DE LA RECHERCHE À L'INDUSTRIE

Optimization analysis of Pressurized Water Reactors in the framework of renewable energies deployment in the french energy mix

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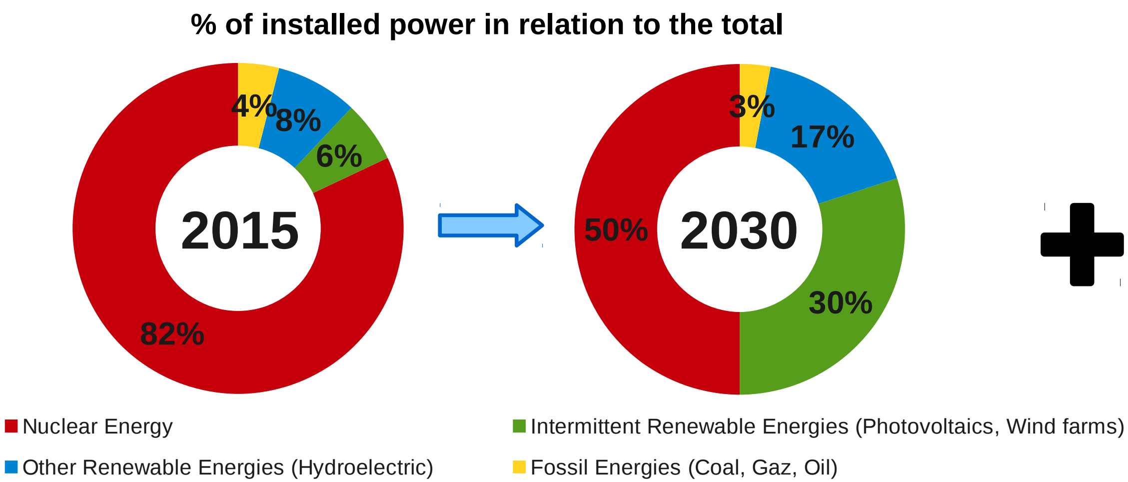
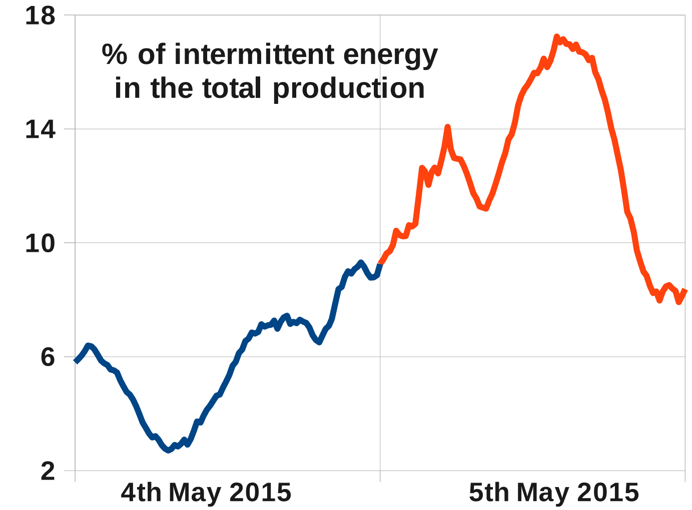


(Source : ADEME)



(Source : RTE eco2mix)

Large scale deployment of **intermittent renewable energies** in France

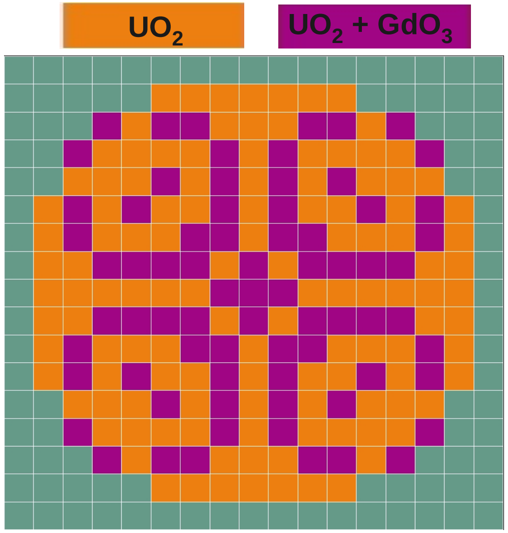
Highly fluctuating production rate (up to 3 times the average)

Increase of the power variations as well in frequency as in amplitude

Introduction

- Challenge : Optimize the nuclear power plant (NPP) toward **better manageability** (meeting the safety constraints), so they can cope with huge power variations
- Methodology :
  - Develop a **multi-physics 3D model** of the NPP in the APOLLO3® code
  - **Optimization** of the control systems using meta-heuristics methods
- The model :
  - Input : power transient
  - Output : boron concentration, temperature, axial offset (AO), linear power
- Problems :
  - **robustness** / **precision** of the model (wide range of configurations)
  - calculation **time** (thousands calculations for one optimization process)

