Economic Effect from Employment of New Russian Fuel at Czech NPPs

Pavel Veselý

CEZ, a. s.

Czech Republic

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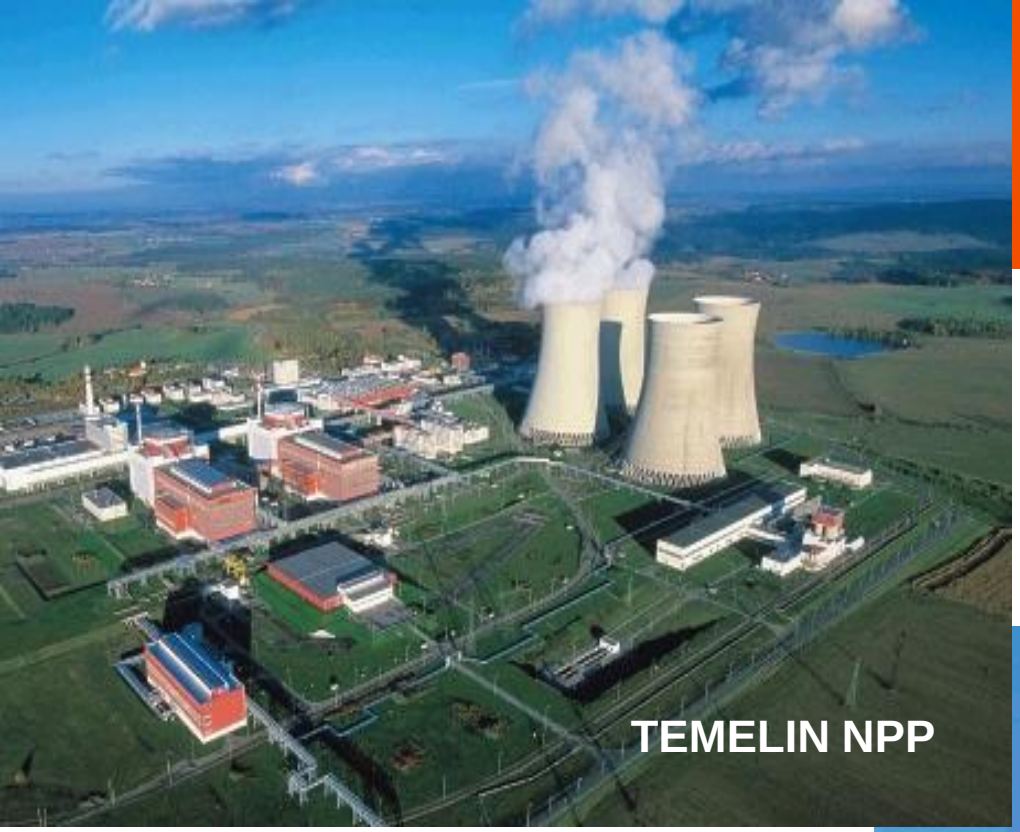


NPP Temelín 2 × 1000 MWe

NPP Dukovany 4 x 440 MWe

NPP OPERATED BY ČEZ - ACTUAL INSTALLED POWER

NPP Dukovany:

- **Unit 1 … ~ 500 MWe (2011)**
- **Unit 2 … ~ 462 MWe**
- **Unit 3 … ~ 500 MWe**
- **Unit 4 … ~ 500 MWe**
- **TOTAL ~ 1962 MWe**

NPP Temelín :

Unit 1 , 2 … ~ 2 x 1012 MWe

NPP OPERATED BY ČEZ - FUEL VENDORS

NPP Dukovany :

Since 1985 operated with VVER 440 Fuel - JSC TVEL, (see below)
- **extensive experience with fuel operation**
- **since 2009 … power uprate licensed up to 105%**

NPP Temelín:

Unit 1 - till 2010: VVER 1000 fuel type VVANTAGE 6, Westinghouse
full scale core refuelling: VV6 ➡ TVSA-T, JSC TVEL

Unit 2 – till 2011: VVER 1000 fuel type VVANTAGE 6, Westinghouse
full scale core refuelling: VV6 ➡ TVSA-T, JSC TVEL

Experience with fuel TVSA-T -only one operation period on Pnom (3000 MWt);
reference design cycle is five year cycle, 320 FPD, 36 FA per reload,

Power Uprate Project up to 104% is just going on (2012)

NPP DUKOVANY - HISTORY OF FUEL CYCLE

Basic Design: 3-years

- WFA 3,6 %
- CFA 2,4 %
- average 116 FAs

4-years cycle

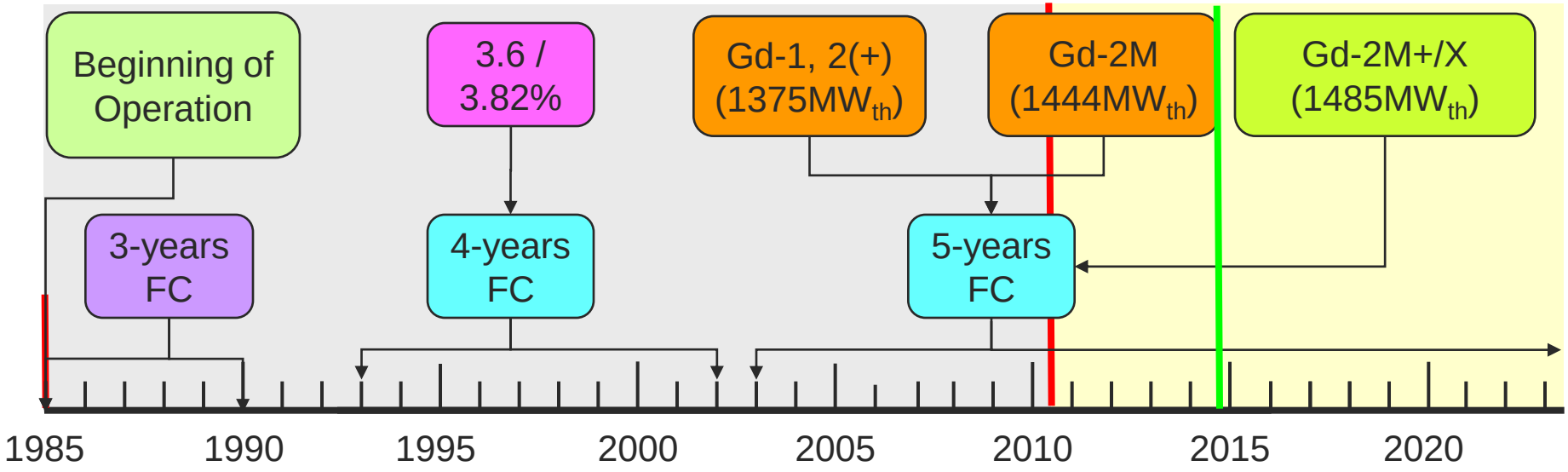
- WFA(prof.) 3.82 %
- CFA 3,6 %
- average 87 FAs

5-years cycle

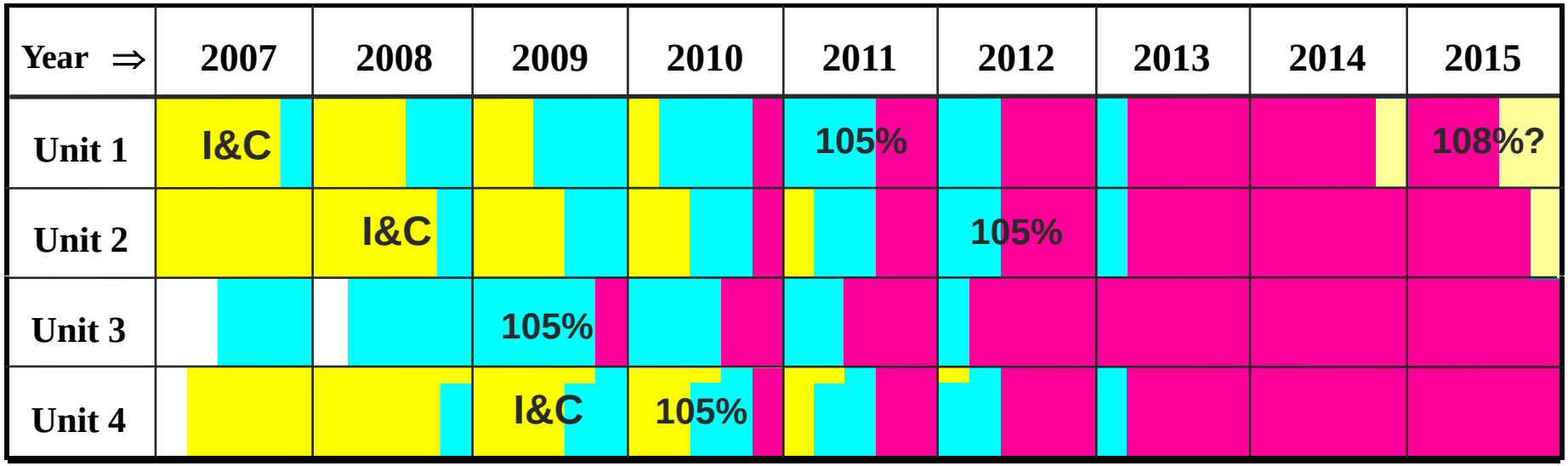
- WFA(Gd) 4.38 % (Gd-1)
- WFA(Gd) 4.25 % (Gd-2+)
- CFA 3,82 %
- average 72 FAs

