29th International Conference Nuclear Energy for New Europe
NENE 2020, September 7 - 10, Portorož, Slovenia

TEPLATOR DEMO: Basic Design of the Primary Circuit

Michal Zeman
University of West Bohemia
Univerzitni 8
306 14 Pilsen, Czech Republic
zema@kee.zcu.cz

Czech Institute of Informatics, Robotics and Cybernetics
Jugoslavskych partyzanu 1580/3
160 00 Prague, Czech Republic

Anna Fortova, Radek Skoda
University of West Bohemia
Univerzitni 8
306 14 Pilsen, Czech Republic
afortova@kee.zcu.cz, radek.skoda@cvut.cz

Czech Institute of Informatics, Robotics and Cybernetics
Jugoslavskych partyzanu 1580/3
160 00 Prague, Czech Republic

ABSTRACT

The TEPLATOR is an original way of district and industrial heating using nuclear power. It means, that TEPLATOR uses spent nuclear fuel from nuclear power plants. The spent nuclear fuel is the one that did not reach its regulatory and design limits. This fuel can be taken either from spent fuel pool or interim storage. This means that the fuel for TEPLATOR is already manufactured and thus no additional cost for fuel arises.

This one of a kind design will be tested in a demonstration unit "TEPLATOR DEMO". This DEMO unit has 50 MW of thermal power with 55 spent fuel assemblies of VVER-440 in the core. The fluid output temperature from the core is 98 °C, thus the whole unit works on atmospheric pressure. It is constructed as three loop system with three main pumps and three heat exchangers. This paper describes the basic design of primary circuit. The main idea concerning the design is explained first. Then the evolution of the design from the first steps to current 3D model is included. Next discussion is focused on individual components of the TEPLATOR (i.e. heat exchangers, pumps etc.) Briefly the construction and operation of compensation means are presented. Finally, the whole concept of TEPLATOR DEMO and its design is summarized.

1 INTRODUCTION

In the overall final energy demand in Europe the heating and cooling accounts for almost 40 %. Heating as one of the human basic needs has a very deep connections with energy sector and energy companies. From the EU perspective almost half of the energy consumption is heating. The heating sector can be divided into three parts; residential, industry and tertiary. It is no surprise that the highest share (45 %) is made by the residential part (mainly households). It is followed by the industry with the share of 37 % and the rest are services (18 %). [1]

The current form of heating consists mainly of coal, gas and oil sources with some minor addition of biomass and waste incineration plant. It also produces large amount of waste heat and has low efficiency. With ever-decreasing pollution limits, it may be a problem in the future to continue operating existing facilities without major investments. These investments may cause an end to some facilities. Therefore, TEPLATOR offers the possibility of using an innovative concept for central and industrial heating with the help of spent nuclear fuel from light water reactors. There are thousands of such partially used nuclear fuels in the Czech Republic.

2 TEPLATOR - GENERAL IDEA

TEPLATOR is an industrial concept of central supply of heat/cold using spent nuclear fuel. It uses only known, verified, and tested components. This concept allows the use of spent nuclear fuel from conventional nuclear power plants (pressurized water or boiling reactor types) without further modifications to this fuel. Spent fuel from a nuclear power plant, one that has already served its purpose in the operation of the power plant, is usually transported from the reactor first to the spent fuel storage pool and after some time is transferred to storage containers, where it remains in interim storage. There, provided it is not reprocessed, it usually ends its life cycle for the operator. TEPLATOR represents another economic use for this fuel. Such fuel will be used in the core of the TEPLATOR and will generate heat, which could be used for industrial or central heating or cooling. After the construction of the TEPLATOR, the fuel costs would be negligible, which would significantly affect the price for the heat supplied and especially its stability. The major parameters can be found in the Table 1 below.

Table 1: Main parameters of TEPLATOR

Reactor type	Pool type reactor
Coolant/moderator	Heavy Water / Heavy Water
Thermal/electrical capacity, MW(t)/MW(e)	50 - 200/Does not produce electricity
Primary circulation	Forced circulation
System pressure (MPa)	0.1
Core inlet/exit temperatures (°C)	45/98
Fuel type/assembly array	VVER-440/hexagonal
Number of fuel assemblies	55
Fuel enrichment (%)	Spent fuel (< 1.0 wt% U-235 equivalent)
Fuel burnup (GWd/ton)	2.3
Fuel cycle (months)	10
Main reactivity control mechanism	Moderator height, Control blades
Design life (years)	60
Distinguishing features	Pool Type Heat Generator Use of Spent Nuclear Fuel, Molten Salt Energy Storage with the ability to store the Residual Power of the Fuel

The general 3D model of TEPLATOR is shown in the Figure 1 below.

