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Application of CNUREAS and MCNP5 codes to VVER-1000 MOX Core Computational Benchmark

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ABSTRACT

In order to strengthen the nuclear design calculation capacity in Turkey, CNUREAS (Cekmece Nuclear Reactor System) was developed to provide easy usage of neutronic and thermal hydraulic nuclear codes included in the CNUREAS package. It was tested and used for research reactors and PWR type power reactors. Modifications were performed to add hexagonal geometry support taking into account VVER type reactors employing hexagonal fuel assemblies that will be built in Turkey. "VVER-1000 MOX Core Computational Benchmark" was used to test new features of the CNUREAS. The maximum deviation in effective multiplication factor results of CNUREAS was 0.7% with deterministic codes and 1.5% with Monte Carlo codes. It was concluded that CNUREAS can be used for neutronic calculations of VVER type power reactors with appropriate cross section libraries and deterministic and Monte Carlo techniques give comparable results when both provided with appropriate cross section libraries.

1. Introduction

Strengthening calculation capabilities of countries embarking on nuclear power has a vital importance. Some of those calculations involve neutronic codes such as WIMS-ANL (Deen et al., 2000) and CITATION (Fowler et al., 1971) and thermo-hydraulics codes such as PARET (Woodruff and Smith, 2001), COBRA (Wheeler et al., 1976), TRANSV2 (Klein and Mishima, 1989), and RELAP5 (Siefken et al., 2001). Generally, a lot of effort is required for input preparation and data transfer from output of one code to input of other code. In order to make those codes available to users from most experienced to beginners, CNUREAS (Cekmece Nuclear Reactor System) (Erdogan, 2008) was developed. CNUREAS is a graphical user interface developed in Cekmece Nuclear Research and Training Center in order to create and control the input and output of the above mentioned nuclear codes. CNUREAS hides these underlying nuclear codes from the user by converting the user specified information into the format required by them therefore simplifying the overall operation. Furthermore, the amount of data requested is minimized since CNUREAS performs necessary intermediary calculations. Results are presented in computer graphics and color maps so as to provide the user with the means to process them fast and effectively.

Performing assembly and core neutronic benchmark problems is a good way to start building up calculation capacity and to validate CNUREAS code. CNUREAS has already been tested and used for calculations related with pool type TR-2 research reactor which is situated in Cekmece Research and Training Center and PWR type power reactors. In the near future, Turkey is going to have VVER type reactors that have hexagonal fuel assemblies. Therefore it is necessary to make adjustments in CNUREAS to model and run problems having hexagonal geometry. Several modifications were performed and benchmarks involving VVER type reactors were used to test and validate CNUREAS. One of those benchmark problems is "VVER-1000 MOX Core Computational Benchmark" (Gomin et al., 2005) which is established by NEA. The benchmark investigates the physics of a whole VVER-1000 reactor core using two-thirds low-enriched uranium (LEU) and one-third MOX fuel and it also contributes to the computer code certification process and calculation method verification process. A total of three solutions were submitted from two countries with each participant using different methods and nuclear data combinations. Two of the solutions are based on continuous energy Monte Carlo methods (MCNP4C (RSICC, 2000) and MCU (Kalugin et al., 2015)), while the other solution is based on collision probability (or similar) method (RADAR). Thilagam et al. (2009) performed same calculations with different codes and Thilagam et al. (2010) used benchmark results

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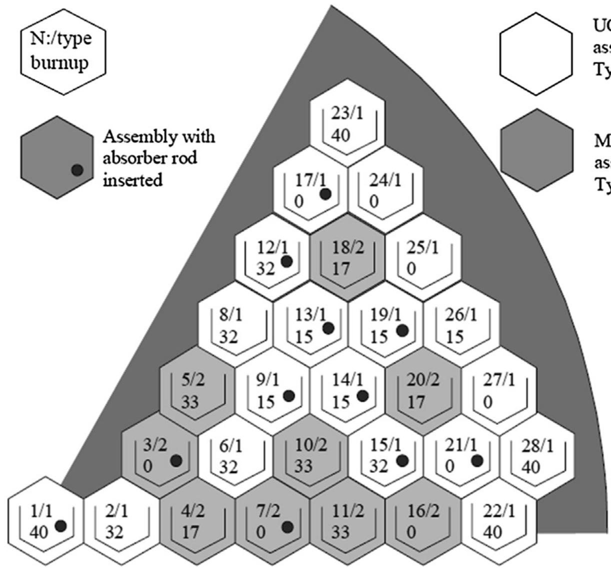

Fig. 1. Pattern of the VVER-1000 core with 30% MOX fuel loading.

to perform inter comparison of evaluated data.