PWR 1300 in a nutshell



Representation of a reactor core

- **PWR 1300** (electrical power : 1300MWe, thermal power : 3800MWth)
- **193** assemblies (120 UO2, 73 UO2+GdO3)
- Dimensions : diameter = 3m, height = 4,5m

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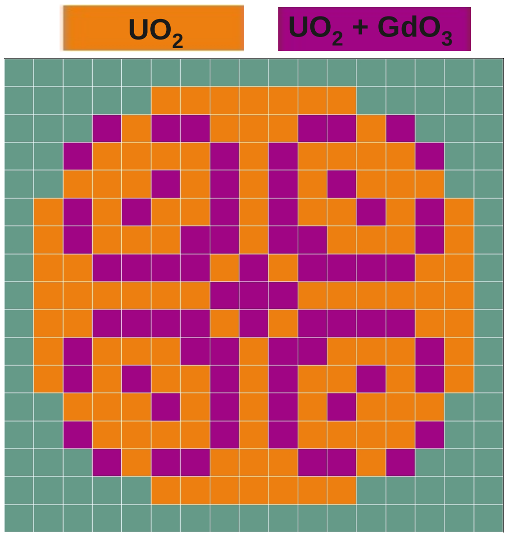

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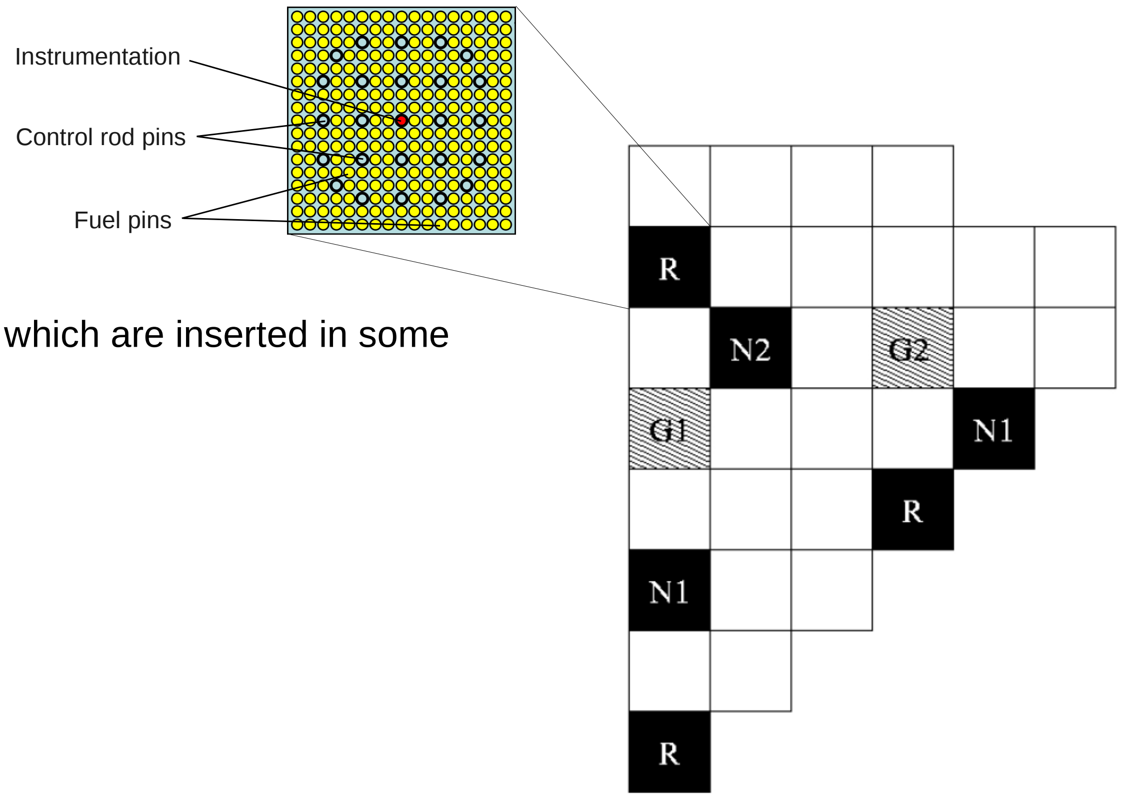

- Each control rod is made of **24 pins** which are inserted in some fuel assemblies

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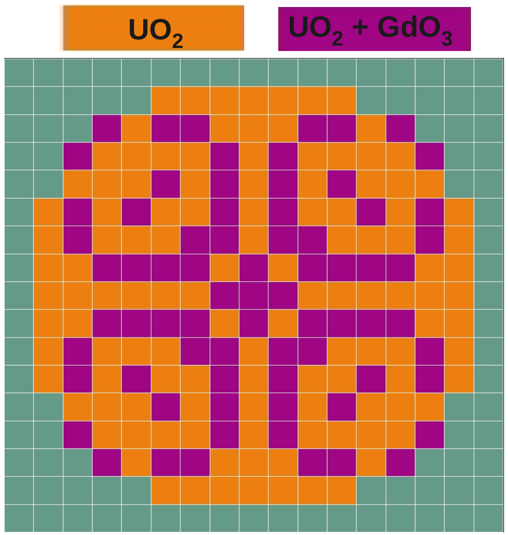

