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BASIC DESIGN OF THE TEPLATOR CORE - CONSTRUCTION

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ABSTRACT

The study shows the base optimization of the TEPLATOR core. One of the most difficult challenges for this concept is dealing with irradiated fuel assemblies. Because spent nuclear fuel has insufficient reactivity, the main aim of this study is to investigate various effects on TEPLATOR operation from the perspective of the core design. The analysis was executed by Serpent and TRITON code and shows the influence of individual components of the TEPLATOR CORE. The crucial role plays the choice of a suitable moderator; it determines the construction fundamentals of the core. Based on this choice an ideal fuel pitch, a dimension of a reflector, and parameters of cooling were arranged. The construction with or without fuel channels was dealt with. After consideration of all these effects, the first core of this kind was designed.

The first DEMO is designed with 50 MW of thermal power and 55 spent fuel assemblies of VVER-440 type in the core, heavy water as both moderator and coolant. More is described in the article.

KEYWORDS: TEPLATOR, VVER-440, spent fuel

1 INTRODUCTION

This study shows the basic principles of the TEPLATOR core optimization process. This research is aimed to main parts of the nuclear core as fuel, moderator and reflector. We are aware that it is a very complex and challenging problem to design the core. For this article, we have chosen a few main parts. But the background of this research contains much more details and many studies. We would like to show the highlight of basic principles and challenges in core designed for the use of nuclear spent fuel. Based on previous studies and principles, we are presenting the 3-D model of the TEPLATOR developed in Monte-Carlo program Serpent. [1]

The TEPLATOR is fuelled with already irradiated nuclear fuel. This is an absolutely essential condition of the core optimization. This fact has an effect on the whole device construction, not only for the core, but also for other technical parts in basic design like primary circuit or reactivity control [2], [3].

Usage of spent nuclear fuel as a “standard” fuel in the core design is challenging and it requires a novel approach in many aspects. In contrast to standard nuclear cores, the TEPLATOR without fresh fuel has much less reactivity when fuelled in the BOC core. Therefore, the design demands an emphasis on materials with low neutron absorption and ideal optimization as much as possible. And due to the main purpose (district heating or cooling), the parameters in the core are very different.

2 BASIC NUCLEAR CHARACTERISTIC OF TEPLATOR

2.1 Fuel

For this simulation, we assumed a standard type of hexagonal nuclear fuel VVER-440 type with a suitable and reasonable burnup level. [5] The calculation was made by TRITON code and we used fuel with enrichment 3.60 % U-235, see Figure 1. As an appropriate burnup, we choose an average 34 750 MWd/MTU from [6]. It represents an average fuel burnup of the spent fuel pool inventory. Due to residual reactivity in the fuel, it could be useful for decades of heat production for dozens of TEPLATORS. It also required to consider the 30 years of cooling times and appropriately address axial burnup profile, see Figure 2. [7] In this research, we tested all types of commonly used fuel assemblies with different fuel enrichments (2,40 %, 3,60 %, 3,82 %, etc.) with various cooling time.

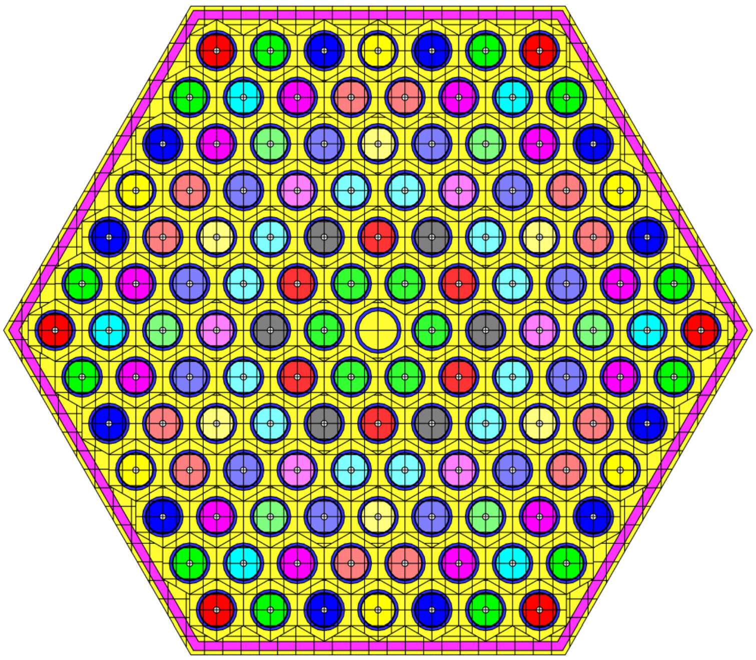

Figure 1: TRITON depletion calculation model of VVER-440 fuel assembly.

