OUTLOOK ON TO FUEL CYCLE PERSPECTIVES AT VVER-440

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ABSTRACT

Current internal fuel cycle in NPP Dukovany 4x440MWe is shortly characterized with new types of fuel assemblies and advanced fuel cycles which have been introduced in the last years. The modernization activities accomplished until now might be extrapolated to the further period in fuel design - mechanic, thermal-hydraulic and neutronic respectively - with additional increase in fuel enrichments and burnups on the way to the 6-year cycle.

Reactor power uprating together with Unit thermal efficiency improvements could bring an increase in the electric output to the value nearly 500 MWe. The reasons are given for long-term cooperation with Fuel Supplier and Plant Designer in the area of fuel cycle as well as in Unit Design Basis. All innovations mentioned in the article including future fuel and fuel cycle changes might be a quite realistic perspective at the end of the first decade of the new century.

1. INTRODUCTION

Design of VVER440 Units originates deeply in the last century and all these reactors have been successfully operated since. Even the new construction of reactors 3 and 4 at NPP Mochovce has been declared this year.

In addition the operation life-time of VVERs is expected to be enlarged over 40 years and new estimates up to 60 years have appeared by evaluation of the life-time extension of primary and secondary systems. From the point of view of fuel management the quality of current fuel is permanently high and the long-term “no leakers“ operation with relatively high burnup belongs to the top indicators among PWRs which is a good basement for further upgrade in the near future.

Let’s have a look into the fuel cycle future from the point of view of fuel cycle manager and core designer at Dukovany.

2. CYCLE LENGTHS. EXTENDED CYCLES?

Transition to the 5x1 year cycle with advanced fuel is just in progress at Dukovany. The cycle lengths have been growing since the first startup mainly in dependence on steadily decreasing outage length which has currently reached app. 30 days. For the near future a zig-zag outage scheme has been developed combining shorter and longer outages with 20 – 24 – 24 - 32 – 20 – 24 – 24 – 63 etc. days. So the average cycle length over 330 FPDs could be expected because a base load operation with only minor portion of power control is being supposed for the Czech nuclear Units.

The current fuel types could be operated in extended cycles 3x18 months. But the economic evaluation has shown that the extended cycles would be less effective in comparison with 12 months cycles (experience of NPP Beznau had shown similar results and it was a good guide). Firstly, 3x18 is less than 5x12 (taking into account that the extended cycles would request a bit longer outages for maintenance) which means lower burnup, secondly, the core design of extended cycles brings an increase in relative fuel cycle costs. Reload batch for 18 months cycle consists of more than 100 fresh assemblies which would prevent an application of advanced L3P design because certain number of fresh assemblies would be placed at the core periphery with increased neutron losses. Additionally, a higher fluence on the reactor pressure vessel would have very negative effect for the life-time extension efforts mentioned above.

Also problems with coordination of six outages at the Czech nuclear sources are a good reason not to hurry with implementation of extended cycles and final solution could be postponed to the time after stabilization of the new Temelín Units.

CURRENT FUEL AND CORE DESIGN. IS IT CONVENIENT TO MODIFY FUEL ENRICHMENT AT EACH RELOAD?

Current advanced fuel types named Gd-2 are the most substantial innovation of VVER440 fuel assembly (FA) design in history. Optimized Uranium-water ratio has decreased the fuel enrichment of 5% without any loss of reactivity. A modified fuel version named Gd-2M with higher enrichment (appr.4,4 wt%) is going to be licensed in 2006-2007. This modification was designed for power uprating to preserve the 5x1 year cycle in working assemblies at the power uprated to 105%.

Due to the existing licensing practice as well as the fuel Contract conditions NPP Dukovany prefers long-term utilisation of defined fuel types instead of modifying FA enrichments for each individual reload. An increase (or reduction…) of the reload batch extent was proved as an appropriate tool for cycle length adjustments. In addition, there is still a chance of re-using the fuel assemblies from the spent fuel pond and finally the possibility to load an assembly for one year more over declared lifetime (FAs designed for 5x1 year cycle are allowed to be loaded into the 6th year if the burnup limit is observed). This procedure with fine variations of reload batches has proved as an effective tool to modify cycle lengths according to the operation needs and to perform effectively the long-term outage planning.