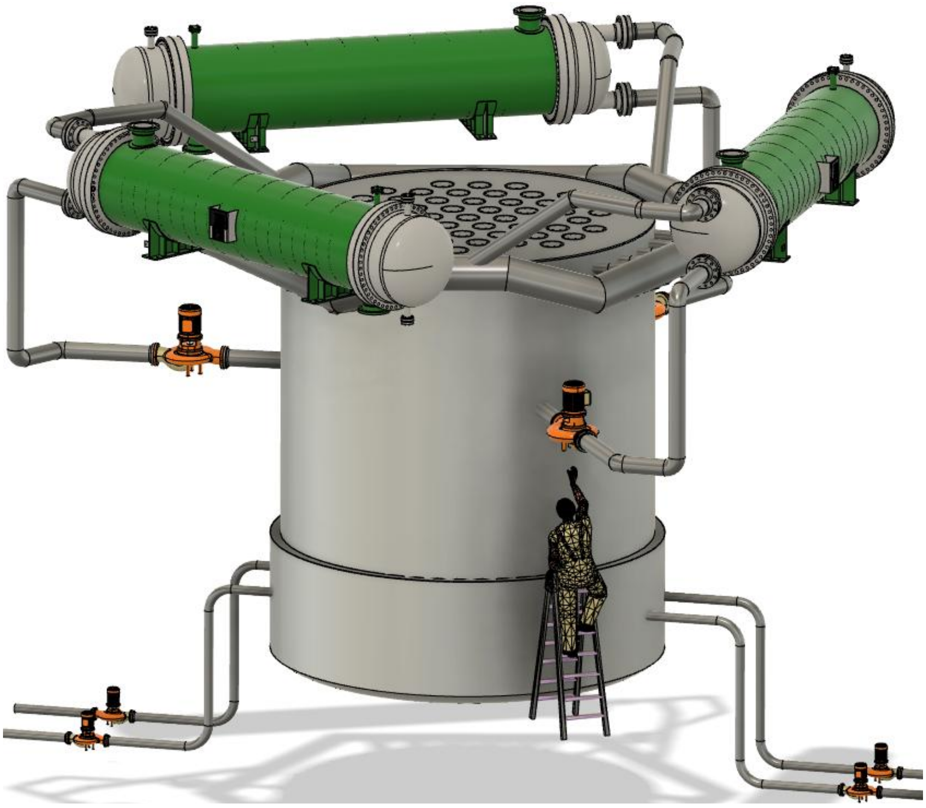

Figure 1: TEPLATOR

3 DESIGN

The design itself includes 3 circuits. The primary circuit includes a so-called calandria, a core with the above-mentioned fuel, three heat exchangers and three pumps; it is therefore a so-called three-loop design. The core is made from graphite channels in which the fuel is based. The space between the channels is filled by the moderator, heavy water. The coolant flows in the channel around the fuel and further it flows through a system of pipes at the outlet of which there is a collector. In this collector the coolant from all channels is collected. Three pipes are led out of this collector, each of which is led into one heat exchanger. The coolant passes through the primary side of the heat exchanger and returns to the fuel channels through the pump and the lower distribution chamber. In the secondary circuit (so-called intermediate circuit) the secondary heat transfer fluid (HTF) flows (according to the operating parameters either water or molten salt is considered). The HTF transfers heat from the primary circuit to the heating circuit itself via the secondary exchanger. The intermediate circuit includes two storage tanks serving as an energy storage system for heating demand peaks. These storage tanks are connected to this circuit and are able to simultaneously dissipate and store heat from the residual power of the fuel. The tertiary or heating circuit is then a set of secondary exchanger and pipes, which distribute the heat to the end customer.

The schematic description of the flow of individual medium can be found below. All three circuits are shown there and also the energy storage circuit with two storage tanks.

