For a low carbon electricity generation : flexibility of the French nuclear fleet

2019 IEA WORKSHOP ON NUCLEAR POWER

25/02/2019

EDF FRENCH NUCLEAR ASSETS

- EDF operates **58 PWR plants**
  - 4 units of 1450 MW
  - 20 units of 1300 MW
  - 34 units of 900 MW

  Total : 63 GW

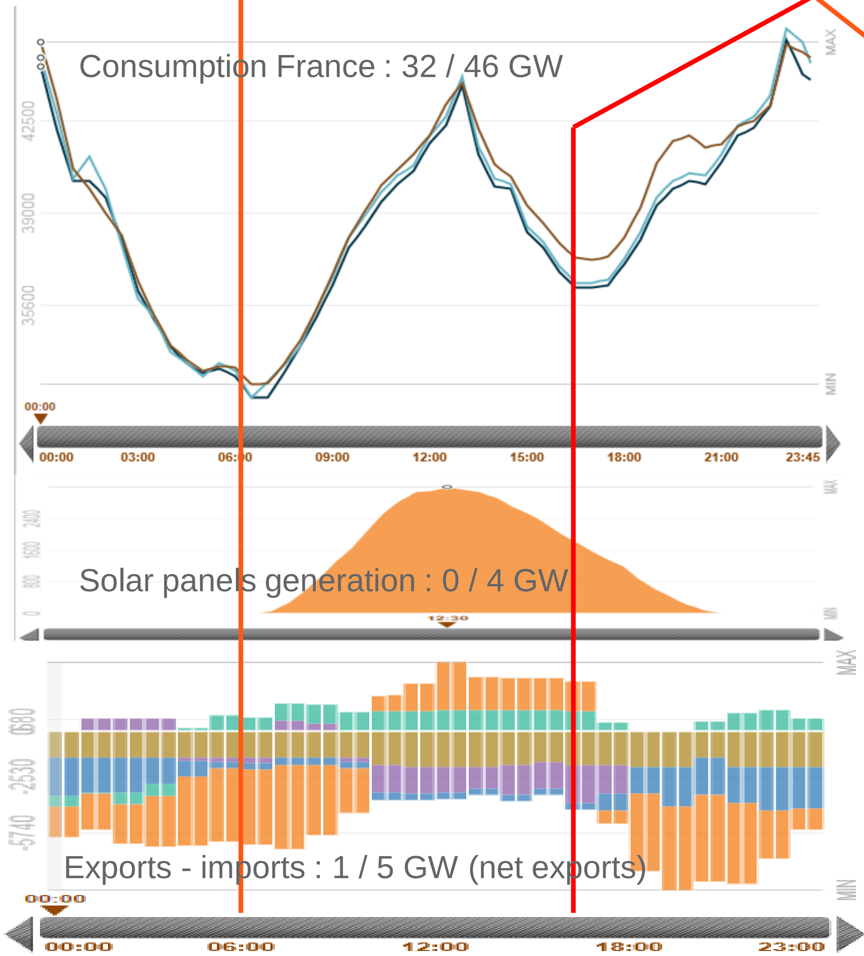
- One EPR (1600 MW) under construction in Flamanville

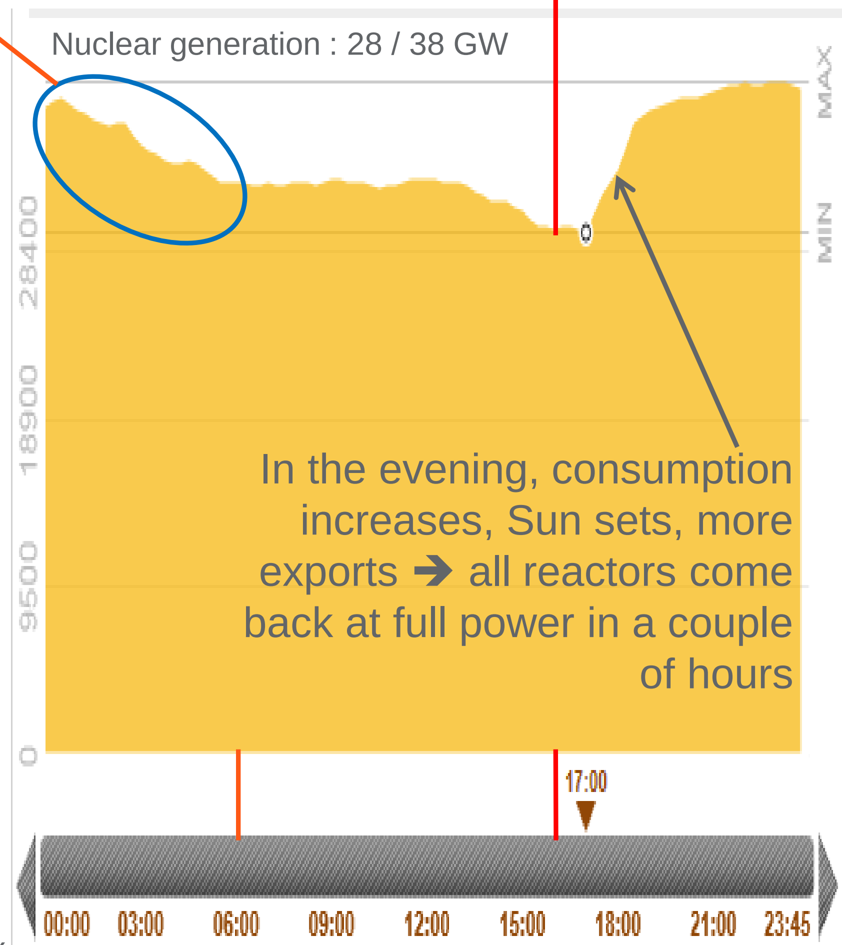
WHY BEING FLEXIBLE ?

