Economic Aspects of Dukovany NPP Fuel Cycle

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1. Introduction

At present, only those producers, which generate electricity cheap and reliable, take more dominant position on opened electricity market. The nuclear power plants generally belong to those sources. New requirements of the electricity market have on the contrary an impact on the whole fuel cycle. Two important factors influencing the fuel costs are the Total Operation Utilization Ratio (NPP Load Factor) as well as the progressive modernizing of the internal fuel cycle. The most important trend consists in higher fuel utilization (burn-up) together with further innovations like increase of power maneuverability according to the needs of the electrical grid.

These trends are generally in line with planned long-term upgrade of Dukovany NPP. The production of electricity has to be competitive during the gradual approaching opened electricity market. This process starts in the Czech Republic in 2002 and after 5 years it will be fully accomplished. In all further fuel cycle modernization the high standards of nuclear safety have to be preserved as well.

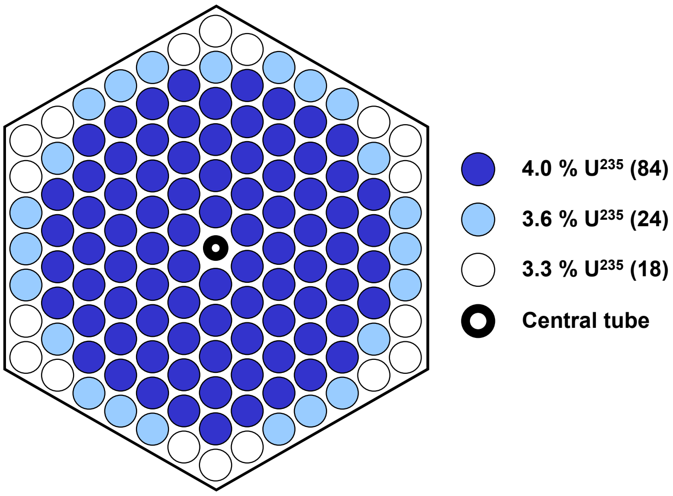

Figure 1. Fuel assembly with mean enrichment of 3.82%

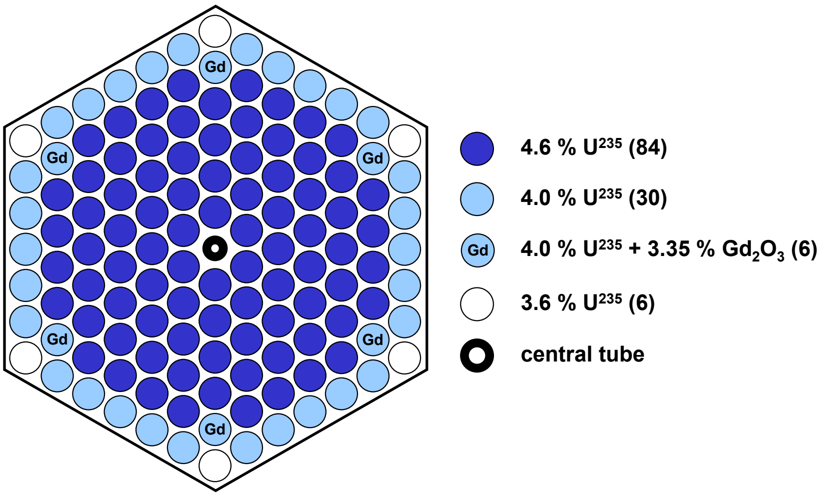

Figure 2. Fuel assembly with mean enrichment of 4.38%

2. Fuel Cycle of Dukovany NPP

All units of Dukovany NPP have worked in annual cycle since the beginning of their operation. The annual cycle was proved to be the best solution from point of view of economy, taking into account the annual grid demands and necessary maintenance intervals. The outage lengths was shortened step by step from 46 to present 32 days for standard outage and from 72 to 58 days for extended outage (performed once per 4 years). This, including decrease of mean reactor non-planned drop-out rate, has brought extension of annual cycle length by 20 FPDs.

