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Mechanism analysis of the contribution of nuclear data to the k_{eff} uncertainty in the pebble bed HTR

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ABSTRACT

As one part of IAEA CRP on HTGR UAM, mechanism analysis of the contributions of nuclear data on the k_{eff} uncertainty for the pebble bed HTR core has been studied through a "step-by-step comparison scheme" and HTR-10 is chosen as the representative core model. Within this scheme, three main types of HTR-10 core states including initial critical configuration, initial core and equilibrium core, have been established by using the continuous energy module named Tsunami-3D-K6 in SCALE6.2.1 to quantify the uncertainty of k_{eff} propagated from nuclear data. Then, the mechanism of the k_{eff} uncertainty difference deriving from the core models, temperature distributions, material compositions and different covariance libraries are analyzed in-depth. Meanwhile, some valuable observations have been made through the mechanism analysis and also the most significant contributors to the total k_{eff} uncertainty have been figured out for HTR-10.

1. Introduction

There has been an increasing demand for the uncertainty analysis for the numerical result from complicated High Temperature Gas Cooled Reactors (HTGRs) system with the continued development of HTGR, because the uncertainty inevitably exists in input parameters and computing models. For example, "best estimation plus uncertainty analysis" currently becomes more popular than safety analysis with conservative assumption because it can provide more information. One Coordinated Research Project (CRP) on the HTGR Uncertainty Analysis in Modelling (UAM) is undergoing supported by IAEA (Reitsma et al., 2012), based on the experience from OECD/NEA LWR UAM (Ivanov et al., 2013), by taking into account of the peculiarities of HTGR designs and simulation requirements. The principal idea is to subdivide the coupled HTGR system calculation into several steps, each of which can contribute to the total uncertainty and to identify input, output, and assumptions for each step. The resulting uncertainty in each step will be calculated by taking into account all main sources of uncertainties including propagating the related uncertainties from previous steps (Bostelmann et al., 2016). There are four different phases with well-defined stand-alone and coupled HTGR modelling and analysis with benchmark cases for both prismatic and pebble bed designs: Phase I (local standalone modelling), Phase II (global standalone modelling), Phase III (design calculations), and Phase IV (safety calculations), the detailed description of which can be found in (Reitsma et al., 2012).

Some in-depth studies has been done for quantifying the contribution of cross-section uncertainties to the eigenvalue uncertainty for representative but simplified pebble bed and prismatic reactor cell calculations as part of the "local neutronics" effect (Reitsma et al., 2016; Bostelmann et al., 2016). As a further study, the work in this paper focuses on the global standalone neutronics calculations for pebble bed HTR. It specially focuses on the contribution of cross section to the eigenvalue in representative pebble bed core calculations and in-depth mechanism analysis has been conducted by quantifying the cross section uncertainty for different pebble bed core models, material compositions, temperature distribution and core sizes.

The following sections describe some details of HTR-10 core and three main realistic core operational conditions, initial critical core, initial core and so-called equilibrium core, are established by using the Monte Carlo module TSUNAMI-3D-K6 in SCALE6.2.1 (Rearden and Jessee, 2016) for quantifying the contribution of nuclear data on the total uncertainty of HTR-10 core k_{eff}. Then, the mechanism analysis of the contributions of nuclear data to the k_{eff} uncertainty are carried out based on a designed "step-by-step comparison

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scheme". Finally, some important conclusion are drawn from the numerical results.

2. Pebble bed HTR model

The HTR-10, one of the representative pebble bed core designs defined for IAEA CRP on HTGR UAM, is selected as the research target in this study. The HTR-10 is a 10 MWt pebble bed reactor with helium cooled and graphite moderated, designed and built by the Institute of Nuclear and New Energy Technology at Tsinghua University in co-operation with Siemens staff that were previously engaged in the HTR-Modul project. A representation of the core design is given in Fig. 1.

The HTR-10 is a small reactor with a equivalent diameter and equivalent height of the cylindrical core of 180 cm and 221 cm respectively. The active core region is formed with a mixture of fuel balls and dummy balls for the initial critical configuration and initial core, and pure fuel pebbles of 6 cm in diameter for equilibrium core with a packing fraction of 61%. The fresh fuel pebble has a uranium loading of 5 g and enrichment of 17 wt%.

