Extension and Verification of the Cross-Section Library for the VVER-1000 Surveillance Specimen Region

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Abstract. The objective of this work is a generation of new version of the BGL multigroup cross-section to extend the region of its applicability. The existing library version is problem oriented for VVER-1000 type of reactors and was generated by collapsing of the VITAMIN-B6 problem independent cross-section fine-group library applying the VVER-1000 reactor middle plane spectrum in cylindrical geometry. The new version BGLex additionally contains cross-sections averaged on the corresponding spectra of the surveillance specimen's (SS) region for VVER-1000 type of reactors. Comparative analysis of the neutron spectra for different one-dimensional geometry models that could be applied for the cross-section collapsing using the software package SCALE, showed a high sensitivity of the results to the geometry model. That is why a neutron importance assessment was done for the SS region using the adjoint solution calculated by the two-dimensional code DORT and problem-independent library VITAMIN-B6. The one-dimensional geometry model applied to the cross-section collapsing were determined by the material limits above the reactor core in axial direction z as for every material a homogenization in radial direction was done. The material homogenization in radial direction was done by material weighing taking into account the adjoint solution as well as the neutron source. The one-dimensional geometry model comprising the homogenized weighed materials was applied for the cross-section generation of the fine-group library VITAMIN-B6 to the broad-group structure of BGL library. The new version BGLex was extended with cross-sections for the SS region. Verification and validation of the new version BGLex is forthcoming. It includes comparison between the calculated results with the new version BGLex and the libraries BGL and VITAMIN-B6 and comparison with experimental results.

1. INTRODUCTION

The broad group cross-section libraries BUGLE [1] and BGL [2] with the same energy group structure (47 neutron and 20 gamma groups) are applied for reactor shielding calculation using the DOORS package [3] based on discrete ordinates method and multigroup approximation for the neutron cross-sections. BUGLE and BGL libraries are problem oriented for PWR or VVER type of reactors respectively. They had been generated by collapsing the problem independent fine group library VITAMIN-B6 (199 neutron and 42 gamma groups) [1] applying PWR and VVER one-dimensional radial model of the reactor middle plane using the SCALE software package [4].

The application of these libraries is not substantiated enough for VVER-1000/320 at the axial distances from the reactor middle plane where one-dimensional model is not adequate. The surveillance specimens (SS) for this type of reactors are located on the baffle 30 cm above the reactor core upper edge in a region where geometry and materials properties differ from those at the middle plane and the neutron field gradient is very high. These conditions result in different neutron spectra. That is why the application of the fore-mentioned libraries for neutron fluence calculation in the SS region could lead to an additional inaccuracy.

In addition, it had been found that the discrepancy between measured and calculated foil monitors' activities at the SS region exceeded 30% [5,6]. This discrepancy could be due to the uncertainty of SS geometry position as well as to the application of inappropriate cross-section data for calculation at the SS region.

Comparison of the neutron spectra on the pressure vessel and at the SS position shows that the difference reaches 80% [7].

2. LIBRARY GENERATION APPROACH

We intended to generate the problem dependent broad group library for calculation at SA position by the same codes, methods and approaches as BGL library using the SCALE software package [4].

The BGL extension has to be done by collapsing the problem independent fine-group structure of 199 neutron and 42 gamma groups (241 groups) of VITAMIN-B6 library to broad group structure of 47 neutron and 20 gamma groups (67 groups) of BGL library using a one-dimensional geometry model appropriate for fine-group library collapsing. The BGL library contains upscattering data for the five thermal groups below 0.5 eV (43-47 groups). The order of scattering of the Legendre expansion is P_7 except for Mo, Nb, Sn, U, Pu and Zr where it is P_5. The library contains cross-sections for 140 nuclides, 22 chemical elements, comprising the materials of VVER-1000. One-dimensional model is used for taking into account self-shielding and for cross-sections collapsing with average neutron flux in each material zone of the reactor.