Dukovany internal fuel cycle was originally designed as a three year cycle of the Out-In-In type. The number of reloaded assemblies was 114, 114 and 121 in subsequent cycles (average reload batch size was 116.3 assemblies). This number was divided into 36 assemblies with enrichment of 2.4% (incl. 12 control assemblies) and 80.3 working assemblies with enrichment of 3.6% (Table 1 and Figure 5). These reloads were not only uneconomical but they additionally increased the radiation load of reactor pressure vessel due to high neutron leakage typical for Out-In-In loading pattern.

The transition to 4-year cycle started in 1987. The neutron leakage from the core was sequentially decreased by insertion of older assemblies at the core boundary. In the first phase the three and half year cycle was accomplished, which means reduction average number of reloaded assemblies to 100.5 (with only 13.5 assemblies enriched to 2.4% incl. 12 control assemblies) and 87 working assemblies with enrichment of 3.6% (Table 1 and Figure 6).

Further fuel cycle development was enabled by increasing of control assemblies enrichment to 3.6% and by improvements in fuel assembly design. The assembly shroud thickness was reduced from 2.1 to 1.6 mm and the zirconium spacer grids were introduced instead of iron ones. The full 4-year cycle was reached just after introduction of new type of assembly with profiled enrichment with average value of 3.82% (Figure 1). Due to increased reactivity of the new assemblies the transition to the partial 5-year cycle could start. Currently the fuel batches consist of working and control assemblies with the same profiling and mean enrichment of 3.82%. The batch size is optimized according to the required cycle length so that the number of fresh assemblies varies usually from 78 to 90 (Figure 7).