5-y with Nr = 1444 /1485MW$_t$

- WFA(Gd) 4.38% (Gd-2M(+))
- WFA(Gd) 4.76% (Gd-2X)
- CFA(Gd) 4,25 % (Gd-2+)
- CFA(Gd) 4,38 % (Gd-2M)
- average 72 FAs



NPP DUKOVANY – FUEL UTILISATION OVERVIEW
TIME APPROACH



- *profiled fuel 3.82%*
- *Gd-1 – 4.38%*
- *Gd-2 (+) – 4.25%*
- *Gd-2M – 4.38%*
- *Gd-2M+/X – 4.38/4.76%*

I&C – *finalization of I&C reconstruction*

105% – *power uprating*

108% – *power uprating ???*

NPP DUKOVANY - FUEL CYCLE TENDENCY

Fuel Cycle Tendency:

- continuous modernization and more efficient fuel loading strategy
- relatively high load factors for NPP
- continuous growth of average and maximum fuel burn-up
- increasing number of Fuel Assemblies loaded into fifth cycle with the perspective of transition to six-year cycle
- no failed fuel type Gd-1 and Gd-2 during NPP operation at the moment

RELOAD BATCHES THE SAME FROM 2002 - 2011
TRANSITION TO 5-YEAR CYCLE

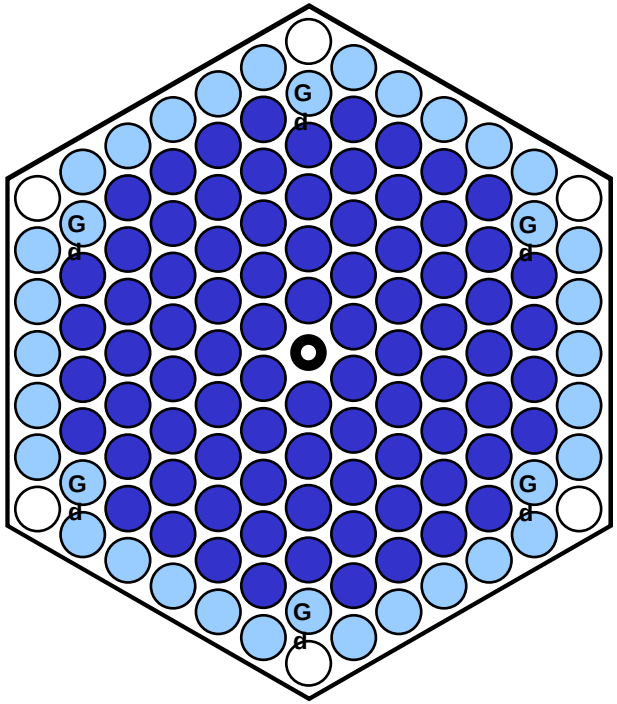
FA = Fuel Assembly *FA + CA = Number of FAs and CAs in reload batch*
CA = Control Assembly *FA5 = Fuel assemblies utilized in fifth year*

	UNIT 1		UNIT 2		UNIT 3		UNIT 4		NPP
Year	FA + CA	FA5	FA + CA	FA5	FA + CA	FA5/6	FA + CA	FA5	FA5/6
2002	84 + 6	0	72 + 6	12	72 + 12	6	84 + 6	0	18
2005	60 + 12	24	54 + 12	48	72 + 6	24	66+6+12	49/6	145/6
2006	66 + 6	61	60 + 6	55	54 + 12	43/12	66 + 6	61/6	220/18
2009	60 + 12	61	66 + 12	61/6	72 + 6	67/6	54+6	55	244/12
2010	66+6	55	60+6	55/6	54+6	55	60+12	61	226/6
2011	66+6*	67	54+6	55	60+6	55/12	66+6*	67	244/12

Profiled fuel assemblies (mean enrichment 3,82wt%)
Gd-1 fuel assemblies
Gd-2 fuel assemblies

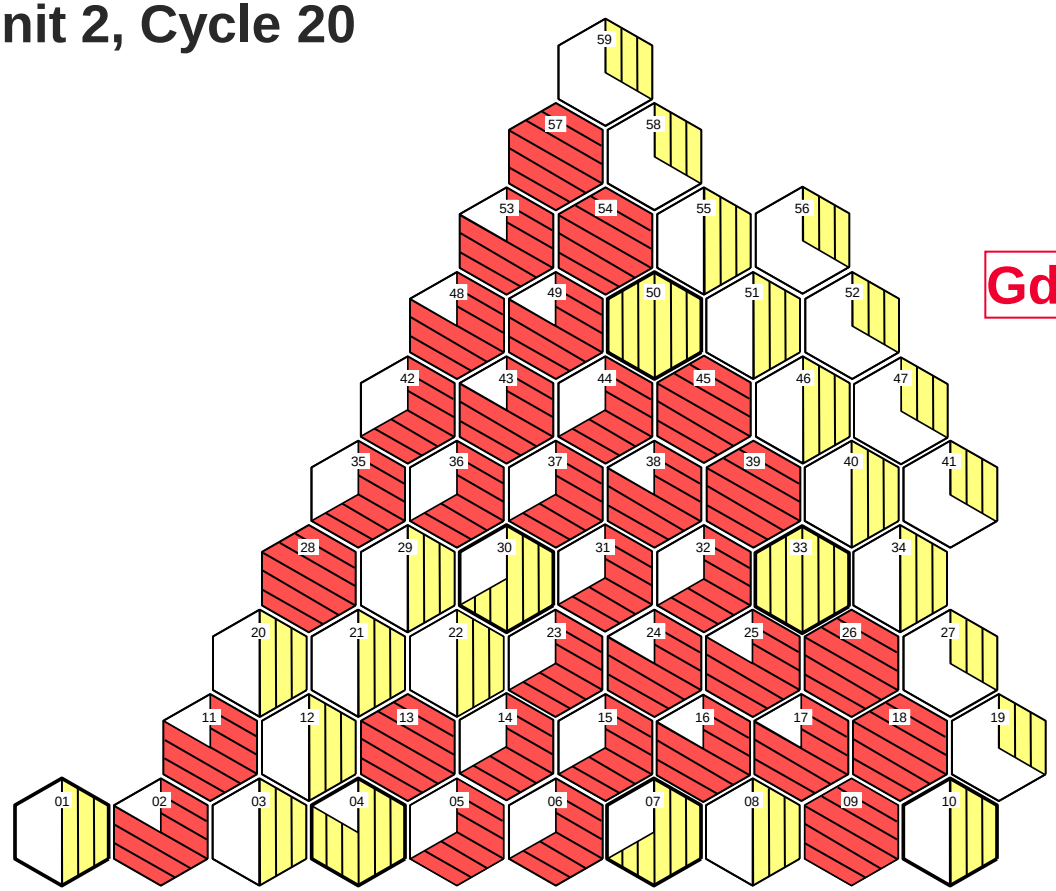
FUEL ASSEMBLY WITH Gd - FIRST GENERATION

Gd-1 with mean enrichment 4.38 wt% U^{235}



NPP DUKOVANY UNIT 2
3rd TRANSIENT RELOAD WITH Gd-1 FUEL (2005/2006)

Unit 2, Cycle 20

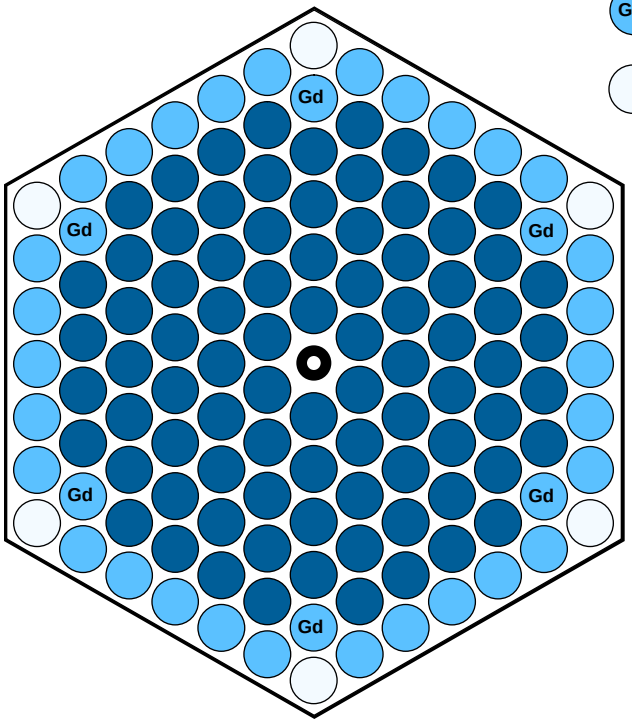


Gd-1

Fuel type	Enrich. [%]	Year	№ FA [pl]
	3.82	0	0 +12 CA
	4.38	0	54
	3.82	1	0 +6 CA
	4.38	1	66
	3.82	2	0 +12 CA
	4.38	1	72
	3.82	3	72 +7 CA
	3.82	4	48

