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On the use of different analytical solutions for recalculation of the YALINA-Booster experiment SC3A

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ABSTRACT

The SC3A experiment in the YALINA-Booster facility in Belarus is described and investigated. For this investigation the very special configuration of YALINA-Booster core, consisting of a fast and a thermal zone, decoupled with a neutron 'valve' is analyzed in detail based on a full HELIOS model for the calculations. The two region design causes unexpected results in the experiments. The special problems for the analysis of the experiments are shown. The results for different analytical solution (one group diffusion, one group P_1 transport and two group diffusion) are analyzed and compared. To model the streaming of neutrons from the thermal area into the fast area, a special two group analytical solution for the space–time dependent neutron flux with two sources is developed from the available Green's functions for two groups. The new analytical solutions show very good agreement in the comparison with the experimental results. Especially, with the two group and two source solution the unexpected behavior at the outermost detector can be reproduced. Thus analytical solutions without separation of space and time are a very promising tool to develop a new method for the analysis of ADS experiments.

1. Introduction

Different current and planned experiments (MUSE (Soule et al., 2004), YALINA (Bournos et al., 2005; Chigrinov et al., 1999), Guinevere (Aït Abderrahim and Baeten, 2008)) are designed to study the zero power neutron physical behavior of the accelerator driven systems (ADS). The detailed analysis of the kinetic space–time behavior of the neutron flux is important for the evaluation of these ADS experiments. This kind of analysis is required for the subcriticality determination during operation of ADS. Up to now the analysis for all these experiments is based on the standard methods (Persson et al., 2005) – Sjöstrand method (1956) and Slope method (Simmons and King, 1958) – both are well known to be accurate in critical systems. These methods are based on the point kinetics equations (Ott and Neuhold, 1985). The point kinetics equations are usually developed from the diffusion equation by the separation of space and time. Separation of space and time does not provide useful and reliable results for cases with space and time dependent external source (Merk and Weiß, 2009). To overcome this problem analytical solutions have been derived for the diffusion equation and the time dependent Telegrapher's equation (Weinberg and Wigner, 1958), both without separation of space and time. Solutions for the Telegrapher's or time dependent P_1 equation have already been provided for a Dirac type pulsed external source (Merk, 2008b), for the start up (Merk, 2007; Merk, 2009), and for the switch off (Merk and Weiß, 2009) of an external source. The time dependent P_1 equation and the diffusion equation without delayed neutron production have been solved completely analytically by using the Green's function method (Merk, 2008a). For the comparison with the experimental results, obtained at the YALINA-Booster facility, a special external source (switch on followed by a switch off after a finite time period) has been used in combination with the Green's function for the determination of the analytical solutions for the neutron flux (Merk et al., 2010a, 2010b, 2009). The derived solutions for the space–time dependent neutron flux have been compared to the detector responses at different detector locations in the fast area of the YALINA-Booster core (HELIOS Methods, 2003; Bécares et al., 2009). Major result of these comparisons is a good agreement for the spatial distributions during the pulse. The analysis of the specific of the YALINA facility (Merk et al., 2010a) forced us to extend the analytical solution for the diffusion equation from one to two energy groups (Merk and Weiß, 2010).

In this work, the specifics of the YALINA facility, here for the experiment in the SC3A configuration, will be discussed in detail. The results for four different analytical solutions will be evaluated

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for the fast zone. The already published one group results (Merk et al., 2010a, 2010b, 2009) will be analyzed and special focus will be given to the difference occurring between the time-dependent diffusion and the time-dependent P_1 solution. In a next step the improvement due to an extension of the analytical solution to two energy groups will be given. Finally, a special flux solution with an additional boundary source is created to improve the representation of the specifics of the YALINA-Booster core with its incomplete decoupling of the fast and the thermal zone.

More comprehensive solutions for the full neutron transport equation with external source can be found in literature. These methods are based on semi analytical solutions (Dulla et al., 2006; Dulla and Ravetto, 2008). For the case of systems without external source extensive work has been published (Ganapol, 1978, 1992, 2000) and some interesting approximation techniques have been used (Mika, 2000). For this publication fully analytical approximation solutions are developed and applied, in contrast to the procedure mentioned above. The solutions are dedicated to the direct analysis of current and future ADS experiments. In a further step the method is foreseen for the sub-criticality determination during operation in a power ADS. Completely analytical approximation solutions, even with reduced accuracy, are more suited for this development. In general the analytical solutions have the big advantage of providing significantly more efficient solutions than numerical methods. This high efficiency is an essential point for a fast determination of the system criticality status during operation of ADS.

