Possible Implementation of Ex-core Measurement in TEPLATOR

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Introduction

Nowadays, the modern nuclear power plants are proposed for power generation and it is challenging to focus on choosing a suitable neutron flux monitoring system. The main advantage of ex-core detectors arrangement is a fast response on neutron flux change, which reflects a change of the reactor power. This paper focuses on feasibility assessments of the ex-core detectors in a graphite reflector, which surrounds a TEPLATOR core. The TEPLATOR is an innovative concept for a district and process heat production developed in the Czech Republic [1]. The main idea of this concept is using already irradiated nuclear fuel from PWRs, which is stored in interim storage or in spent fuel pools. The concept provides lower environmental footprint and efficient utilization of the nuclear fuel. There are several variants for TEPLATOR and one of them is TEPLATOR DEMO.

This design uses atmospheric pressure, 55 irradiated fuel elements, heavy water as the moderator in a calandria and as a coolant in a fuel channels and graphite as a reflector. The assumption is to operate for two standard winter heating seasons. There is also a solution for countries that do not operate PWR and do not own irradiated fuel and this solution can be using special fuel made of SEU or natural uranium designed for the TEPLATOR construction [2].

Model in Serpent

The main idea of this paper is to implement the ex-core neutron flux measuring apparatus into the TEPLATOR core. A simplified model of TEPLATOR was created in the Serpent 2.1.30 [3]. The TEPLATOR DEMO will use the already irradiated fuel from PWRs. For this simulation, a standard type of hexagonal nuclear fuel VVER-440 type with an average burnup 34 750 MWd/MTU is assumed, which represents average fuel burnup of the spent fuel pool inventory. The fuel assemblies are placed in hexagonal channels. The fuel channels are placed in a calandria filled with heavy water, which is surrounded by the graphite reflector. Whole model with a critical level H_{cr} of the moderator can be seen in Figure 1a and Figure 1b. All calculations were carried out with 25 000 neutrons, 10000 histories, 50 inactive cycles and the ENDF/B-VIII.0 nuclear data library was used. An uncertainty of the calculations is around 3 % in thermal and epithermal groups. For the fast neutrons the uncertainty is around 13 %.

