the multi-physics interface and the ability to work on a random TRISO distribution. These calculations resulted in temperatures higher by only about 10 K, which can be regarded as a margin of error during normal reactor operation. However, the studies should be continued in order to determine the meaning of other factors connected with the properties of the mesh or TRISO particles and to allocate the methodology to a full core model.