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zavorkajirka@gmail.com

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BASIC DESIGN OF THE TEPLATOR CORE - CONSTRUCTION

Jiri Zavorka[1*], Martin Lovecky[1], Radek Skoda[1,2]

[1]University of West Bohemia [2]Czech Technical University in Prague

*Corresponding author: E-mail address: zavorkajirka@gmail.com

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. For this presentation, 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 3D 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. NUCLEAR CHARACTERISTIC

FUEL

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. It also required to consider the 30 years of cooling times and appropriately address axial burnup profile, see Figure 2. [7]

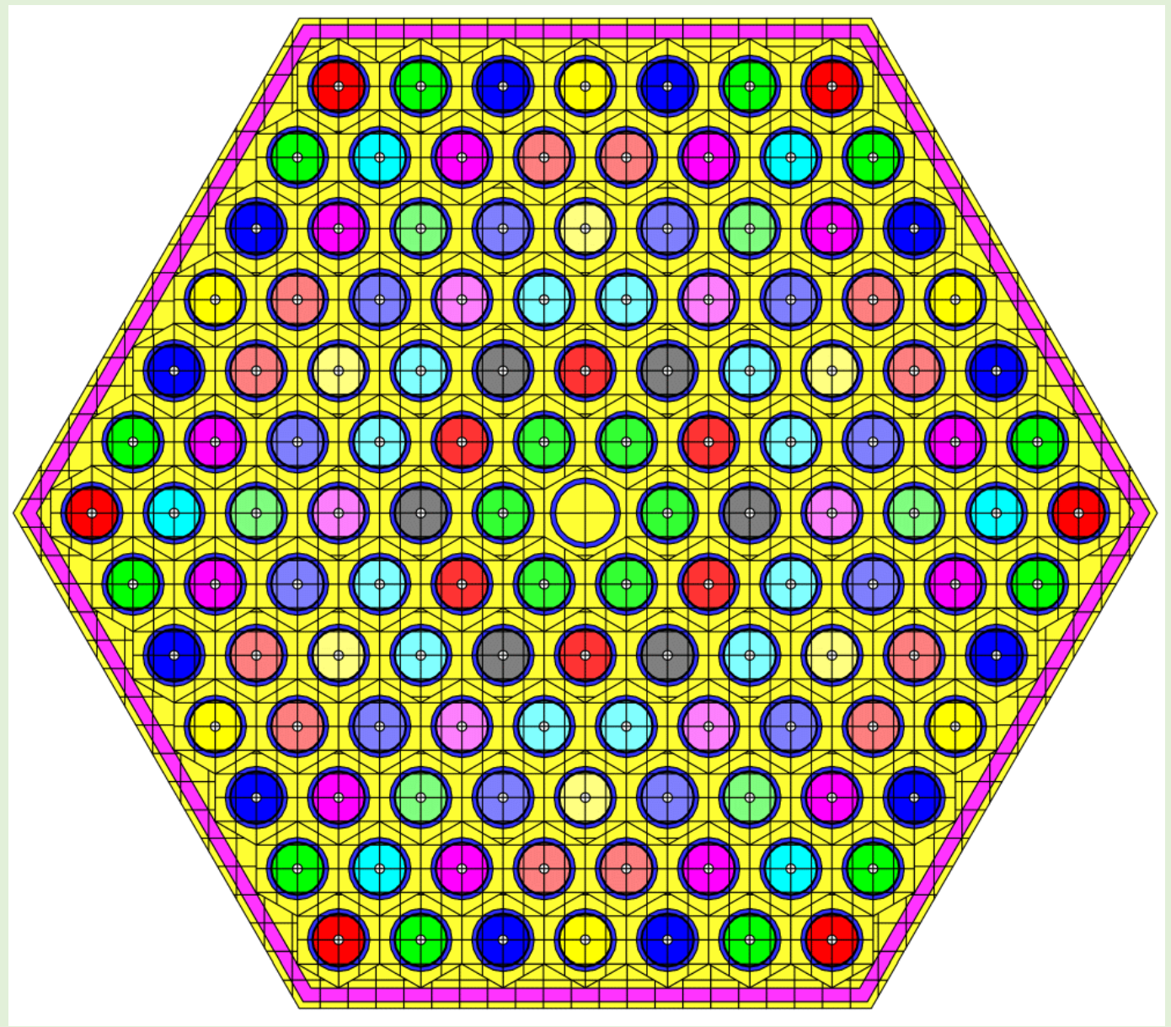

Figure 1: *TRITON depletion calculation model of VVER-440 fuel assembly.*

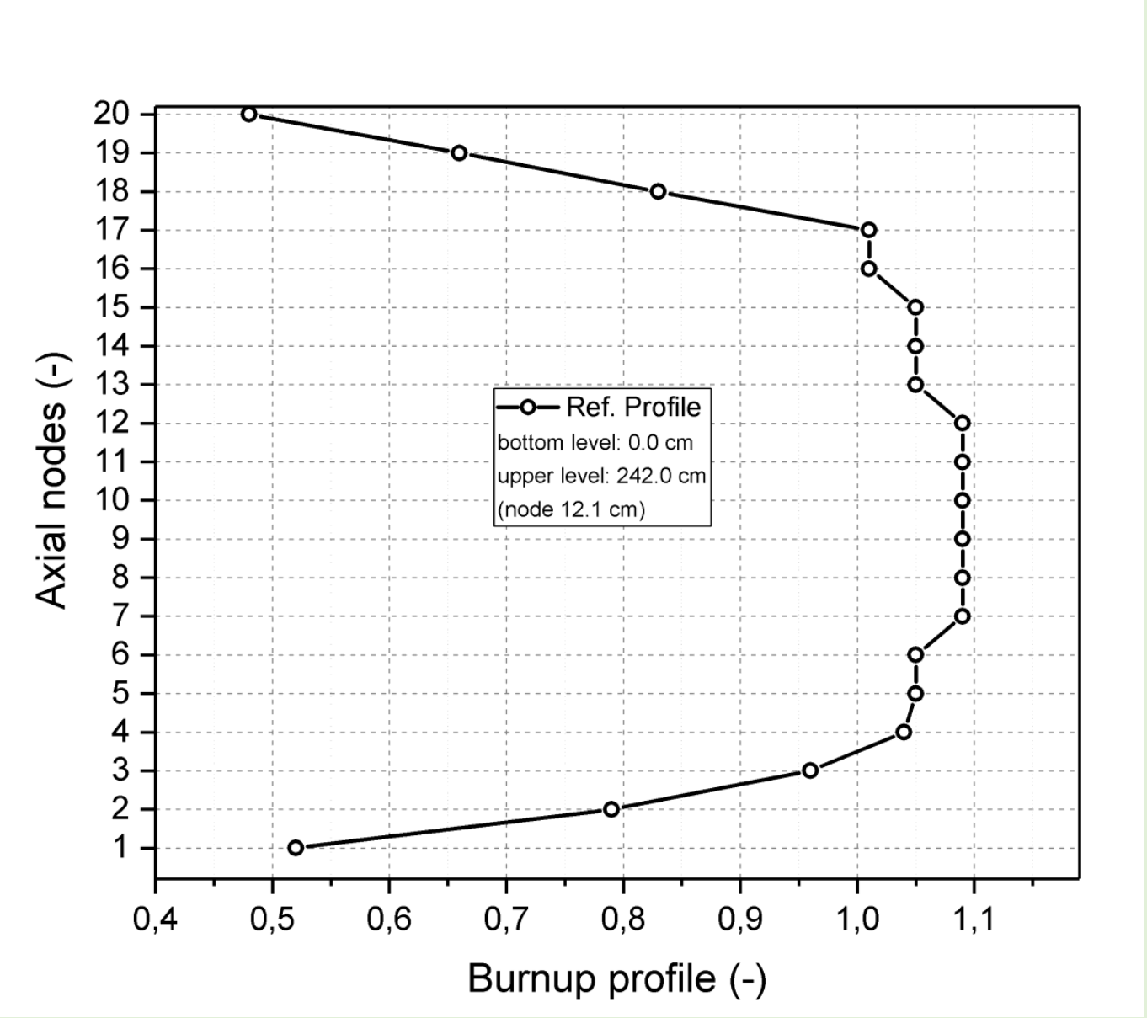

Figure 2: *Axial burnup profile for VVER-440 spent nuclear fuel. [7]*

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.