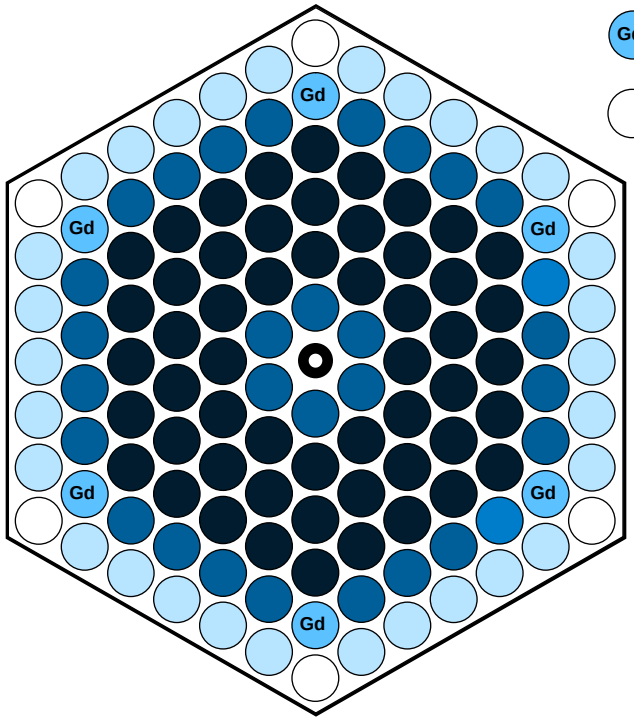
Gd-2 FUEL ASSEMBLY
MEAN ENRICHMENT 4,25 wt% U^{235}

TVEL Design Gd-2



- 4.4 %
- 4.0 %
- Gd 4.0 % +3.35% Gd_2O_3
- 3.6 %

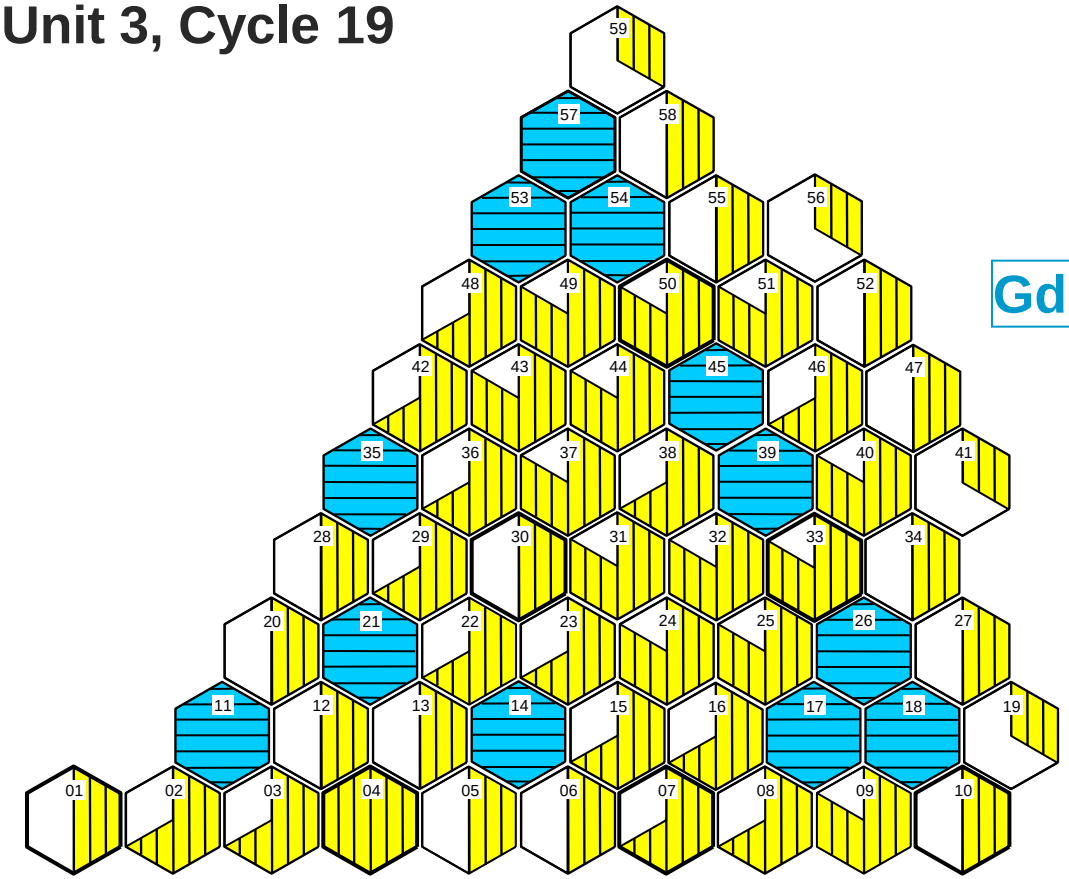
Optimized Design CEZ/SKODA Gd-2+



- 4.4 %
- 4.6 %
- 3.7 %
- Gd 4.0 % +3.35% Gd_2O_3
- 3.3 %

NPP DUKOVANY UNIT 3
1ST RELOAD WITH Gd-2 FUEL, 1375 MWT (2005/2006)