Sunday, May 8th, 2016

0 am to 6 am : consumption decreases, exports are stable ➔ nuclear generation slightly decreases, one reactor after another

4 pm : low consumption, high solar generation, low exports ➔ 13 reactors at their minimum

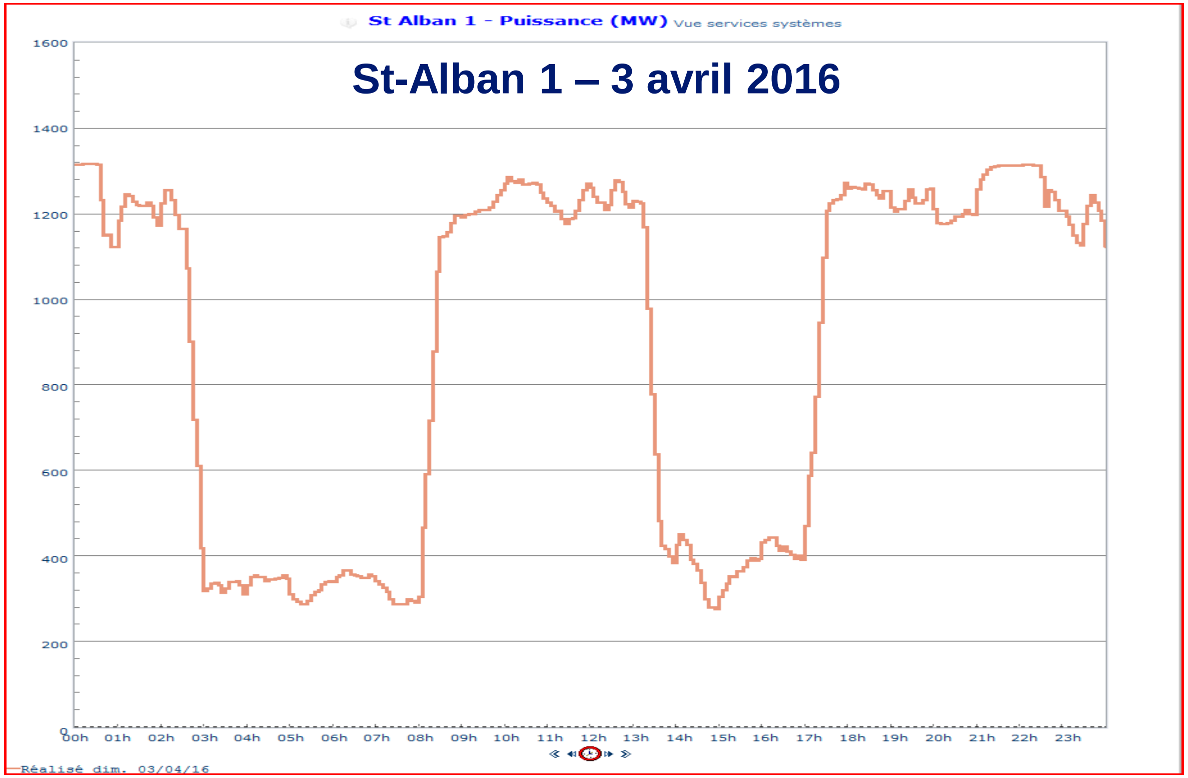




Sources : RTE, Application éco2mix

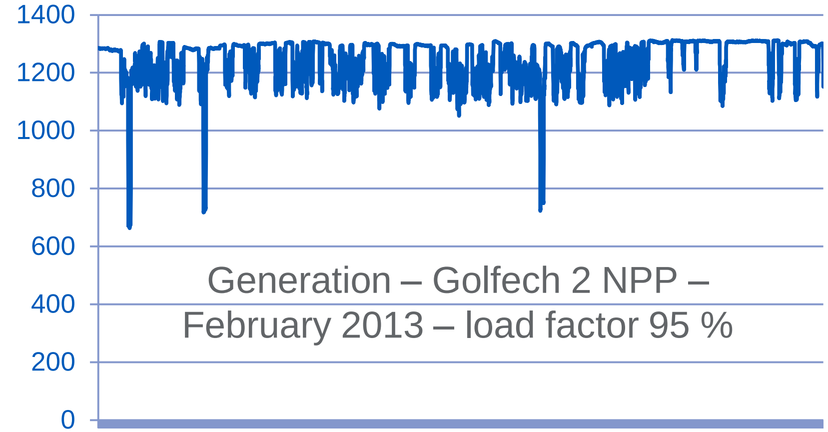
WHEN BEING FLEXIBLE ? On a daily basis

Designed and observed capacities for EDF reactors (900 MW CPY and 1300 MW)