A possibility of additional change in Uranium-Water Ratio is probably exhausted. Certain reserve in reactivity still exists in minimizing of the fuel pellet hole. But the annular VVER fuel concept has proved its quality and taking into account the existing licensing and experimental basis there is no hurry to change it.

In Fig.2 two current reloads at Dukovany are presented. It can be recognized that the advanced L3P reload scheme was applied with the most discharged FAs at the core boundary. The coast-down operation with steam pressure decrease followed by the reactor power decrease became standard arrangement of the cycle end with the lengths app. 20/30 FPDs (See Fig. 3). Effectiveness of this approach depends on economic environments, currently the optimum coast-down length decreases and it may increase the cycle length again.

Current core design limits developed from safety limits using relevant uncertainties are:

$$K_r \leq 1{,}61 \qquad K_q \leq 1{,}44 \qquad q_l \leq q_{l\ \mathrm{lim}} / 1{,}13$$

The reactor inlet temperature, assembly output temperatures and sub-channel reserve to the saturation temperature are checked within the standard core design procedure as well.

The major tool for fuel cycle modernization has been the optimization code OPTIMAL utilizing elements of evolution theory. An advanced optimization code is just under development.

X-YEAR CYCLES. IS THE 6-YEAR CYCLE REALLY ACHIEVABLE?

Various multiple cycles in working assemblies in combination with various cycles in control assemblies (See Table 1) could be realized theoretically. In practice only the 12-months cycles 3+A, 4+B and 5+B have been realized up to now. There is an interesting task to analyse the cycles 6 ½+E and the extended 18-months cycle 4+A having in mind the fact that in such cases the fuel enrichment may get over the 5% boundary.

It is obvious that certain reserve still exists in fuel enrichment up to the worldwide accepted limit 5 wt% U235. Taking into consideration the possible profiling of enrichment the maximum achievable FA enrichment may lie between 4,8 and 4,9 wt% U235. Preliminary analysis has shown that still available reserve in enrichment would not cope with the 6x1 year cycle under existing core design limits. Without additional increase in fuel reactivity only a hybrid 5½x1 year cycle could be realized.

Of course, the 6x1 year cycle with uprated reactor power means a very high burnup. In comparison with existing limit 65 MWd/kg (pin average value, current maximum still below 60) the burnup over 75 MWd/kg would be reached which belongs to the top among PWRs in any case. No occurrence of fuel leakage at VVER440 gives a hope that certain space for burnup increase still exists. But it is necessary to have in mind that PCI and cladding corrosion effects start their growing after 50 MWd/kg which must be taken into consideration by the fuel designer.

A special problem is the management of control assemblies (CA). To preserve the 1/12 core symmetry they are still reloaded in 4x1 year cycle (see Tab.1). Next possibility could be the scheme 4 1/3 (C) which is now under evaluation. The enrichment/reactivity increase in this fuel group is limited due to its impact on core loading and core operation strategy.

3. POWER UPRATING. WHY ONLY 105%?

Power uprating to 105% in Dukovany was agreed after the technical and economical evaluation where the income from higher energy production should compensate the investments and losses due to increased relative fuel cycle costs. By the same core design limits the higher core power makes necessary the less effective reload types with higher neutron leakage. Of course the economic conditions are permanently changing and market with electricity is more favourable nowadays comparing with situation 5 years ago. Therefore it is reasonable to apply certain additional power reserve in design of great investments connected with power uprating - like upgrades of turbines, generators and transformers.

105% is still the value which probably does not request an increase in primary flow and reconstruction of main cooling pumps. Two Dukovany Units have only small reserve to primary flow design limit even by existing pumps and this fact minimizes the possibility of coolant flow increase.