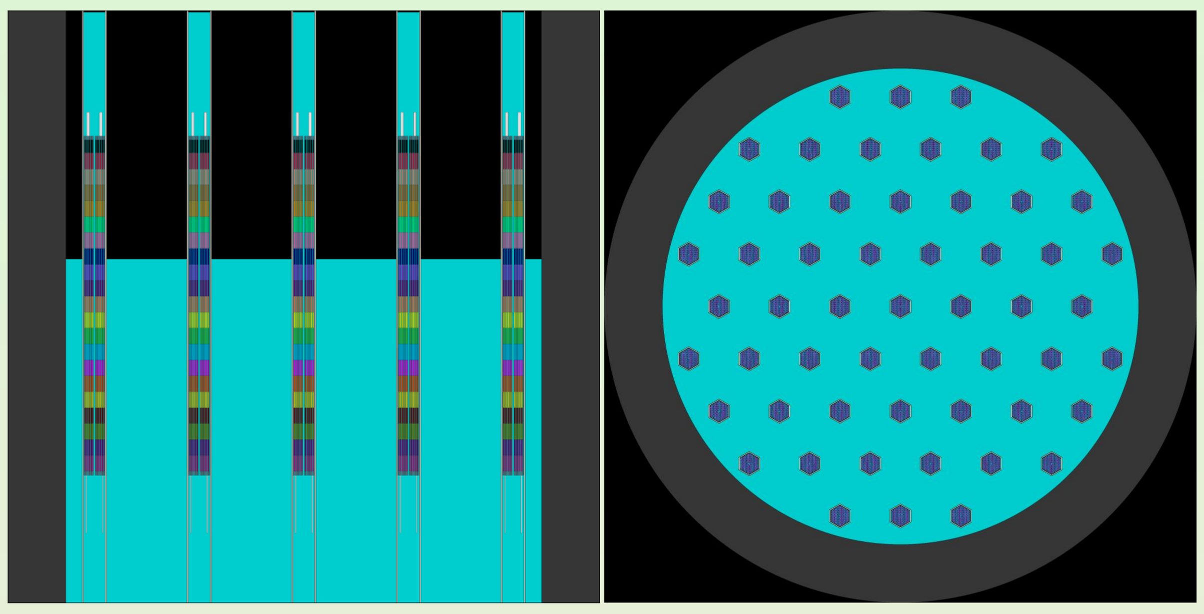
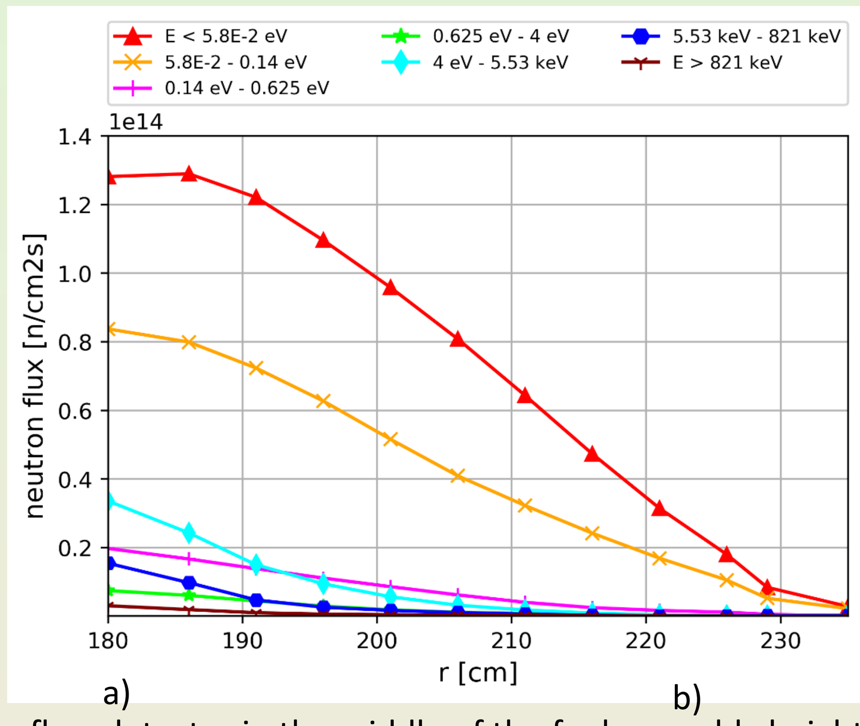


Figure 1: The model of TEPLATOR core – a) side view, b) view from above



a) b)

Figure 2: Radial neutron flux, detector in the middle of the fuel assembly height under the moderator level

