FEATURES OF THE RADIAL REFLECTOR SIMULATION FOR GENERATION OF TWO-GROUP XS's FOR THE VVER REACTOR CORE IN SERPENT MONTE CARLO CODE

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ABSTRACT

Few group constants for fuel assemblies (FA) and radial reflector of VVER nuclear reactor have been calculated by continuous-energy Monte Carlo (MC) reactor physics burnup calculation code Serpent. The constants are to be used in reactor dynamics code DYN3D.
Both detailed and homogenized models of the reflector are developed for calculations. Five types of the radial reflector cells can be considered taking into account design features of the baffle of VVER reactor.
Two-group cross sections have been calculated for the three-layer reflector of DYN3D full core model for both detailed and homogenized reflector models. The assembly and reflector discontinuity factors (so-called ADF and RDF factors) were also under consideration. The RDF factors were additionally corrected to account for the influence of nearby FAs. XS library generated has been tested using typical first loading of VVER-1000 core based on four different FA types.
Verification of the two-group XS's for reflector was been carried out by comparing the results of the full core calculations in DYN3D and Serpent codes. The results obtained by using the last code were considered as reference. Fast-to-thermal transfer cross-sections were adjusted taking into account the heating of the thermal neutrons to account for two-group version character of DYN3D. The resulting XS libraries have been used in DYN3D for calculating the criticality and normalized power distribution in the reactor core during operation at zero power.
The results of the DYN3D calculations with the Serpent cross section sets agree very well with those of the Serpent full core MC calculations. The difference in k_{eff} is 175,8 pcm and -10,7 pcm for homogenized and detailed models of the reflector, respectively.

1. Introduction

Deterministic safety analysis is an essential tool for demonstrating the safety of nuclear power plants. The best estimate computer codes have been developed for the simulation of complex processes that occur in the core of modern nuclear reactors. At present, these are employed in the prediction of the safety margins of nuclear power plants during normal and off-normal operating conditions.

The DYN3D is three-dimensional dynamic code used to calculate the dynamics processes in the nuclear core with quadratic or hexagonal fuel assembly geometry [1]. It is successfully applied to conservative estimations and best estimate calculations in safety analyses. The computer code DYN3D can be coupled with the thermohydraulic code (eg ATHLET [2]) to apply to the whole spectrum of operational and transient accidents, small and intermediate leaks, up to large breaks of coolant loops at PWRs/VVERs and BWRs.

The neutron kinetic model is based on the solution of the three-dimensional two-group neutron diffusion equation by nodal expansion methods. To use the DYN3D for NPP safety analysis it is necessary to generate the constants library for each fuel loading of the NPP reactor.

SERPENT Monte Carlo reactor physics code [3] can be used as tools for generation of two-group constants library for DYN3D code. For generation of constants library using the Monte Carlo code SERPENT it is necessary to carry out a very large number of simulations. To obtain reliable results in a reasonable time, it can use a supercomputer and parallel computing.

The details related to the modeling of the radial reflector for the VVER reactor core in SERPENT (version 2.1.26) Monte Carlo code are discussed below. Due to design features of the baffle of VVER reactor five types of the radial reflector model can be considered.

The XS library of the reflector in the full core model contains values of the following characteristics, which are calculated in the two-group approximation:

- transport cross section ($\Sigma_{tr1,2}$);
- absorption cross section ($\Sigma_{abs1,2}$);
- group-transfer cross section (Σ_{S12}).
- reflector discontinuity factor (RDF)

For correct work of the DYN3D two-group version the fast-to-thermal transfer cross-sections (Σ_{s12}) were adjusted taking into account thermal-to-fast transfer (the heating of the thermal neutrons) (Σ_{s21}):

$$\Sigma'_{s12} = \Sigma_{s12} - \Sigma_{s21}\frac{\Phi_2}{\Phi_1}$$

Reflector discontinuity factors were calculated using additional correction which taking to account for the influence of nearby FAs (Kord S. Smith, PHYSOR 2016) [4]:

$$RDF = \frac{DF_{ref}}{Df_{fuel}} ADF$$

Testing of the reflector XS library has been performed using typical first loading of VVER core based on four different FA types [5]. The library has been prepared for radial reflector as well as for each of individual FAs using SERPENT. The two-group cross sections were calculated taking into account discontinuity factors at the "FA-FA", "FA-reflector" boundaries (so-called ADF and RDF factors, respectively).

