Monte Carlo Calculation of the Spatial Weighting Function of Ex-Core Detectors for the WWER-440 Reactor Using MCNP-4C2 Code

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ABSTRACT

The aim of the work is to design and describe the methodology of determination of the spatial weighting function of ex-core detectors for the WWER-440 reactor type using Monte Carlo N-Particle Transport code MCNP-4C2, taking into account the different operational parameters such as power, burn-up, boric acid concentration and position of control assembly group No 6. The spatial weight function provides relationship between the spatial neutron flux density distribution or the fission density distribution in the reactor core and the detectors placed outside of the reactor core (ex-core detectors).

The spatial weight function will be used for interpretation of reloads startup rod drop measurements, assessment of the ex-core detectors response at deep subcritical reactor stage and for other applications.

1 INRODUCTION

The contribution of the fuel assemblies to the response of these detectors does not only depend on the power, but also on the position of the given assembly in the reactor core. The weight of the inner fuel assemblies is several orders of magnitude lower than that of the outer ones. Therefore, the signal of the ex-core detectors for a given reactor power is strongly influenced by the spatial power distribution and, indirectly, by the parameters which determine the distribution, such as load pattern, time elapsed in the cycle, etc.
2 PROBLEM SPECIFICATION

Spatial weighting function of ex-core detectors gives relationship between spatial neutron flux density distribution or fission density distribution in the reactor core and ionization chambers (ex-core detectors) placed outside of the core.

The weighting function is possible to define in various ways in dependence on solved problem. In this case the spatial (three-dimensional) weight function gives the average number of reactions occur in the ionization chamber for one neutron born with Watt fission spectra created in the twentieth of a fuel pin in a different reactor core position. The function will be calculated at a twentieth-of-pins level of fuel assemblies within acceptable statistical uncertainty and computing (CPU) time.

From definition of the weighting function follows that response of the ex-core detector (number of reactions occurred) is given by the weight function and the fission density distribution function (as two spatial functions) product and its integration over the reactor core or its part. Practically it is sufficient to integrate over the core region where the product of these two functions is negligible different from zero.

3 CALCULATION METHODOLOGY

Considering the complicated geometry of WWER-440 reactor core, space between the core and the ex-core detectors, transport Monte Carlo method as a technique allowing uncompromising treatment of three-dimensional geometry was chosen. The calculation will be performed by transport Monte Carlo code MCNP-4C2 run in forward mode which gives more accurate results contrary to adjoint mode of running. The application of the forward mode will make possible to eliminate the approximations which could result from the homogenization of the cross sections libraries of the fuel assembly material and from the using of group-wise nuclear data in case of the adjoint mode of calculation. Calculation by MCNP-4C2 transport code will be performed to determine the reaction rate in the ex-core detector caused by fission neutron produced in the twentieth of a fuel pin. All geometrical details and material compositions are modelled with high accuracy. It is assumed to obtain sufficiently low standard deviation within reasonable computation time by using some appropriate variance reduction method such as weight window. Investigation of influence of other operational parameters such as power, burn-up, boric acid concentration, position of control assembly group No 6 on the weight function will be taken into account. The fission density distribution will be determined in an independent calculation by BIPR-7 or MCNP-4C2 code.

4 GEOMETRIC AND MATERIAL MODEL

Geometric model consists of detail model of the WWER-440/V213 reactor core – fuel assemblies including fuel rods, spacer grids, Zr-Nb tubes, spacer capture rod, casing, assembly head and bottom, control assemblies; space between the core and ex-core detectors – core basket, barrel, reactor pressure vessel and its cladding; biological shielding, ionization chamber channels and ex-core detectors. With respect to planned replacement of the existing KNK-4 ex-core detector for new detector type in the near further, the spatial weight function will be reached for channel of the ex-core detector and than will be determined additional transfer function between ex-core detector channel and new known detector.

Considering the fact that investigated ex-core detectors are used for the startup reactivity measurements, furthermore that these three ex-core detectors are located symmetrically (120% symmetry), it is sufficient to model only one of the ex-core detectors and the core region in its vicinity. The geometrical model extends to the region from which
the contribution to the ex-core detector response is not negligible. Considering the symmetry conditions it is not necessary to calculate contributions from both part of the symmetry plane. The model of the reactor core is divided into two regions – source region created by fuel assemblies from which neutrons are started and scattering region created by fuel assemblies from which neutrons are not started, but they are present in the core model due to their neutron scattering effect. The model of the reactor core for calculation of the weight function is shown in Figure 1.

![Model of the reactor core](image)

Figure 1: Model of the reactor core for calculation of the weight function.

Regarding material model the fuel assemblies have radially-zoned enrichment distribution; at present, individual fresh enrichments are 3.3%, 3.6% and 4.0%, average enrichment of the fuel assembly is 3.82%. The fuel pellets are charged in Zr-Nb1% tubes. Compositions of all used materials will be modelled to the highest accuracy. There will be investigated influence of two burn-up levels and two boric acid concentration levels – zero and the highest on the weight values. The isotopic composition of the fuel for given burn-up level will be calculated by ORIGEN code. Considering that neutrons which became thermal in the concrete of the biological shielding have a significant contribution to the ex-core detector signal, the element composition of the concrete will have significant influence on the calculated weight value accuracy. Because accurate element analysis of the concrete and its mass density is not available normative values will be used in the material model. This will
have significant impact on the weight function accuracy; therefore investigation will be performed to determine the influence of the concrete mass density and element composition on the function. If there will be shown weight function independence on the operational parameters such as burn-up and boric acid concentration, coolant temperature and other parameters during the whole reactor operation cycle, we could consider the weight function as invariable, i.e. generalize the function, and determine the ex-core detector response to neutron flux density distribution in the whole cycle of operation. A simply flow diagram for determination of the ex-core detector signal is shown in Figure 2.

Figure 2: Simplify flow diagram for problem solving
5 FITTING AN ANALYTICAL FUNCTION

An analytical function will be fitted onto the single weight values obtained by MCNP calculation in two steps. The fitting will be performed using an own program which will be based on the method of flexible polyhedra. The first step of the fitting task will be to find the optimal analytical function which follows well vertical distribution of the calculated weight values. Second step will be horizontal fitting which means that a horizontal analytical function will be fitted onto calculated and by vertical fitting “smoothed” weight values.

6 SUMMARY

The exact knowledge of the spatial weighting function of the ex-core detector response will be very useful for solution and interpretation of various reactor physical, operational and safety problems, in particular for interpretation of reloads startup rod drop measurements, assessment of the ex-core detectors response at deep subcritical reactor stage. The goal of the work was to design and describe the calculation method for determination of the weighting function at a twentieth-of-pins level within acceptable statistical uncertainty and computing time using MCNP-4C2 transport code. The input file for calculation of the weight values is now almost completed and prepared for testing and running. Fitting the analytical weight function will be performed by own program which will be developed for multi-dimensional regression.

REFERENCES