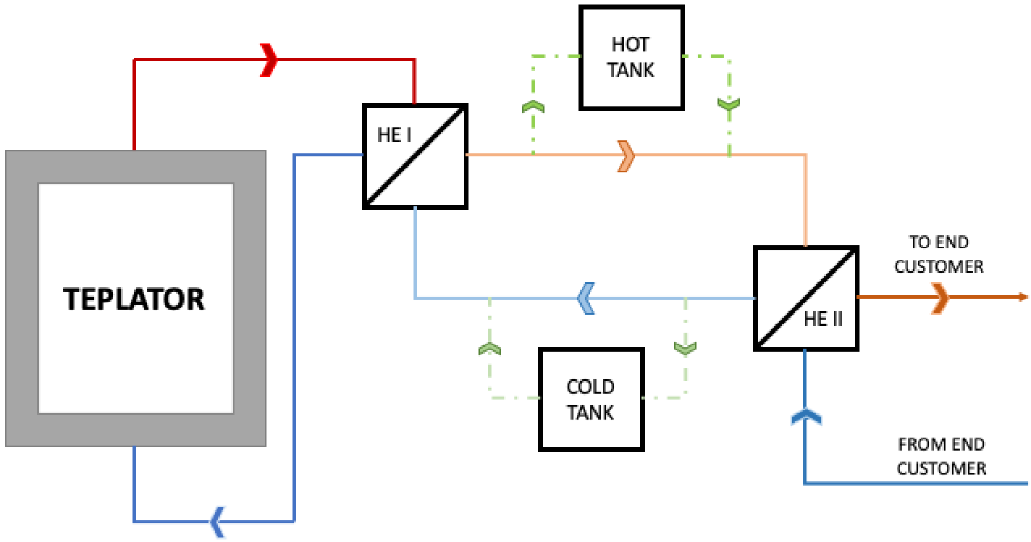

Figure 2: Basic diagram

3.1 Evolution of the design

The design process to this basic design lasted several months. We tried several variants of basically each component in the design. Individual approach to different component is described below. Overall the DEMO TEPLATOR is a 50 $MW_{(th)}$ unit with 55 fuel assemblies of VVER-440. The dimensions of the calandria are 4.75 m in diameter and a total height of 6.5 m.

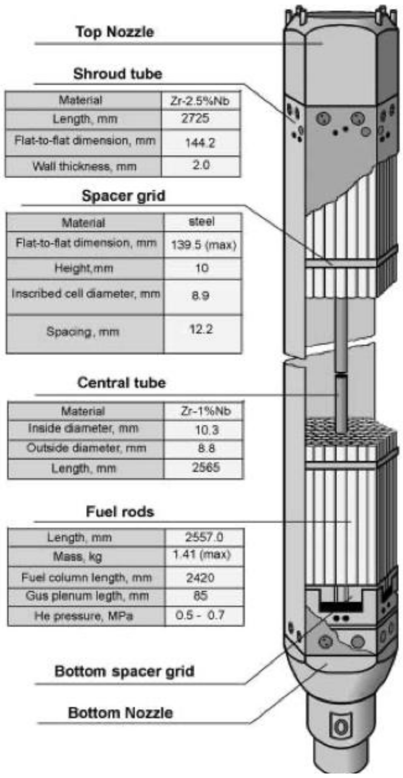

Figure 3: VVER-440 fuel assembly [2]

3.1.1 Fuel channels

The first thing that was going through the process of improvement was the fuel channel. We started first with tubular fuel channels. Soon it was realized that the channels would need to be much larger than hexagonal channels to be able to work neutronically. This led to the conclusion to use hexagonal channels.