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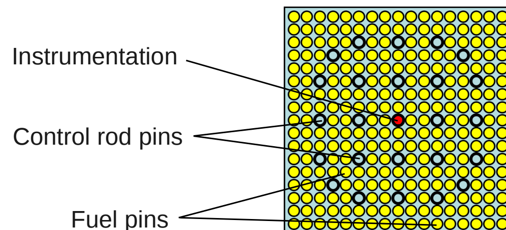
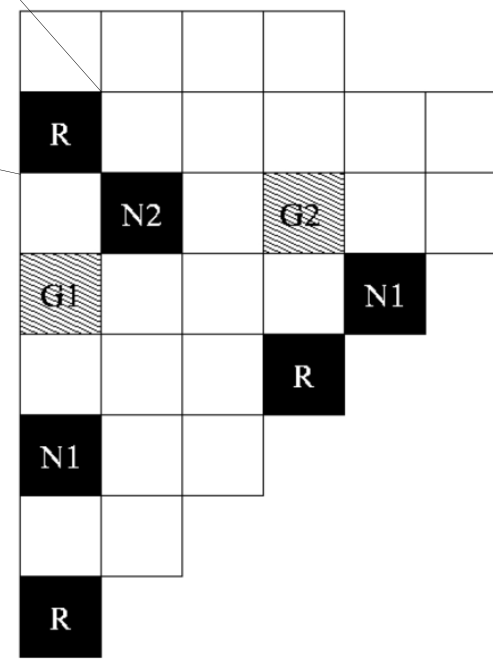




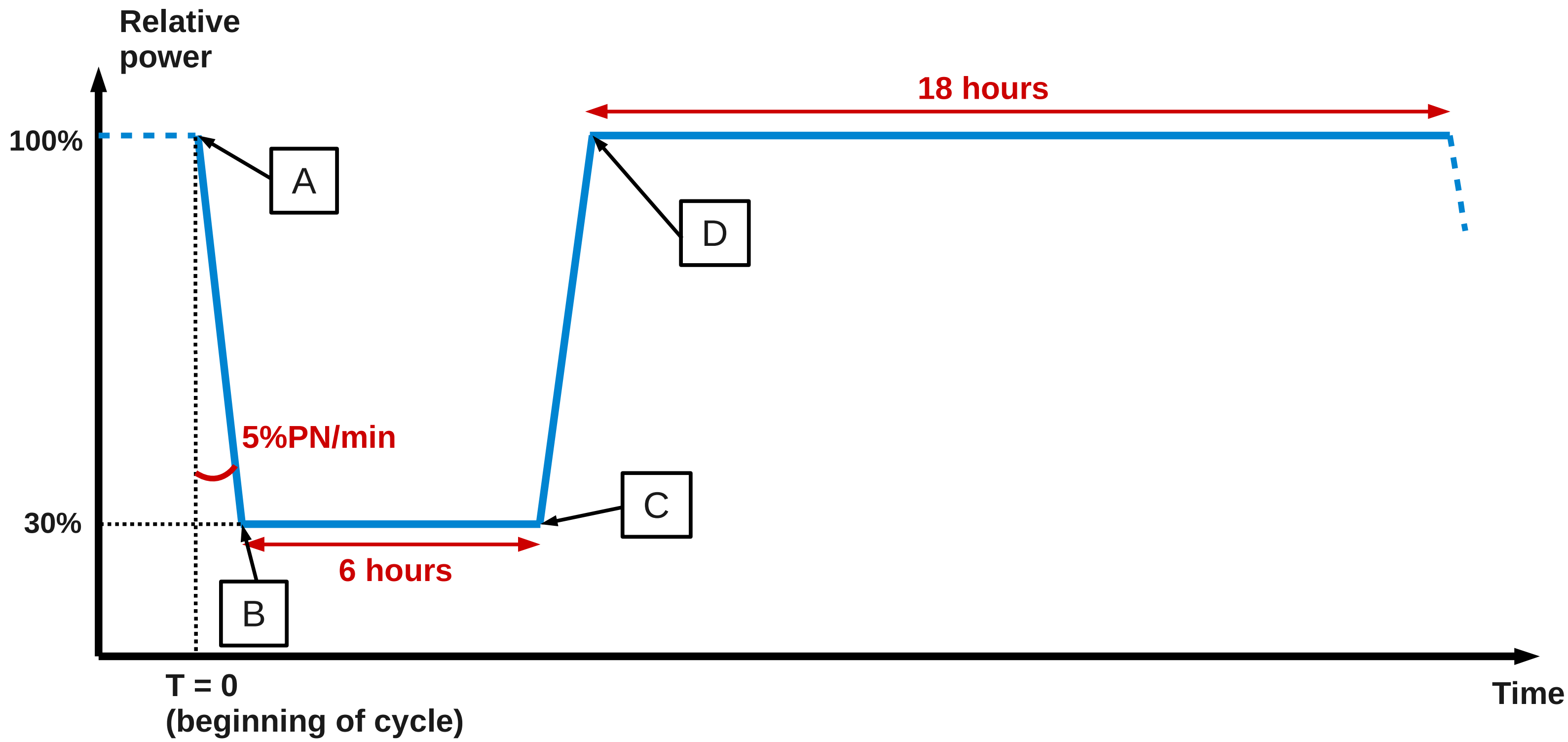
- Each control rod is made of **24 pins** which are inserted in some fuel assemblies
- **Temperature regulation** (R) : 9 “black” rods (B4C in the half top, AIC in the half bottom)
- **Power shimming** :
  - 4 “gray” rods G1 (AIC and stainless steel)
  - 8 “gray” rods G2
  - 8 “black” rods N1
  - 8 “black” rods N2