However, this choice also has its challenges. 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. 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. 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.

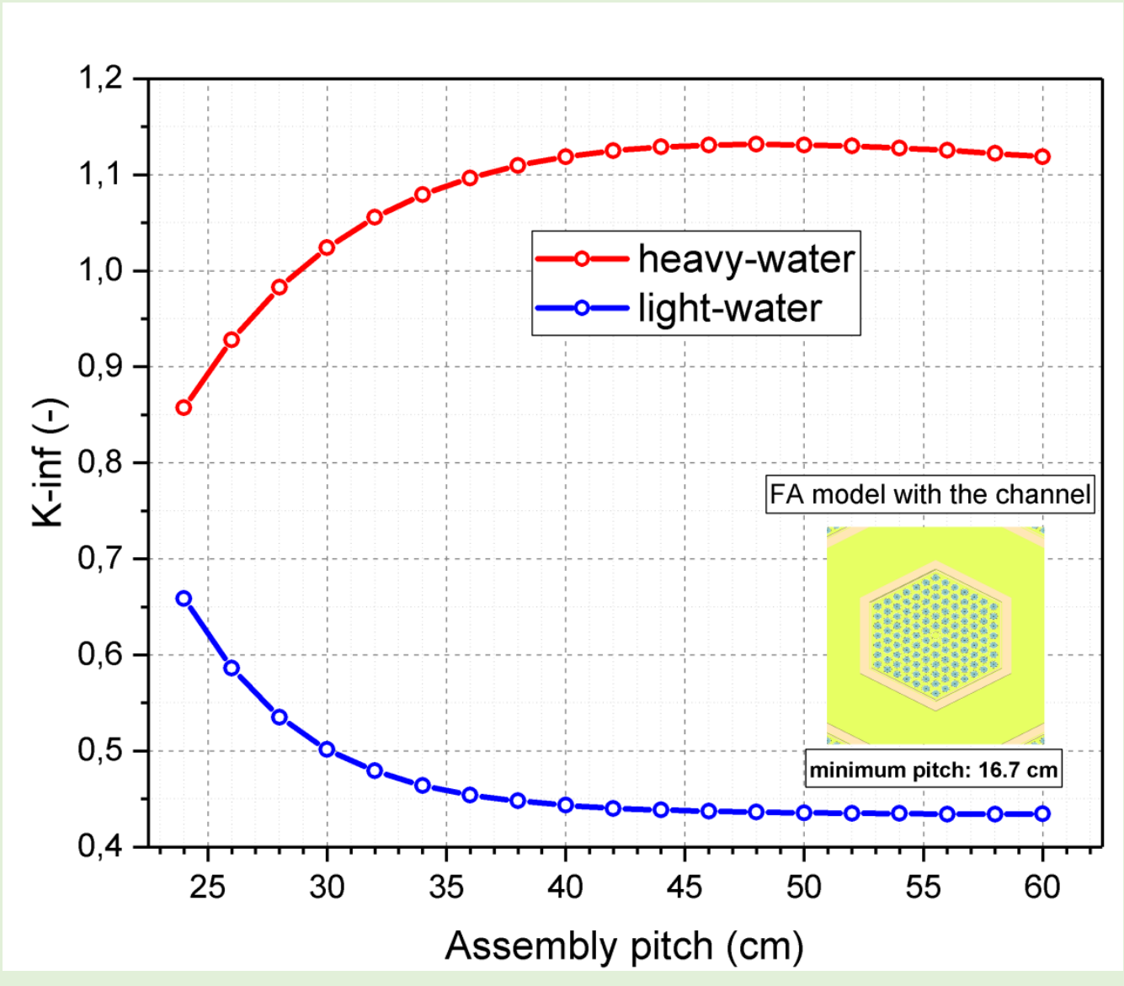

