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Natural Uranium as Alternative Fuel for TEPLATOR

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Introduction

The TEPLATOR is designed as a new type of reactor for operation with an irradiated VVER-440 fuel assembly with optimal burnup. The reactor will be used as a district heating station. This solution could be interesting for countries, which operate VVER-440 reactors, and which have a large amount of irradiated fuel assemblies stored in interim storage. If some country or operator wants to operate the TEPLATOR and they do not own the irradiated fuel, is it possible to use a special fuel made of SEU or natural uranium.

This article focuses on natural uranium fuel type development, which is based on the novel TEPLATOR geometry. Set of calculations was performed using Serpent neutronics code to find an optimal geometry and materials of the fuel assemblies. The input parameters were taken from the existing TEPLATOR design: dimensions of a reactor vessel, materials of the core, reflector and finally pitch of the fuel channels [1].

Fuel design

First of all, it was necessary to choose a type of fuel and suitable geometry. There are only some possibilities of the fuel geometry design due to defined arrangements and a size of reactor core [1]. Only two materials of the fuel were considered for these purposes – uranium dioxide and metal uranium. First approach was to use the VVER-440 fuel assemblies with a natural enrichment or CANDU fuel bundles. Unfortunately, these fuel geometries cannot be used, because the reactor did not reach criticality (VVER type). The CANDU fuel type has big disadvantage – big void coefficient during LOCA accident. These all aspects led to creation of completely new fuel type geometry - a tubular geometry, which has not been used yet in any LWR power reactor type but is widely used in a research and experimental reactors [2]. The two different types of tubular fuel were calculated - cylindrical and hexagonal tubes (Figure 1). One, two and three concentric tube fuel arrangements for both types of fuel assemblies were evaluated. The thickness of cladding was set to 1 mm, which is made of Zircaloy-4. The gap between the individual fuel tubes was set to 5 mm due to sufficient flow of cooling heavy water (IRT-4M is only 1.35 mm with two times higher heat flux [2]). The height of fuel assembly is 3.2 m and the outer diameter of fuel assembly is 7.1 cm in both cases. Figure 2 presents the whole model of the reactor core. The optimal fuel layer thickness for metal uranium and uranium oxide was determined by set of calculations (see Figure 3 and Table 1). All calculations of designed fuel parameters and whole reactor core were performed by using Serpent 2.1.30 code [3]. Each model was calculated with 1 000 active generations, 50 inactive generations and with 30 000 neutrons per one history. All calculations were performed in ENDF/B-VII.1 nuclear data library. The uncertainty of all calculations is between 8 to 15 pcm.

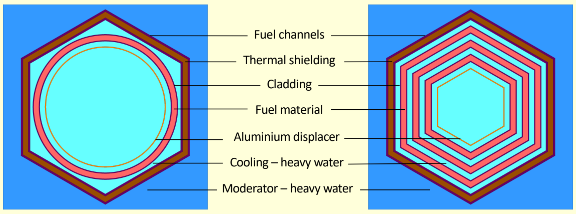

Figure 1. Description of the single CYL tube and three HEX tube fuel assembly

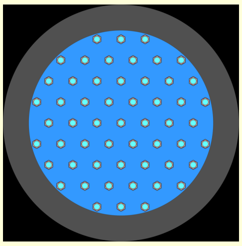

Figure 2. The schematic model of TEPLATOR reactor core – floor plan

Table 1: The highest value of k_{eff} for all cylindrical and hexagonal tube modifications and fuel thickness d for different fuel material

Modification	fuel type	d [cm]	k_{eff}	Modification	fuel type	d [cm]	k_{eff}
1 CYL tube	U metal	1.0	1.06619	1 HEX tube	U metal	1.0	1.0669
	UO_2	1.0	1.03038		UO_2	1.0	1.03578
2 CYL tube	U metal	0.6	1.04854	2 HEX tube	U metal	0.6	1.04888
	UO_2	1.0	1.03482		UO_2	1.0	1.03547
3 CYL tube	U metal	0.5	1.03568	3 HEX tube	U metal	0.5	1.03467
	UO_2	1.0	1.02940		UO_2	1.0	1.02959

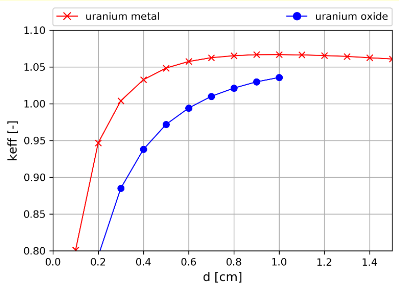

Figure 3. Hexagonal fuel assembly – dependence of k_{eff} on the fuel layer thickness d

Mitigation of void coefficient

Possibility of reduction of a positive coolant void reactivity coefficient is placing a special coolant displacer in the centre of the fuel assembly. This displacer was designed as special 1 mm thick aluminium tube with a welded bottom. There is a small drilled hole in the centre on the bottom of the displacer and the top of the displacer is open, see Figure 1 and Figure 4. The hole on the bottom of the displacer ensures at least a small flow of coolant trough displacer. The displacer significantly extends a time until the fuel channel is dried in case of single cooling channel LOCA, which greatly slows down a positive reactivity insertion. For instance, the time to full dry-out of the displacer is around 35 min with a 2 mm hole in diameter. The displacer affects the k_{eff} during normal operation negligibly. The main benefit of the displacer is reduction of positive reactivity insertion during LOCA accident due to positive coolant void coefficient. The difference between cases with or without the displacer shows Table 2.

