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# Analysis of VENUS-2 benchmark using Serpent 2 code

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ABSTRACT

In the paper the development and validation of a 3-D computational model of VENUS-2 benchmark using Serpent 2 code is presented. This paper provides the comparative analyses of calculated results obtained with Serpent and MCNP against experimental results (measured data). Overall the Serpent results are in almost perfect agreement with MCNP results and in good agreement with experimental results. An average deviation of pin power distribution from the experiment in the case of 3.3 wt% $UO_2$ fuel is 1.5%, 2.1% for 4.0 wt% $UO_2$ fuel and 2.8% in the MOX fuel.



## 1. Introduction

In spite of increased capacity of modern computers it is still a common practice in the determination of nuclear reactor criticality and power distributions to introduce three or two stages of homogenization. Even with the introduction of Monte Carlo (MC) method two stages of homogenization are commonly used and tested by several authors. The idea of using Monte Carlo (MC) method for homogenization is relatively new. The use of MC codes for homogenization is increasing, especially in the field of research area. For example the OpenMC (Romano et al., 2015) and the Serpent (Leppänen et al., 2015) neutron transport codes feature capability of producing homogenized cross sections for diffusion codes. Here at Jožef Stefan Institute (JSI) the Serpent code is used. One of the main focus of Serpent development is the generation of homogenized few group constants for full core simulators. Among Serpent user community satisfactory results have been obtained in their particular areas of application. For homogenization over fuel assemblies and coupling with the reactor dynamics code DYN3D several results have been published for PWR reactors (Fridman and Leppänen, 2011; Fridman and Leppänen, 2012; Fridman et al., 2013). Moreover the Serpent-PARCS coupling has been performed for the Swiss Reactors (Hursin et al., 2013) and at the VTT the sequence with the ARES code was developed (Leppänen and Mattila, 2016). Homogenization using MC method is usually carried out at the fuel assembly level, however in our case the coupling between Serpent and GNOMER is performed on the unit cell level. GNOMER (Trkov, 1994) solves the neutron diffusion equation in three dimensional Cartesian geometry by Green's function nodal method.

Considering the full core calculations, the neutronic characteristics in reflector region are different as it is for unit cell. In the case of the reflector the partial currents along the boundary (fuel-reflector) change significantly, thus the neutronics properties between the core and reflector regions requires a special treatment of the reflector. This is a challenging task due to geometry complexity, material and structural heterogeneity of radial and axial reflectors. The correct modeling of the reflector is important for accurate predictions of power core distribution especially in regions close to the reflector. At the Jožef Stefan Institute (JSI) the WIMSD-GNOMER sequence is used for core design calculations of pressurized water reactors. WIMSD (Askew et al., 1966) is a deterministic lattice code for cell calculations and GNOMER is the neutron diffusion code developed at the Jožef Stefan Institute used for fuel assembly and core calculations. This sequence has been used since the 90's and provides accurate and fast calculations (Kromar and Trkov, 2009). Full core simulation starts with the lattice cell calculation with homogenized group constants produced using deterministic code WIMSD. Group constants are then used as an input for fuel assembly calculation using nodal diffusion

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method, GNOMER code, and finally full core calculations is preformed solving two group diffusion equation using the GNOMER code.

Recently the WIMSD code was replaced by the Serpent 2 code. In this calculational scheme (Serpent-GNOMER) the homogenization in unit and reflector cells are generated with effective diffusion homogenization (EDH) (Ćalić et al., 2016) method using simple 1-D geometry. 1-D reflector model is still the legacy of previously used WIMSD code since we are unable to model the reflector region in 2-D geometry. Geometry modeling has no restrictions with the Serpent code, therefore this paper is the foundation to develop future 2-D model based on VENUS-2 benchmark. VENUS-2 MOX core benchmark exercise provides excellent case study for validation studies of its calculational methods and to identify possible improvements of modeling methods.