Any power increase over 105% (with the current value of primary and secondary pressure as well as the coolant flow rate) decreases the reserve to saturation temperature in hot subchannel which again makes necessary to design less effective loading pattern with higher neutron leakage and increased fuel consumption.

Licensing process of the power uprating will be accomplished with extensive participation of domestic and Russian organizations where especially support at Design Basis and by fuel licensing is expected. This support becomes the important condition to upgrade VVERs to the level necessary for 21st century.

4. KARKAZ FUEL ASSEMBLIES FOR VVER440?

There is a new possibility of the mechanical design upgrade at working fuel assembly with not negligible impact on fuel reactivity. It is introduction of KARKAZ type relieved assembly shroud composed from straps and angles instead of existing compact shroud (See Fig.4). KARKAZ was developed for VVER1000 reactors as a fully original concept to solve mainly the permanent problem at PWRs which is fuel Twist&Bow. In addition, it simplifies the manipulations with fuel and together with original spacers gives a full prevention against fretting. After all efforts and speeches around the Robust Fuel Program just KARKAZ seems to be the only solution available giving expected results approved now also by in-pile testing.

Adaptation of KARKAZ shroud to VVER440 fuel is probably a possible concept for future innovation. Of course it needs long time for development and testing mainly from the point of view of fuel and the core thermal hydraulics. There were no problems with twist & bow or fretting at VVER440 up to now but the increase of fuel reactivity is not negligible income on the way to more efficient fuel cycle.

5. UNIT THERMAL EFFECTIVENESS INCREASE. A NEW RESERVE DISCOVERED?

A new and unexpected contribution to the electric production has appeared at Dukovany without any relation to the fuel and reactor side. It is the thermal efficiency and electric output increase as a consequence of turbine upgrade at the same thermal reactor power. After replacement of low pressure rotors newly designed by SKODA ENERGO Pilsen at Unit 3 (See Fig. 5) the electric output increased of nearly +4%. The scheduled replacement of high pressure rotors (among other great investments connected with reactor power uprating) will increase electric output additionally by 1,5%.

The final planned electric output increase at Dukovany can be summarized as:

+ 5 % due to power uprating – increase of reactor thermal power

+ 3,5 % due to new LP turbine rotors – increase in Unit thermal efficiency

+ 1,5 % due to new HP turbine rotors (under designing) – increase in Unit thermal efficiency
= +10 % in electric output of the Unit

As a result of all those activities the designed Dukovany output 440 MWe would be transformed to nearly 490 MWe. It may be taken as a successful modernization process in any view.

6. CONCLUSION

All reflections mentioned above could be closed with the following statements:

- there are open possibilities of innovation in technology, fuel and fuel cycle at VVER440
- it is advantageous to link up the regular innovations of major plant systems with power up-rating
- long-term cooperation with Russian Designer, Fuel Supplier and their Technical Support could bring a benefit and important help by solving of various technical problems.

Table 1: Multiple cycles

n-tuple cycle	Number of loaded working assemblies	n-tuple cycle	Number of loaded control assemblies
3	102 – 102 – 108	3 (A)	12 – 12 – 12
4	78 – 78 – 78 – 78	4 (B)	12 – 6 – 12 – 6
5	60 – 66 – 60 – 66 – 60	4 1/3 (C)	12 – 6 – 6 – 12 – 6 – 6
6	54 – 54 – 48 – 54 – 54 – 48	5 (D)	12 – 6 – 6 – 6
6 1/2	48 – 48 – 48 – 48 – 48 – 48 – 48	6 (E)	6 – 6 – 6 – 6 – 6 – 6