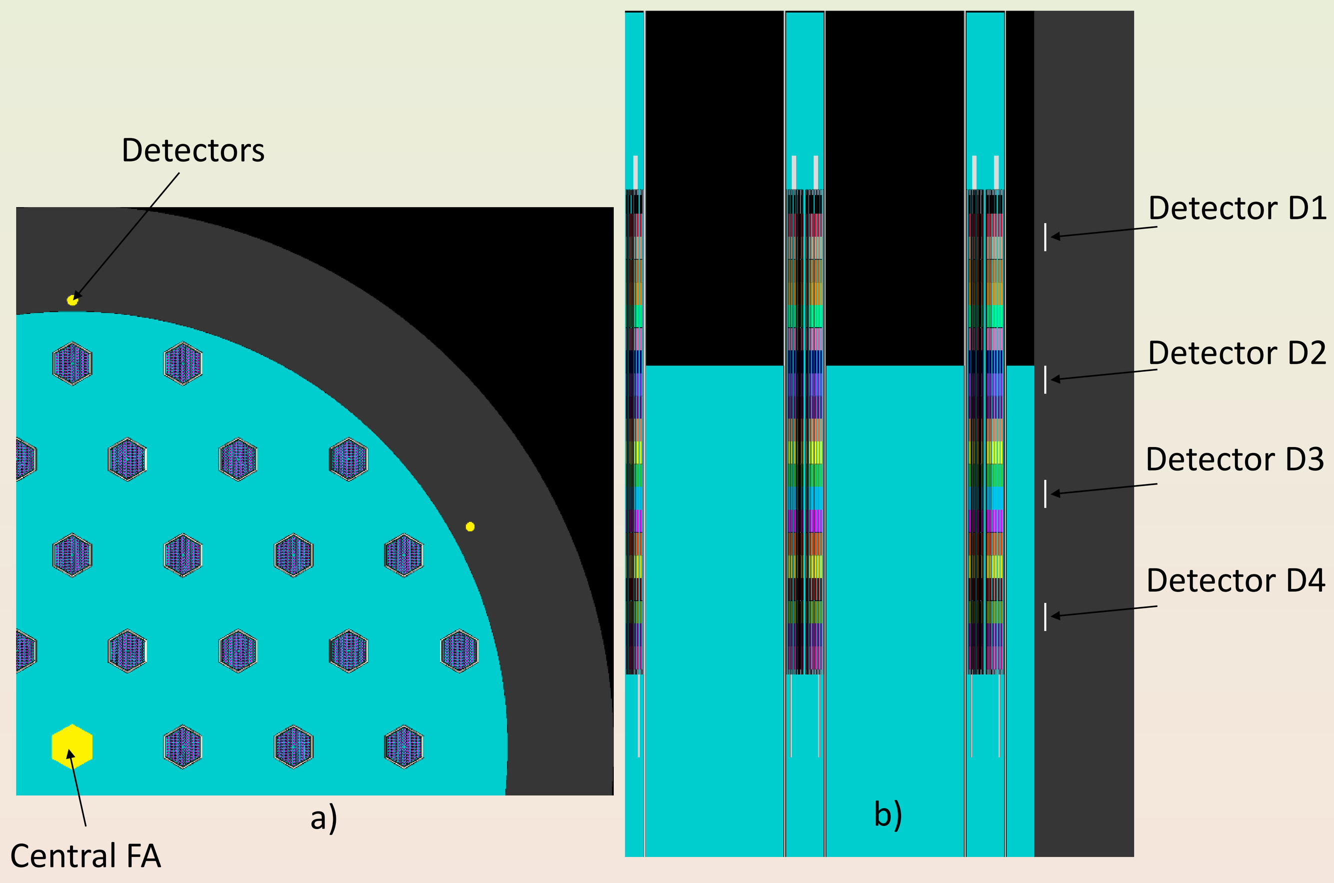


Figure 3:) 60° symmetry of the detectors b) Axial position of the ex-core detectors