The BGL library is in ANISN card image format. It contains data for: σ_a - absorption cross-section, $\nu\sigma_f$ – number of neutrons produced per fission times fission cross section, σ_t – total cross-section, $\sigma_{g'\rightarrow g}$ (g'>g) – uppscattering cross-section, $\sigma_{g\rightarrow g}$ – within-group scattering cross-section, $\sigma_{g'\rightarrow g}$ (g'<g) – down-scattering cross-section.

3. GEOMETRY

There are six sets of surveillance assemblies (SS) in the VVER-1000/320 type of reactors. Each set is placed within 60°-sector of symmetry of the reactor core (RC) and contains five assemblies - SAL1 – SAL5, placed on the baffle (Fig. 1, 2). Each assembly contains fourteen containers with surveillance specimens and iron, niobium, and copper foil neutron detectors. The containers are arranged at two axial levels (seven containers at each level), symmetrically around the axial axis of the assembly [5].

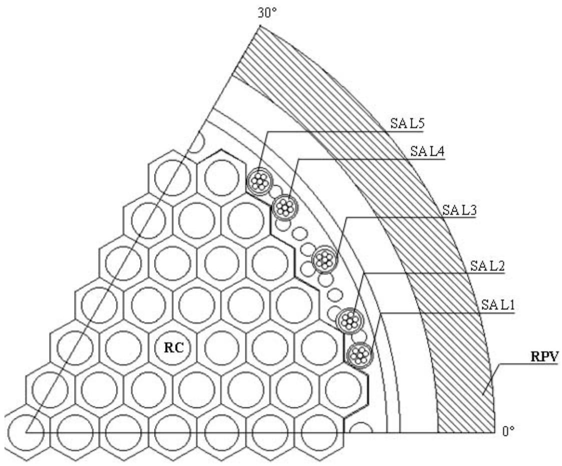

Fig. 1. Azimuth position of surveillance assemblies in 60°-sector of symmetry

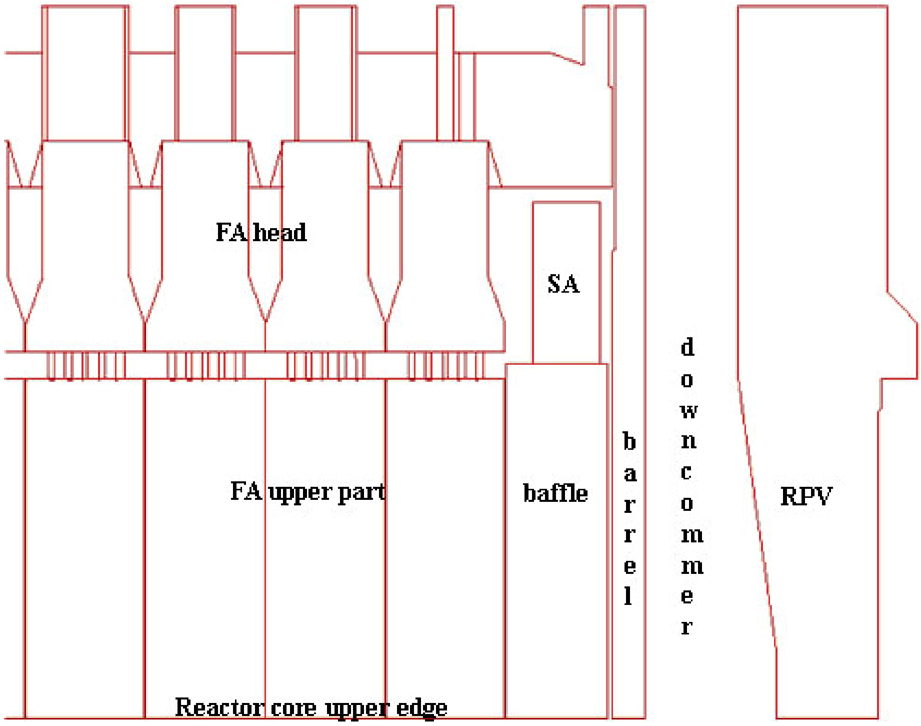

Fig. 2. Axial position of the surveillance assemblies

4. CALCULATIONS AND ANALYSIS

Comparative analysis of the neutron spectra for different one-dimensional geometry models that could be applied for the cross-section generation using the software package SCALE, showed a high sensitivity of the results to the geometry model. That is why a neutron importance assessment was done for the SS region using the adjoint solution [8] calculated by the two-dimensional code DORT and problem-independent library VITAMIN-B6 (Fig. 3).