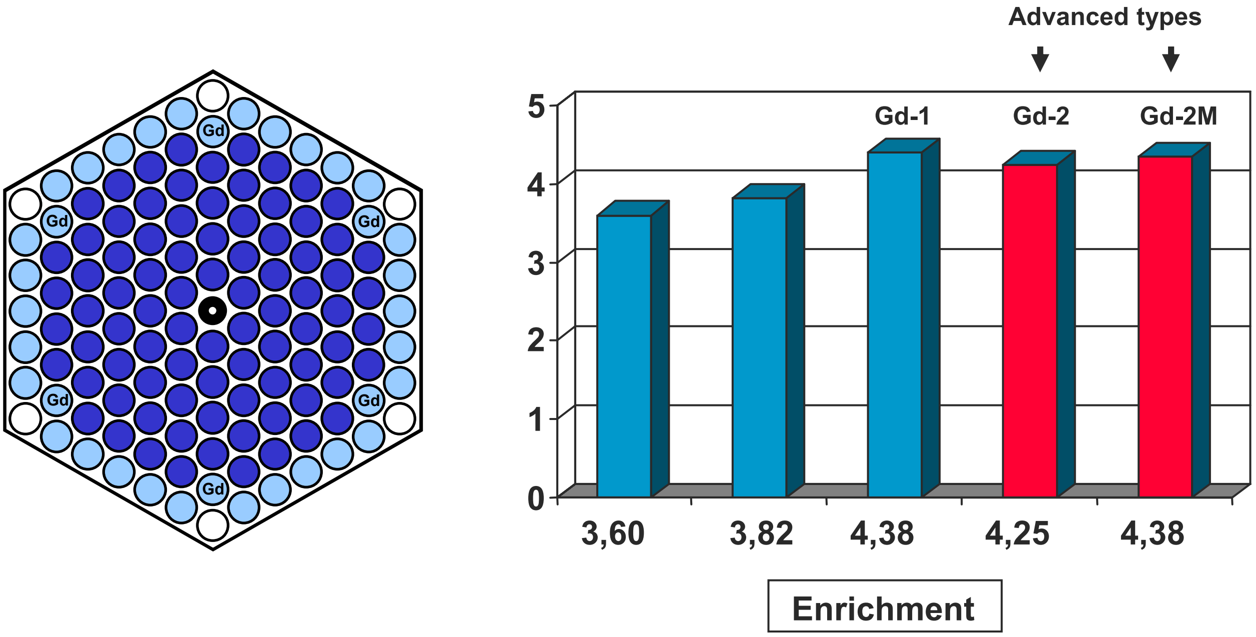
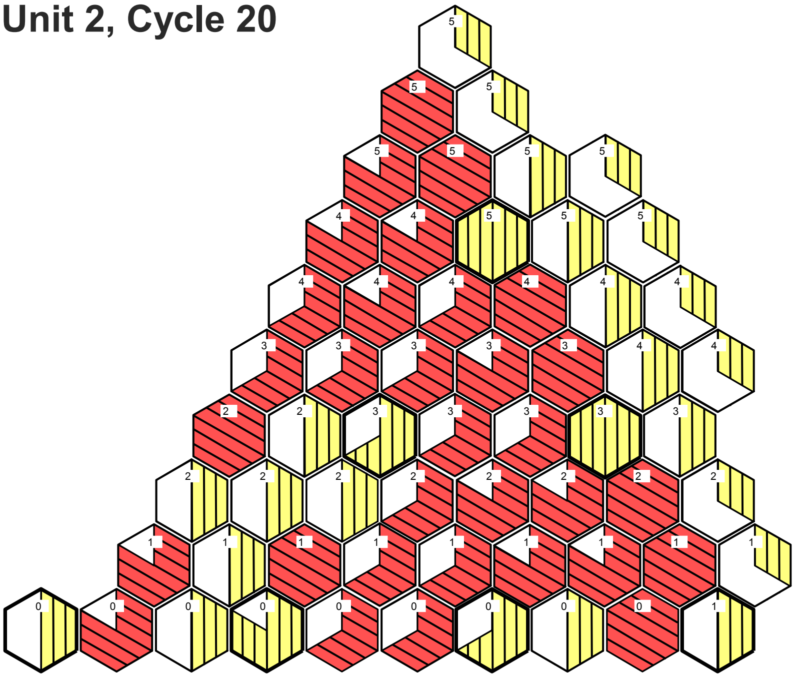
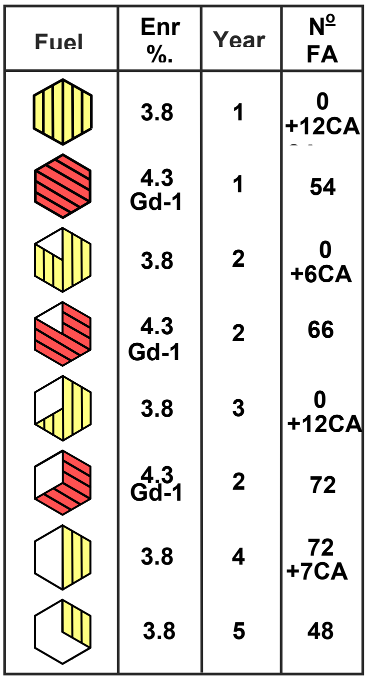