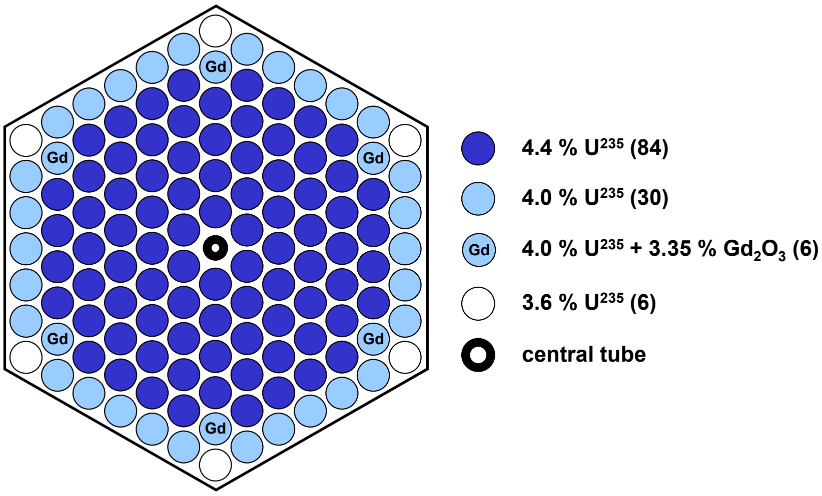

Figure 3. Fuel assembly with mean enrichment of 4.25%

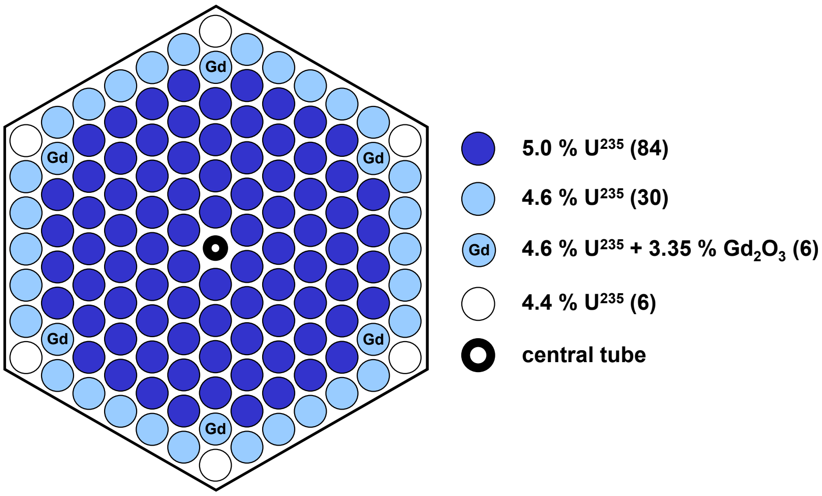

Figure 4. Fuel assembly with mean enrichment of 4.86%

Introduction of power control at Dukovany NPP was caused by acceptation of conditions and rules of the European grid. The company CEZ, plc, owner of Dukovany NPP, granted the program for reevaluation of fuel performance in load follow conditions to the Russian supplier. These analyses were finished in 2000 and new limits were postulated for fuel and core operation in secondary and tertiary load follow modes. Co-operation with fuel supplier resulted also in certain changes in fuel assembly design, mainly development of dismountable type of assembly, which is necessary for future fuel inspections and repairs.

From economic evaluation and comparison with fuel cycles of European NPP's follows that ever 4-year cycle would not be competitive in near future on Czech and European electricity market. Therefore, the fuel and core design was focused in introduction of 5-year cycle. As a consequence of increased fuel enrichment it was necessary to introduce burnable absorbers into the WWER-440 fuel assembly design. The new Amendment to current Fuel Contract, which covers these new types of fuel assemblies for 5-year cycle, was signed in April 2000. The mean enrichment was set to 4.38 or 4.21% respectively (Figure 2) and six fuel pins in one assembly was doped with Gadolinium as burnable absorber (BA). The “neutron sphere“ – certain increase of neutron density around the upper nozzle of WWER-440 control assembly, which influences fuel pins in neighborhood, was suppressed by joining plates with Hafnium to upper nozzle of control assembly. This fuel will be loaded into Dukovany reactors starting 2003.

In the same time the company CEZ launched a new tender for a long-term fuel supply for Dukovany after 2004. In the frame of this tender the Russian fuel supplier offered an advanced type of fuel assembly