The one-dimensional geometry model applied to the cross-section collapsing were determined by the material limits above the reactor core in axial direction z (Fig. 3) as for every material a homogenization in radial direction was done. The material homogenization in radial direction was done by material weighing Ψ (Fig. 4) taking into account the adjoint solution Φ* as well as the neutron source Q:

$$\Psi(r) = Q(r)\Phi^*(r) \tag{1}$$

The weighing function Ψ is normalized by volume:

$$2\pi \iint \Psi(r) r dr dz = 1 \tag{2}$$

The weighing function Ψ distribution in radial direction for different axial levels (Fig. 4) shows that the neutron importance getting higher as going closer to the SS region (above the baffle water channel). That is why for every axial level we homogenize materials in radial direction weighed by function Ψ:

$$m_{\text{hom}} = 2\pi \int_0^R \Psi(r) m(r) r dr \tag{3}$$

The one-dimensional geometry model comprising the homogenized weighed materials was applied for the cross-section generation of the fine-group library VITAMIN-B6 to the broad-group structure of BGL library. The new version BGLex was extended with cross-sections for the SS region.

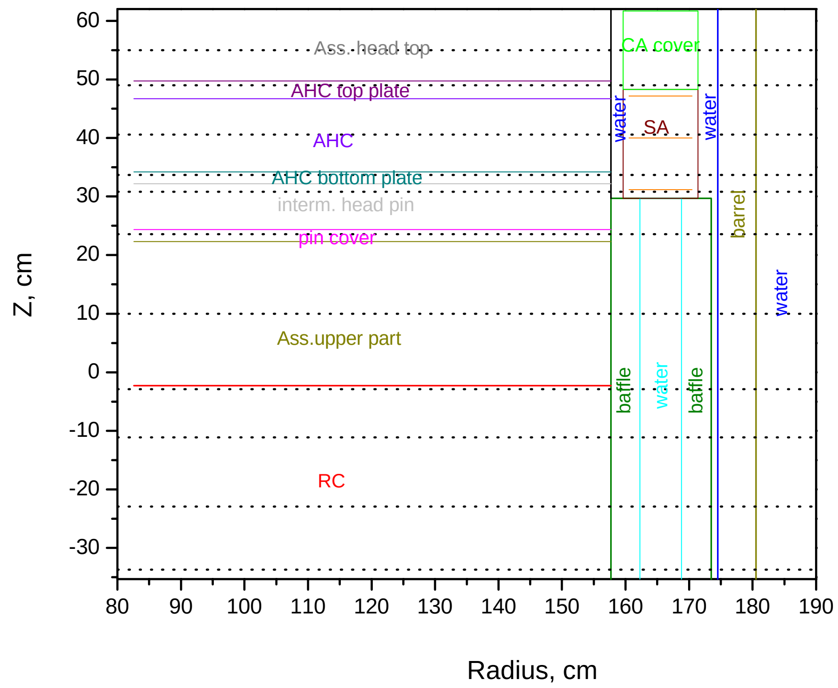

Fig. 3. Two-dimensional geometry model of the SS region and the axial levels of the material homogenization