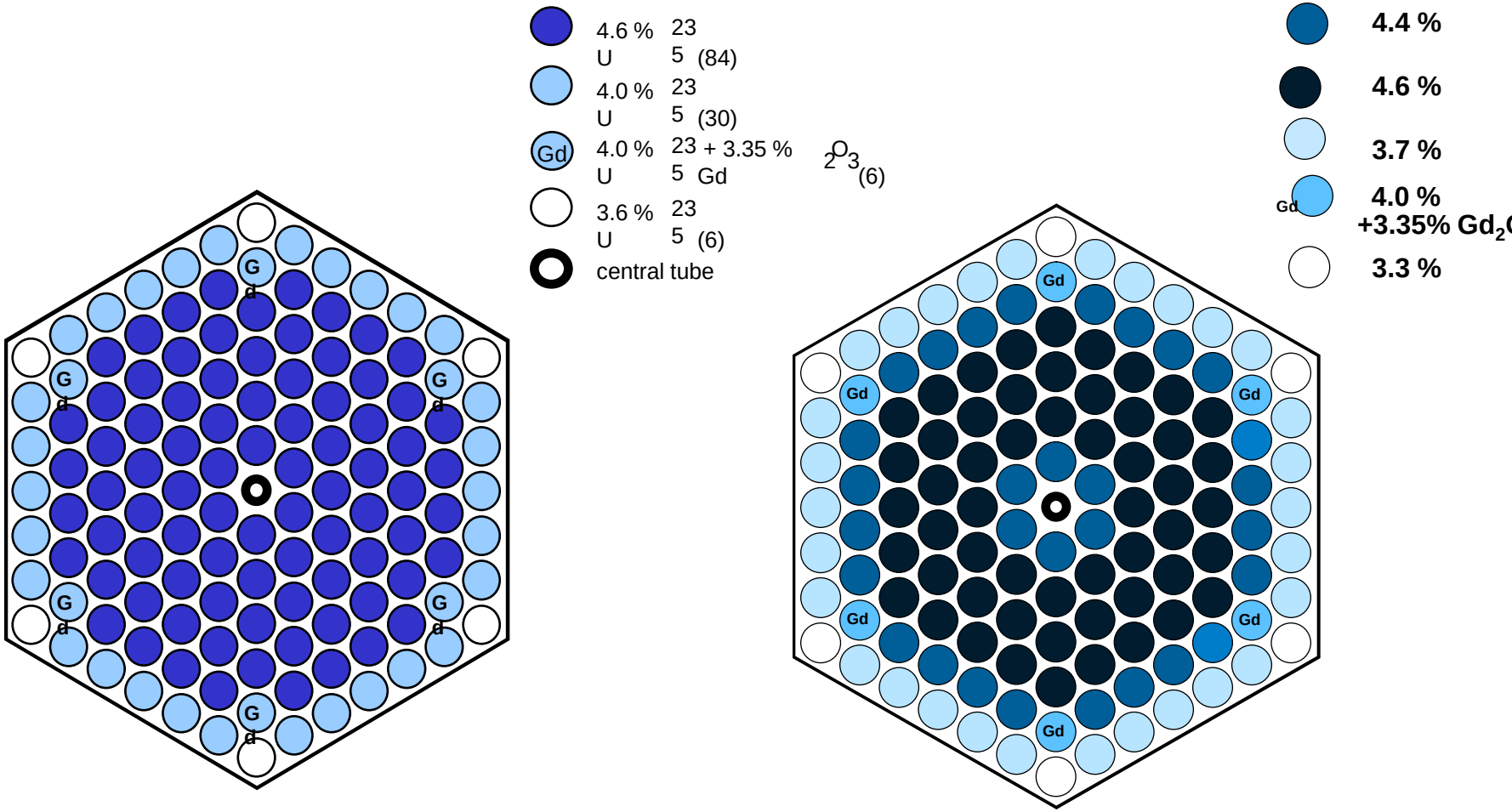
Unit 3, Cycle 19



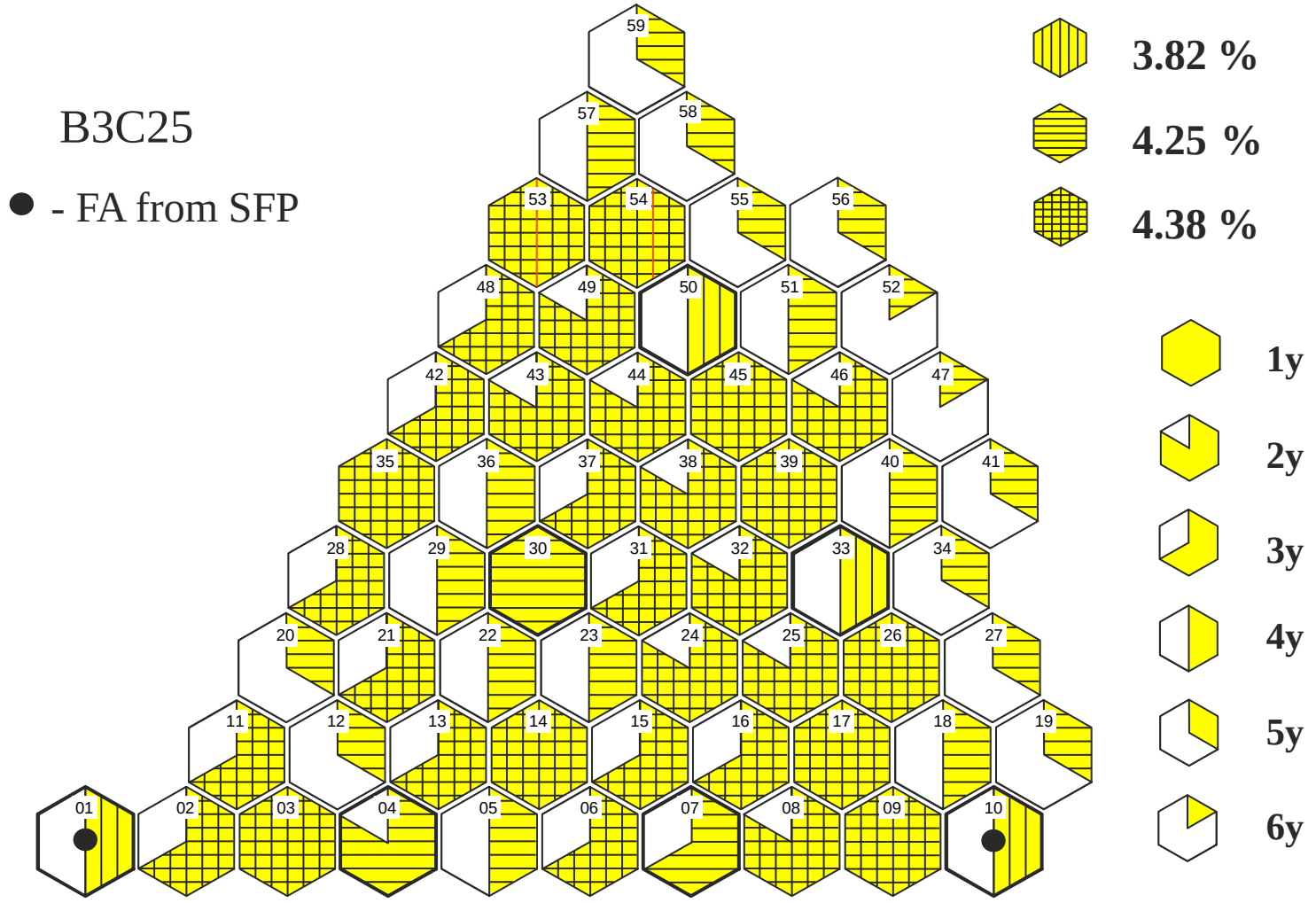
Gd-2

Fuel type	Enrich. [%]	Year	№ FA [pl]
	3.82	0	0 +6 CA
	4.25	0	72
	3.82	1	66 +12 CA
	3.82	2	78 +6 CA
	3.82	3	72 +13 CA
	3.82	4	24

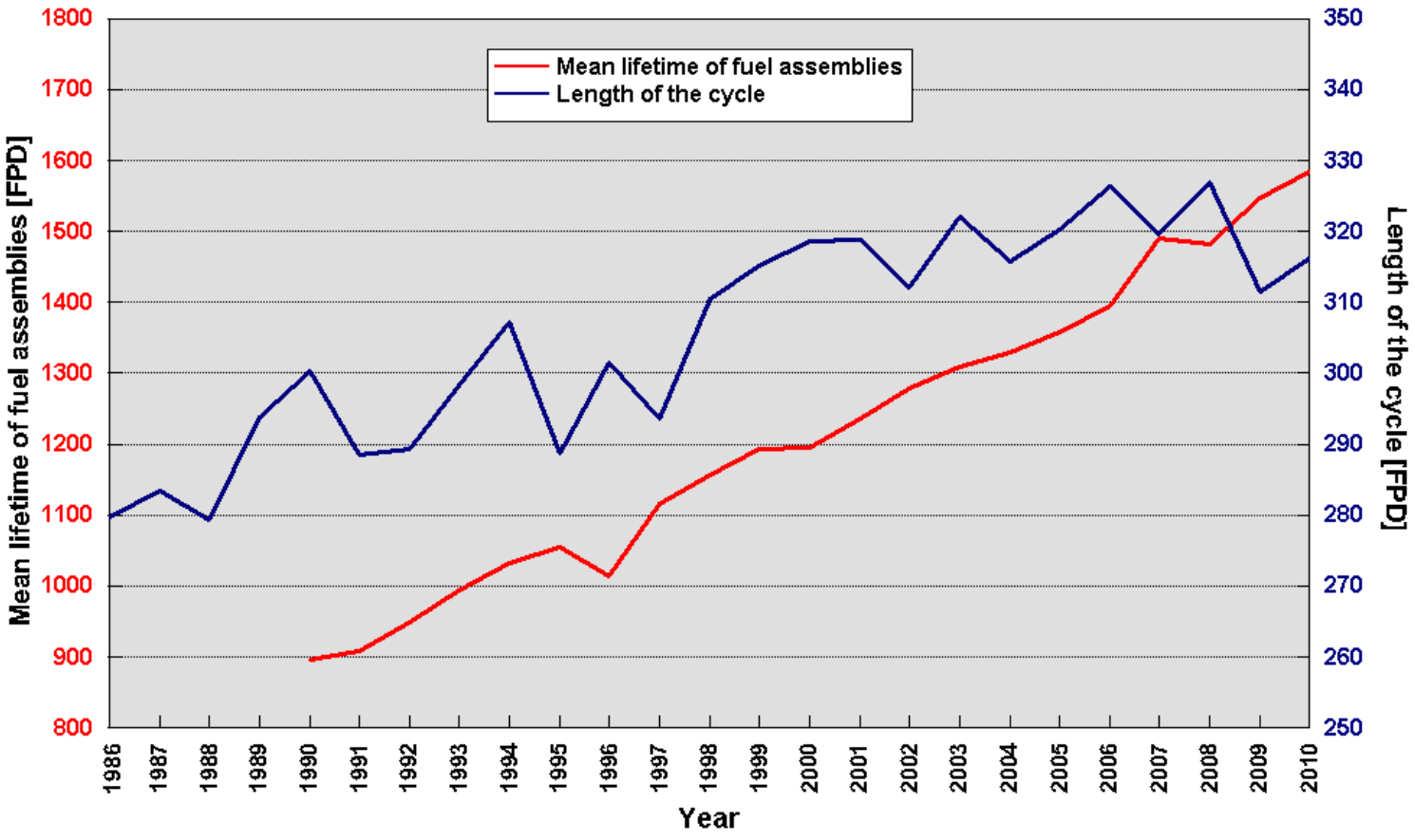
Gd-2 M FUEL
MEAN ENRICHMENT 4,38/4,25 wt% U^{235}



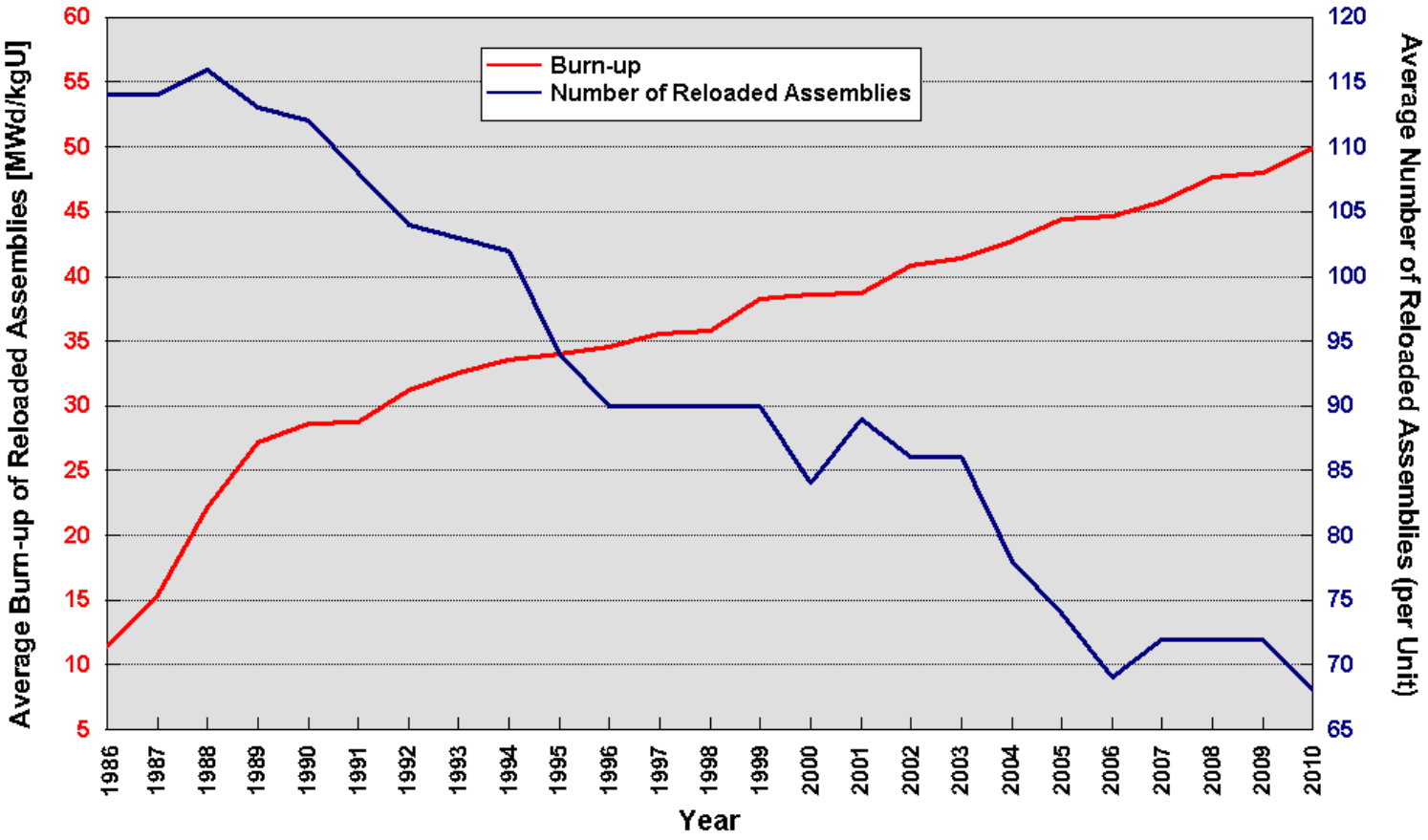
NPP DUKOVANY UNIT 3
2011 RELOAD WITH Gd-2M FUEL, 1444 MWT