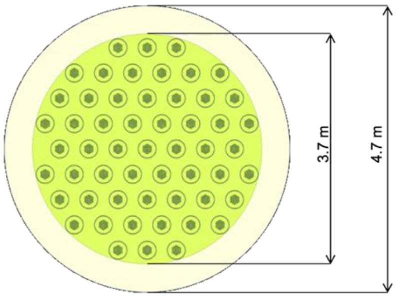

Figure 4: Tubular channels

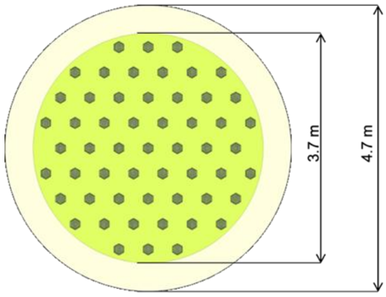

Figure 5: Hexagonal channels

3.1.2 Reflector, calandria and channel outlet

All of the TEPLATOR internals are placed in a calandria which at the bottom has a collector so it looks like it is double layered. This has its reason, because through this so-called collector the coolant flows back to the channels. The coolant flows through the heat exchanger, pump and to this collector where is then distributed to individual channels. The calandria is filled with heavy water, the total volume of heavy water in calandria is around 30 m^3. The channels are surrounded by a graphite reflector from all sides. Heavy water flows inside the fuel channels and the total volume of D_2O in the primary circuit is approx. 26 m^3. Since TEPLATOR works on atmospheric pressure, the calandria does not need to be very thick. The channel outlets are in four rows above each other, this was also a subject of evolution since all of internal parts needed to fit there without blocking each other. All of the channel outlets are led to the upper collector. This collector is an anulus around the TEPLATOR calandria. At the beginning the anulus was larger and it was divided into three separate parts, one for each heat exchangers. As the designing process continued, we realize that one collector for all the heat exchangers is better, mainly because of the safety point of view.

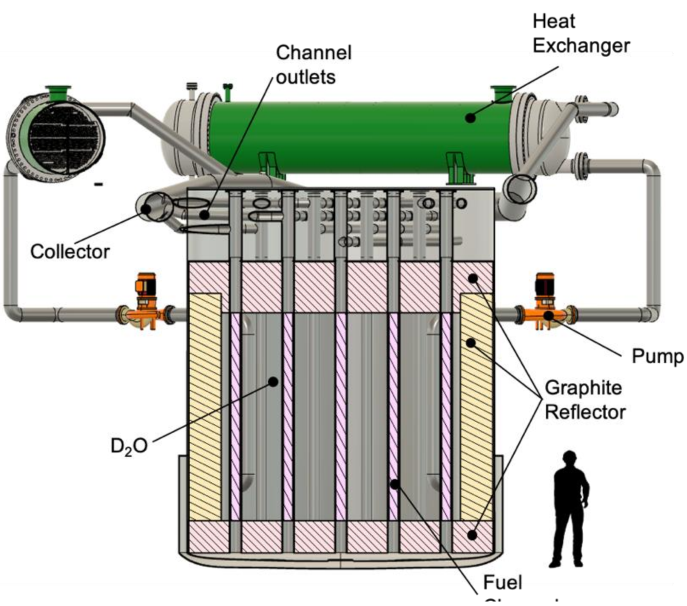

Figure 6: TEPLATOR – cut

3.1.3 Heat exchangers and pumps

In the case of the heat exchangers, the obvious question was whether to use vertical or horizontal heat exchangers. Since one of our main targets was to have the dimensions as small as possible, the horizontal heat exchanger was chosen. The design is a three-loop, so there are three heat exchangers. The heat transfer surface of one heat exchanger is 520 m2. Each heat exchanger is able to cool 100% of the power, in case of failure of the others. The pump system consists of three standardized pumps, each has a nominal power of 130 kW and the volume flow rate is 450 m^3/h.