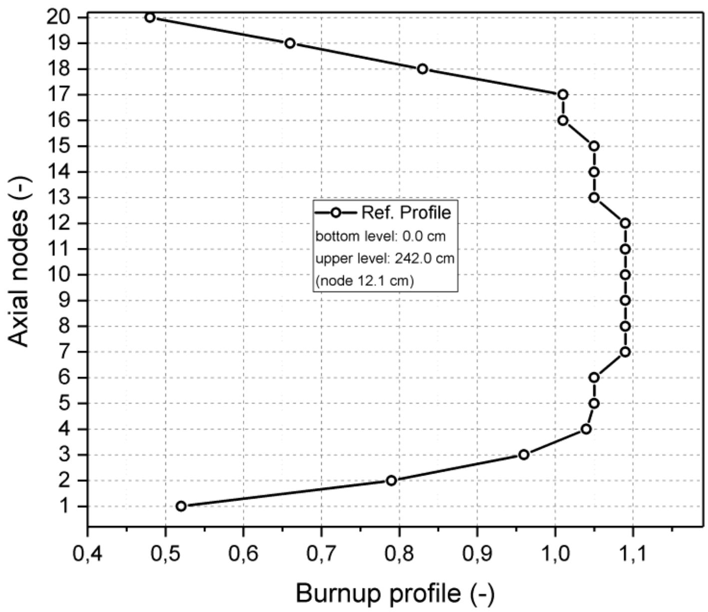

Figure 2: Axial burnup profile for VVER-440 spent nuclear fuel. [7]

2.2 Moderator

Unfortunately, the reactivity of the spent fuel is not sufficient for standard light water moderator; it would not be possible to operate any TEPLATOR in this conditions event with relatively low operation temperature and pressure (98°C and atm. pressure). So we had to choose a better moderator with much lower neutron absorption. For several reasons, our choice fell for heavy water. From neutronics point of view, it is an ideal moderator for fuel with a very low level of reactivity. The next reason is that we are able to control reactivity (if we use fuel channels) by changing water level (unlike with graphite or beryllium moderators).

However, this choice also has its challenges. In this article, we are presenting two of them. The first one has an effect on the design of the entire device; it is an optimal pitch. The heavy water as a moderator has a low probability of absorption of neutrons but slows down neutrons less effectively than hydrogen or light water. The fuel assembly pitch must then be several times higher than in standard light water core and it causes much larger core with expensive heavy water. It was very difficult to find an optimal ratio between the optimal power of TEPLATOR and the core size. As an example see Figure 3, the K-inf dependency on fuel assembly pitch for heavy and light water in the same conditions: 98°C and atmospheric pressure. We can observe that the optimal pitch is much higher than in the case of light water. Hence, the final core will be larger than a typical LWR.

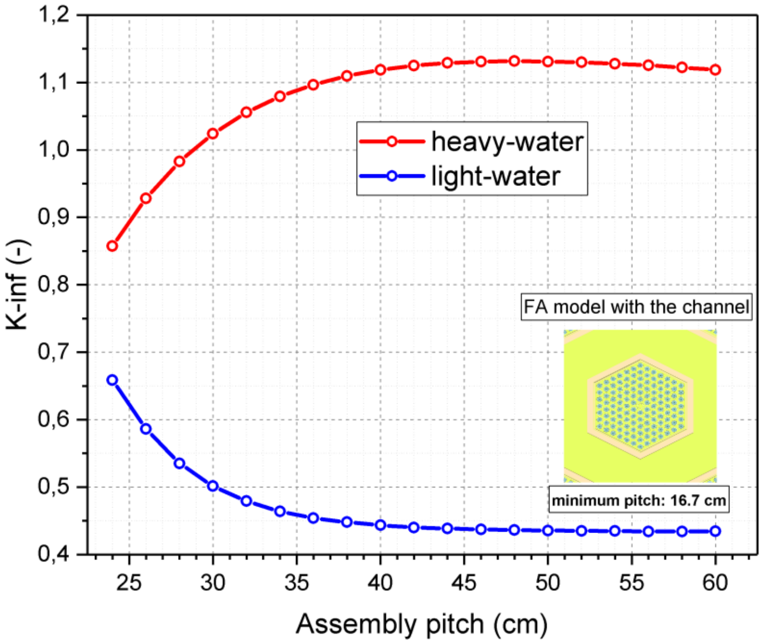

Figure 3: The results for a different assembly pitch.

The next very important challenge is heavy water by itself. We investigate many of D_2O parameters and influence on operation. In this part, we present one of the most important; it is the purity of heavy water, basic condition for the TEPLATOR operation. Figure 4 shows results for heavy water purity in the final 3-D TEPLATOR model in operation conditions for the beginning of cycle. It is necessary to keep purity higher than 99.5 %. We recommend keeping 99.8 % purity of heavy water.