Each fuel pebble contains 8335 fuel particles and each fuel particle has a spherical UO_2 kernel surrounded by four carbon-based layers. The active core is encased by a bulky layer of graphite and carbon bricks without metallic components. And in the reflector region there are 20 coolant flow channels of 4 cm in diameter, 10 control rod channels of 6.5 cm in diameter, 3 irradiations channels with a diameter of 4.6 cm and 7 absorber pebble channels. With all the models studied in this paper, all control rods are withdrawn. More details of HTR-10 design and fuel specification can be found in the reference (Terry, et al., 2009). Some important material and geometry information used to develop the HTR-10 core model are summarized in Table 1. Except for the active core

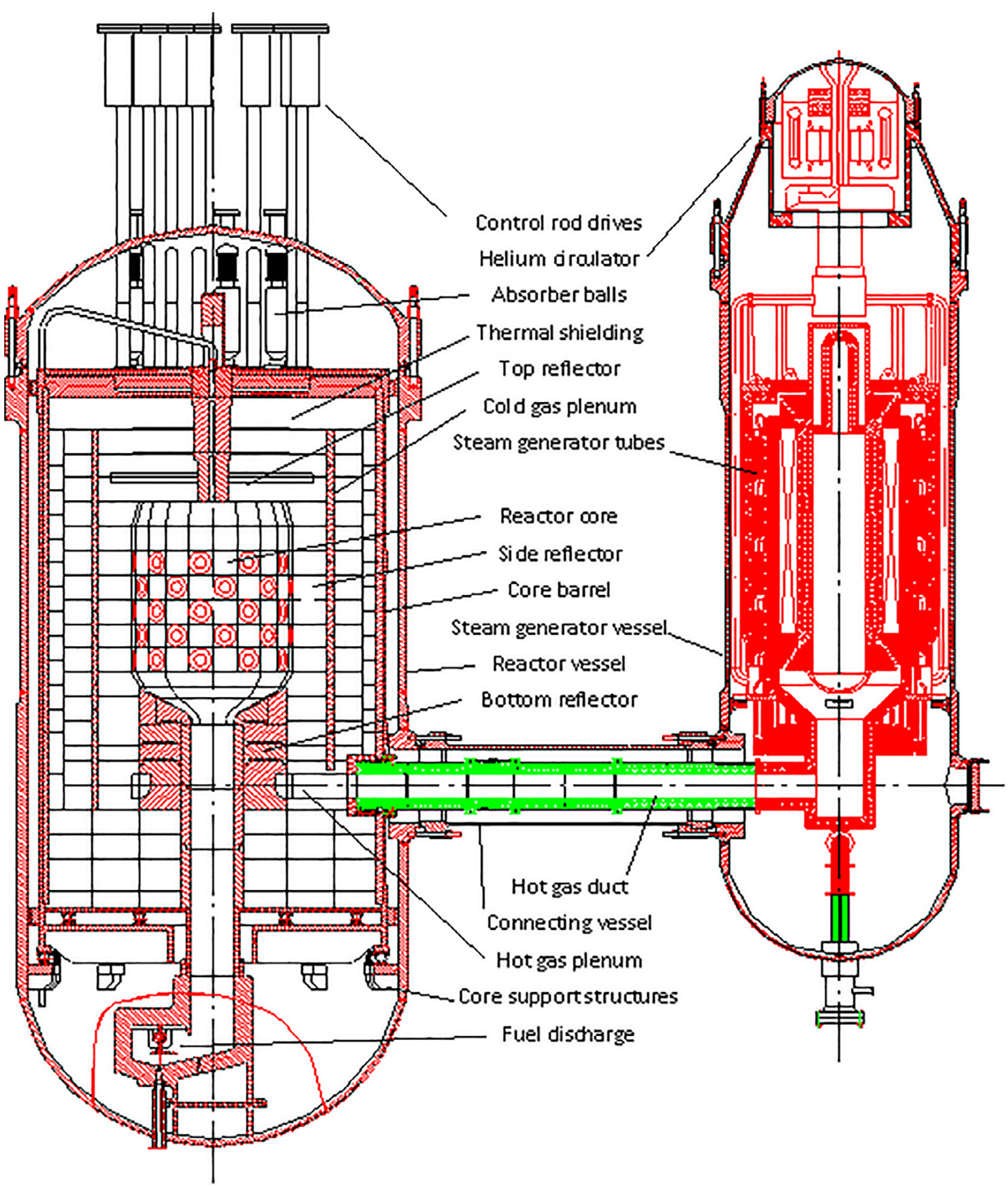

Fig. 1. Layout of the HTR-10 test core.