NPP DUKOVANY
LENGTH OF THE CYCLE AND MEAN LIFETIME OF FA



AVERAGE BURN-UP OF FA AND AVERAGE NUMBER FA PER RELOAD



New Fuel Cycle implementation – economic evaluation and sensitivity analyses are made

Cost per KWh:

$$C = CF + Cop + Cad$$

CF – fuel cost in accordance with 1)2) (U+SWU+Fab and Reference Fuel Cycle (RFC))

Cop – operation cost (load factor, length of outage)

Cad – addition cost (summary of licensing work for new fuel, impact on management of fresh and spent fuel, additional efforts)

1-The Economics of the Nuclear Fuel Cycle, Nuclear Energy Agency, OECD 14. 2003

2-Zu.M.Semchenkov, et all. Fuel cycles of VVER-440, 17th Symposium of AER, September 24-29, 2007, Yalta, Crimea,Ukraine

PROCEDURE FOR INCREASE OF FUEL CYCLE EFFECTIVITY

Two „optimization“ procedures (SW) :

- **„OPTIMAL“ – product of NRI Řež**
- **„OPAL“ – developed in Škoda**

Objective :

- **calculation of reference cycle parameters (for Contract RFC)**
- **making single cycle optimization of each reload**
- **making data for multi cycle optimization**

PROCEDURE FOR INCREASING FUEL CYCLE EFFECTIVITY

Results of fuel cycle optimizing :

- **Design of optimal reloads – experience confirmed extension of design cycle with comparative RFC - practically up to 10 days or more in individual cases; or real reduction of FA number in reload (the direct saving of the fuel cost)**
- **Supplementary operation time for NPP and shortening the outage period (minimal length of outage is now on the level ~ 22 day)**
- **Increase the load factor of NPP and burn up of unloaded FA ►►**

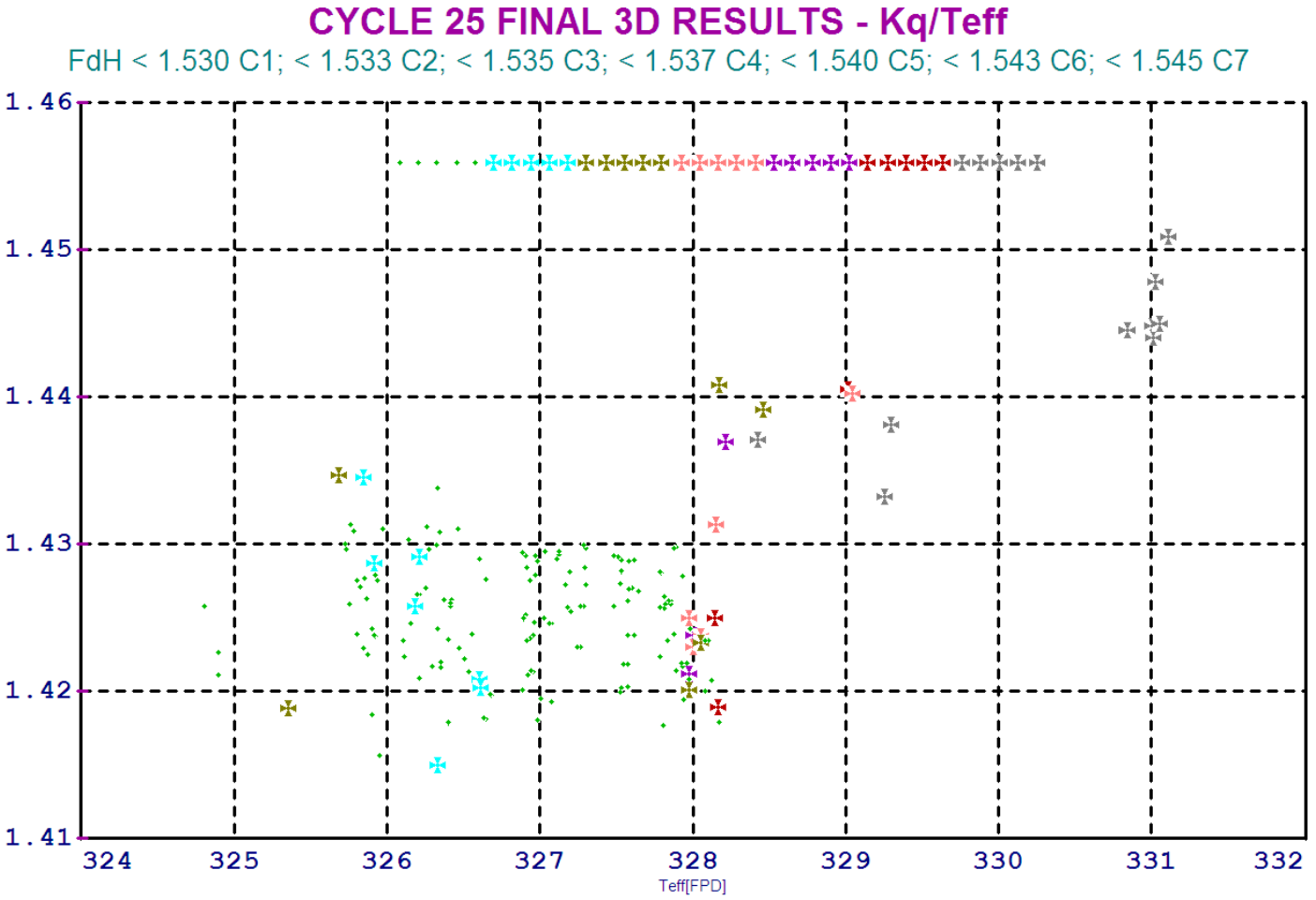
this part representes the main source of future profit

Important presumption :

- **Reliability of the fuel (now changes of core design in time stress)**

Remark – Zero leak for FA type Gd1 and Gd2 (from 2003)

EXAMPLE OF FUEL CYCLE STUDY BY OPTIMAL



NPP DUKOVANY: BURN UP OF UNLOADED FA AVERAGE/MAXIMUM (MWD/KG U)

	2008	2009	2010	2011
U-1 (Gd-1)	50.5 / 51.6	50.1 / 51.9	50.7 / 51.4	–
U-2 (Gd-1)	51.2 / 56.3	51.1 / 51.8	51.6 / 52.0	51.1 / 52.0
U-4 (Gd-1)	–	52.2 / 52.6	51.8 / 53.3	–
U-3 (Gd-2)	–	–	50.5 / 52.3	51.4 / 52.4

LICENSING OF THE NEW FUEL – IMPORTANT PART OF ADDITIONAL COST

Requirements of The Czech State Office for Nuclear Safety (SONS):

- New fuel types and fuel cycles should be licensed in accordance with the Czech "Atomic" Act and with the international practice (IAEA documents, US NRC codes, NUREG 800, …)

Licensing documents require:

- Amendment to SAR(TOB) and topical reports prepared by the fuel vendor (part of the fuel delivery contract)
- Topical reports (safety analyses and supplementary alternative safety analyses on the deterministic or BE approach) and Final Amendments to SAR prepared by national Czech organizations (separate agreement with CEZ)
- Special records for RAIs explanation

Reload safety analysis Checklist – standard routine

Additional cost of licensing – a few million USD per licensing case

FUEL MANAGEMENT AND HANDLING

PART OF ADDITIONAL COST

Fuel Management and Handling:

Implementation of New Fuel – increase of enrichment and mass of fuel in FA → subcriticallity impact (verification of subcriticallity and coollability of SFP are part of licensing work)