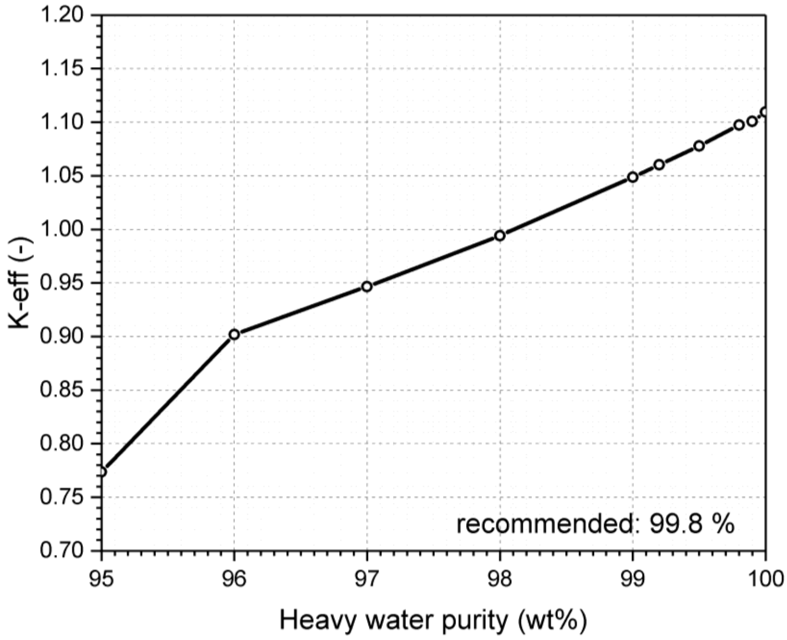

Figure 4: The results of different heavy water purity.

2.3 Reflector

The last example of basic design of the TEPLATOR will be focus on the reflector. Each core is surrounded by a neutron reflector or baffle. The reason is that it reduces neutron leakage and increases K-eff. From an economics point of view and especially due to moderator it is not economical to use the heavy water in the reflector. In this study, we tried several variants of possible materials and thicknesses of a reflector. As the best option, we have chosen graphite with 45 cm of thickness. The graphite reflector has very good neutronics properties; also it is well known and relatively inexpensive material. In Figure 5 one can observe the influence of heavy water and graphite reflector with different thicknesses for the TEPLATOR.

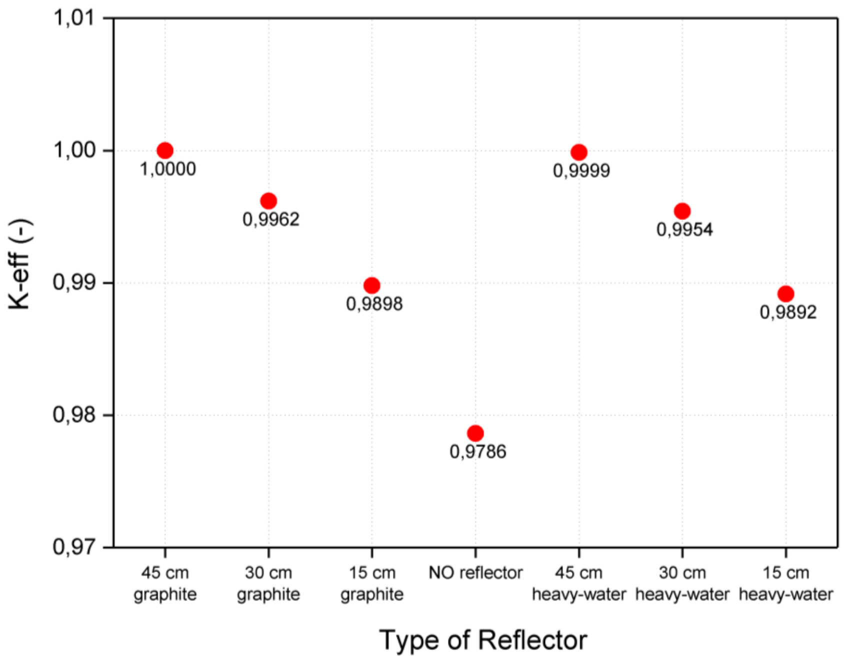

Figure 5: The results for different types of reflector and thicknesses.

3 3-D TEPLATOR MODEL

Based on detailed neutronics and thermal hydraulics analyses we have chosen a core with 55 fuel assemblies (VVER-440 type) in a hexagonal lattice with heavy water moderator and graphite reflector. The TEPLATOR is able to operate with spent nuclear fuel. For TEPLATOR DEMO the fuel cycle will be around 300 day long with thermal power 50 MWt. But it is possible to increase power up to 150 MWt. Also operation with fresh SEU is possible.