Fig.1: A typical fuel assembly enrichment profiling and the mean enrichments

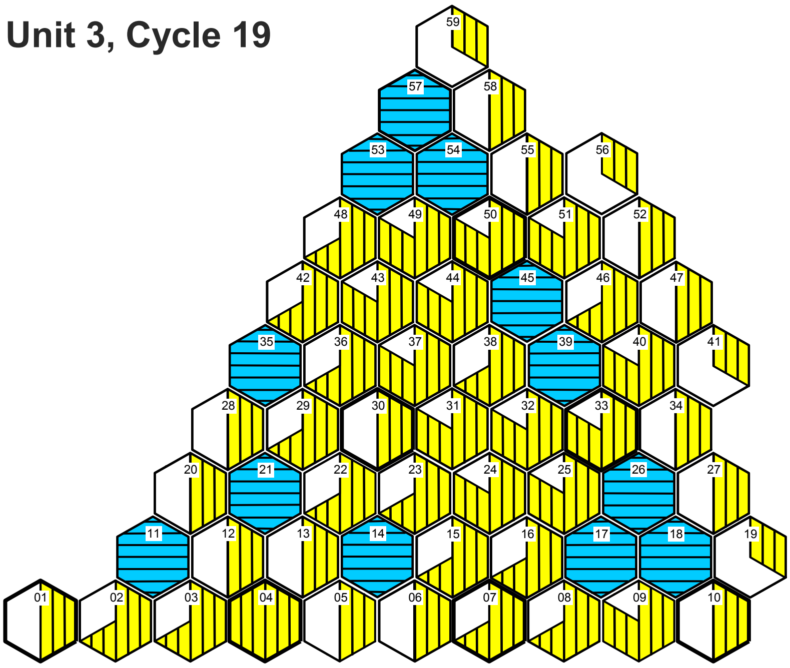
Unit 2, Cycle 20

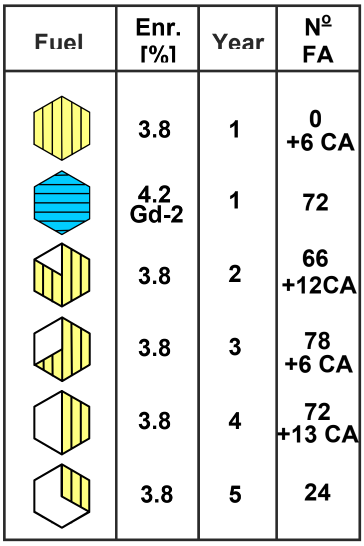




Fuel	Enr %.	Year	Nº FA
▥	3.8	1	0 +12CA
▤	4.3 Gd-1	1	54
▥	3.8	2	0 +6CA
▤	4.3 Gd-1	2	66
▥	3.8	3	0 +12CA
▤	4.3 Gd-1	2	72
▥	3.8	4	72 +7CA
▥	3.8	5	48