Lower volume of fuel per reload → prolongation of fuel cooling in SFP (7-9 year) before loading to Cask (CASTOR 440 M)

Impact of new fuel on back-end activities must be taken into account:

- **Increased radiation dose (neutron factor) and residual heat from high burnup fuel and**
- **Subcriticallity problem → virtually can decrease number of FA per Cask → increase the cost of spent fuel management**

Increase of back-end cost represents the important factor which is able to break the tendency to increase burn up of fuel – we can lose, roughly speaking, e.g. up to thousand EUR per FA for additional dry storage activities

NPP DUKOVANY: NEW REQUIREMENTS FOR FUEL CYCLE FOR THE NEXT PERIOD OF OPERATION

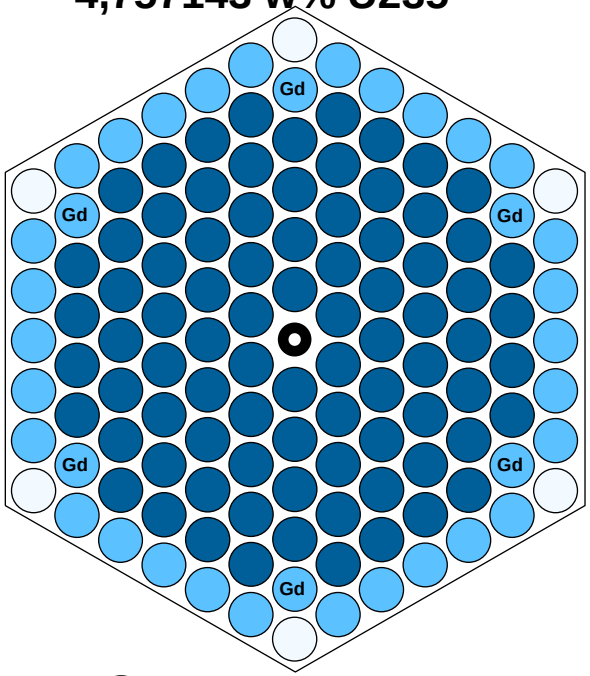
New Requirements:

- Increase the power of NPP up to 1485 MWt (licensed power)
- Extension of length of operation up to 335 FPD for power 1444 or 1485 MWt
- Execution of five year cycle (L^3P «loading pattern») 66 – 72 FA per reload with perspective next 20 year of operation (low neutron dose on vessel)
- Goal – increase production from 14 TWhe up to 16 TWhe

ADVANCED FUEL CYCLE AFTER 2014 - TWO OPTIONS

QFS; Q6S

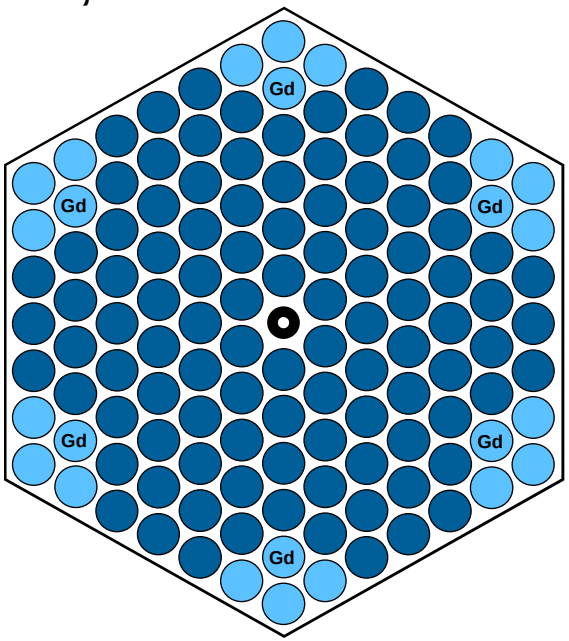
Average enrichment
4,757143 w% U235



- **4.95w% U^{235}**
- **4.40w% U^{235}**
- Gd — **4.40w% U^{235} +3.35 % Gd_2O_3**
- **4.20w% U^{235}**

SLO; SL6; SLF

Average enrichment
4,873810 w%U235

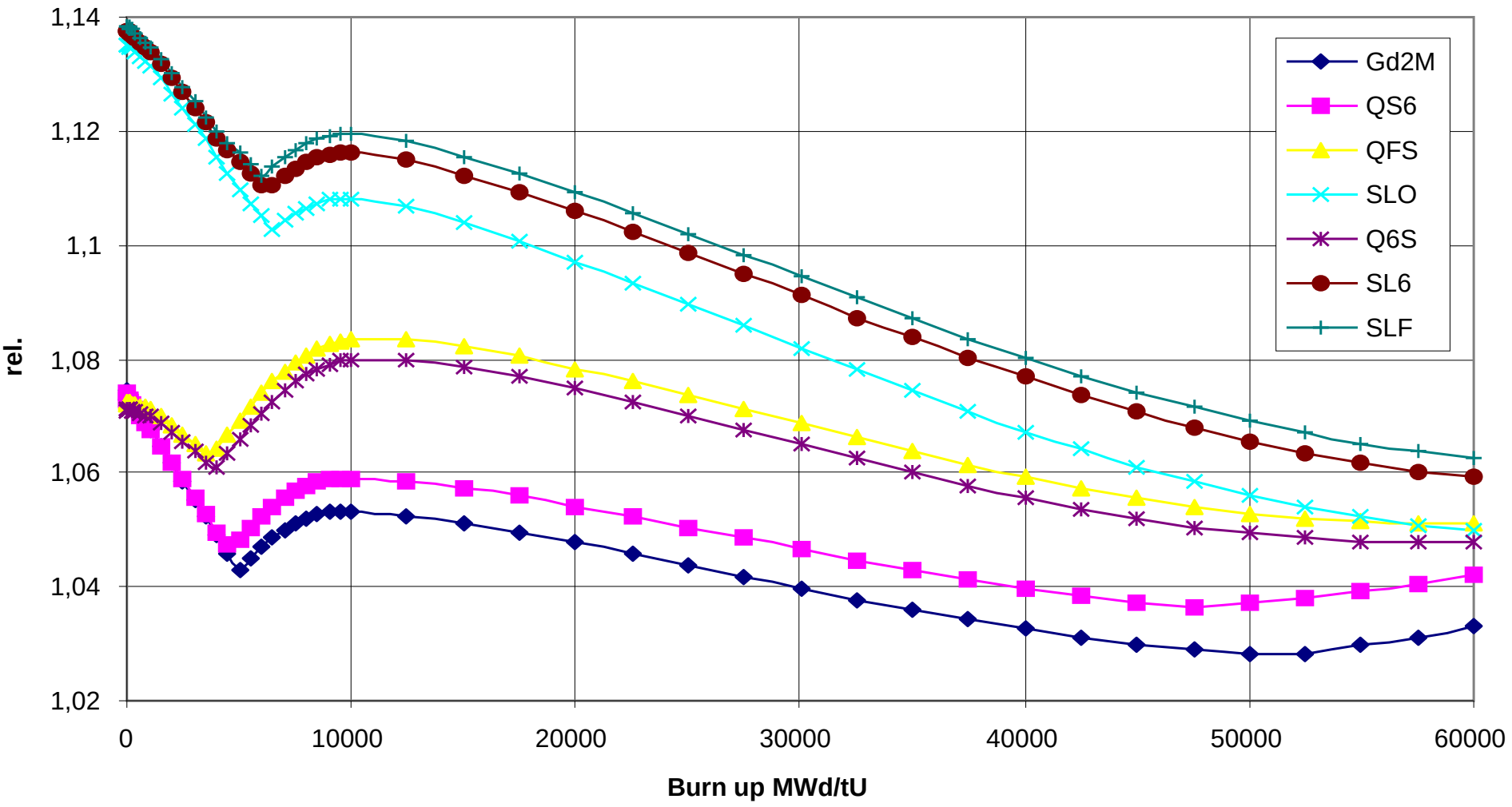


- **4.95w% U^{235}**
- **4.60w% U^{235}**
- Gd — **4.40w% U^{235} +3.35 % Gd_2O_3**