Design of the multi-physics model

Core			
Neutronics	Thermalhydraulics	Fuel	Boron management
Geometry : **3D** Type : **quasi-static** Solver 3D : **Diffusion** Number of groups : **2**	Geometry : **multi1D** Calculation : **enthalpy balance** Type : **stationary**	Geometry : **multi1D** Calculation : **thermics** Type : **stationary**	**Operator model**
Primary – Secondary heat exchanges			
Steam generator model			

- **load-follow** type transient (6/18 : **day/night** consumption)

- Lower plateau at 30%PN and power variation of 5%PN/min = **more penalizing**

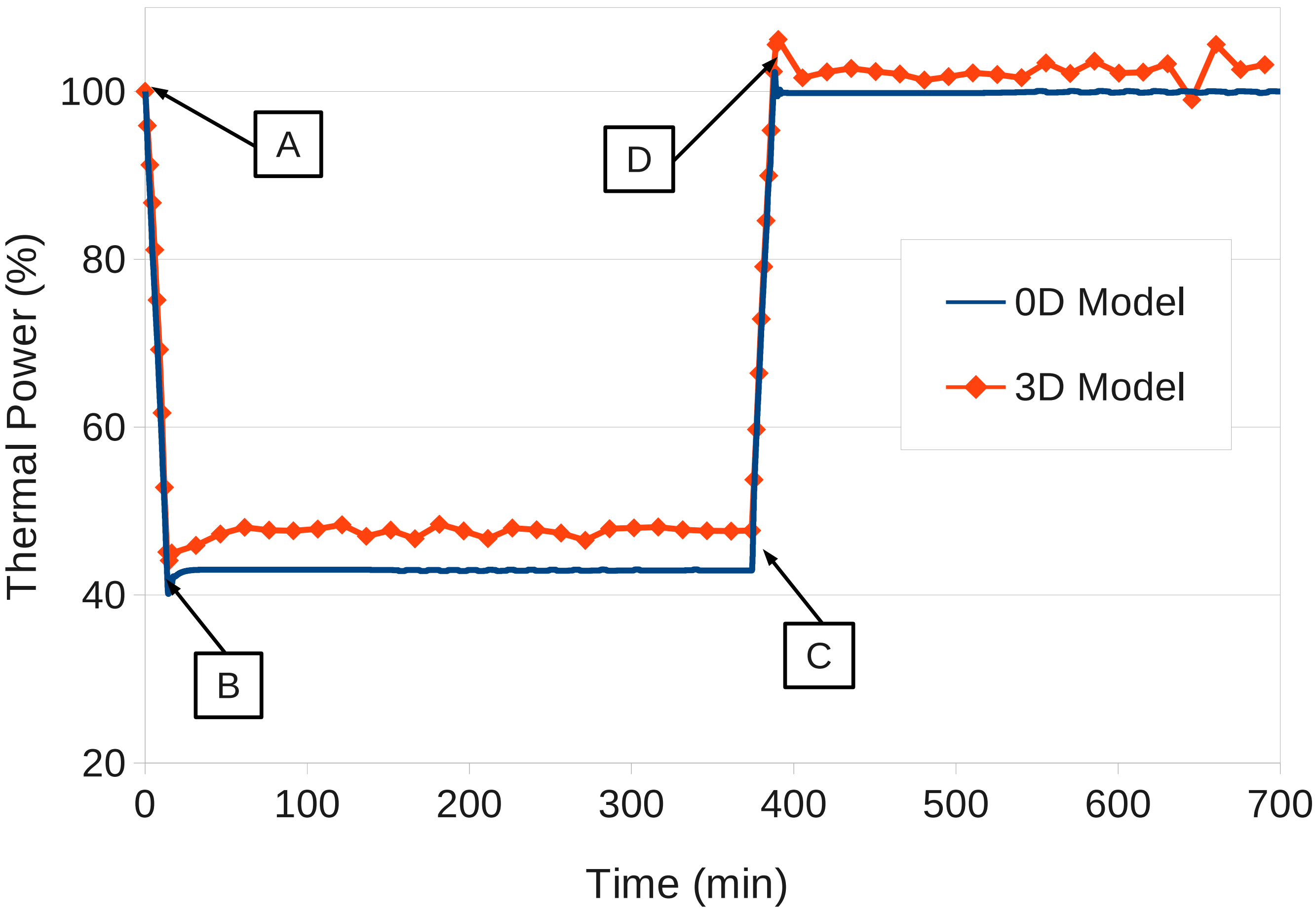


- We compare our model to the 0D Model described in [1]:
  - **Point kinetics**
  - Better description of the **secondary loop**
  - **Simulator** approach
  - Compared to data from **NPP in operation**

