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INNOVATION AT PAKS NUCLEAR POWER PLANT

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ABSTRACT

In the summer of 2014 at the Maintenance Division of Paks Nuclear Power Plant Ltd. in Hungary there was an opportunity to take part in the preparatory work a new and innovative project for introduction. This is a charge-planner software support using the tests related the new fuel. The necessary calculations were completed and after obtaining the results the conclusion is that the actual 12 month operating period – the so-called campaign length – can be increased to 15 months, by using and shuffling the new fuel with higher enrichment, and by loading six fuel assemblies with gadolinium oxide into the unit. Conclusion is the new Gd-2_4.7 fuel initial expectations were met and managed to find a favorable average enrichment not only considering nuclear physics, but also economic, risk management, material structure and security points of view as well. Testing can be started in the summer of 2015, and the fuel can be loaded into Unit 3 for a test period of 365 days.

Keywords: new nuclear fuel, capacity increase, advantages

1. INTRODUCTION

In the summer of 2014 at the Maintenance Division of Paks Nuclear Power Plant Ltd. there was an opportunity to take part in the preparatory work for the introduction of the innovative project of a 15 month long operating interval (project C15). The main objective of the project C15 was to extend the actual 12 month operating period to 15 months, by means of using and shuffling the higher enriched fuel, and by disposing 6 fuel assemblies with gadolinium oxide into the block. Therefore the actual 4.2% average enrichment goes up to 4.7%. In the Reactor Physics Division computer simulations, such as HELIOS 1.9, C-PORCA 7.0, CERBER and EGYS helped to determine the necessary arrangement and enrichment percentage of the fuel assembly. The computer softwares do not only help to determine the optimal design of the fuel bundle, but also enable to carry out simulations about the process of radioactive decay and the physical impacts on the reactor vessel. It is also necessary to examine the returns/outcomes of the project, and it is expedient to design an opinion poll based on a representative sample [4] [5] [6].

2. STRATEGIC PLAN OF THE PAKS NUCLEAR POWER PLANT LTD.

In Paks, the four VVER 440 units reach their originally planned 30-year operation time between 2012 and 2017. Altogether, the four blocks operate at 2000 MW total capacity and they provide 50.7% of Hungary's total energy production. Based on these facts, the management of the power plant decided to examine the possibility of a life time extension. It is important to point out that the nuclear investments and improvements must always meet the fundamental requirements of nuclear safety, economic efficiency and social acceptance. With regard to these aspects, Unit 1 received its 20 years lifetime extension permission in 2011, while Unit 2 in 2014. Examination of lifetime extension of Unit 3 is still in progress, it is expected to get the permission in late 2015, while Unit 4 in 2016. Therefore, further operation of the power plant is guaranteed, along with the capacity increase. The innovative project C15 examines the benefits of using fuel assembly with gadolinium and increased enrichment. It is also important that the 15 month operation period is in accordance with the national and international safety regulations at all times [1] [3] [6] [8].

2.1. Carrying out project C15

In 2009, the nearly 5% enriched U-235 fuel assemblies designed for VVER-440 reactors were brought to the market by Russian fuel producers. Suppliers offered a fuel assembly with 4.87% average enrichment and 6 rods containing Gadolinium. This fuel was introduced and used with success in Slovakia as well, in

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the 12 month- long operational period. The applied manufacturing technology and the favorable operating experiences showed that the fuel can be used up to a high level (95%) of burn-out with safety, therefore Paks also started to examine the possible introduction of this fuel. Results of inner studies showed that the level of enrichment advised by the supplier is not optimal because of the too high level of unequal heat and capacity distribution within the fuel assembly therefore it would have been disadvantageous for Paks. As a consequence, the management of the power plant decided to consult with the Russian partners and the Centre for Energy Research of the Hungarian Academy of Sciences in order to specify the optimal fuel assembly design. While carrying out the analysis, researchers tried not to change the fuel geometry, and decided that for the necessary modifications only one step should be taken at a time. Furthermore, the flux level that reaches the reactor vessel should not be higher than the originally measured level (while using the Gd-2n fuel assembly).

The first step was to examine the given fuel assemblies: the U-235 (4.95%, 4.6%, 4.4%, 4.0%), the U-235-Gd (4.4%, 4.0%) and the Gd content (3.35%). Simulations of the possible versions (4.87%-4.65%) were carried out by HELIOS software (determination of pp-max, pp-gd levels). The next step was the determination of the optimal zone surface with the VERONA TH subchannel codes (determination of subchannel maximum). As the following step we specified the possible geometries by the HELIOS software for 4 versions. Calculations with the equilibrium operating cycle were carried out with EGYS models, while simulations of the transitional operating cycle were determined by C-PORCA 7.0 software (Fig. 1).