2. Radial reflector model

To calculate the two-group XS the models for the five types of radial reflector were developed. These models consist of a reflector cells (r1.1 – r5.3) and fuel assemblies (FA). Radial reflector of VVER reactor core consists of baffle, barrel, coolant and the vessel. For XS calculation the modeling area is superimposed a grid of hexagonal cells, the size equal to the size of FA (23.6 cm step). Taking into account 60° symmetry of the core and features of baffle design of VVER, we have five types of radial reflector cells with different material composition (see. Fig 1) [5].

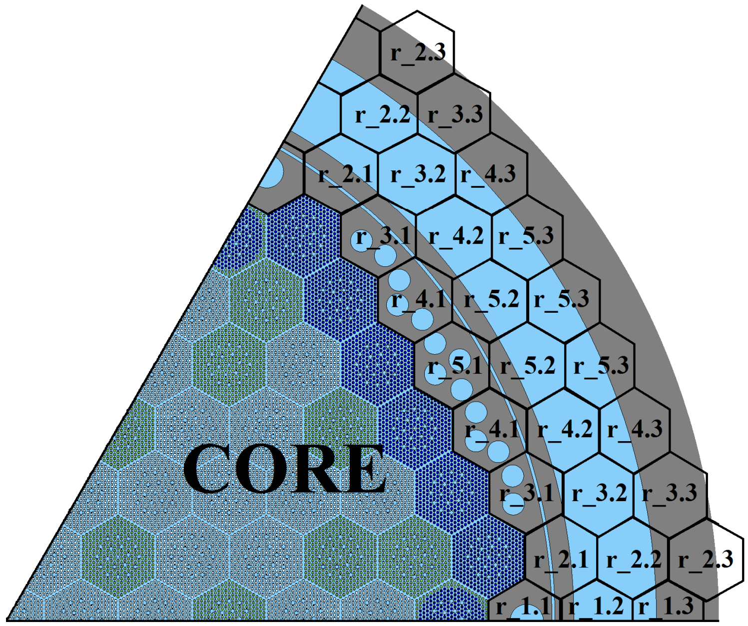

Fig 1. 60° sector of the core with the radial reflector of VVER reactor

The structure of the model of each type of radial reflector is determined by the features of the boundary conditions in the SERPENT. Model of each type of radial reflector under consideration consists of three layers of hexagonal nonfuel assemblies (see Fig 2).

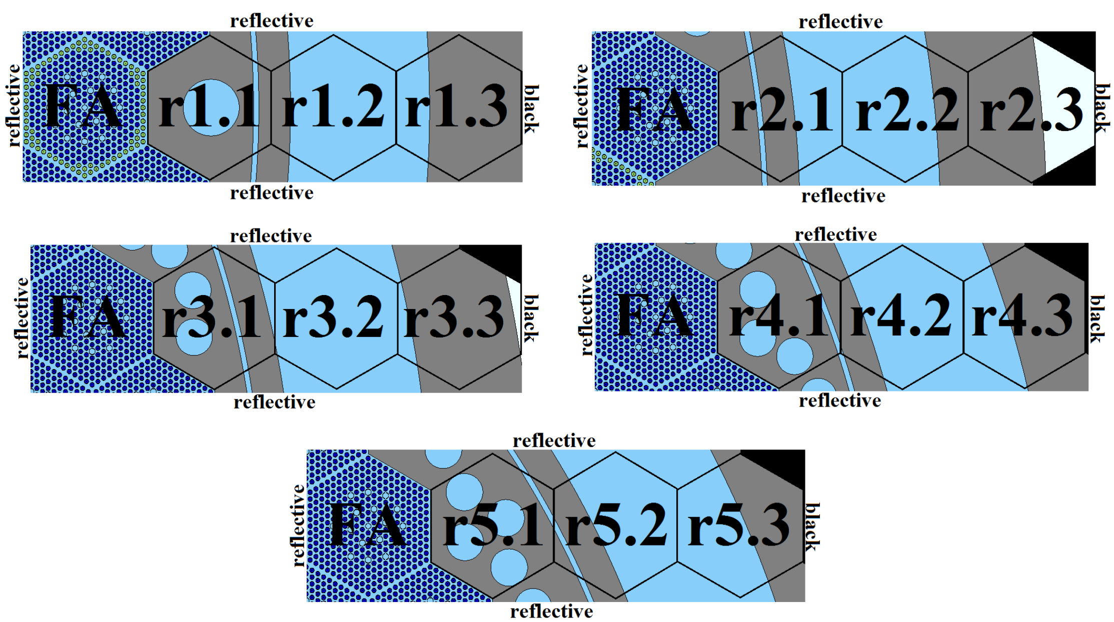

Fig 2. Models of radial reflector in Serpent code

Homogeneous and heterogeneous models of the reflector have been developed. In the heterogeneous model the cells are taken with considering full geometry of design features. In the homogeneous model the cells are filled with a mixture containing water and steel at the ratio similarly to the same heterogeneous cells. Volume ratio between materials compositions in the hexagonal cells for VVER-1000 reactor [4] are the following:

- r1.1: water - 21.89%, steel - 78.11%;
- r2.1: water - 43.05%, steel - 56.95%;
- r3.1: water - 25.14%, steel - 74.86%;
- r4.1: water - 27.76%, steel - 72.24%;
- r5.1: water - 34.23%, steel - 65.77%;
- r1.2: water - 88.91%, steel - 11.09%;
- r2.2: water – 75.53%, steel - 24.47%;
- r3.2: water - 99.96%, steel - 0.04%;
- r4.2: water - 83.75%, steel - 16.25%;
- r5.2: water - 71.70%, steel - 28.30%;
- r1.3: water - 21.75%, steel - 78.25%;
- r2.3: water – 0.0%, steel - 58.06%, air - 41.94%;
- r3.3: water - 6.65%, steel - 89.52%, air – 3.83%;
- r4.3: water - 34.53%, steel - 65.47%;
- r5.3: water - 54.66%, steel - 45.34%.

3. XS ganaration for the radial reflector

Verification of the two-group XS's for reflector was carried out by comparing the results of the full core calculations in DYN3D and SERPENT codes. The SERPENT model of the core considered as reference includes all full core and radial reflector (see Fig 3) an analogous model with a three-layered reflector was developed in DYN3D.

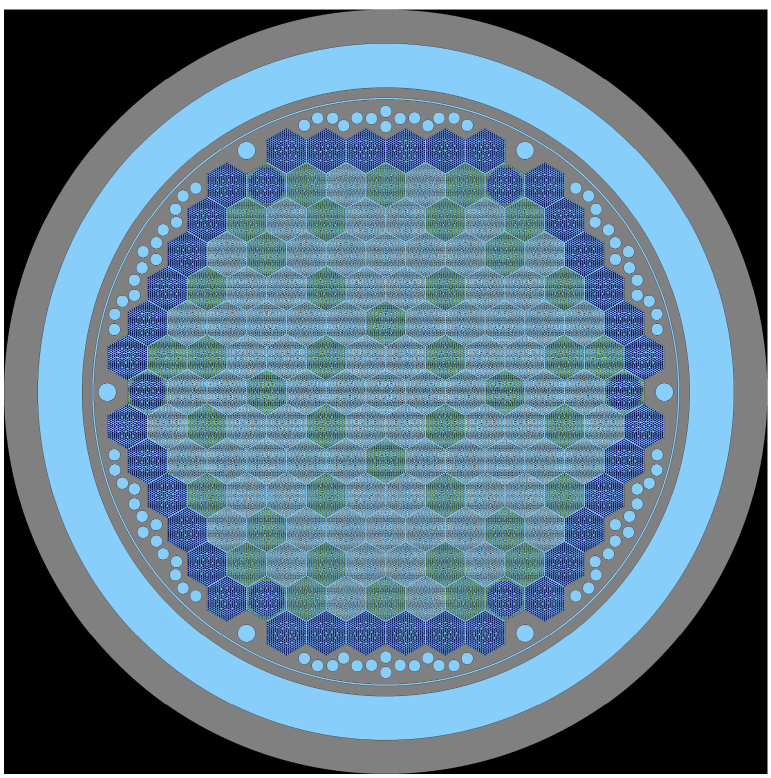

Fig 3. Full core model of the core in Serpent code

Parameter which was taken as a reference points are shown in Tab 1. Criticality and normalized power distribution was calculated in Serpent for each of this points.

Tab 1: Value of parameter in reference point

T_f, K	T_m, K	ρ_m, g/cm^3	P, MPa	C_b, g/kgH_2O
600	553	0.764759	15.83	0
600	575	0.723001	15.83	0
600	600	0.662183	15.83	0

Parameter in reference point has been used in Serpent for XS generation for FAs and radial reflectors.

4. Verification calculations

The resulting XS libraries have been used in DYN3D for calculating the criticality and normalized power distribution in the reactor core during operation at hot zero power for different moderator temperature (see Tab 1). Differences (Δ) between the values in calculating criticality in the model of "core+radial reflector" for heterogeneous and homogeneous model for Tm= 553 K in Tab 2.