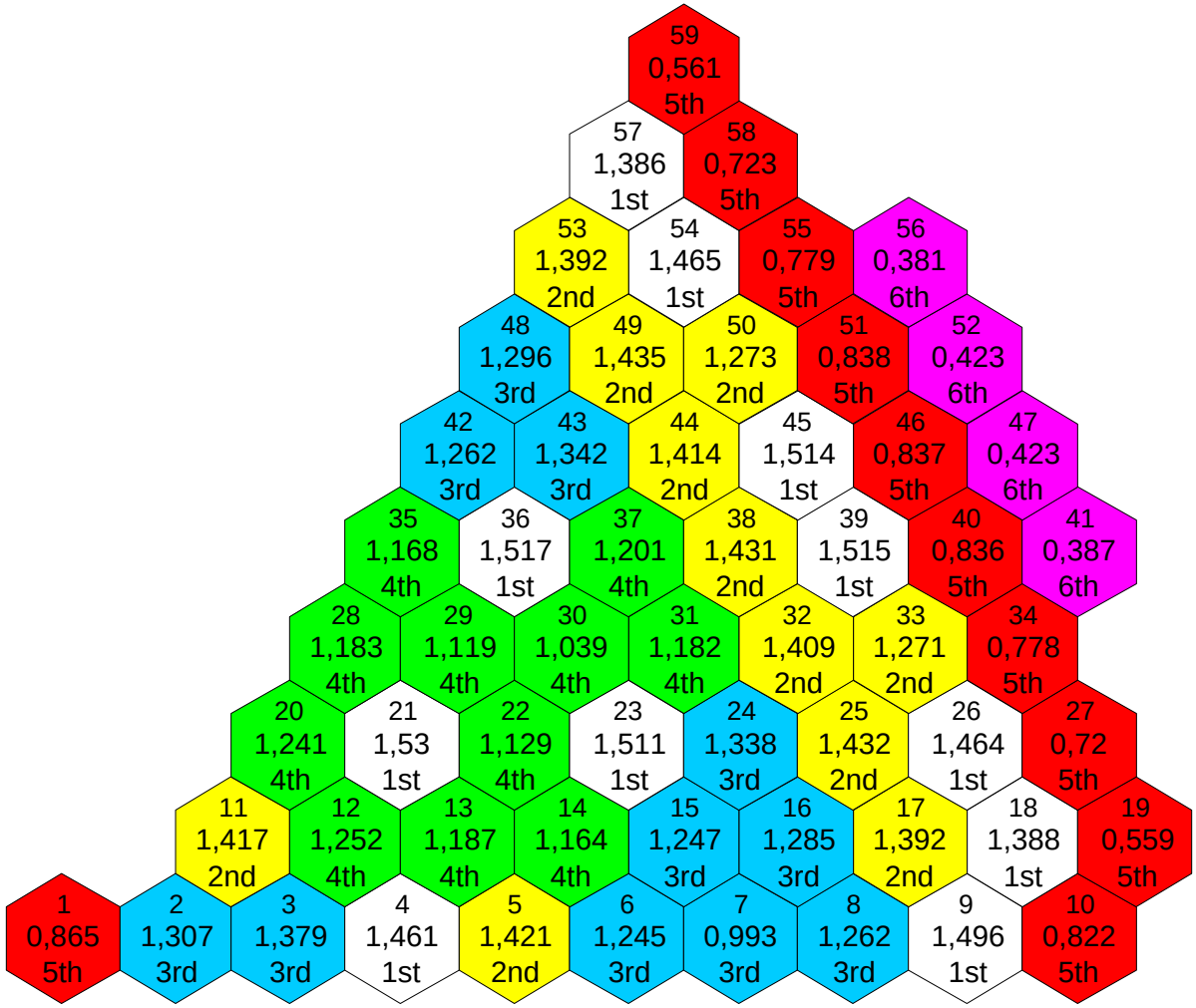
New Fuel - Type Gd 2M+

Parameters	TVEL		TVEG	
	FA	CFA	FA	CFA
FR Length , (mm)	2601,5	2540	2601,5	2540
Fuel Column length,(mm)	2480	2360	2480	2360
Fuel mass per FR ,(g)	1230	1170	1141	1085
Cladding tube (E110):				
Outside diameter (mm)	9,1±0,04			
Inside diameter (mm)	$7,93^{+0,06}$		$7,73^{+0,06}$	
Fuel pellets :				
Outside diameter (mm)	$7,80_{-0,03}$		$7,60_{-0,03}$	
Inside diameter (mm)	-		$1,2^{+0,3}$	
grain size(μm)	≤ 25		6-25	

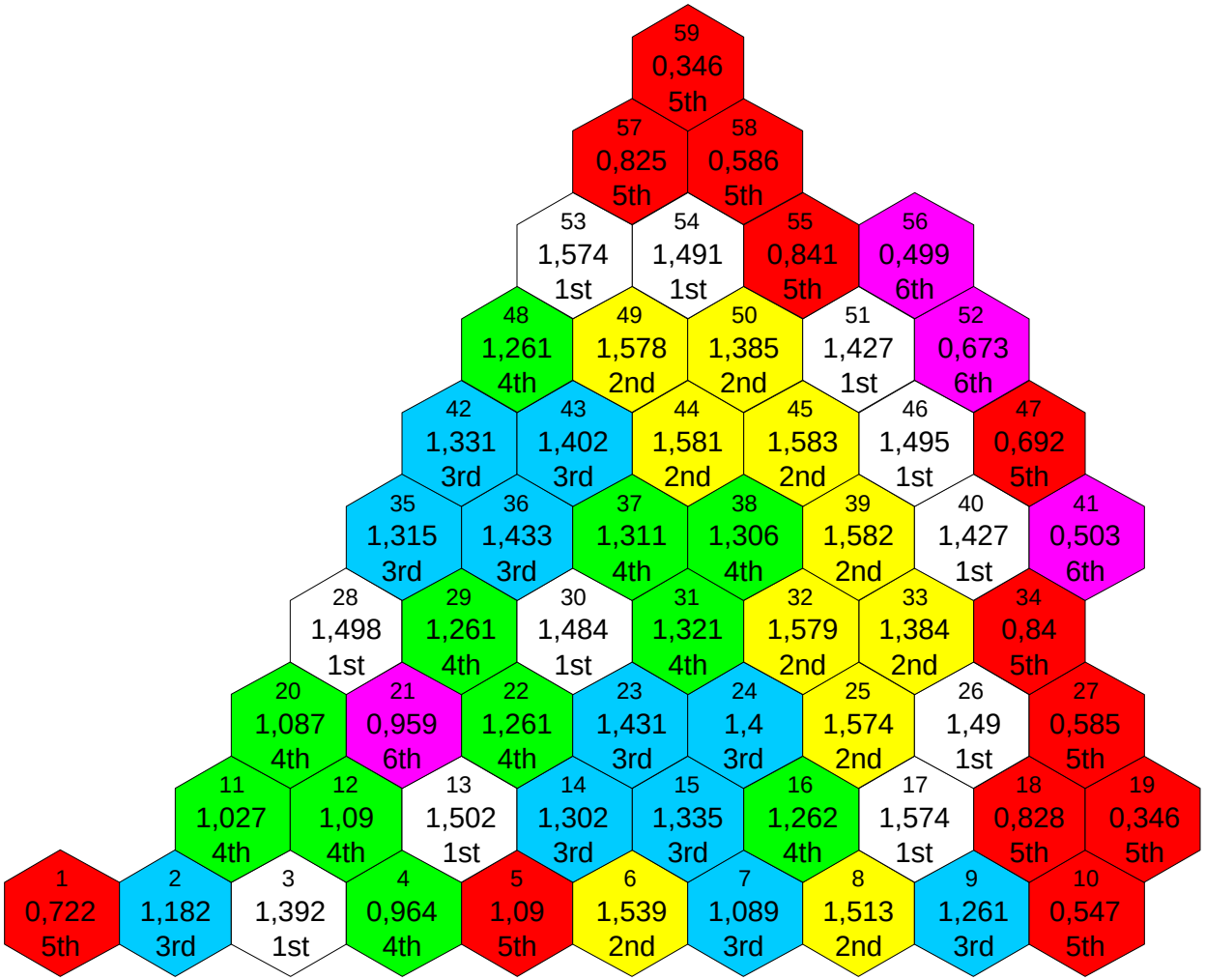
THE MAXIMAL VALUE OF Kr FOR DIFFERENT TYPES OF FUEL



OPTIMIZED RELOAD
WITH THE FUEL TYPE QFS (4,76%)



OPTIMIZED RELOAD
WITH THE FUEL TYPE SLF (4,87%)



BETTER STRATEGY OF CFAs IN GENERAL

Strategy	Number of CFA/average	Cycle [years]
12 – 12	12	3.08
12 – 6 Present situation	9	4.11
12 – 6 – 6	8	4.63
12 – 6 – 6 – 6 Advantage cycle CFA	7.5	4.93
12 – 6 – 6 – 6 – 6	7.2	5.14