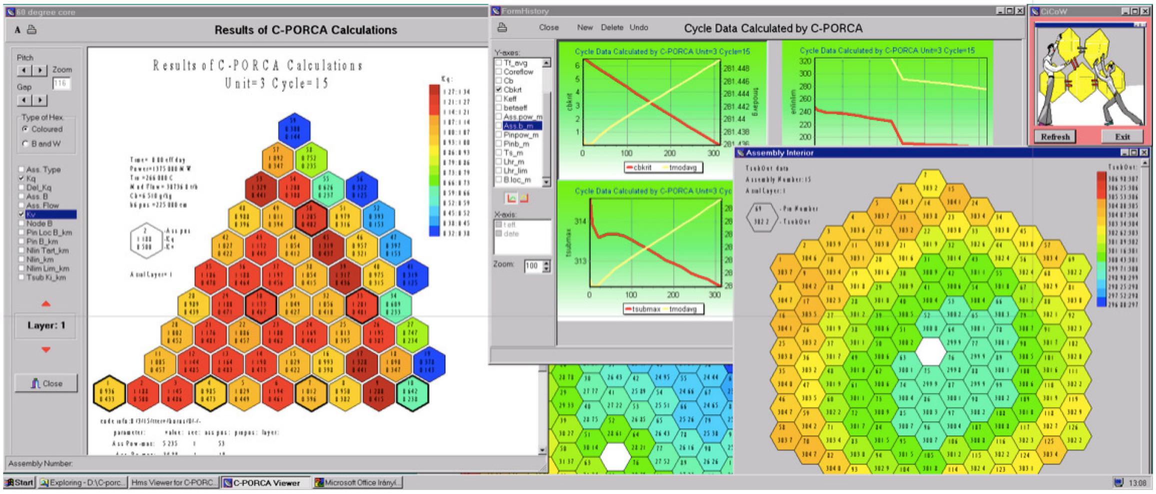

Figure 1. C-PORCA 7.0

2.2. Gd-2_4.7 fuel assembly

The Gd-2_4.7 is a Hungarian invention, a new type of fuel assembly planned by Imre Nemes head of department at the Reactor Physics Division. Simulations showed that the tank wall received less, or the same amount of radiation exposure than with the lower, 4.2% average enrichment fuel assemblies as during the 12 months cycle. The reason for this enhancement is that the use of 4.95% U-235 made it possible to use 6 rods of gadolinium oxide helping to decrease the inequalities in capacity within the fuel assemblies, and a total of 4.7% enrichment can be achieved. The 4.2% enrichment technology made it possible to use only 3 Gd rods, therefore it is less effective. The Gd-2_4.7 requires 102 new fuel assemblies every 15 months: 66 of them with 4.7% and 36 with the currently used 4.2% enriched fuel. In case of longer operational period the ratio of 4.7% fuel assemblies can be increased (Fig. 2), therefore an effective operational period of 425-428 days can be fulfilled. As a consequence, the advantage of the mixed

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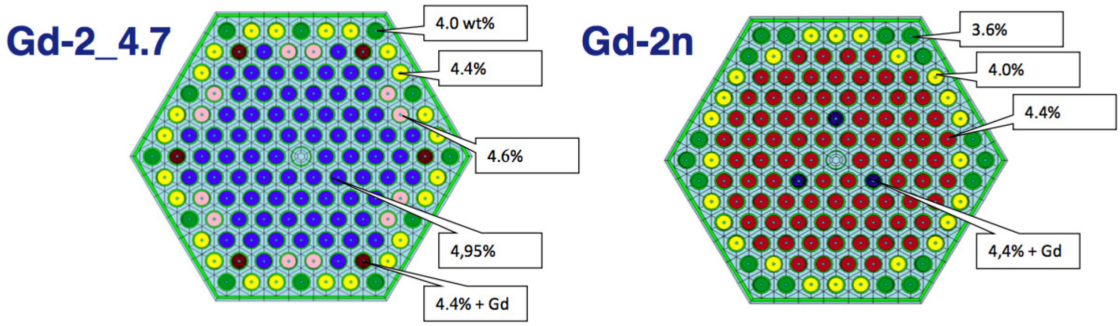
application of the fuel assemblies with different level of enrichment is that it makes the operational period more flexible. A further advantage is that the new configuration allows the possibility to use up a large amount of the 4.2% enriched fuel reserve. The third advantage is that this technique decreases the number of the burnt-out fuel assemblies in the long run [3] [5] [7] [8].



