

OPTIMIZATION OF THE VVER-440 CYCLES WITH NEW TYPES OF FUEL

Ing. Jan Prehradný^{1,2}, Ing. Roman Čada³

¹ Czech Technical University in Prague, Faculty of Mechanical Engineering, Technická 4, 166 07 Prague, Czech Republic

² ŠKODA JS, Orlik 266, 316 06 Pilsen, Czech Republic

³ University of West Bohemia, Department of Mathematics, Univerzitní 8, 306 14 Pilsen, Czech Republic



ŠKODA JS a.s.



INTRODUCTION

ATHENA code was developed in collaboration of ŠKODA JS a.s. and University of West Bohemia. ATHENA is designed as a "Black Box" that controls its own optimization, regardless of any computer code that calculates the neutron-physical characteristics, cycle length and progress of key variables.

ATHENA uses expert heuristics for combinatorial landscape problems, combining methods such as line and branches, and randomized algorithms. Optimization process maximizes the length of cycle together with meeting the required limits like power peaking factors K_q , $F_{dH}(Kr)$.

PARAMETERS OF THE CYCLES

The cycles were optimized from 29. cycle at unit 1 Dukovany NPP from the stable state with Gd-2M fuel to the stable state with Gd-2M+ fuel (cycle 39) and again to the stable state with Gd-2X fuel (cycle 46).

Basic parameters of the cycles:

$N_R = 1485 \text{ MW}_t$ (108% N_{nom})