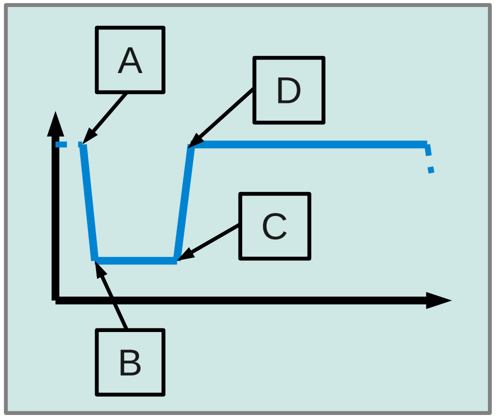
↳enable to ensure a good behavior of our model

[1] H. GRARD, *Physique, fonctionnement et sûreté des REP*, EDP Sciences (2014)

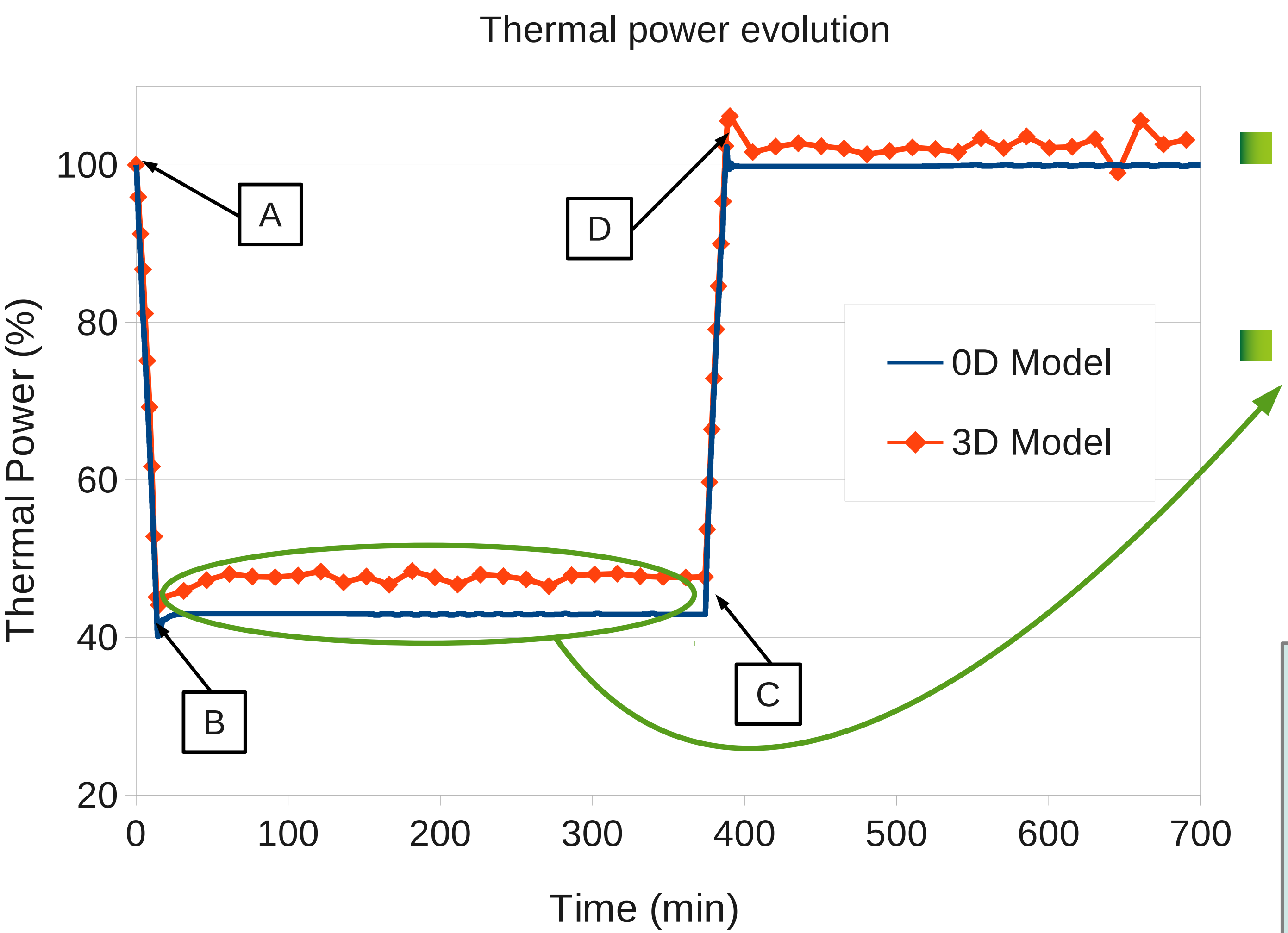
Thermal power evolution



