Experimental investigation of the axial neutron flux distribution in an Accelerator Driven System

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INTRODUCTION

An Accelerator Driven System (ADS) is a subcritical fission reactor coupled to an external neutron source consisting of a particle accelerator that delivers charged particle beam onto a neutron producing target located inside the reactor core.

Neutronics characteristics of an ADS differ from those of a critical reactor. In this paper we describe the experimental investigation of the inhomogeneity in neutron flux distribution (and consequently the power distribution) brought by introducing an accelerator beamline and a neutron producing target into a reactor core. The impact of the asymmetrical target position (off-centered compared to the middle of the core) will be also shown.

The presented work is being performed within the framework of the FREYA project [1] (a continuation of GUINEVERE [2]). In general, it serves the investigation of licensing and design tasks for MYRRHA as an ADS demonstrator [3] (of an industrial scale and power level and with the option to be operated in critical mode too) as well as for the Lead Fast Reactor core neutronics.

The main aims of FREYA (*Fast Reactor Experiments for hYbrid Applications*) are validation of methodologies for online reactivity monitoring of an ADS and validation of nuclear data and neutronic codes. Furthermore, the experimental characterization of fast critical and subcritical cores (flux traverses, spectral indices, control rod worths, delayed neutron parameters) representative for MYRRHA are being investigated.

EXPERIMENTAL SETUP

The research is being performed at the VENUS-F installation at SCK·CEN in Mol, Belgium. VENUS-F [4] is a zero-power, lead-based, fast reactor that can be operated in two configurations: critical and subcritical. In the latter, the GENEPI-3C [5] deuteron accelerator (220 kV) with a tritium target is coupled to the core and acts as an external neutron source of quasi mono-energetic 14 MeV neutrons that are almost isotropically produced in the T(d,n)α reaction.

The VENUS-F reactor uses 30%wt enriched metallic uranium as fuel and solid lead as a coolant simulator. Fuel and coolant are combined in 97 fuel assemblies in a 12×12 stainless steel (SS) grid. The rest of the assemblies are Pb reflector. The grid is surrounded by an additional Pb reflector (from sides, top and bottom). In the subcritical configuration, the inner four fuel assemblies are replaced by the beamline and target (Figure 1).

The core size is about 60 cm in height and 90 cm in diameter (while MYRRHA is planned to be 65 cm in height and 105 cm in diameter). The radial reflector is about 35 cm thick; the top and bottom reflectors are 40 cm thick and are separated from the fuel by 7 cm thick SS blocks, see Figure 2.

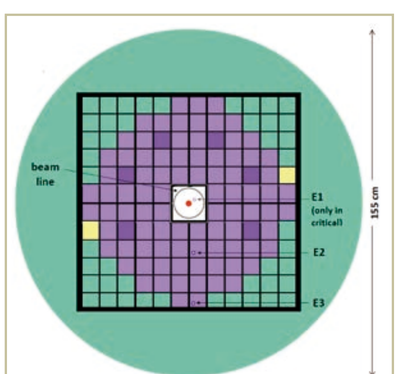

Figure 1. Horizontal cross section in the midplane of the VENUS-F reactor in the subcritical configuration: violet – fuel assemblies, violet shaded – safety rods (B4C with a fuel follower), green – lead, yellow – control rods (B4C), black – stainless steel, red – tritium target.

The presented results were measured at the first critical core (only lead as reflector and coolant simulator) and the first subcritical core (k_{eff} = 0.963). More complex cores (e.g. Pb+Bi coolant, SS reflector) and other subcriticality levels (k_{eff} = 0.89-0.97) will be investigated in 2014-2015.

AXIAL TRAVERSES

The axial traverses (fission rate distributions, i.e. neutron fluxes times fission cross-sections) through the active zone and top and bottom reflectors were measured using two fission chambers (FC). One FC with a fissile deposit (1 mg of U235) for assessment of the whole energy spectrum and one FC with a fissionable deposit (5 mg of U238) for assessment of the fast neutron part.

The FCs were inserted in specially designed holes (*d*=1 cm) in fuel assemblies at three radial locations (E1, E2, E3 in Figures 1 and 2) in the critical configuration, while only the E3 position was available in the subcritical

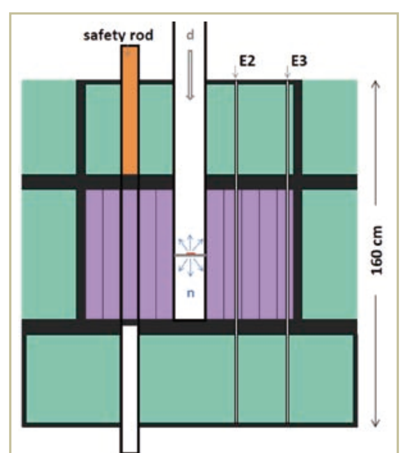

Figure 2. Vertical cross section of the VENUS-F reactor in the subcritical configuration: orange – B4C part of a safety rod, red – tritium target in the core midplane (vacuum is above and air under the target).