$T_{in} = 270,0^\circ\text{C}$

$h_{6CR} = 214 \text{ cm}$

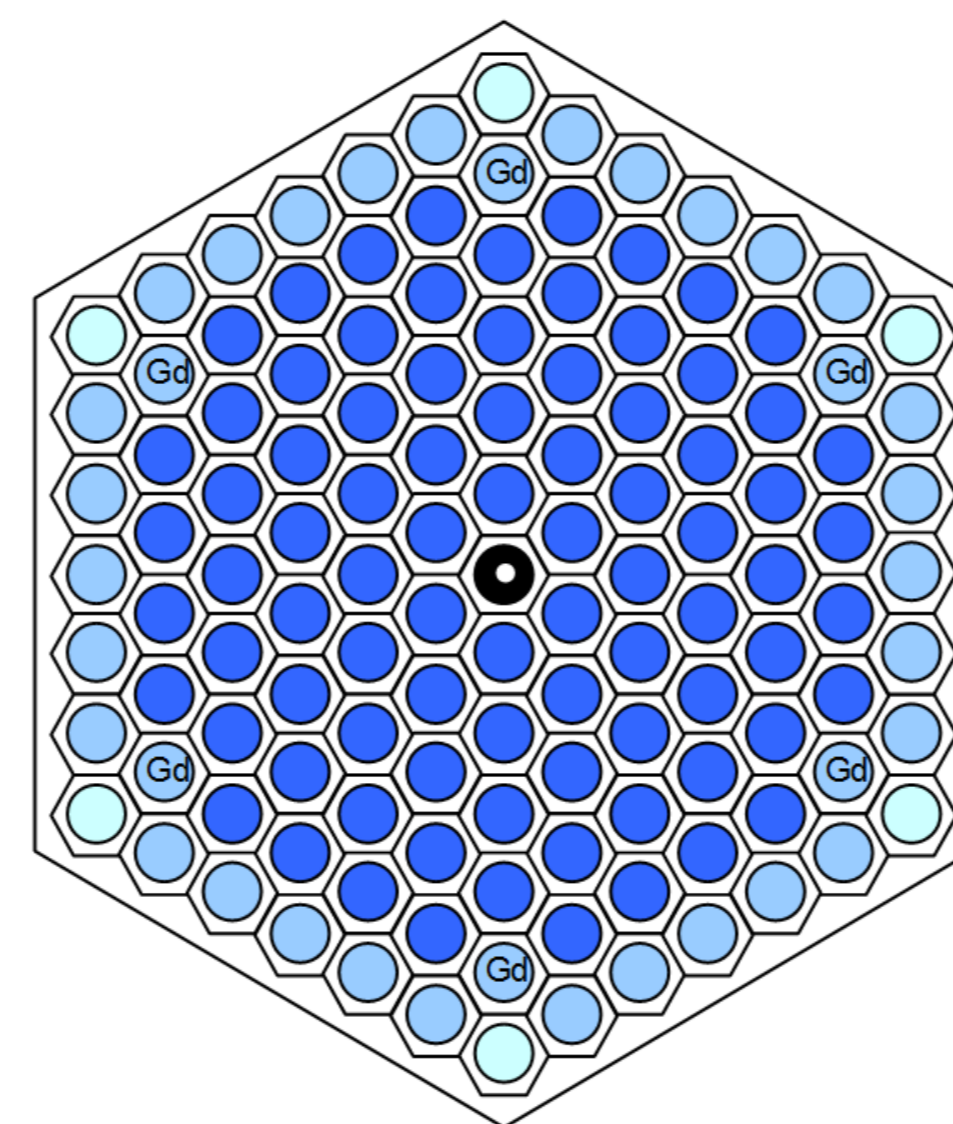
$K_q = \text{not limited}$

$Kr \leq 1,56$

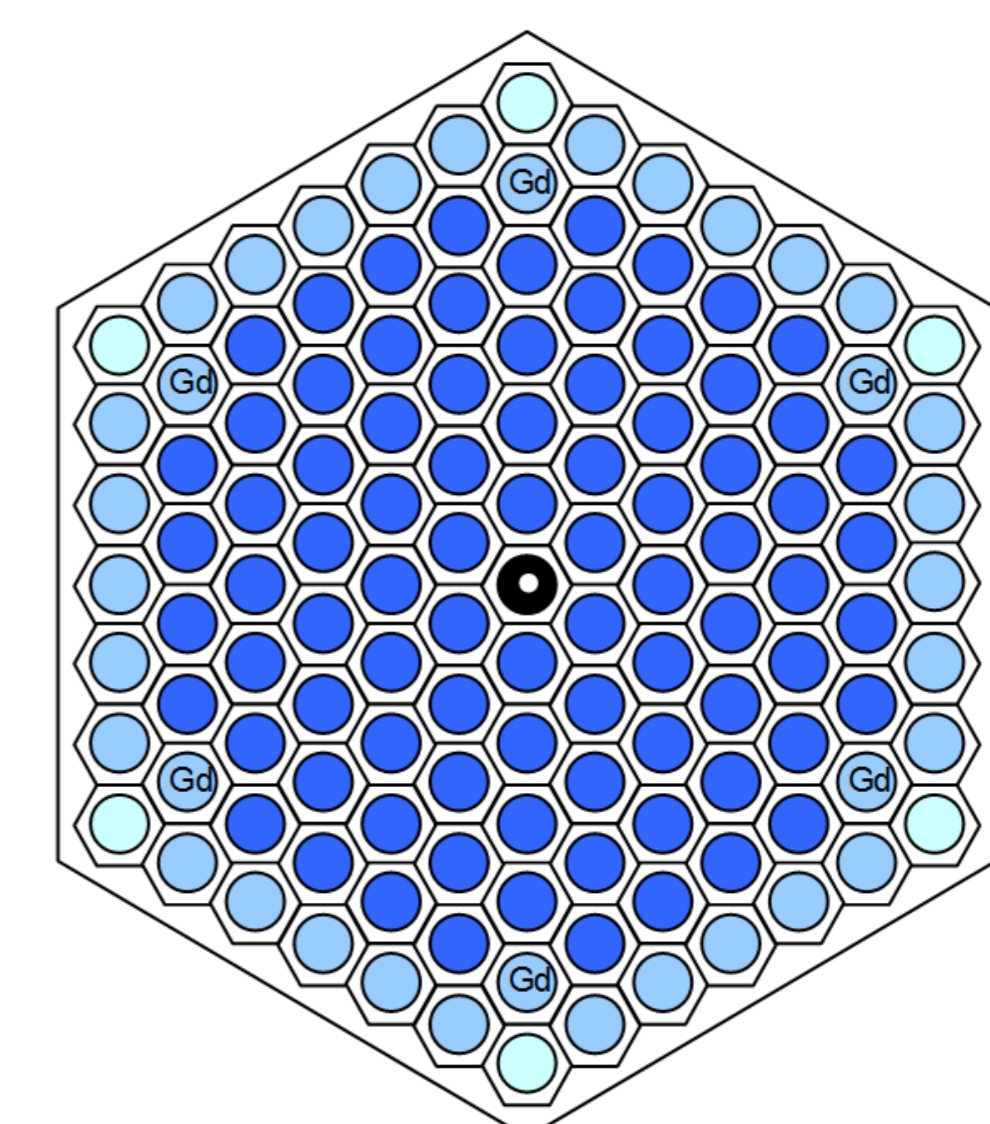
Length of cycles = 335 days

Power stretch-out = 20 - 35 days

FUELS



- 4.6 % U^{235} (84)
- 4.0 % U^{235} (30)
- 4.0 % $U^{235} + 3.35\% \text{ Gd}_2\text{O}_3$ (6)
- 3.6% U^{235} (6)
- Central tube



- 4.95% U^{235} (84)
- 4.4% U^{235} (30)
- 4.4% $U^{235} + 3.35\% \text{ Gd}_2\text{O}_3$ (6)
- 4.2% U^{235} (6)
- Central tube

Fig 1: Schematic structure of Gd-2M+ fuel

Fig 2: Schematic structure of Gd-2X fuel

Basic parameters of Gd-2M+ fuel: (fig 1.)

- Assemblies with cover
- Pellet diameter – 7,8 mm without central hole
- Average enrichment 4,38 w% of ^{235}U

Basic parameters of Gd-2X fuel: (fig 2.)

- Assemblies with cover
- Pellet diameter – 7,8 mm without central hole
- Average enrichment 4,76 w% of ^{235}U

Gd-2M+ FUEL RESULTS

The most important results from Gd-2M+ fuel optimization are in table 1. The final lengths of cycles are 335 days. Important are numbers of fresh fuel assemblies. We have to load average 73 fresh fuel assemblies with control rods.

The lengths of cycles with Gd-2M+ fuel					
Number of cycle	Number of fresh FAs	Number of fresh CRs	Length without stretch-out [days]	Final length [days]	Power at the end of cycle [MW_{rep}]
C 30	72	12	312,3	335	1395
C 31	66	6	309,3	335	1395
C 32	66	6	307,2	335	1350
C 33	60	12	308,4	335	1395
C 34	66	6	312,5	335	1440
C 35	66	6	308,5	335	1395
C 36	60	12	304,9	335	1350
C 37	66	6	309,1	335	1395
C 38	66	6	308,8	335	1395
C 39	60	12	305,2	335	1350
Average	64,8	8,4	308,6	335,0	1386,0