Unit 3, Cycle 19





Fuel	Enr. [%]	Year	Nº FA
▥	3.8	1	0 +6 CA
▤	4.2 Gd-2	1	72
▥	3.8	2	66 +12CA
▥	3.8	3	78 +6 CA
▥	3.8	4	72 +13 CA
▥	3.8	5	24

Fig.2: Two current reloads at Dukovany

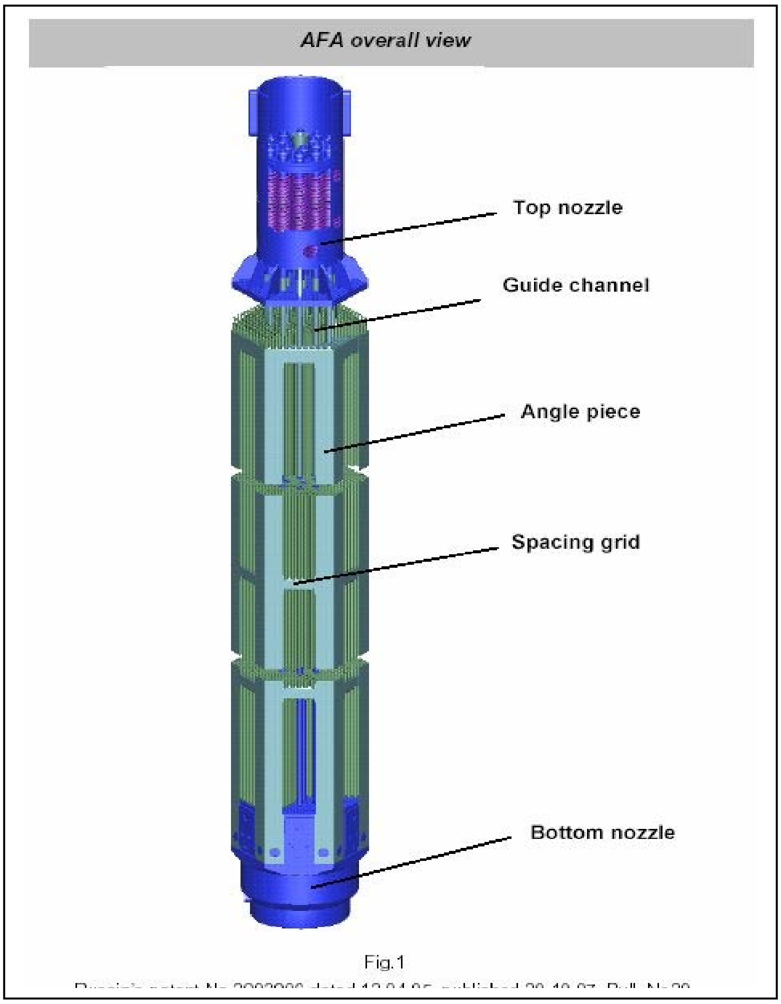


Fig.4:
KARKAZ type fuel assembly at VVER1000.
According to the paper by V.I.Aksenov at all: Results of alternative FA development…, Proceedings TOPFUEL 2001, Stockholm 2001