Figure 3: *The results for a different assembly pitch.*

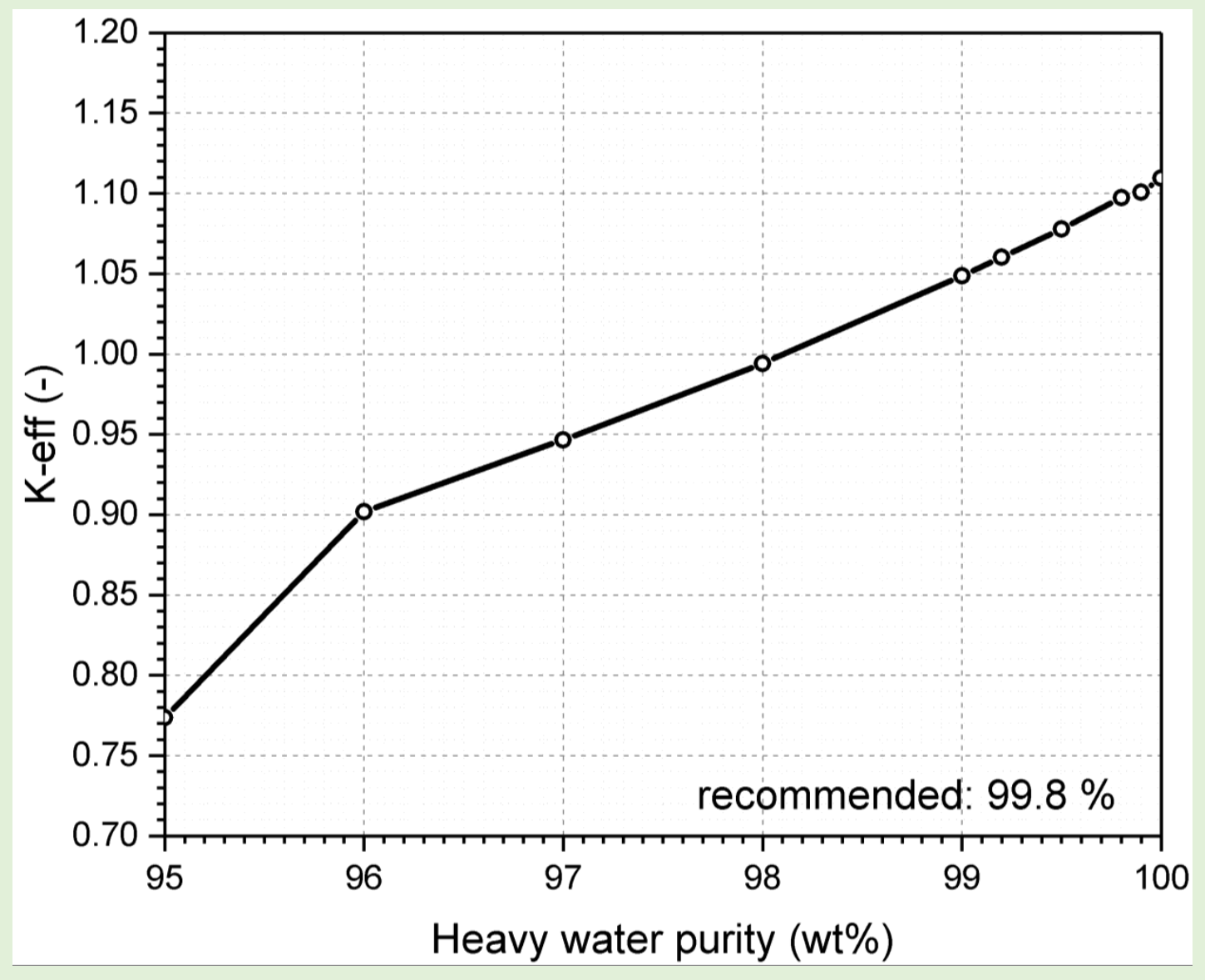

Figure 4: *The results of different heavy water purity.*

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 3D 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.