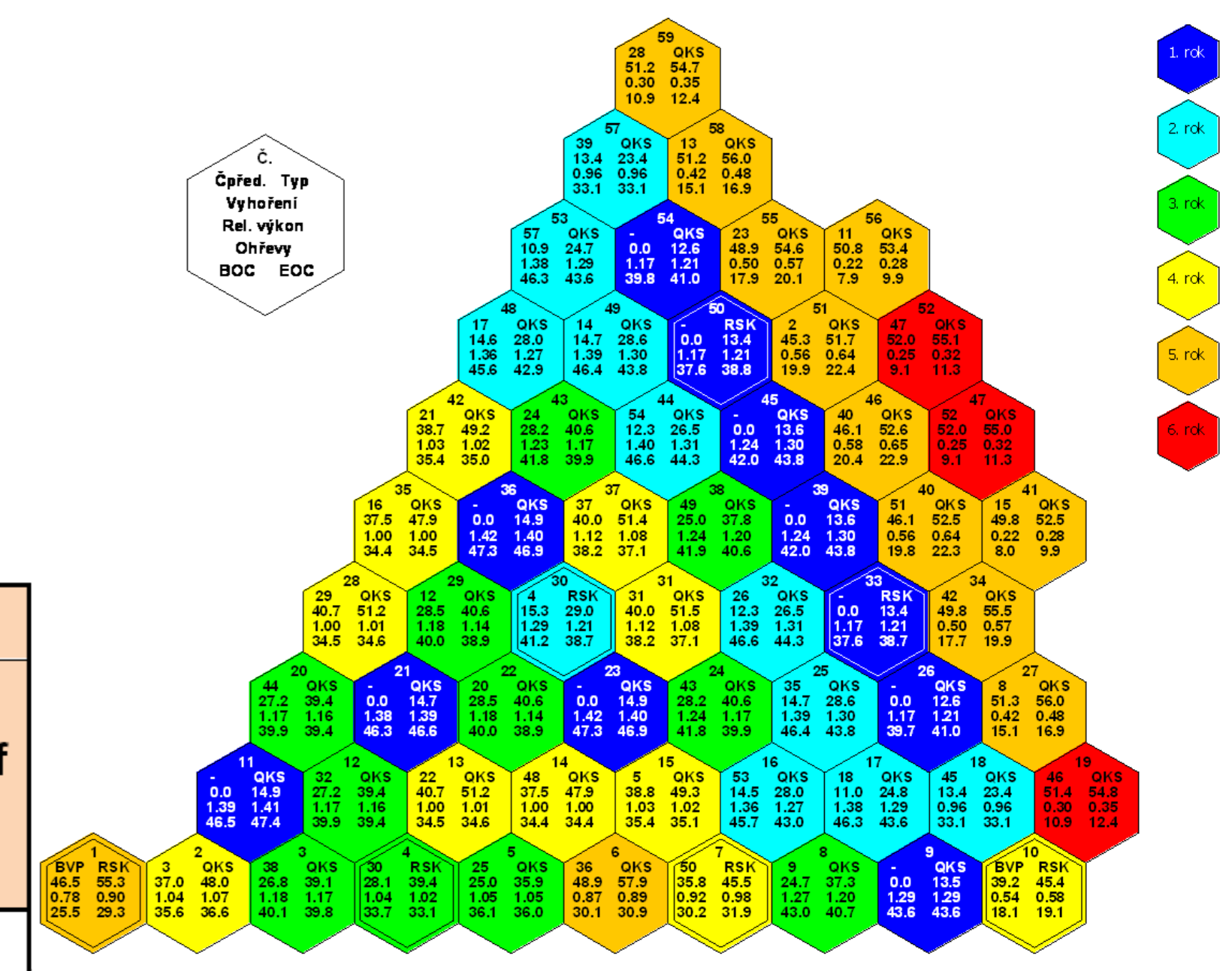
Tab 1: Cycles with Gd-2M+ fuel

Gd-2X FUEL RESULTS

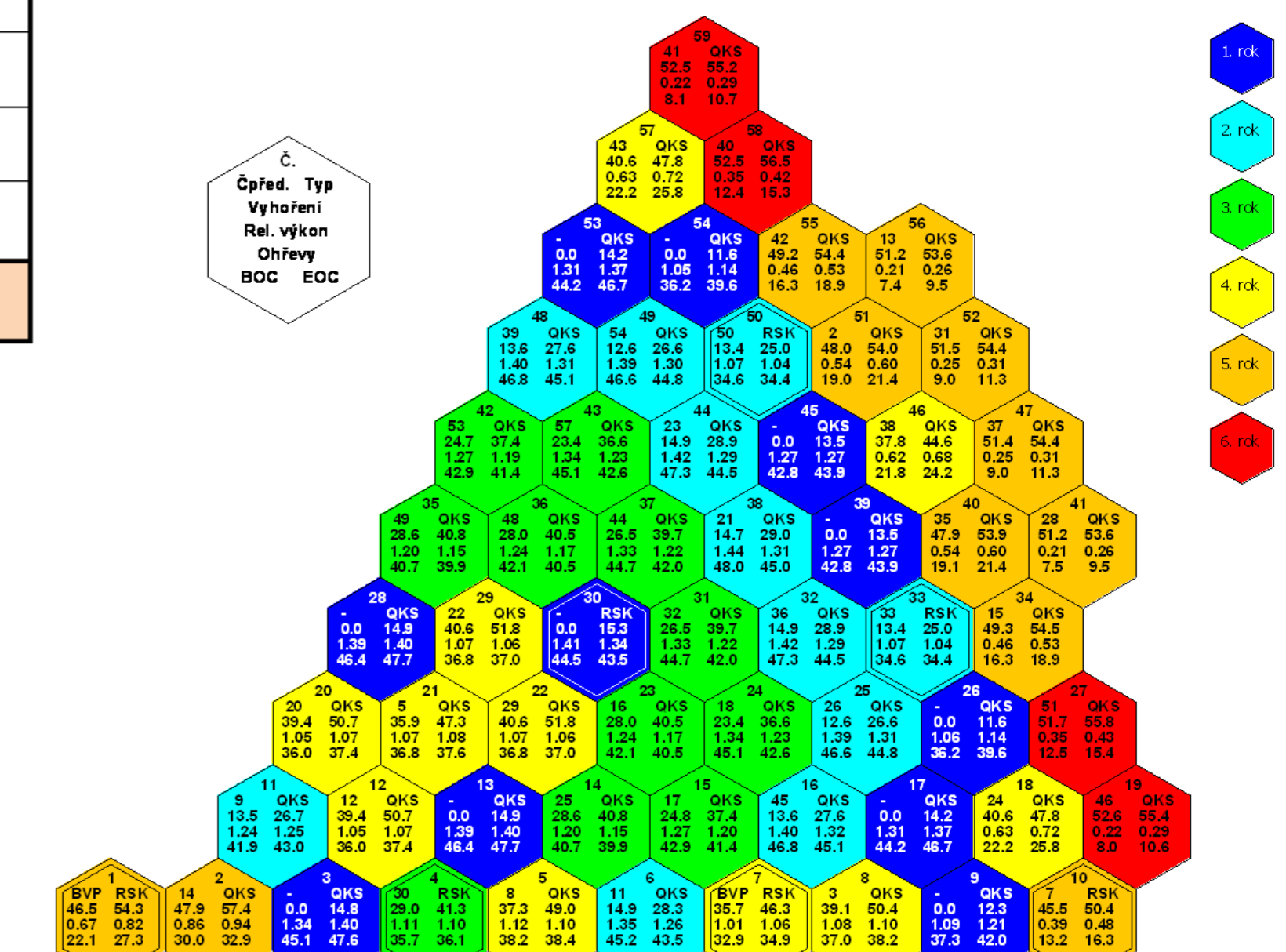
The most important results from Gd-2X fuel optimization are in table 2. The final lengths of cycles are 335 days again. Important are numbers of fresh fuel assemblies - we have to load average only 68 fresh fuel assemblies with control rods. Gd-2X fuel is stronger and more effective. On the other hand Gd-2X fuel is more expensive and the usability depends exactly on the price of the fuel assemblies.

The lengths of cycles with Gd-2X fuel					
Number of cycle	Number of fresh FAs	Number of fresh CRs	Length without stretch-out [days]	Final length [days]	Power at the end of cycle [MW_{rep}]
C 40	66	6	306	335	1350
C 41	66	6	317,4	335	1485
C 42	54	12	323,5	335	1485
C 43	60	6	321,3	335	1485
C 44	60	6	318,3	335	1485
C 45	54	12	312,8	335	1444
C 46	60	6	323	335	1485
Average	60,0	7,7	317,5	335,0	1459,9