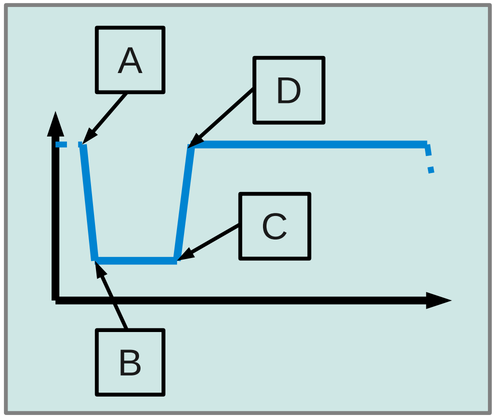
- **Shape** of the 0D Model well reproduced



Power transient
Comparison of the models

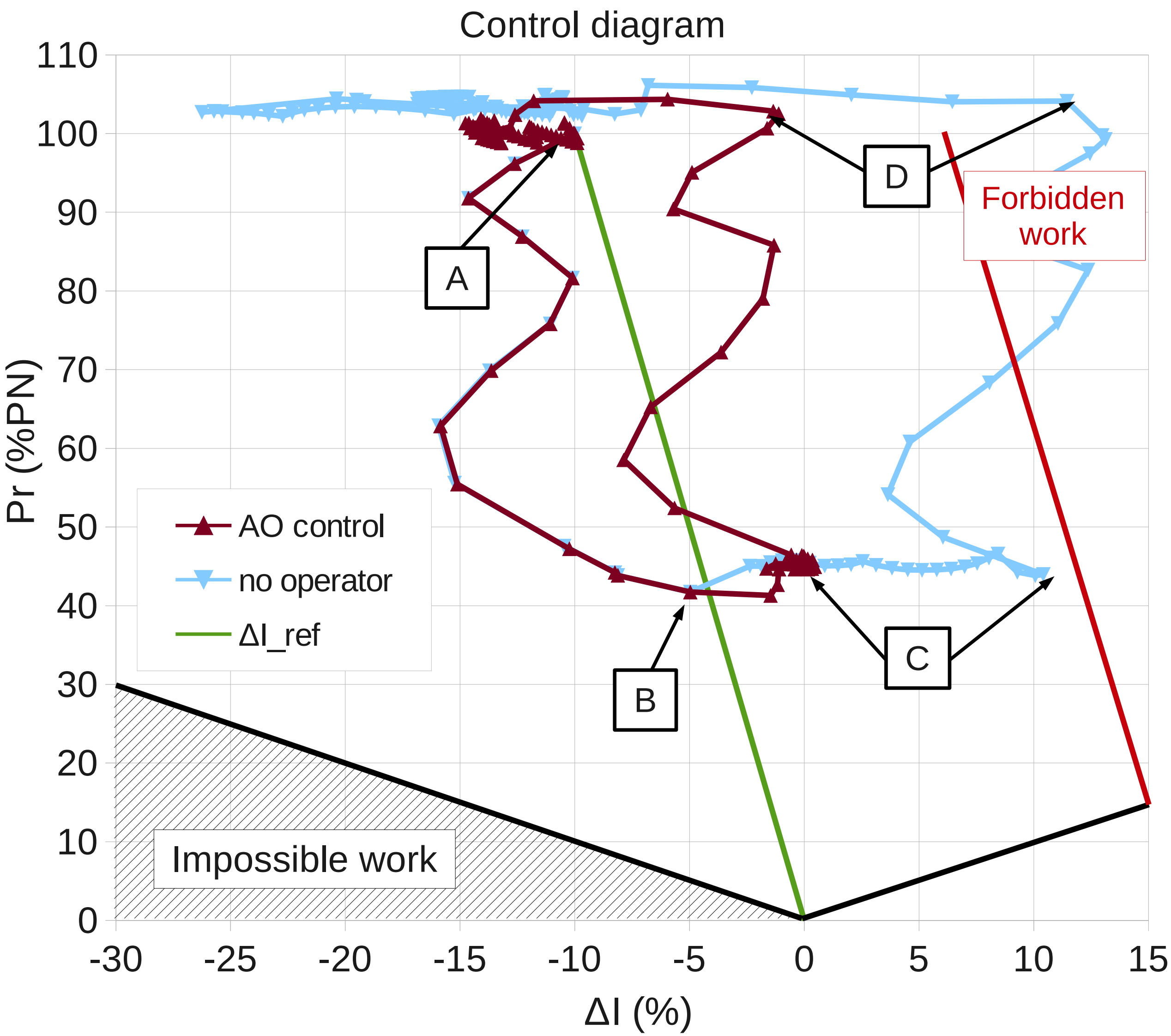


- **Shape** of the 0D Model well reproduced
- **5%PN** difference on the lower plateau
  ↳ why ?