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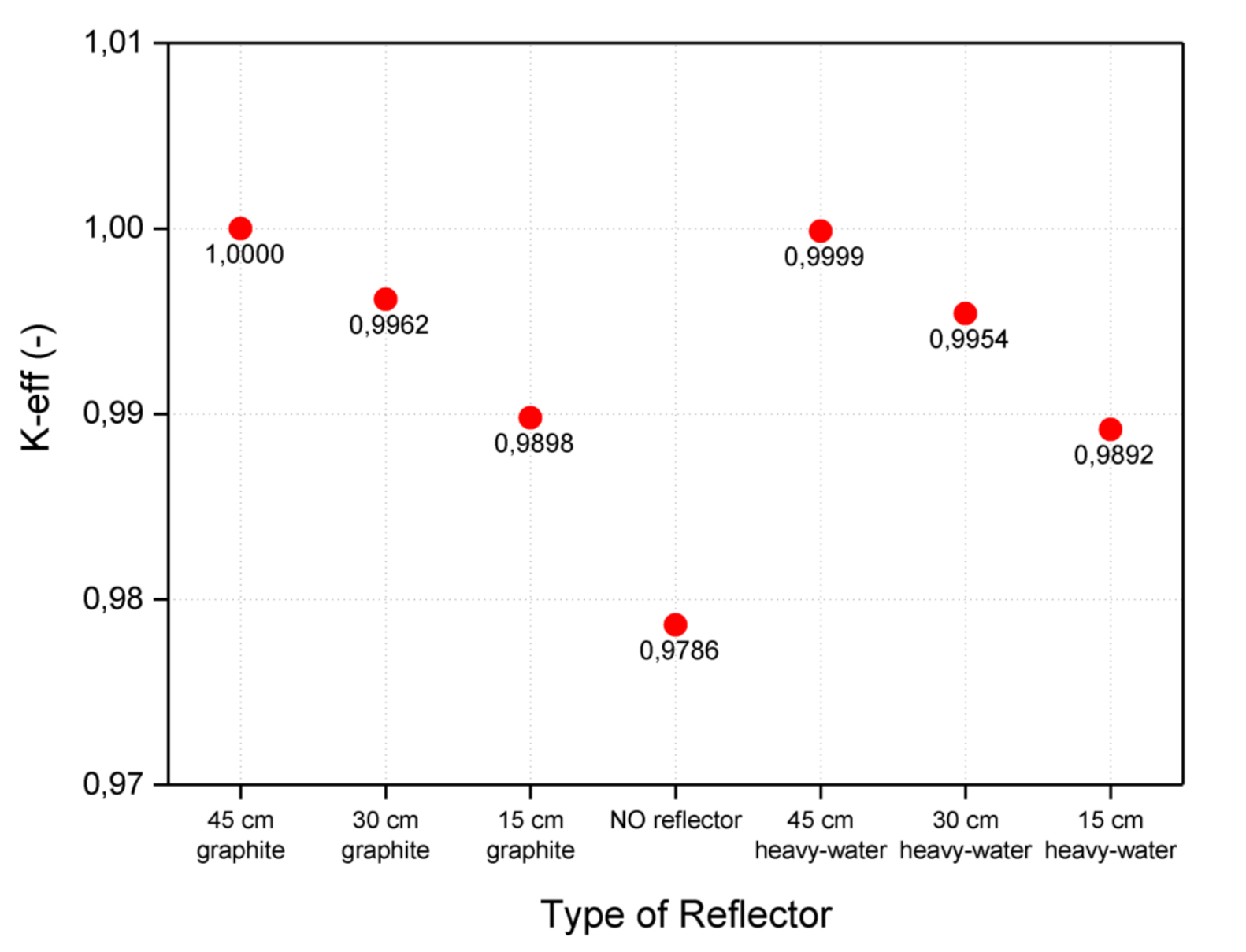

Figure 5: *The results for different types of reflector and thicknesses.*

REFLECTOR

Each core is surrounded by a neutron reflector or baffle. The reason is that it reduces neutron leakage and increases K-eff. 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.