EXPECTATION FROM NEW CFAS STRATEGY

Burn-ups

a) inner positions - ~50 MWd/kgU after 4 years

– will be discharged

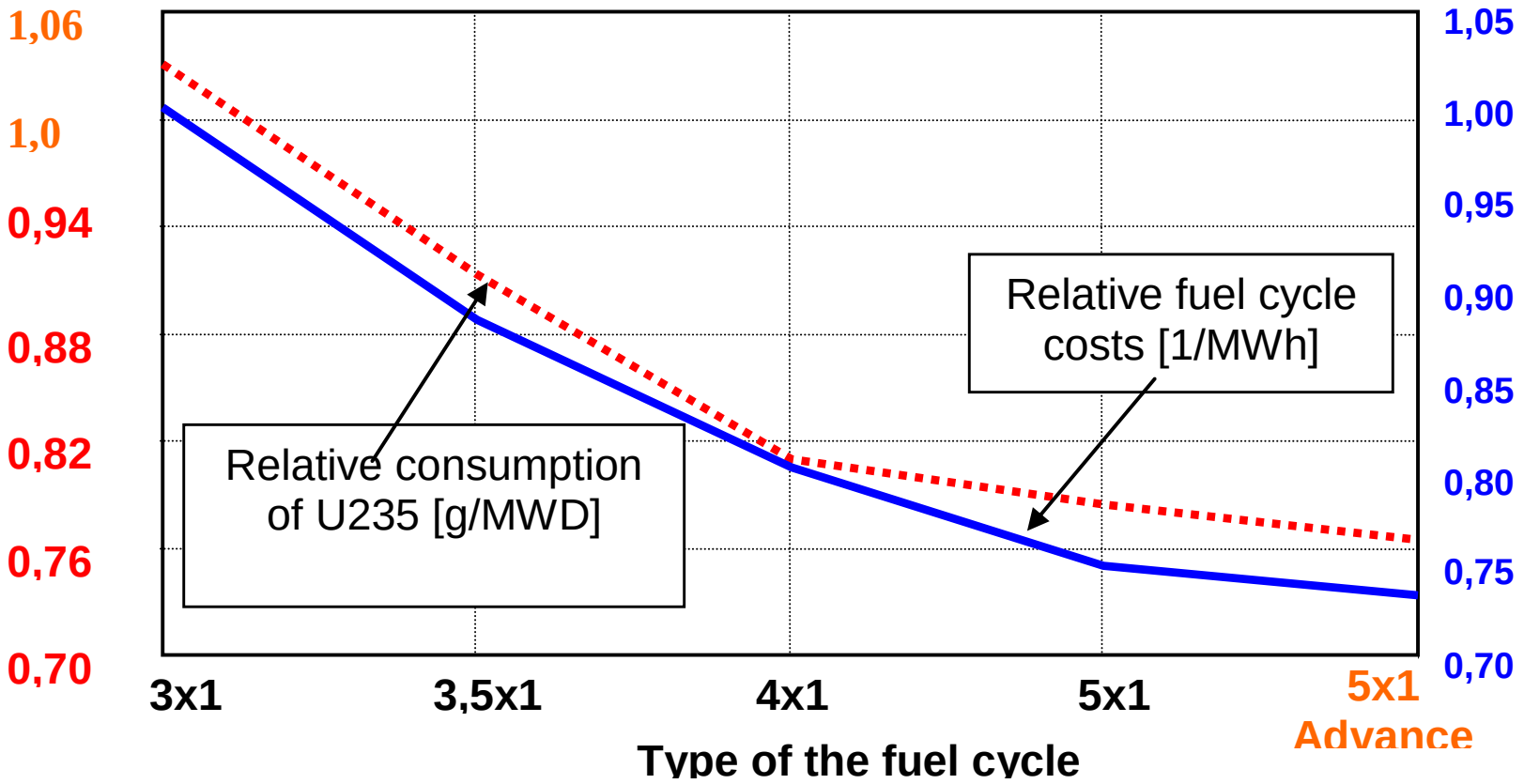
b) groups 3 and 4 - ~40 MWd/kgU after 4 years

– enable use for 1-2 cycles

→ central position 6c in 5-th year from group 3

→ group 1 – 5-th and 6-th year from group 4

NPP DUKOVANY: Dependence of the Consumption of U235 and Relative Fuel Cycle Costs for advanced fuel cycles (example)



FUEL CYCLE CHARACTERISTICS AND COMPARATION

FA = Fuel Assembly
CA = Control Assembly
FPD = Full Power Days
RFCC = Relative Fuel Cycle Costs

FA Type : CA Type :	Profiled fuel Profiled fuel	Gd-1 Profiled fuel	Gd-2 / Gd-2+ 1) Profiled fuel	Gd-2M Profiled fuel
Enrichment [wt% U235] FA / CA	3,82 / 3,82	4,38 / 3,82	4,25 / 3,82	4,38 / 4,25[1)]
Average reload batch	78 FA + 6 CA	63 FA + 9 CA	63 FA + 9 CA	63 FA + 9 CA (60+6)
Average cycle length [FPD]	310	315	325	325*)(315)*
U / MWd [kg]	0,204 (0,207)	0,183	0,178	0,177(167)
SWU / MWD	0,117	0,128	0,122	0,124(118)
RFCC [%]	100	95	94	92(89)

[1)] *Improve profiled fuel*
*) *1444 MWt*

FUEL CYCLE CHARACTERISTICS AND COMPARATION - NEW EXPECTATION

FA Type	Gd-2M+	TVSA-T
NPP	**440**	**1000**
Enrichment	**4,76/4,38**	**4,53 ****
Avereg reload Batch	**60+7,5**	**36**
Average cycle length (FPD)	**365 ***	**315**
U/MWd (kg)	**0,182**	**0,168**
SWU/MWd	**0,112**	**0,120**
RFCC	**92,7**	

*) 1444 MWt

**) FA with blanket

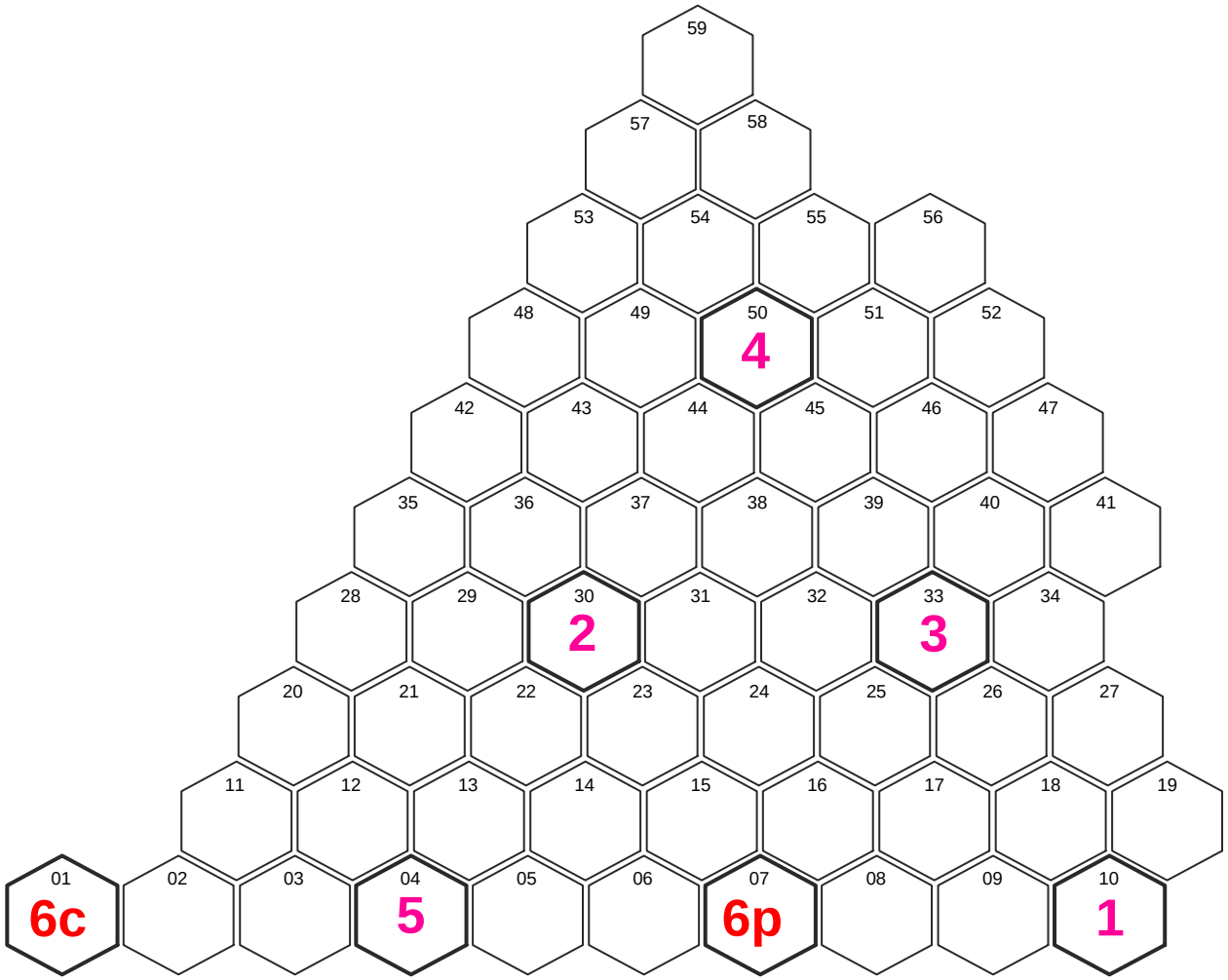
CONCLUSIONS

- **Five year cycle with Gd-1 and Gd-2 fuel was successfully realized; good agreement between calculated and measured core data acknowledged; low-leakage core design adopted for all type of FA (L3P)**
- **Implementation and next innovation of advanced fuel cycles saved the fuel cost and stabilize the production cost ; Number of FAs per reload were reduced to level 66 to 72 for fuel Gd-2M also for operation on the power level 1444 MWt for VVER 440**
- **Next upgrade of the fuel design shall be specific for future requirements of the ČEZ. New type of fuel for uprated power up to 108 % (Gd-2M+ type in perspective) shall be procured by the Fuel Contract and it is assumed to be licensed in Dukovany in period 2012- 2014**
- **New Fuel type TVSA-T and RCCA were licensed in 2010 and loaded in to NPP Temelín; power uprate up to 104 % and scheduled RFC shall be reached during a few next year**

„Requirements of the Regulatory Body (SONS) to keep the highest level of nuclear safety are the basic condition and priority for any changes in fuel cycle“

Thank you for your attention

CFAs GROUPS MAP



NEW CFAS STRATEGY 12-6-6-6

- strategy 12 – 6 – 6 – 6 – … fresh CFAs in 4 sequential loadings
  - 12 CFA to groups 3 and 4
  - 6 CFA to group 2
  - possible movement: 2 → 5 → 6p → 6p
  - 2 loops – inner positions (2, 5, 6p)
    – outer positions (3, 4, 1, 6c)
- strategy in period of testing