New fuel

	Enriched	Pieces	UO2
	4%	12	48
	4.4%+Gd	30	132
	4.6%	12	55.2
	4.95%	72	356.4
∑	-	126	591.6
Δ	-	**4.695238%**	

Actual fuel

	Enriched	Pieces	UO2
	3.6%	18	64.8
	4.0%	24	96
	4.4%+Gd	84	369.6
∑	-	126	530.4
Δ	-	**4.209524%**	

Figure 2. Gd-2_4.7 – Gd-2n fuel

2.3. The engineering tasks necessary for realization of the project C15 [3] [5] [7] [8]

The introduction of the C15 operational period involves three basic technical changes that affect the power plant:
- Usage of fuel with higher percentage of enrichment;
- Continuous system and subsystems operating periods lasting 3 months longer than previously;
- Lower amount of occasions for scheduled checks, changes, maintenance of the state monitoring systems and pressure tests;

Because of the devices' increased availability, along with fewer occasions for maintenance and periodical checks, each system and system element classified in different safety classes rise the question of necessary technical changes. There are three methods to overview these:
a) Verification of adequacy (e.g. measuring crack propagation);
b) By changing state maintenance programs belonging to the system element: for instance if the system element generalization cannot be verified by crack propagation calculations, changing the state maintenance program in its quality or period can verify the detection of the propositions causing the malfunction;
c) By changing the system element (e.g. changing the blade wheel of the main circulation pump);

The introduction of the C15 mainly means the task of alternating the documentation relating to previously mentioned points a) and b). Altogether only two technical modifications are necessary: changing the impeller of the main circulation pump in Unit 4, and updating the VERONA core-monitoring system (the VERONA system update is necessary for the on-line monitoring of the increased capacity of the Gd containing fuel assemblies) [3] [5] [7] [8].

2.4. Steps of authorization for introducing C15

The introduction of Paks Nuclear Power Plant's 15 months operating period has to be officially authorized. To use the Gd-2_4.7 fuel assembly the first step is to obtain the certifications for the long time storage, as well as the environmental permission for the Temporary Container of Burnt-out Fuel (the authorization for guaranteeing the safe disposal of the burnt out fuel). Furthermore it is necessary to modify the permit of operation of the storing establishment. It is also necessary to get authorizations for the fuel assembly tests and the carrying containers. Having obtained all the previously mentioned licenses and authorizations, testing could start in the summer of 2015, and 12 Gb-2_4.7 fuel assemblies could be loaded into Unit 3 for a test period of 365 days. For introducing the 15 months long campaigns, modifications had to be made in Paks Nuclear Power Plant's environmental regulations: the operative application form also had to be modified in order to use the Gd-2_4.7 fuel assembly's complete load. In addition, changing the power plant's scheduled state maintenance and operational period to 15 months needed a complex application of modifications. These are all the requirements for starting the 15 months operating cycle. C15 will be applied at first to Unit 2, then 3, 1 and 4 according modifications based on the operational documentations. When the first successful 15 month operational period and evaluation is over at Unit 2, modifications can be made in the permit of operation for Units 1 and 4. Regarding that the introduction of C15 is a complex process, National Security Service classified its case into Category 1, and public hearings will have to be held before all four cases of modifications in the operating permits. The purpose of the public hearings is to inform the public audience and to give chance to share their experiences, express their opinions about the matter, so that the authority can take them into account before bringing a final decision. Notices can be taken on the matter, questions can be asked from the licensed authority and from those who take part in the decision making [3] [5] [7] [8].