3. TEPLATOR 3D MODEL

Coolant / moderator	Heavy Water (D_2O) / Heavy Water (D_2O)
Thermal /electrical capacity, MW(t) / MW(e)	50 / does not produce electricity
Primary circulation	Forced circulation
NSSS Operating Pressure (primary / secondary), MPa	Ambient/Ambient
Core Inlet / Outlet Coolant Temperature (°C)	45 / 98
Fuel type / assembly array	VVER-440 / hexagonal with 126 fuel pins
Number of fuel assemblies	55
Fuel enrichment (%)	Spent fuel (< 1.2 wt% U-235 equivalent)
Core Discharge Burnup (GWd/ton)	2.3
Refuelling Cycle (months)	10 months with online option
Reactivity control mechanism	Moderator height, Control blades
Approach to safety systems	Inherent and passive safety with built/in decay heat sink
Design life (years)	60

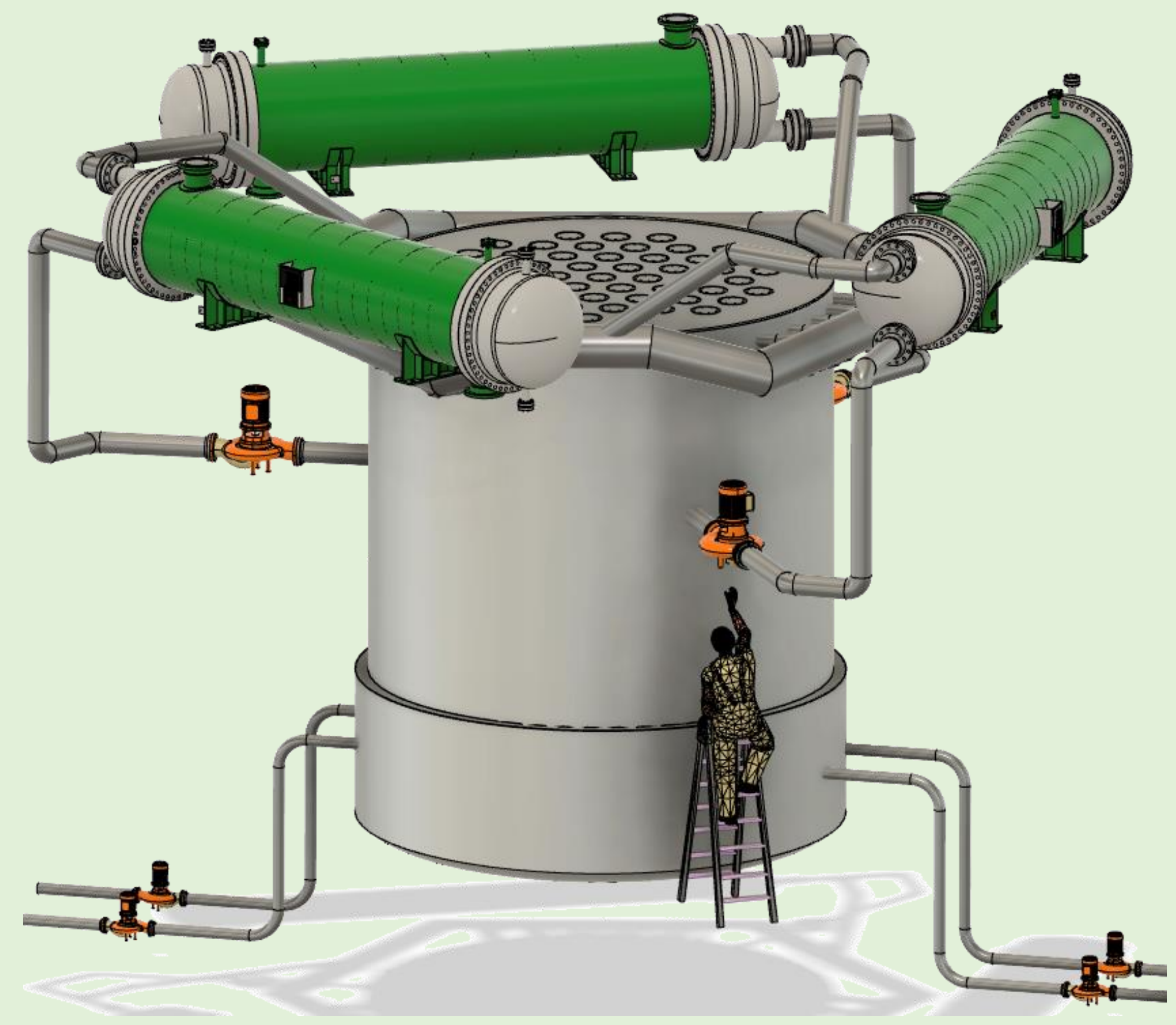

Figure 6: *TEPLATOR 3D visualization.*

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.