With the Monte Carlo codes we are also capable of modeling the 3D heterogeneous problem, which represents the best available reference solution. This paper will serve as first publication validating Serpent-GNOMER code sequence using 2D reflector model, including comparison to calculational results and experimental

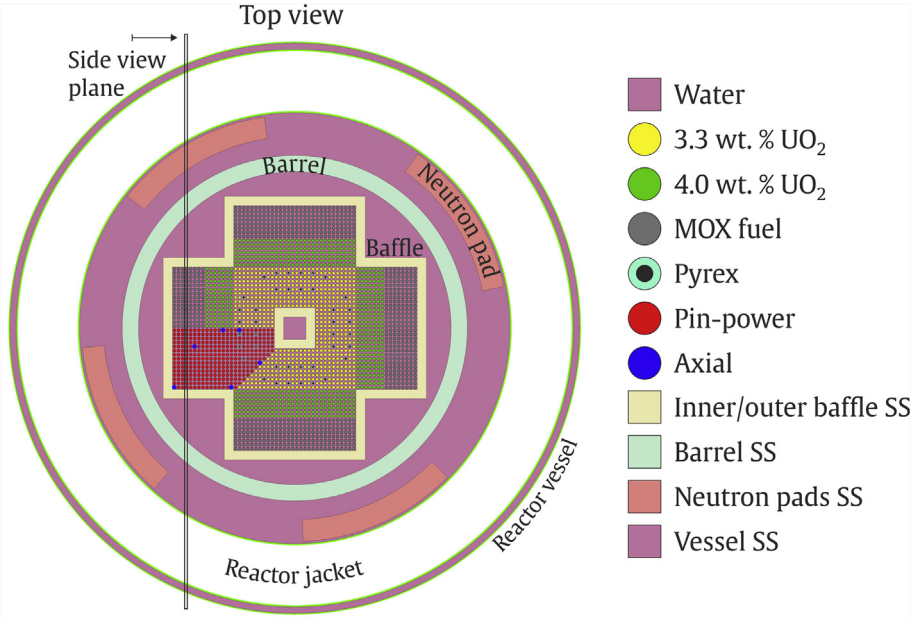


**Fig. 1.** Radial view (xy view) of the VENUS-2 benchmark model in the Serpent 2 code.

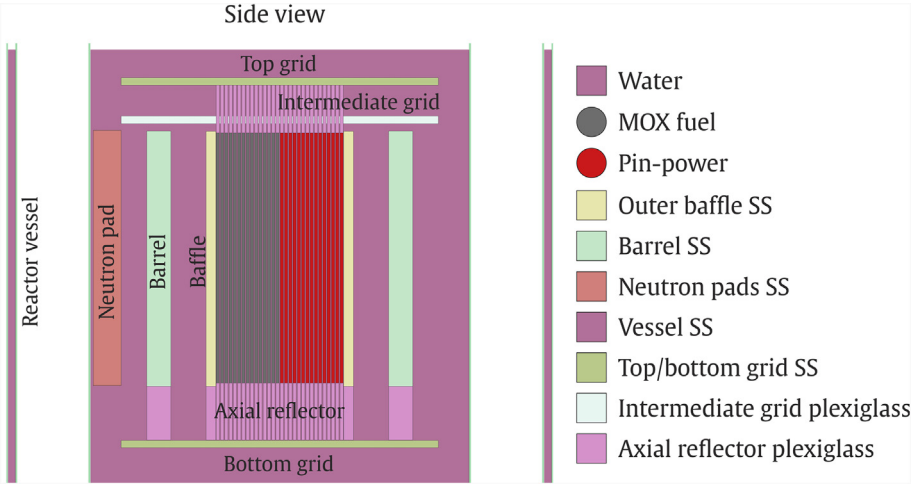


**Fig. 2.** Axial view (xz view) of the VENUS-2 benchmark model in the Serpent 2 code.

**Table 1**
Multiplication factor ($k_{inf}$) and $\Delta k$ with relative statistical error values of cell calculations using Serpent (S), MCNP (M) and benchmark GRS (G) results.

| Fuel type | Multiplication factor $k_{inf}$ | | | $\Delta k_{inf}$ | |
|---|---|---|---|---|---|
| | S | M | G | S-M | S-G |
| 3.3 $UO_2$ | 1.41180 ± 0.00008 | 1.41186 ± 0.00009 | 1.40690 | −0.00006 | 0.00490 |
| 4.0 $UO_2$ | 1.34272 ± 0.00009 | 1.34269 ± 0.00009 | 1.33798 | 0.00003 | 0.00474 |
| MOX | 1.26381 ± 0.00011 | 1.26382 ± 0.00010 | 1.25859 | −0.00001 | 0.00522 |