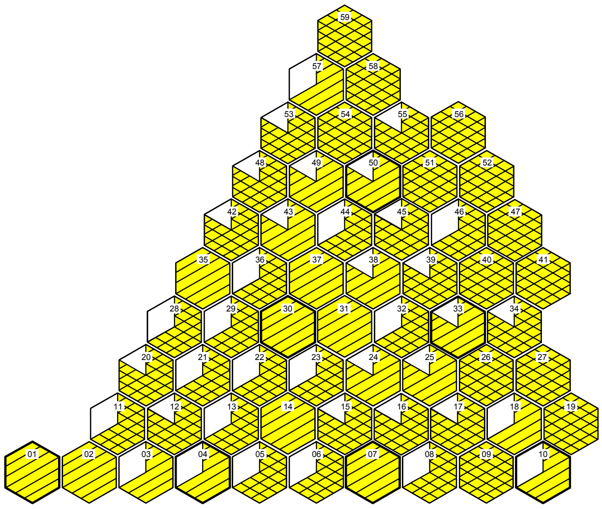

Figure 5. Typical loading pattern of 3-year cycle

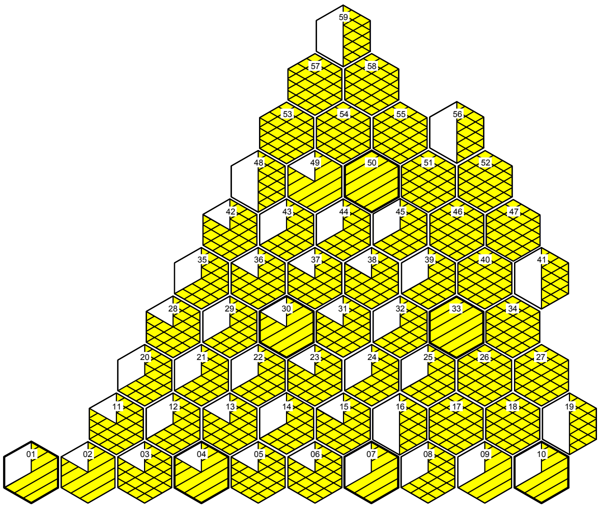

Figure 6. Typical loading pattern of 3.5-year cycle

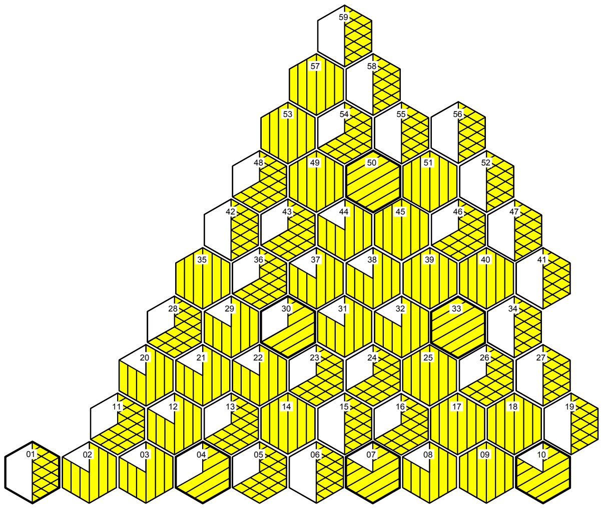

Figure 7. Typical loading pattern of 4-year cycle

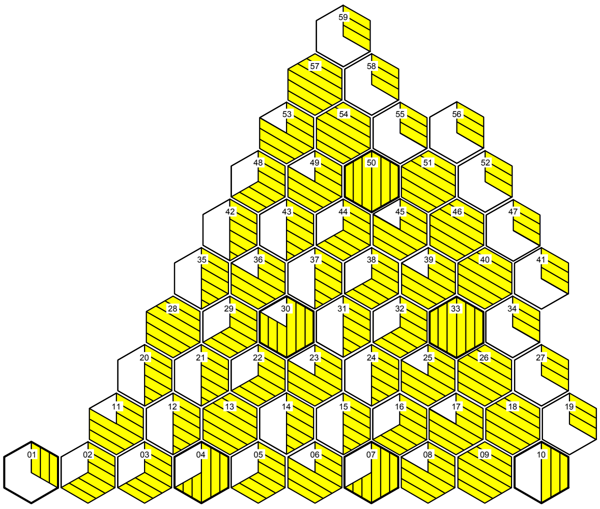

Figure 8. Typical loading pattern of 5-year cycle

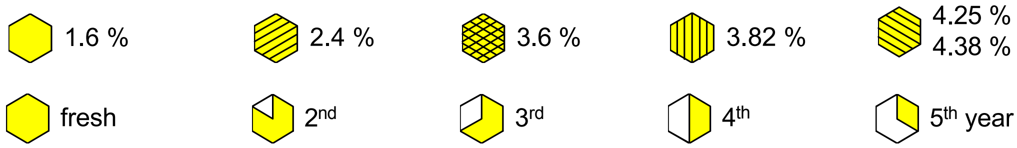

Table 1. Comparison of fuel cycle options

Type of fuel cycle	Cycle length, [FPD]	U total cons., [kg/FPD]	^{235}U cons., [kg/FPD]	Number of control assemblies			Number of working assemblies					U total cons., [kg]	^{235}U cons., [kg]	^{235}U cons., [g/MWd]	Relative costs, [MWh^{-1}]
				2.40	3.60	3.82	2.40	3.60	3.82	4.38	4.25				
3-year	291.1	47.74	1.54	12.0			24.0	80.3				13896.00	449.14	3.51	1.000
3.5-year	301.4	39.81	1.37	12.0			1.5	87.0				12000.00	413.28	3.12	0.884
4-year	316.6	32.81	1.22	6.0	4.5				76.5			10387.50	385.87	2.77	0.804
5-year	314.9	27.29	1.18			9.0				63.0		8595.00	370.67	2.69	0.751
5-year advanced	328.4	27.46	1.15			9.0					63.0	9018.00	376.90	2.62	0.735