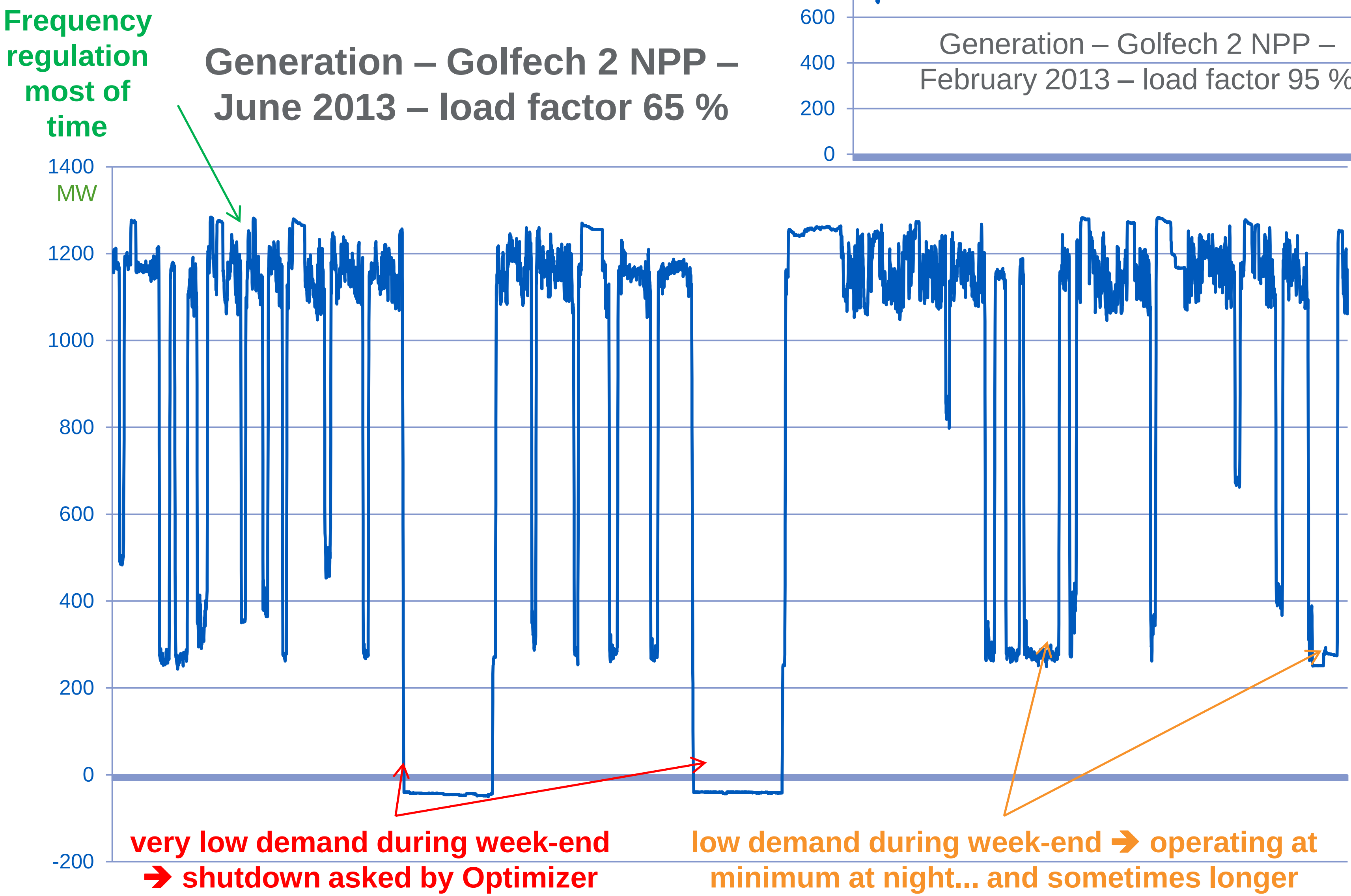


- 2 variations per day
- Down to 20% of max power
- 30 minutes between minimum and maximum power
- Frequency regulation

WHEN ? On a monthly basis

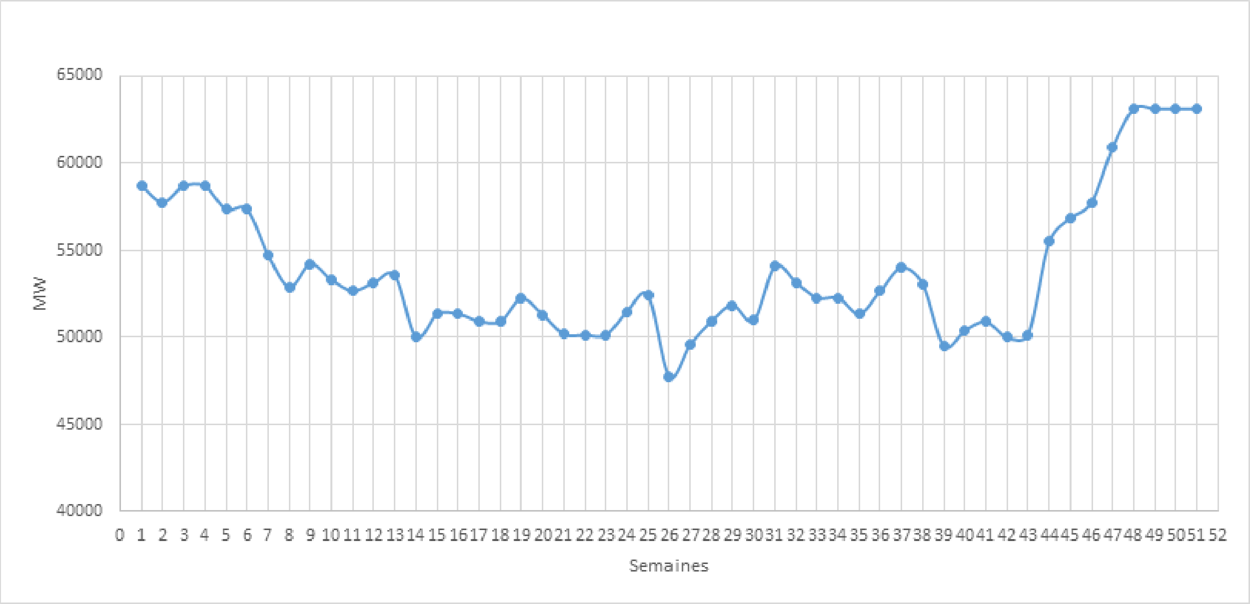


Generation – Golfech 2 NPP – June 2013 – load factor 65 %



WHEN BEING FLEXIBLE ? On a yearly basis

Choosing the right moment to plan outages is another way to make nuclear generation being flexible



Constraints exist for the planning of outages (mostly due of the burning of fuel), but there is some place to manage it :