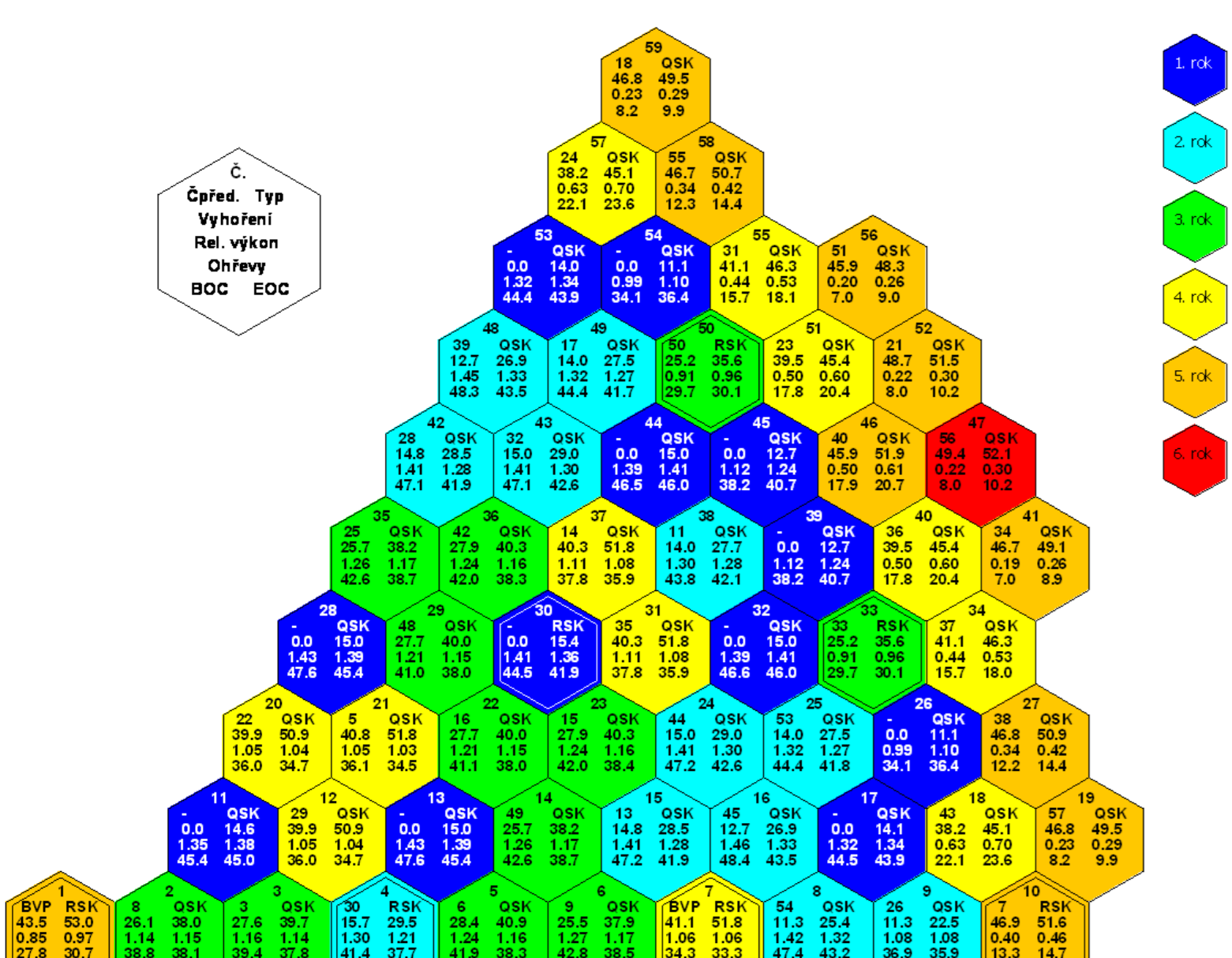
Tab 2: Cycles with Gd-2X fuel



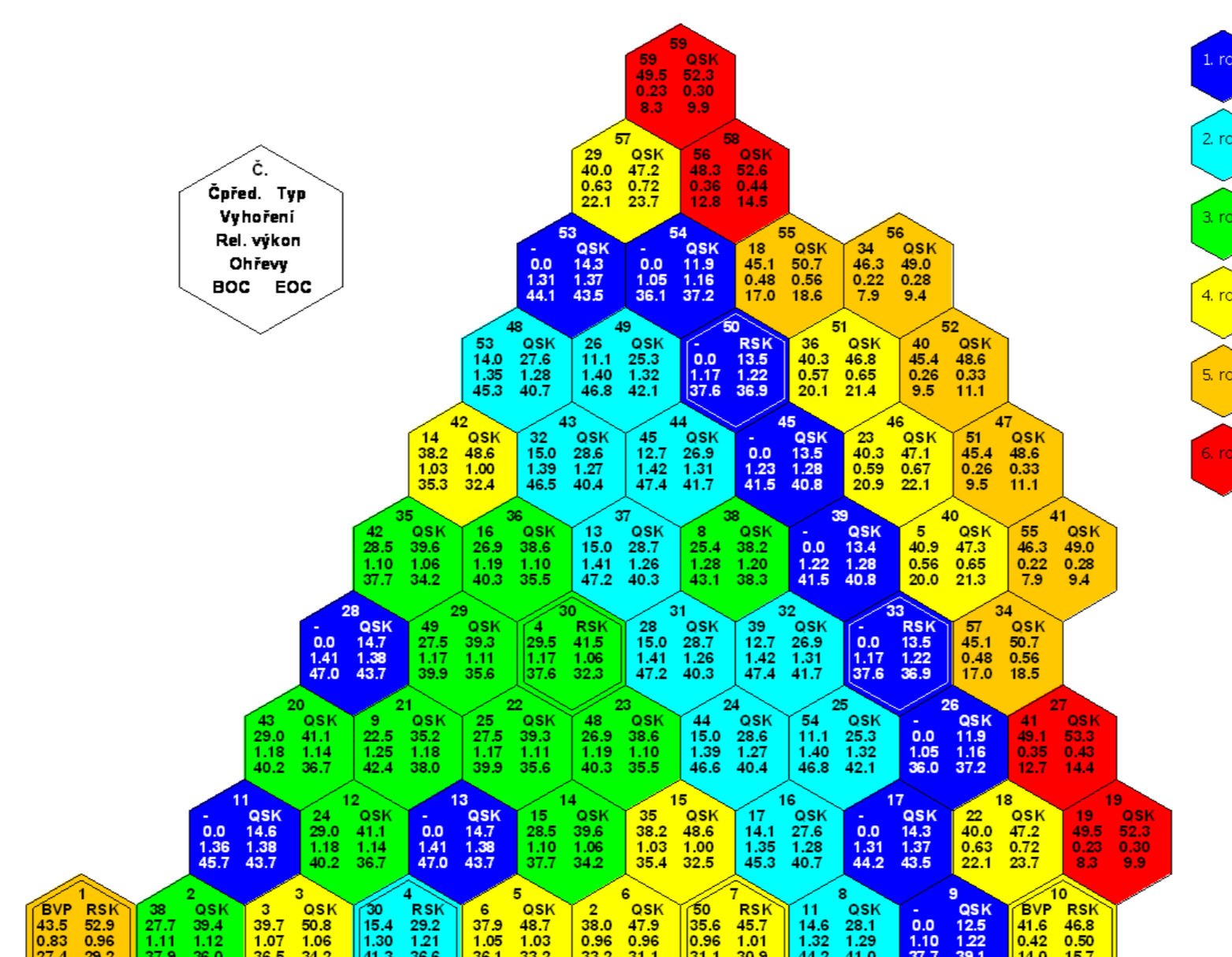
Schematic loading pattern of the cycle 45 with Gd-2X fuel



Schematic loading pattern of the cycle 46 with Gd-2X fuel



Schematic loading pattern of the cycle 37 with Gd-2M+ fuel



Schematic loading pattern of the cycle 38 with Gd-2M+ fuel

CONCLUSION

We managed to find steady state with Gd-2M+ fuel loading during ten cycles and steady state with Gd-2X fuel loading during seven cycles. Based on these results we are able to determine the practical applicability of new fuel types and determine benefits from these new types of fuel.