cons.=consumption

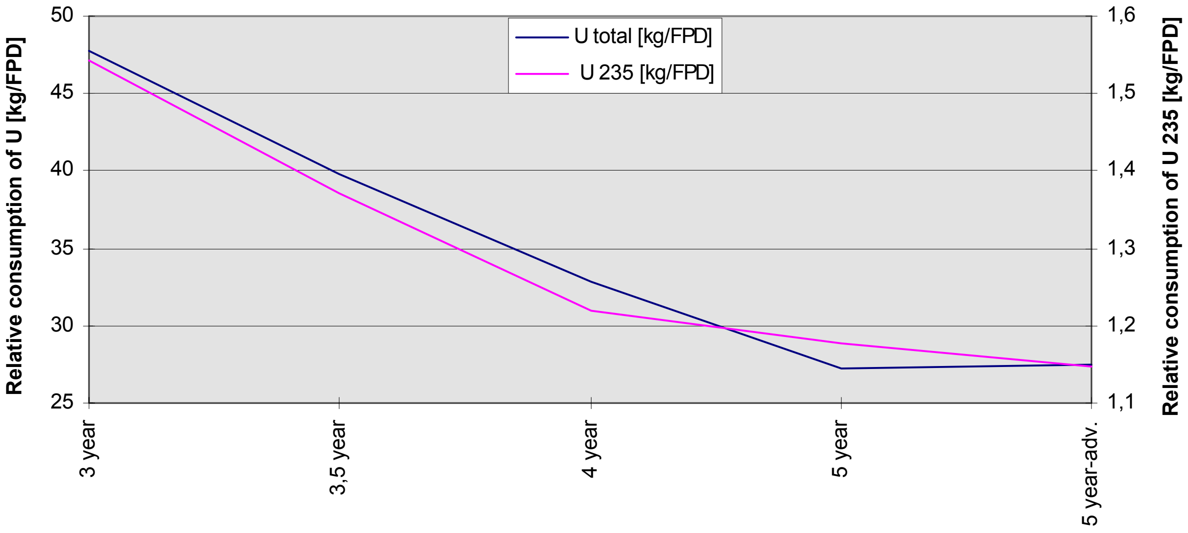

Figure 9. Relative Uranium consumption

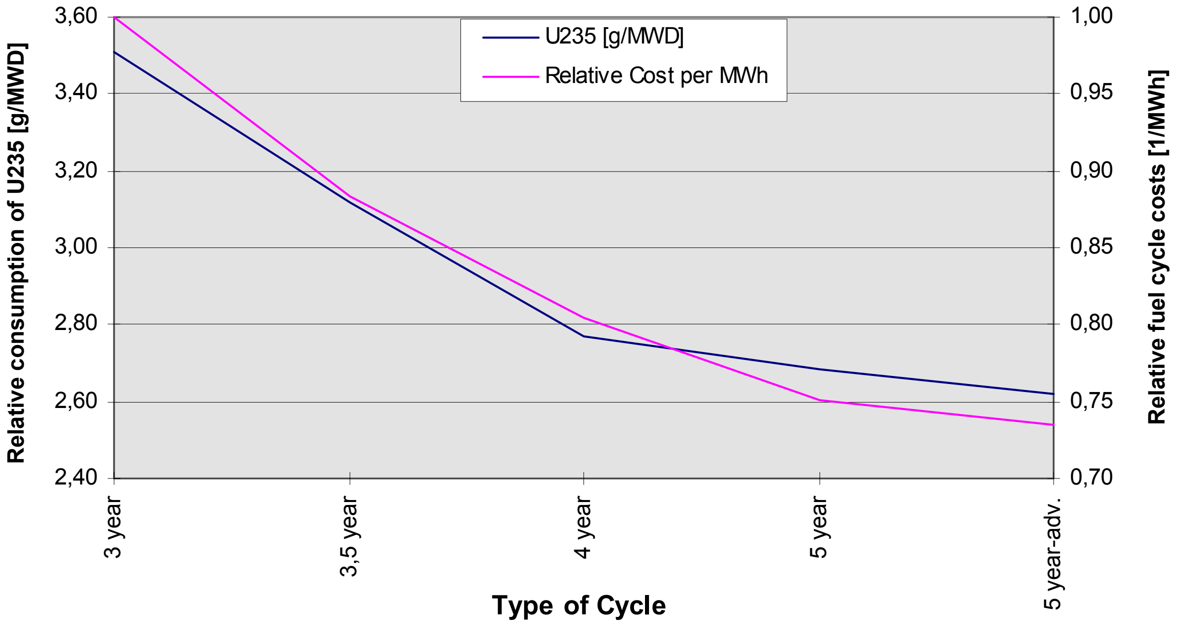

Figure 10. Relative ^{235}U consumption and relative fuel cycle costs

for five year cycle. This advanced fuel assembly could be characterized by an optimum uranium-water ratio (enrichment could be decreased), burnable absorbers, dismountable assembly shroud and nozzles and some other innovations. Fuel enrichment could be reduced to 4.25% (reactivity of this assembly is a bit higher comparing with previous assembly 4.38%). Contract for supply of advanced fuel was signed in June 2001. In long term outlook an increase of enrichment to 5% limit could enable an introduction of full 6-year cycle around 2010.

Typical equilibrium 5-year cycle could be represented by 72 loaded assemblies. Nine of them are profiled control assemblies enriched to 3.82% (without BA), remaining 63 working assemblies are enriched to 4.38% or 4.25% (Figure 3, 8 and Table 1). Reference calculation of the transition to an equilibrium cycle has proved the fulfillment of all postulated fuel and core limits.

3. Evaluation of Fuel Costs

This comparison was performed through evaluation of relative price of one MWh. Another indicators were checked as well, e.g. consumption of Uranium for particular cycle (weight consumption of uranium per Full Power Day) or weight consumption of ^{235}U per FPD (Figure 9). The following reference prices were used for this evaluation:

- Uranium - 28.0 $/kgU;
- Converting - 5.5 $/kgU;
- Enrichment - 100 $/SWU;
- Manufacture - 300 $/kgU;

The prices above are not the true contract prices, but reference values reflecting real situation on world market according to the Ux Weekly.

Results of the comparative study for particular options of fuel cycle are shown in Figure 10. It could be seen that after certain remarkable decrease of fuel costs, which is connected with transition to 4-year cycle the further decrease is rather slow. Cycles with advanced gadolinium assemblies (with lower enrichment) reach certain economical profit despite of their higher consumption of Uranium. This effect is caused by their optimized material and mechanical design. Even if the fuel cost savings are only one percent, this represents significant amount of money, which entitle the modernization activities.