Power transient

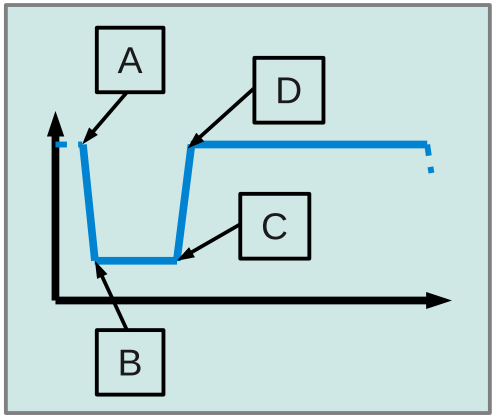
Core management



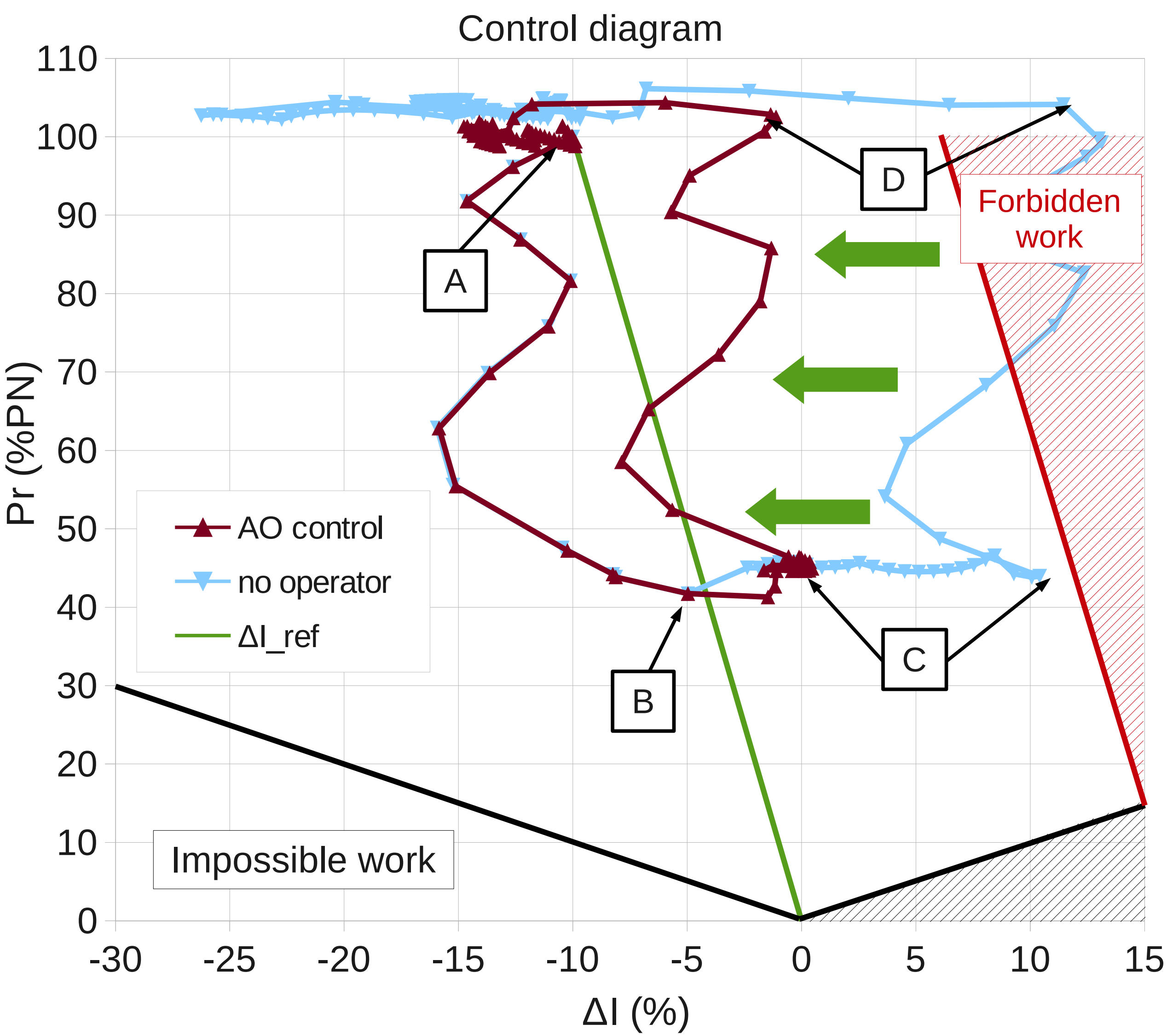
$$AO = (P_t - P_b) / (P_t + P_b)$$

$$\Delta I = Pr * AO$$

Control the state of the core **during operation**



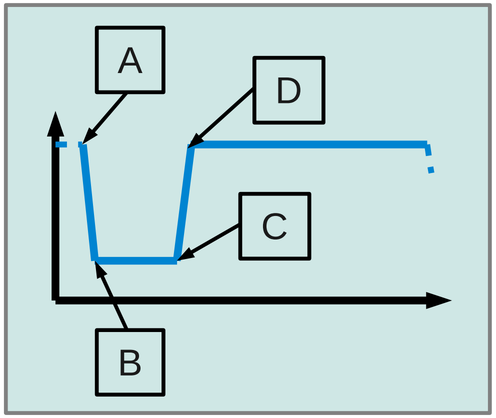
Power transient
Core management



$$AO = (P_t - P_b) / (P_t + P_b)$$

$$\Delta I = Pr * AO$$

- Control the state of the core **during operation**
- Avoided **drift** on the plateau
  ↳ operator effect (axial offset control)



Optimization

- Optimization methodology :

  1) with the **actual mix**

  2) after **massive deployment** of intermittent energies

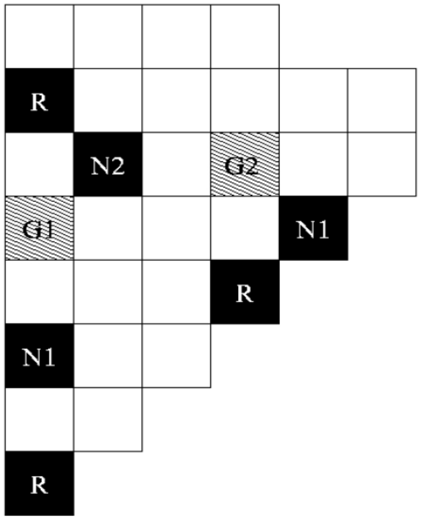