The DEMO unit includes fuel channels in the core with heavy water. It improves economics of heavy water and manipulation with spent fuel and enables to control the chain reaction by changing of moderator level. The coolant fluid output temperature from the core is 98°C and the whole primary circuit works at atmospheric pressure. The view of the 3-D core can be seen in Figure 6.

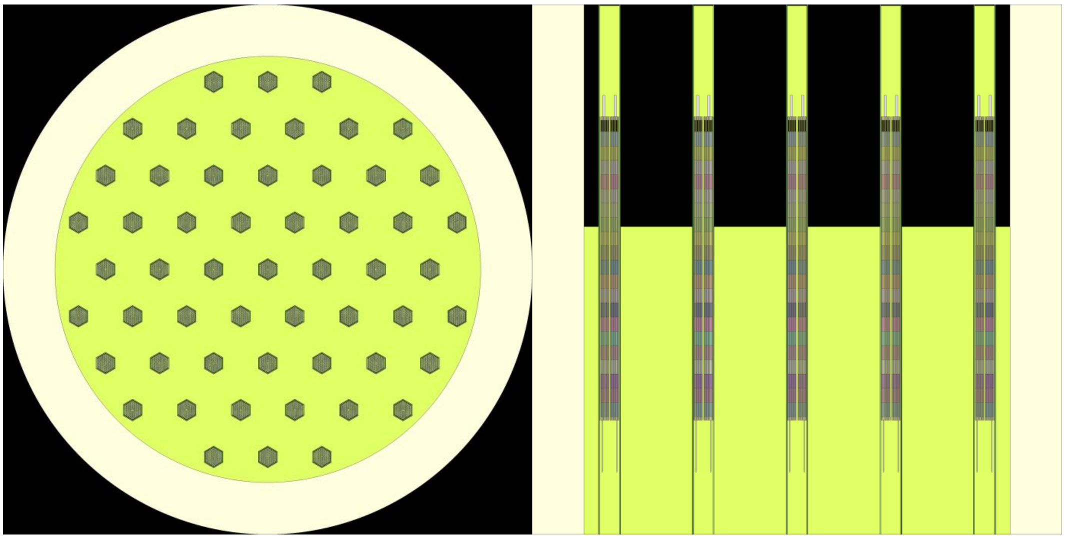

Figure 6: TEPLATOR DEMO core with 55 fuel assemblies in hexagonal lattice.

4 CONCLUSION

This article presents the preliminary basic design of the TEPLATOR DEMO. We introduced a basic nuclear optimization for Fuel, Moderator and Reflector. Nevertheless, it was only a part of a complex study; witch was done and still is in progress by several research organizations.

Initially we are focusing on nuclear safety, reliability and economics for district heating applications. Now, we are testing all possible safety systems and calibrating two independent reactivity control systems. Nowadays, thanks to the new computational codes and modern methods we are able to simulate and verify different designs and choose the most suitable one which was not the case several years ago.

The TEPLATOR is an innovative concept how to use spent nuclear fuel for district heating or cooling. Due to the optimized core design, it is possible to operate the TEPLATOR as long as it is necessary for standard district heating or cooling seasons and harvest more energy from already manufactured and irradiated nuclear fuel assemblies.

ACKNOWLEDGMENTS

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REFERENCES

[1] Leppänen, J., et al.: The Serpent Monte Carlo code: Status, development and applications in 2013, Ann. Nucl. Energy, 82 (2015) 142-150.

[2] Zeman, M., Fořtová, A., Škoda, R.: TEPLATOR DEMO: Basic Design of the Primary Circuit. Proceedings of the International Conference Nuclear Energy for New Europe, Portorož, Slovenia, September 7–10, 2020.

[3] Vilímová, E., Peltan, T., Jiřičková, J.: Possible Implementation of Ex-core Measurement in TEPLATOR Graphite Reflector, Proceedings of the International Conference Nuclear Energy for New Europe, Portorož, Slovenia, September 7–10, 2020.

[4] Burket, D.,: Palivové vsázky se zdokonaleným palivem na Jaderné elektrárně Dukovany. Dissertation theses, ČVUT-FJFI, Prague, 2003.

[5] International Atomic Energy Agency, WWER-440 fuel rod experiments under simulated dry storage conditions. Vienna: International Atomic Energy Agency, 2004.

[6] VVER reactor fuel performance, modelling and experimental support: proceedings of an international seminar held in St. Constantine, Varna, Bulgaria, on 7-11 November 1994, ISBN 9789549002522.

[7] Jutier, L., et al.: Burnup Credit Implementation for PWR UOX Used Fuel Assemblies in France: From Study to Practical Experience, Nuclear Science and Engineering, 181:2, 105-136, DOI: 10.13182/NSE14-51.