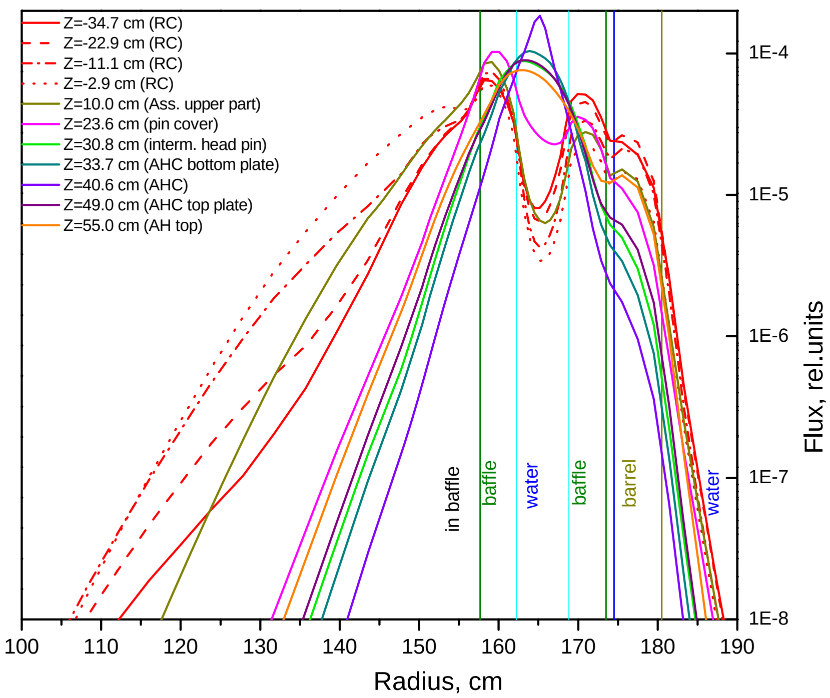

Fig. 4. Weighing function Ψ distribution in radial direction for every axial level z

5. CONCLUSION

The extension of BGL library evolves from to the fact that the surveillance specimen of VVER-1000/320 are located on the baffle above the reactor core upper edge in a region where geometry and materials differ from these ones of the middle plane and the neutron field gradient is very high which would determine a different neutron spectrum. That is why the application of the BGL library for the neutron fluence calculation in the SS region could lead to an additional inaccuracy. In addition the discrepancy between measured and calculated foil monitors' activities exceeded 30%. This discrepancy could be due to the uncertainty of SS geometry position as well as to the application of inappropriate cross-section library for calculation at the SS region.

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REFERENCES

[1] D.T.INGERSOLL et al., Production and Testing of the VITAMIN-B6 Fine-Group and the BUGLE-93 Broad Group Neutron/Photon Cross-Section Libraries Derived from ENDF/B-VI Nuclear Data, ORNL-6795 (Draft Febr. 1994)

[2] J. BUCHOLZ, S. ANTONOV, S. BELOUSOV, BGL440 and BGL1000 Broad Group Neutron/Photon Cross Section Libraries Derived from ENDF/B-VI Nuclear Data, IAEA, INDC(BUL)-15, (April 1996).

[3] DOORS3.2, RSICC ORNL, Code Package CCC-650 (1998).

[4] SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, ORNL/TM-2005/39, Version 5, Vols. I–III (April 2005).

[5] BELOUSOV, S., ILIEVA, K., POPOVA, I, "Calculation of Neutron Flux/ Responses at the Surveillances and Pressure Vessel of VVER-1000/320 Type of Reactor", Proc. of RP&S Topical Meeting, Nashville, (1998), USA, ANS, I 440-447

[6] ILIEVA, K., ANTONOV, S., BELOUSOV, S., "Calculation Modeling of Detector Activity in the VVER/ PWR Reactor Pressure Vessel Surveillance", Nuclear Science and Engineering 122 1 (1996), p. 131-135

[7] KIRILOVA D., BELOUSOV, S., ILIEVA, K., "Extension Of The BGL Broad Group Cross Section Library", Proc. of the 13th ISRD, Netherlands, 2008

[8] A. HAGHIGHAT, H. HANSHAW, J. WAGNER, "Radiation Protection And Shielding", Proc. of the 1996 topical meeting, No. Falmouth, Massachusetts, USA (1996) Vol.1, 173