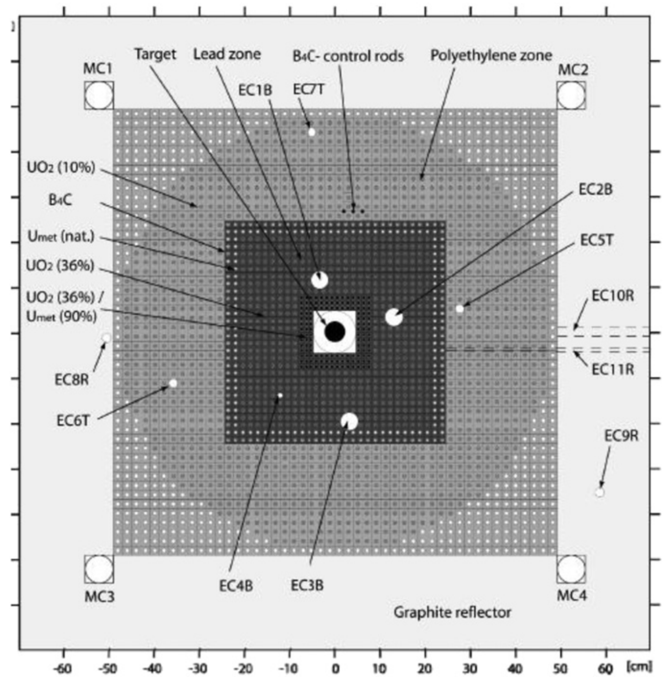

Fig. 1. General configuration of the YALINA-Booster core.

2. Specific of YALINA-Booster

The YALINA-Booster facility (Bournos et al., 2005; Kiyavitskaya et al.) is a zero power mock-up for ADS. It is located in Belarus at the Joint Institute for Power and Nuclear Research – Sosny (JIPNR). Researchers of the European Community have performed experiments in this facility in the frame of IP EUROTRANS in the domain ECATS of the 6. framework program of the EC (Bécares et al., 2009, 2010; Berglöf, 2009). The facility consists of a deuterium accelerator with a tritium target coupled to a sub-critical core. In the center of the core external neutrons are procured via a D-T reaction in a tritium target. In the reference configuration, the surrounding sub-critical assembly consists of a central ring-like region with 90% enriched uranium metal (U_{met} 90%) rods in a lead matrix. This central region is surrounded by another fast region consisting of a lead matrix with 36% enriched uranium oxide (UO_2 36%) rods located in holes. In this fast region the three experimental channels (EC1B, EC2B, and EC3B) are located (see Fig. 1). The complete fast region is decoupled from the surrounding thermal region by the so-called 'valve' consisting of one row of natural uranium metal (U_{met}) rods and one row of boron carbide (B_4C) rods. The surrounding thermal region consists of a polyethylene matrix with holes, which are filled either with 10% enriched UO_2 fuel rods or with air. The core is surrounded by a graphite reflector. The over all dimensions are very limited, since the core without reflector has a dimension of 1 m square meter.

The SC3A configuration of the EUROTRANS/ECATS experiments (see the HELIOS model in Fig. 2) in the YALINA-Booster facility is used for the comparison with the different analytical solutions. The above described reference configuration is modified by replacing the 90% enriched uranium metal fuel rods of the inner fast zone by 36% enriched uranium oxide fuel rods (tight rows of bright pink rods, which surround the red target zone) to create the SC3A configuration. The thermal region in green contains the 10% enriched fuel rods in deep blue and the empty positions in brown, respectively. The graphite reflector is shown in rose. The 2D HELIOS calculation has been corrected with a leakage term in the third dimension to reach a comparable result to an MCNP calculation (Berglöf, 2009) using the input buckling B^2 option of the HELIOS input description.

For the comparison of the analytical solutions with the real experiment cross section sets are needed. These cross section sets are calculated with the licensing grade code module HELIOS 1.9 (2003). The YALINA-Booster facility is reproduced in a two dimensional model of a quarter of the core in all details in unstructured mesh. The experimental channels are all relocated into the modeled core quarter, but only with the weight of 25%. The relocation of the experimental channels can cause some minor

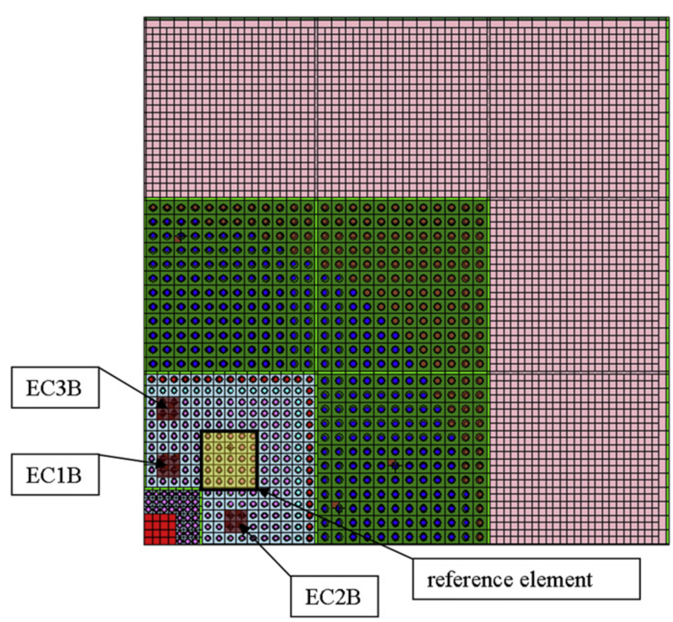

Fig. 2. SC3A configuration of the YALINA-Booster core in the HELIOS model for XS preparation based on integral neutron transport.