In this study, CNUREAS and MCNP5 (X-5, 2003) codes were employed to analyze VVER-1000 MOX core Computational Benchmark. The results are compared with benchmark results not only to make sure that CNUREAS passes the data from user to codes correctly so as to generate geometry and outputs but also to check the integrity of exchange of data form one code to another. In addition, deterministic and probabilistic approaches were compared.

2. VVER-1000 MOX Core Computational Benchmark

The benchmark model consists of a full-size 2-D VVER-1000 core with heterogeneous 30% MOX-fuel loading. The system basically consists of fuel assemblies and a reflector. Twenty-eight assemblies in 60° rotation symmetry angles are considered as seen in Fig. 1. The system has an infinite axial dimension and vacuum condition on the side surface. The core consists of fresh and burned fuel assemblies (FA) of graded UOX FA with U–Gd burnable absorber (BA) rods as seen in Fig. 2 and graded, profiled MOX FA with U–Gd BA rods as seen in Fig. 3. Fuel materials have isotopic composition according to assembly burn-up. A reflector consists of the following elements ordered from center to periphery: water gap, steel buffer with water holes, steel barrel, downcomer (water) and steel vessel as seen in Fig. 4. Six different state calculations were performed. The reactor state is described by material temperatures and the presence of absorber rods in the core. These states are described in Table 1. For each state k_{eff} (effective multiplication factor), assembly average fission reaction rate distribution for the 28 assemblies in the core, and cell average fission reaction rate distribution within several assemblies (3, 21, and 27, see Fig. 1) for 331 cells per each of the three assemblies for state 1 are requested from participants. The other detail of the core geometry and isotopic compositions of the fuel materials, fuel cladding, central and guide tubes, absorber cladding, absorber rod, steel buffer, steel barrel, and steel vessel are presented in Gomin et al. (2005).

3. Results and discussion

The VVER-1000 MOX core shown in Figs. 2–4 was modeled with MCNP5 and CNUREAS and calculations were performed for 6 different states presented in Table 1. The full core was modeled with MCNP5 without any geometrical assumptions. CNUREAS modeling required a little bit of more effort since WIMS does not support hexagonal cell model. Therefore, FA cylindrical models having equivalent areas as hexagonal assemblies were generated as seen in Figs. 5 and 6. These FA were then used to generate core model for calculations as seen in Fig. 7. In order to see the performance of WIMS with cylindrical assemblies, Assembly 25 in Fig. 1 was selected and criticality calculations were performed with MCNP5 and WIMS. In MCNP5 model, reflected boundary condition was applied to make the results comparable. Results showed that k_{inf} calculated by WIMS is about 3% higher compared to the results of MCNP5.

MCNP5 was used with 5000 active neutron production cycles with 20000 neutrons per cycle resulting total of 100×10^6 neutrons

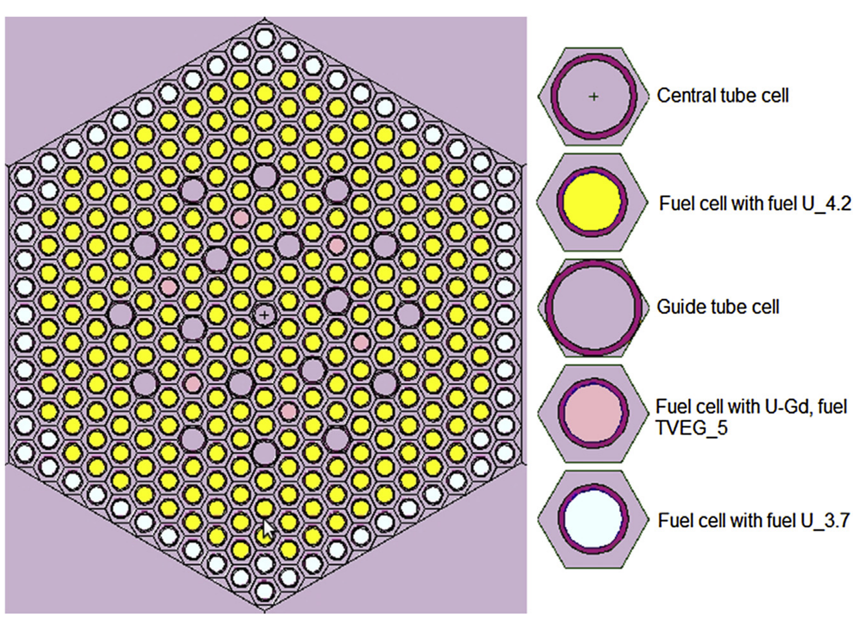

Fig. 2. Pattern of graded UOX fuel assembly (MCNP5 model).