- Parameters of the **control rods** are targeted (speed program, overlap, insertion sequence, etc.)

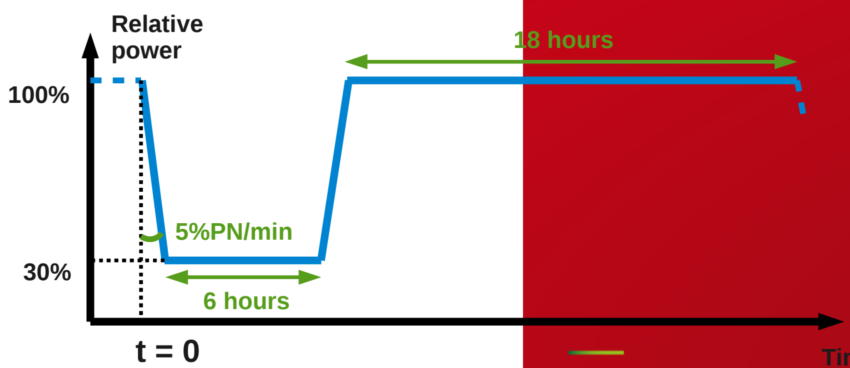
- Work in progress :
  - Compute **good criteria** (control diagram characterization / PCI)
  - Research and develop efficient **evolutionary algorithms**

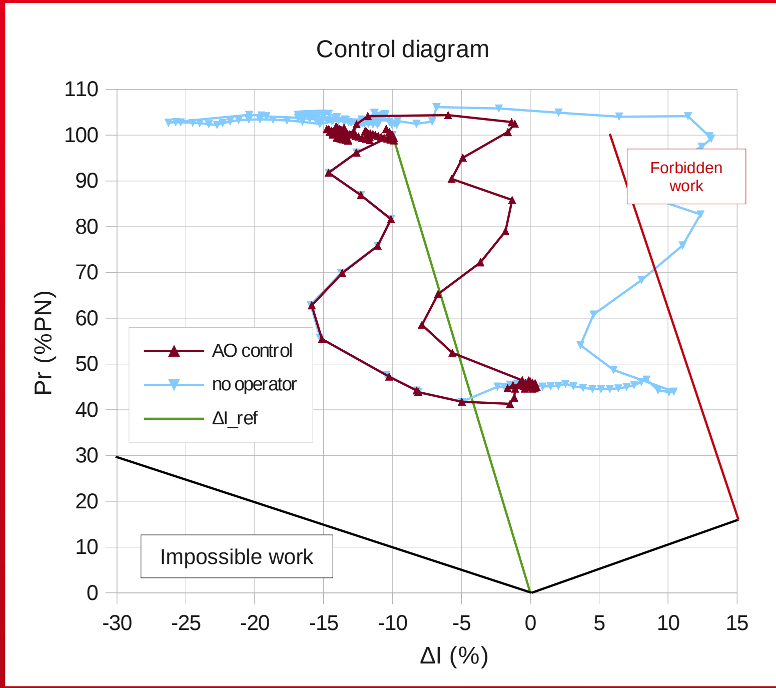
Conclusions

- **Satisfactory** 3D model as regard to :
  - The 0D Model
  - Its performance (operator behavior, calculation time)
- Remaining work on the model : reduce the **calculation time** (cross sections)
- Perspectives : launch the **optimization process**

Thank you for your attention !
Any questions ?







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