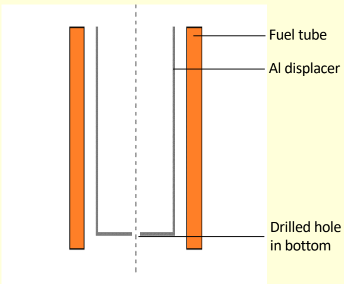

Figure 4: Schematic cut of displacer

Operation time

The final goal was verification of the TEPLATOR operation time at full output power with the new designed fuel. The highest k_{eff} is for the hexagonal geometry with the 1 cm thick fuel layer, which shows Table 1. The cases with 0.9 cm thick layer and 1.1 cm thick layer reach almost the same k_{eff} so these three variants were considered to the following burnup calculations. The comparison of the layers is in the Figure 5. It can be observed that the operation time is much higher for 1.1 cm thickness than for 1 cm thickness with the highest calculated k_{eff}. This phenomenon can be explained by the fact that there is more uranium in the reactor core for the case with the 1.1 cm layer compared to the 1 cm layer. The longest operation time 1682 EFPD reaches 1.1 cm thick fuel layer, which corresponds to 15 718 kg of metal uranium (see Table 3).

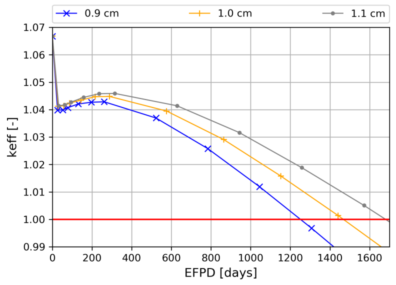

Figure 5. Influence of fuel layer thickness on operation time, EFPD – Effective Full Power Day

Table 2: The comparison of k_{eff} in standard operation and during LOCA accident in seven central cooling channels after channel drying – cases with and without the displacer

Modification	d [cm]	without LOCA	LOCA - without displacer	LOCA - with displacer	Δk_{eff} [pcm]
1 CYL tube	1.0	1.06619	1.07473	1.06890	+583
1 HEX tube	1.0	1.06690	1.07757	1.07168	+589

Table 3: One hexagonal tube - three different fuel layer thickness d, k_{eff} on beginning of cycle, weight of uranium metal m and time of operation *EFPD*

d [cm]	BOC k_{eff} [-]	m U metal [kg]	EFPD [days]
0.9	1.06677	13066.2	1252
1.0	1.06682	14403.7	1468
1.1	1.06673	15718.4	1682

Conclusions

The two fuel materials, uranium oxide and metal uranium, were tested in a few new geometry types of fuel. All the calculations were performed by the neutronics code Serpent. As the best geometry type the tubular geometry was chosen and two types of tubes were examined – cylindrical and hexagonal. One, two and three-tube structure for each type of geometry (cylindrical and hexagonal) were tested and the best thickness of the fuel layer were found. The burnup calculations were carried out for the chosen thicknesses of the fuel layer. The calculations also prove that the designed fuel can be operated for at least 5 heating seasons (10 months each). Optimization of the fuel quantity, operation time and the other aspect are now under investigation.

Finally the paper proposes an unique structural element of the fuel, the special displacer. This special displacer suppresses influence of the moderator positive void coefficient. This tool retains a significant amount of coolant for a certain time during leakage so it can be used as a mitigation of the Loss of Coolant Accident effect. All results obtained in this article are part of the first investigation and further research of the fuel cladding thickness, material, fabrication of metal uranium layers, thermohydraulic analysis etc. will be done. Burnup calculations and other results confirmed that there are several possibilities of fuel geometry, which can be used with natural uranium as the alternative fuel for the TEPLATOR.

References

[1] J. Závorka, M. Lovecký, R. Škoda, Basic Design of the TEPLATOR Core – Construction, International Conference Nuclear Energy for New Europe, Portorož, Slovenia 2020

[2] E.P. Ryazantsev, P. M. Egorenkov et al., Testing of the IRT-4M type FA with LEU UO_2-Al fuel in WWR-CM reactor, 2000 International Meeting on Reduced Enrichment for Research and Test Reactors, Las Vegasm Nevada, 2000

[3] J. LEPPÄNEN ET AL., “The Serpent Monte Carlo code: Status development and applications in 2013” Annals of Nuclear Energy (2015)

Acknowledgement

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