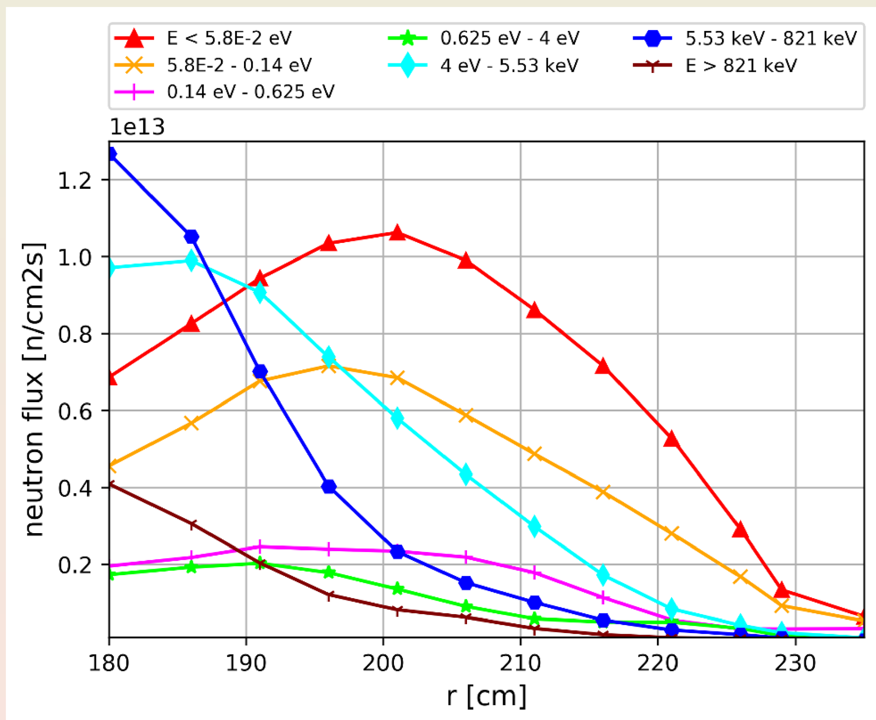


Figure 4: Detector D1 – Radial neutron flux

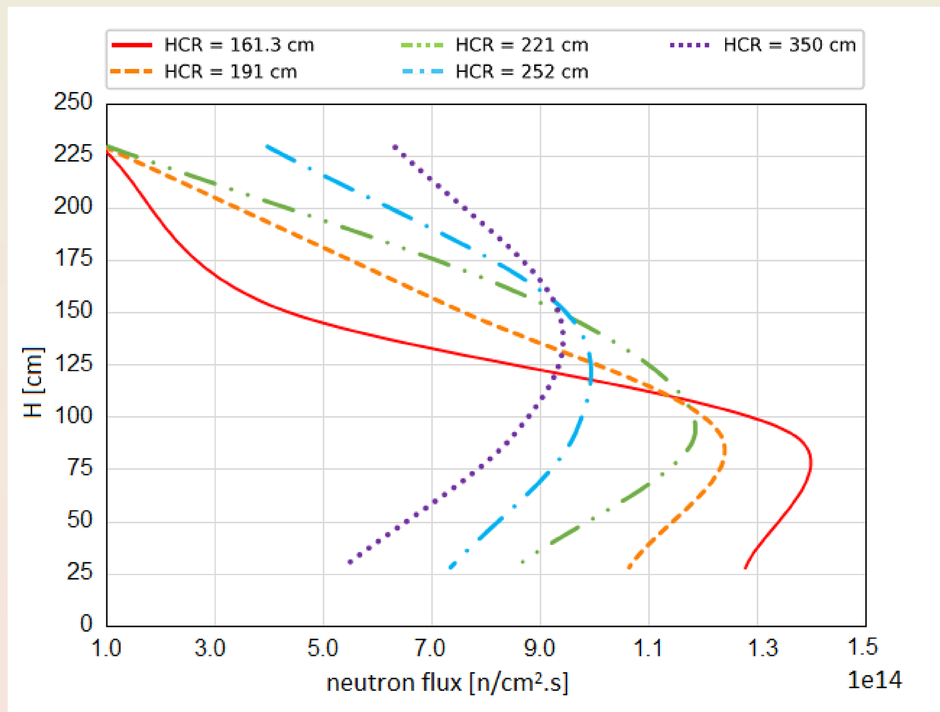


Figure 5: Effect of the moderator level on axial neutron flux profile distribution 1.group thermal neutrons

Neutron flux profile

A set of calculations were made with 5 cm step to show a radial neutron flux profile in the reflector (Figure 2). The detector was placed in the middle of the fuel assembly height, where the highest neutron flux was assumed. A 7-group energy structure was used. The detectors reach the best response to thermal neutron in very first centimetres of the reflector. A layout of the ex-core detectors based on these results was designed and a 60° symmetry of the core was used as shown in the Figure 3a. Due to the regulation by moderator level and the fuel assembly length, the 4 axial ex-core detectors were chosen, which is shown in the Figure 3b. Fast neutrons contribute much more to the total neutron flux in the detector D1 than in detectors under the moderator level (Figure 2 and Figure 4). The neutron flux is flattened and slightly shifted towards the reactor core in these three underwater detectors. These results confirm that the position of detectors is propriate in very first few centimetres (around 5 cm). The Figure 5 demonstrates distribution of the axial thermal neutron flux profile during the TEPLATOR operation.

As the fuel is burning up, the level of moderator (to maintain criticality) is rising. Another 4 moderator levels were set for determining the axial profile during operation with equal distance. The calculations were carried out with the fuel at the beginning of cycle – “fresh fuel”.

Conclusion

This article aims at possibility of the ex-core measurement implementation in the TEPLATOR, which is the new concept of the reactor using already irradiated fuel for district heating. We tried to find a suitable placement of detectors in the reactor. First 5 centimetres of the reflector appear as the most appropriate position of detectors in radial direction obtained from the results. The axial profile shows the change of neutron flux distribution during operation time.

Further research will aim at detailed analysis during the fuel burn up and on the behaviour of the neutron measurement during operation time. Also, an effect of the radial and axial position of the detectors in the reflector and optimization of the detectors’ response will be investigated. The next step is to find out a possibility to map a distribution of the neutron flux in the whole reactor core both in radial as well as in axial directions, as is it possible when using the standard in-core detectors.

References

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Acknowledgments

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