3. OPERATING AND MAIN REPAIRS UNDER C15

The introduction of the 15 month operational period involves significant changes in scheduling main repairs. From 2016 in Units 1-4 fuel reallocations will be carried out in three months cycles. The first shut down is planned to be in February, the second in May, the third in August and the fourth in November. Therefore the shut downs can be divided into four equal parts of the year, having nearly two months of pause after each event. These will happen 15 months later in the next year for each unit: the shut down in February will reoccur only in the May of the following year, the unit shut down in May will be conclusively stopped in next August, and the one stopped in November will stop operating in February.
In the first year, just as the actual sequence of unit shut downs is the following: Unit 1, Unit 4 then Unit 2 and 3. After 420 effective days of operation Unit 3 skips the first year and will be shut down only in the February of the following year. In the first year there will be only three unit shut downs, while in the zeroth year unit there will be four. The second year of operation for Unit 2 will be operated during a whole year, while in the fifth year all the units have to be shut down in sequence. Therefore the four units have a cycle of 5 years (or 60 months) but each of them shuts down only 4 times during this period (5x12=4x15=60). Considering the whole power plant with 4 blocks we can state that in a 5 year period in every 4 years there are only 3-3 shut downs.

Every fourth of the unit repairs takes more time and involves more work. As a consequence, in the fourth operating cycle it takes approximately 42 days, while in the eighth operating cycle, due to the pressure tests of the main circulating water, it takes approximately 56 days. The cyclical main repairs require approximately 26 days (Tab. 1). If the longer shut downs are scheduled to those years when only three units have to stop operation, both the production and the time required for maintenance can be made nearly equally proportioned during the five years period: two shorter and one longer stop takes nearly as much time as the four shorter shut downs in total. The following charts represent the cycle differences between the actual C12 and planned C15 fuel assemblies. The 26 days long values show the short, the 42 days long represent the middle and the 56 days long values indicates the length of the main reparations (the values are approximate, the exact figures are determined according to the given unit's main reparation schedule (Tab. 2). The "∑" columns represent the total number of days spent with maintenance each year.

Table 1. C12 operational periods:

Block	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26	42	26
2	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26	42
3	26	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26	26
4	26	26	42	26	26	26	56	26	26	26	42	26	26	26	56	26	26
Σ	120	120	120	134	134	134	134	120	120	120	120	134	134	134	134	120	120

Table 2. C15 operational periods:

Block	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1	26	56	26		26	26	42	26		26	26	56	26		26	26	42
2	42		26	26	26	56		26	26	26	42		26	26	26	56	
3		26	42	26	26		26	56	26	26	26	26	42	26	26		26
4	26	26		42	26	26	26		56	26		26		42	26	26	26
Σ	94	108	94	94	104	108	94	108	108	104	94	108	94	94	104	108	94

The main economical advantage of C15's realization is that the reduced number of days spent with main reparations involves the increase of the units' availability time (Tab. 3). The decreased number of the days spent with main reparations can be seen in the following chart (Δ represents the difference between C12 and C15).

Table 3. Real availability time

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Δ	26	12	26	40	30	26	40	12	12	16	26	26	40	40	30	12	26

Introduction of C15 equalizes the resource requirements for maintenance between 12 and 40 days in a year - on the average 26 days of savings - which means that the power plant can produce more electricity by 2% [3] [5] [7] [8].

3.1. Economic outlook

In the following the main items of the cost-benefit analysis will be discussed.

- "The income increase of the MVM Hungarian Electricity Ltd.": it includes the annual average income increase following the initial period of C15. The calculation is based on the average 25 additional block days; of course, the actual number of days varies between 12 and 40.

- The "fuel cost increase" originates from the higher cost of increased fuel assembly enrichment. After the introduction, this additional cost will be reduced proportionally to the used up amount of the 4.2% enriched reserves, because in the first years a power plant uses only 4.2% fuel assemblies and buys only 4.7% enriched fuel which costs approximately 15% higher than the Gd-2n. After having used up the Gd-2n reserves, the proportion of Gd-2_4.7 fuel assemblies can be increased, this can mean further fuel-cost optimization. The conservative cost-benefit analysis employed by the power plant omits this change.

- "The decreasing cost of maintenance" part: it counts with the expected decreasing cost of main repairs that includes the reduced costs of contractors and materials. In order to realize the benefits of the decreased costs and volume of work, modifications have to be made in contracts/drawdown.

Analecta
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- The "growing turnover of MVM Partner Ltd." comes from the electricity sold by the power plant to other contracted energy traders. The MVM Partner Ltd. sells the electricity as a complex product to the universal service providers for a set price. Energy traders realize profit from the difference between the set price of Paks and the actual market price of electricity. By changing to C15, energy trader companies can get nearly 300 GWh more electricity from Paks Nuclear Power Plant Ltd. in a year, which equals to HUF 1 bn, calculated with the currently positive margins, price level and increasing electricity selling [3] [5] [7] [8].

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