It must be emphasized that comparison of fuel costs presented here is based on above defined constant reference prices. Real fuel costs comprise other important items like licensing expenses, delivery and fuel handling costs, insurance, etc. In addition, all prices entering the evaluation are time dependent, which makes a real evaluation much more complicated. Nevertheless, the results presented here can be representative for the real situation.

Our experience has shown that fuel and core technical data defined in the reference design and presented by the fuel supplier during the licensing procedure are usually rather conservative. Therefore, certain possibility exists to reach an additional saving due to optimal core design and reload planning. An important tool for this purpose should be a high quality loading pattern optimization computer program which is linked with the basic and precise code for core design calculation. For example, it could be demonstrated by the improved loading pattern scheme of the 4-year cycle where a part of assemblies was left in the core for the 5-th cycle (meeting all limits for burnup and peaking factors). In this case the fuel cycle costs can be considerably reduced. Similar effects can be expected in case of 5-year cycle, when a part of fuel is left in the core for 6-th year. Another savings of the fuel costs can be accomplished by fuel transport and insurance due to decreased number of assemblies. The large savings in fuel handling and storage can be expected from the same reason.

4. Conclusion

It was shown that introduction of the high burnup program decreases relative fuel cycle costs. Additional savings can be reached in fuel cycle front-end and back-end including pure financial costs like insurance etc. Especially the back-end costs have not been systematically evaluated because of absence of definite decision at major nuclear operators. But transition to advanced cycles is the right procedure to ensure competitiveness of nuclear energy in the Czech Republic in the near future.