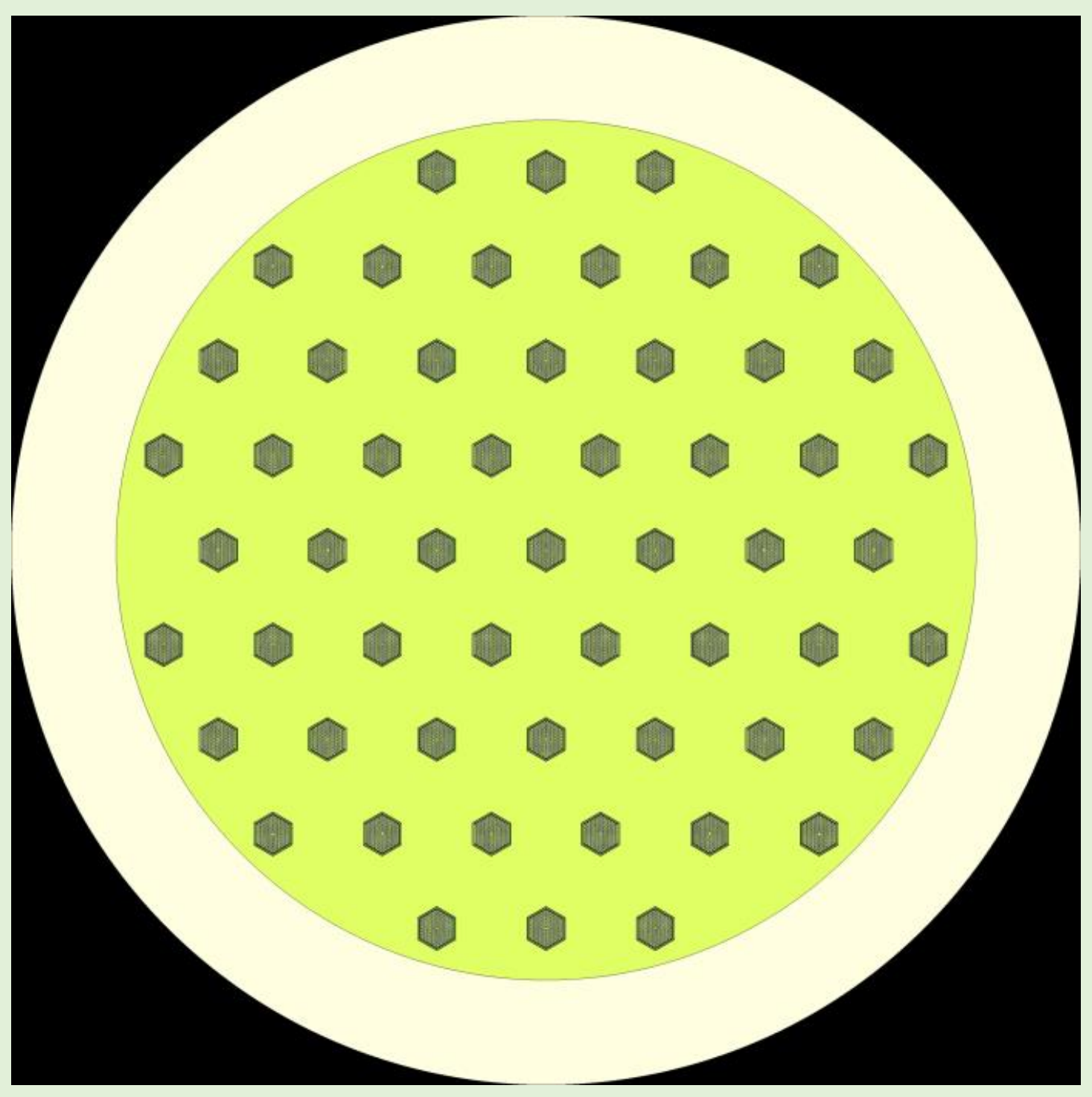

Figure 7: *TEPLATOR core visualization.*

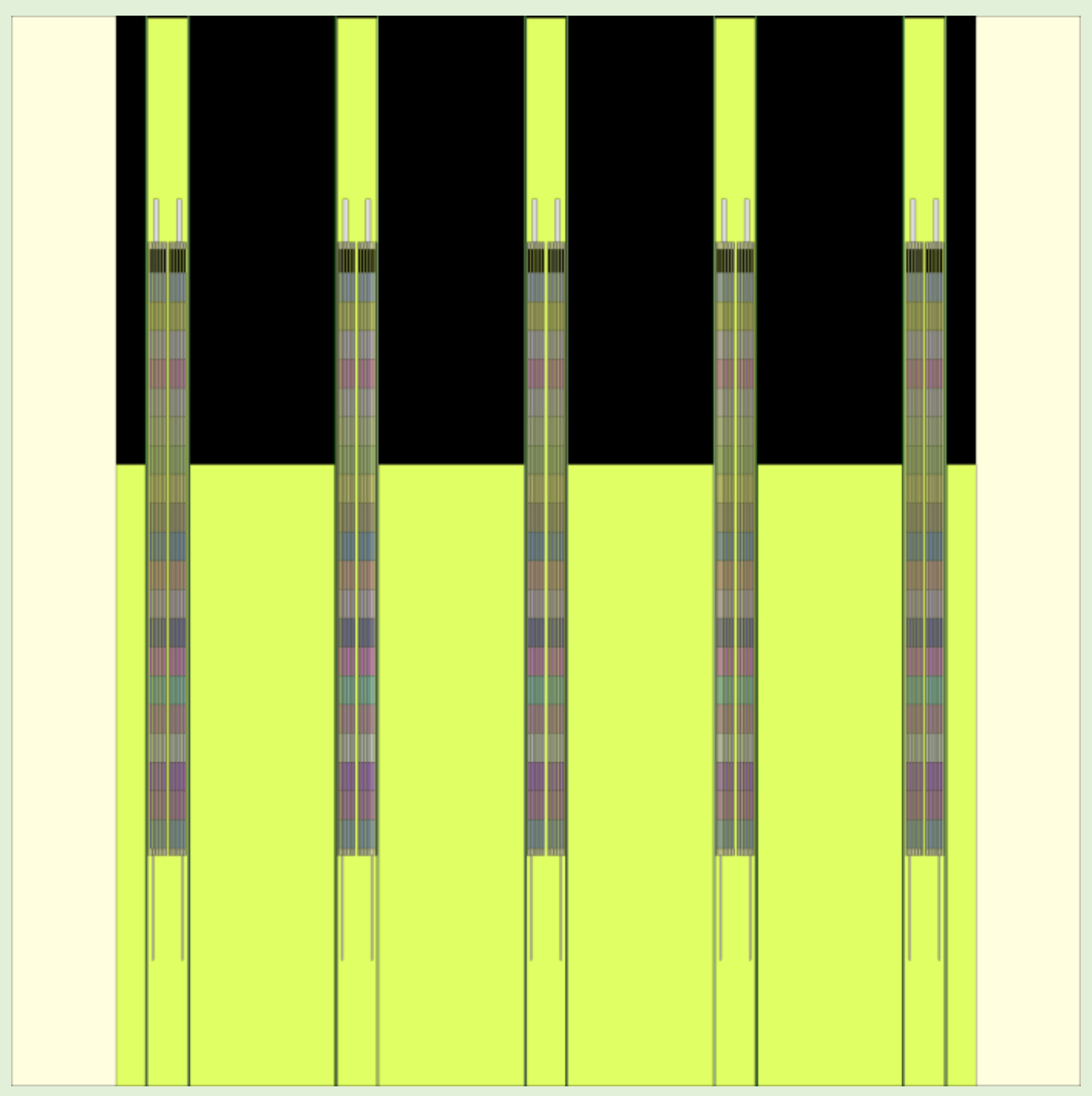

Figure 8: *TEPLATOR cut.*

4. CONCLUSION

This research 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.

- 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.

5. REFERENCES

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Acknowledgments

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