Tab 2: Keff comparison

Model	Serpent	DYN3D	Δ, pcm
heterogeneous	1.168945	1.169052	-10.7
homogeneous	1.168945	1.167187	175.8

In Fig 4 are presented the value of normalized power distribution calculated using Serpent and DYN3D codes for 163 fuel assemblies that are part of the initial fuel loading of the VVER reactor core for Tm= 553. The first value is FA number, second – normalized power distribution calculated using Serpent, third – normalized power distribution calculated using DYN3D, forth – difference between Serpent and DYN3D values (Serpent - DYN3D). Value shown in Fig 4 was calculated using heterogeneous model of radial reflector.

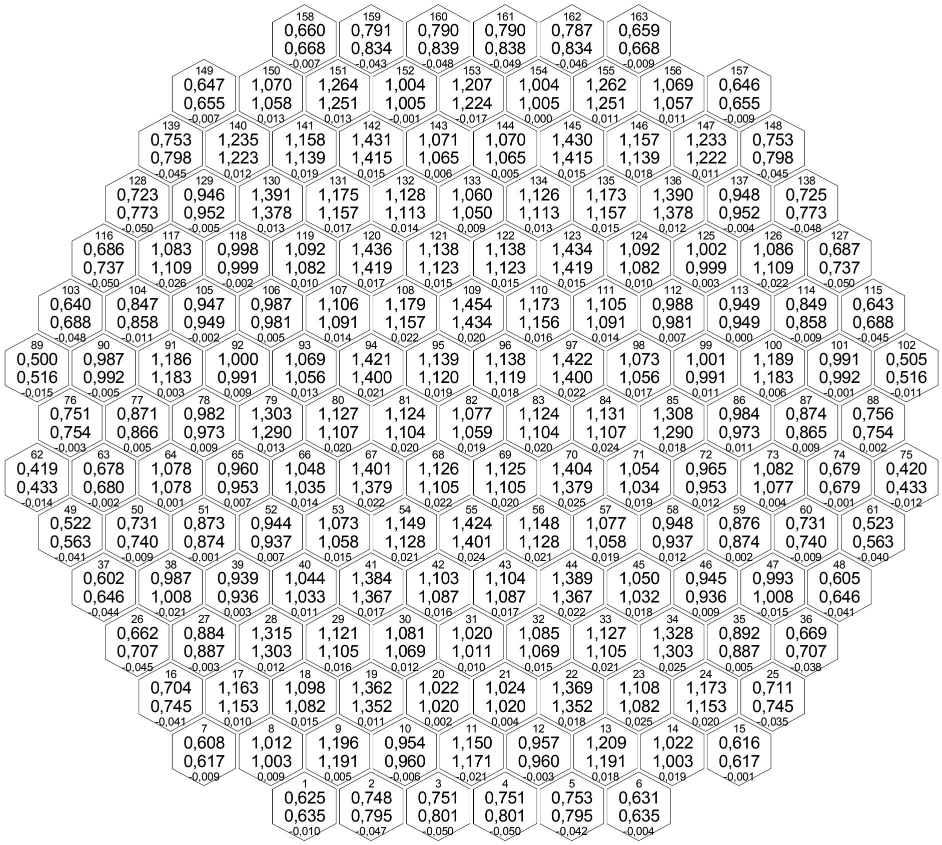

Fig 4. Normalized power distribution calculated using Serpent and DYN3D

Maximum difference between the values in calculating criticality in the model of "core+radial reflector" for heterogeneous model was 11 pcm, for homogeneous - 176 pcm for Tm= 553 K. In both cases the maximum difference in the calculation of normalized power distribution does not exceed 6% in the peripheral layer of FAs. Average value of normalized power distribution for heterogeneous model is less than 2%, for heterogeneous – less than 4%. But for the homogeneous model for Tm= 553 K maximum difference between the values in normalized power distribution in the center of the core are exceed 5%.

Conclusion

The SERPENT code gives value of the parameters needed for creating the DYN3D XS library of VVER radial reflectors with high accuracy.

Due to design features of the baffle of VVER reactor five types of the radial reflector model was described. Heterogeneous model gives good agreements between reference full core calculation in SERPENT and DYN3D using two-group XS's. The XS library generation method presented above can be used for developing the model of the radial reflector for Belarusian NPP with VVER-1200 reactor core.

References

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