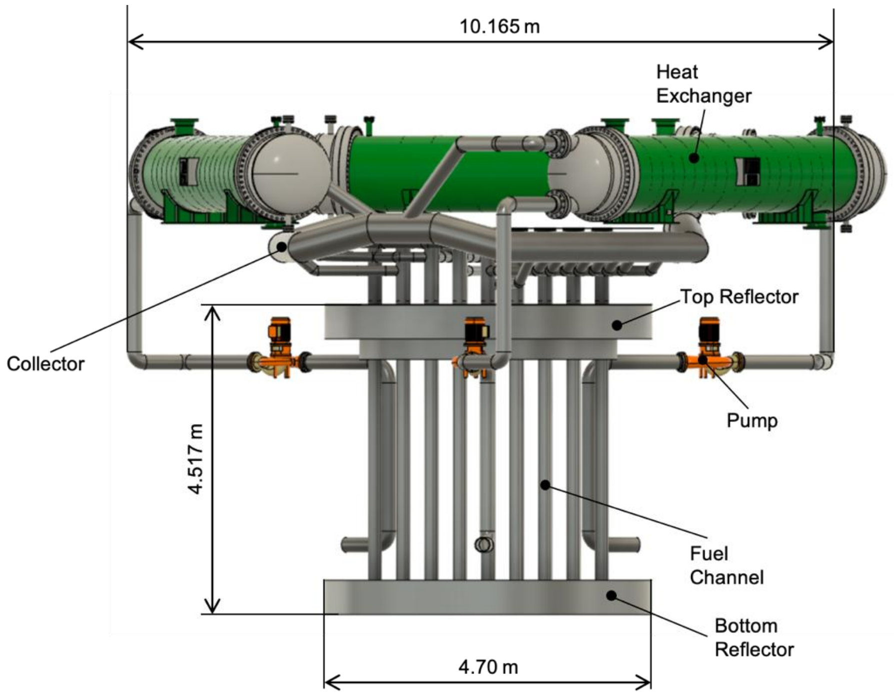

Figure 7: The look on the TEPLATOR without the reflector and outer shell

3.1.4 Control and safety means

The control of the TEPLATOR is achieved by controlling the moderator (heavy water) level in the calandria. The pump system ensures the filling or draining of heavy water. There are two pipe systems, one for the calandria and one for the channels. As a safety means of TEPLATOR the blades from absorber material (B_4C) are used. These blades are in a louver arrangement so they would not take as much space in the upper part of TEPLATOR. They are placed below the upper lid and graphite reflector in a third symmetry. In case of accident they will fall into the moderator and stops the reaction, see figure below.

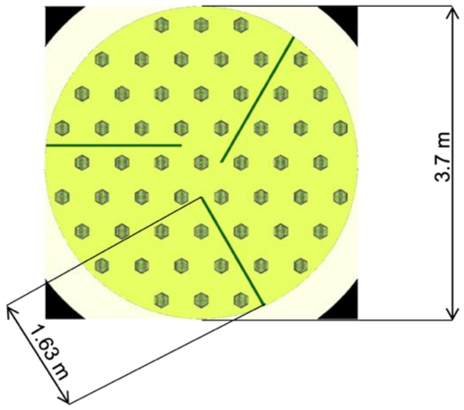

Figure 8: Safety B4C plates

4 CONCLUSION

The TEPLATOR is an innovative way of district heating or cooling using spent nuclear fuel. Before the full scale TEPLATOR can be build, the demonstration unit needs to be utilized. The demonstration unit has a 50 $MW_{(th)}$ and this paper dealt with the preliminary basic design. The first steps in the constructional design were taken and first 3D model of TEPLATOR was obtained. In this step all of the main components, circuits and the overall construction were designed. The control and safety measures of TEPLATOR were also taken into account. For controlling the TEPLATOR we use the control of D_20 level. Heavy water is filled into the calandria from the storage tank or it is drained from the calandria, ensuring the desired level of power is obtained. As a safety means the absorber plates from B_4C are used. They are utilized in a louver arrangement in order to safe space in the upper part of the calandria. This preliminary basic design is a start to a more comprehensive process which will take place now. Our team is already working on a more detailed design of the TEPLATOR, which will take into account all the valves, auxiliary pumps, the secondary and tertiary (heating) circuit and the plant layout itself as well.

ACKNOWLEDGMENTS

Research and Development has been funded by the Czech Science Foundation through project no. SGS-2018-023.

REFERENCES

[1] K. Kavvadias, J. P. Jimenez Navarro, a G. Thomassen, *Decarbonising the EU heating sector: Integration of the power and heating sector*, 2019. vyd. European Commission: Publications Office of the European Union.

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

[3] D. D. Andrews *et al.*, *Background Report on EU-27 District Heating and Cooling*

Potentials, Barriers, Best Practice and Measures of Promotion. Luxembourg: Publications Office of the European Union, 2012.

[4] R. Škoda *et al.*, „TEPLATOR: nuclear district heating solution", prezentováno v Nuclear Energy for New Europe 2020, Portorož, Slovenia, 7. - 10. 09 2020.

[5] J. Závorka, M. Lovecký, a R. Škoda, „BASIC DESIGN OF THE TEPLATOR CORE - CONSTRUCTION", prezentováno v Nuclear Energy for New Europe 2020, Portorož, Slovenia, 7. - 10. 09 2020.

[6] A. Fořtová, M. Zeman, a J. Jiřičková, „TEPLATOR: Residual heat removal by energy storage", prezentováno v Nuclear Energy for New Europe 2020, Portorož, Slovenia, 7. - 10. 09 2020.

[7] J. Škarohlíd, O. Burian, A. Fořtová, M. Zeman, a R. Škoda, „Thermal energy storage for TEPLATOR: technology, utilisation and economics", prezentováno v Nuclear Energy for New Europe 2020, Portorož, Slovenia, 7. - 10. 09 2020.