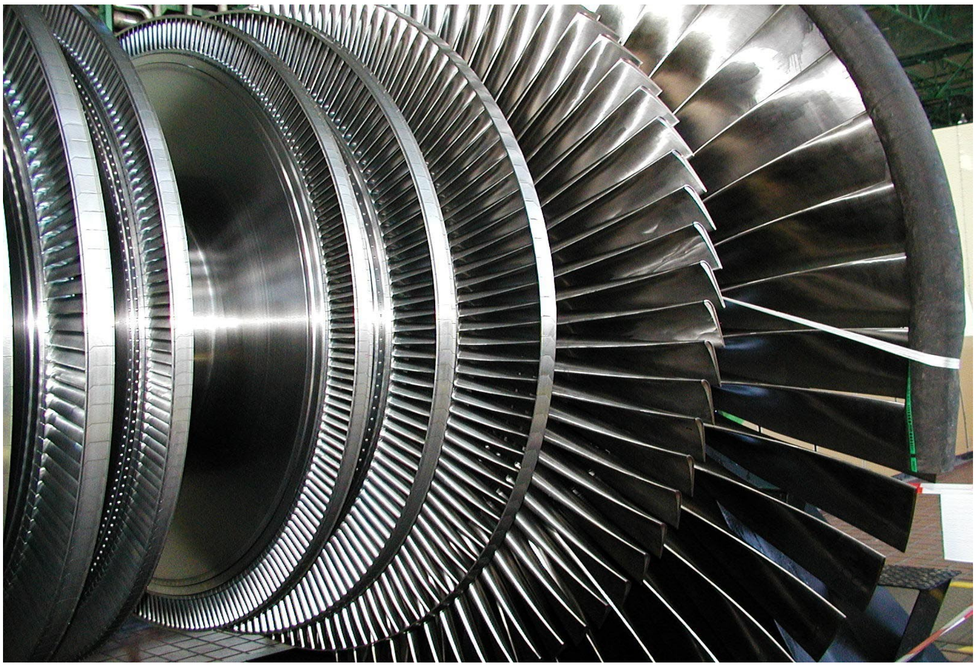


Fig.5:
New LP rotors at Dukovany Unit 3 designed by SKODA ENERGO Pilsen.
Due to higher thermal efficiency the electric output of Unit 3 increased of ≈ 4%

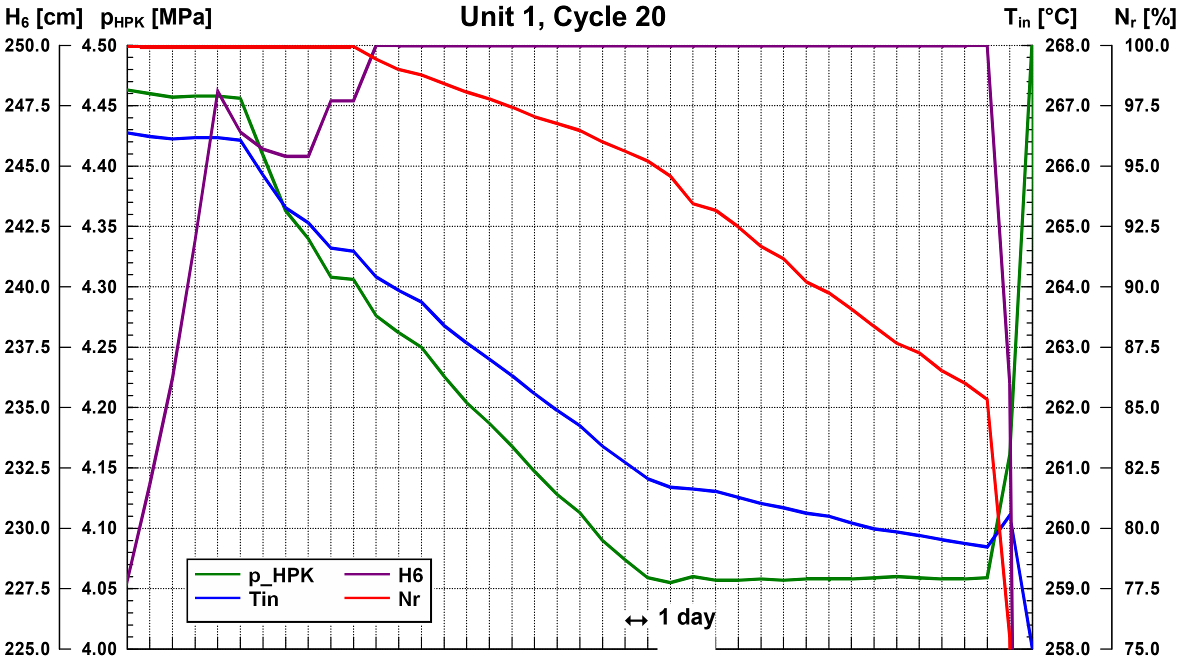


Fig.3: A typical coast-down operation and major parameters