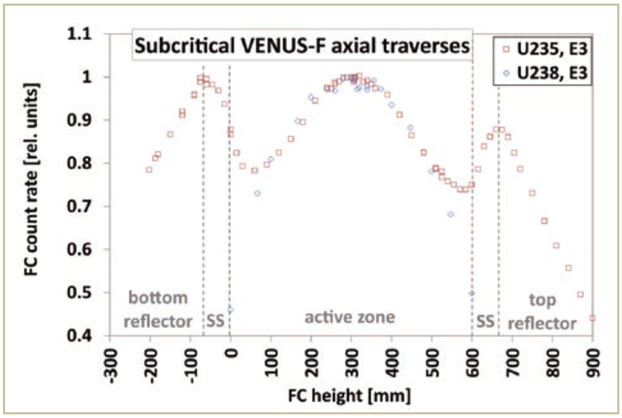

Figure 3. The U235 and U238 axial traverses on the periphery of the active zone (the E3 position) in the subcritical configuration.

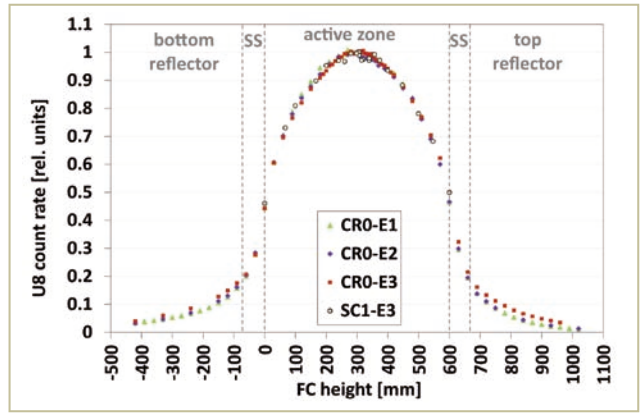

Figure 4. The U238 axial traverses at three positions in the critical configuration (CR0) and one position in the subcritical configuration (SC1).

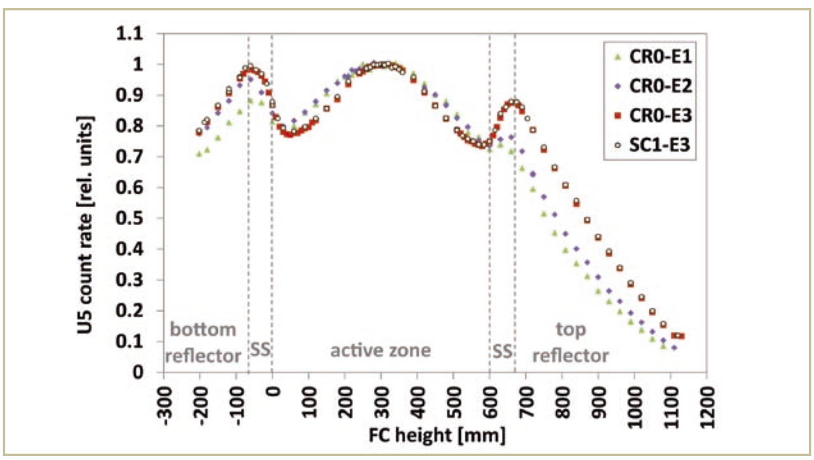

Figure 5. The U235 axial traverses at three positions in the critical configuration (CR0) and one position in the subcritical configuration (SC1).

configuration. The fission rates were measured in steps of 1-3 cm, corrected for power changes, and the middle point was normalized to 1.

The shapes of the U235 and U238 axial traverses (Figure 3) are the same within 20 cm from the core midplane. Behind it, the U238 fission rate steeply drops, while the U235 fission rate reaches its local minimum and starts increasing. When passing the SS block between the fuel and reflector, it reaches local maximum and then steadily decreases.

The U238 axial traverses (Figure 4) are symmetrical around the core midplane in the active zone, while they are about 10% smaller through the bottom SS block than through the top SS block. In the contrary, the fission rates in the bottom reflector are about 40% higher than in the top reflector. The shapes in the E1 and E2 positions agree with each other in the whole length, while with E3 only in the active zone. The values in E3 are higher than in E1 and E2 by about 20-30% in the bottom reflector and 30-90% in the top reflector.

The critical and subcritical U238 axial traverses in E3 agree with each other, however, slightly smaller values (by 3%) were observed for the subcritical case in the region within 5 cm above the core midplane.

The U235 axial traverses (Figure 5) in the active zone are flatter in E1 and E2 than in E3. The traverses are asymmetrical outside the active zone – the local maximum in the bottom SS reaches higher than in the top one. This effect is more pronounced in E2 than in E1, and more in E3 than in E2. The probable reason is the absorption of neutrons in the safety rods, which are in such a position during the reactor operation that their B4C parts are lifted up into the top reflector and the fuel follower is in the active zone. Moreover, E3 is the furthest position from the safety rods.

The subcritical U235 axial traverse in the E3 position in the active zone seems to be slightly flatter than the critical one, however, the difference is within uncertainties.

CONCLUSION AND OUTLOOK

We measured the U235 and U238 axial traverses of the lead fast VENUS-F reactor in the critical configuration and the subcritical one with the external source located in the core centre. The shapes of the axial traverses at the core periphery agree with each other within the uncertainties. The subcritical configuration with the external source located at the border between the active zone and the top reflector will be also examined. The measurements will be compared with MCNP calculations.

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