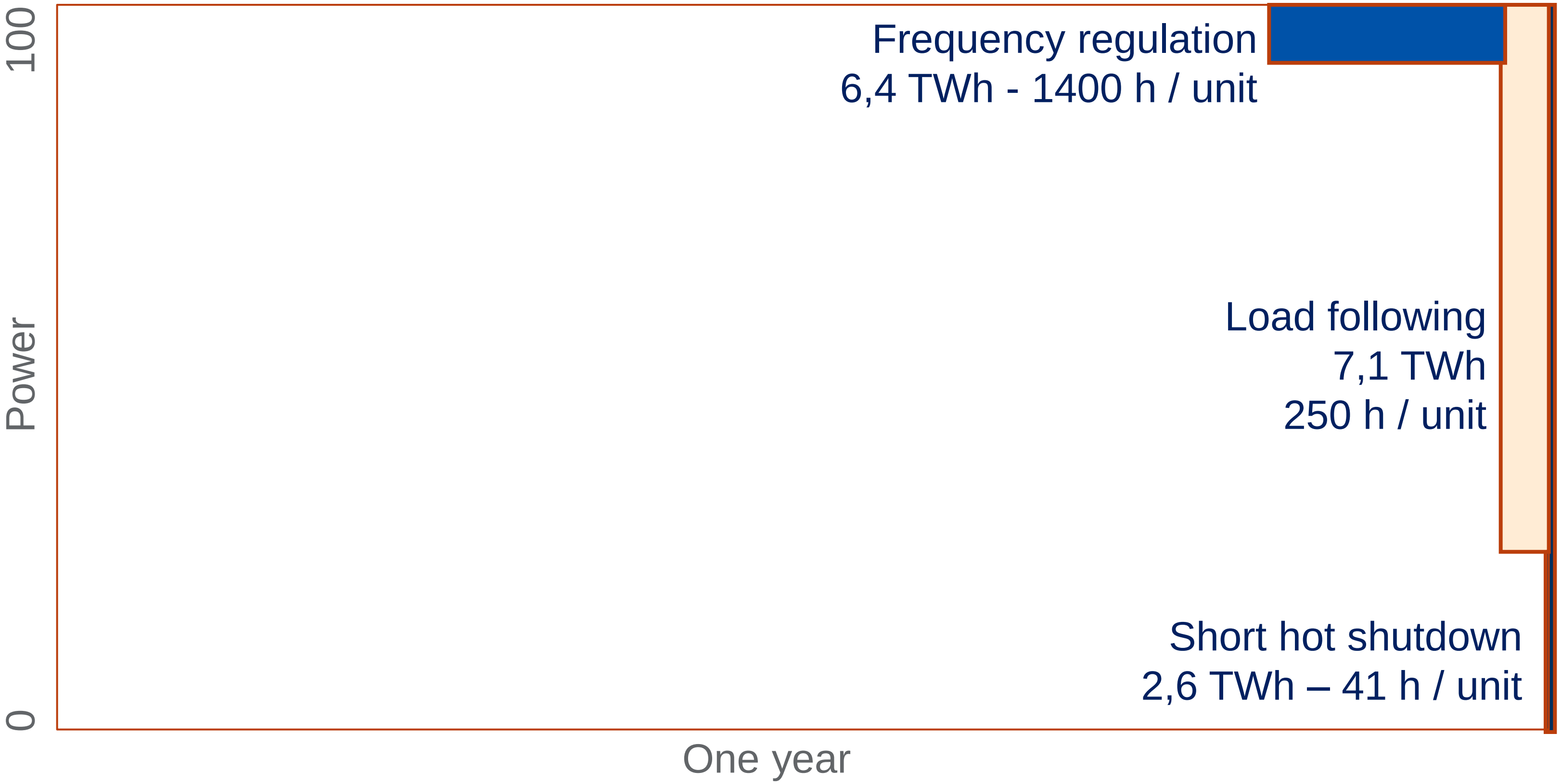
- **Stretch period : up to 60 days more of power generation at the end of each fuel cycle**

- **Studies in progress to introduce more flexibility in fuel reloading assembly.**

HOW MUCH ? Realized by year

About 4 % (16 TWh) of available generation is not generated to deliver frequency regulation and load following.

Depends on availability and demand.



DESIGN, SKILLS AND PERFORMANCES

1. DESIGN

Plants are initially designed for flexible operation ➔ Fuel power and temperature variations stay beyond safety limits proven to be hazardless on fuel integrity. Those limits allow flexible operation everyday if necessary => No need to do more than the initial design capability.

2. SKILLS

Load following is part of control room operator training and qualification ➔ Full scope simulators are used for training and Technical Specifications and procedures give general instructions

3. PERFORMANCES

A lot of experience feedback from our fleet: no loss of performances in the long run.

- **No additional safety event (on IAEA event scale).**
- **Primary circuit stay stable in pressure, very low variations in temperature. No consequences/constraints on the vessels, pipes or steam generators.**
- **Temperature transients are real for secondary systems ➔ no significant modifications in the operational performances of the plant**

In alliance with renewables, flexible nuclear operation allows a low carbon generation mix

Thank you

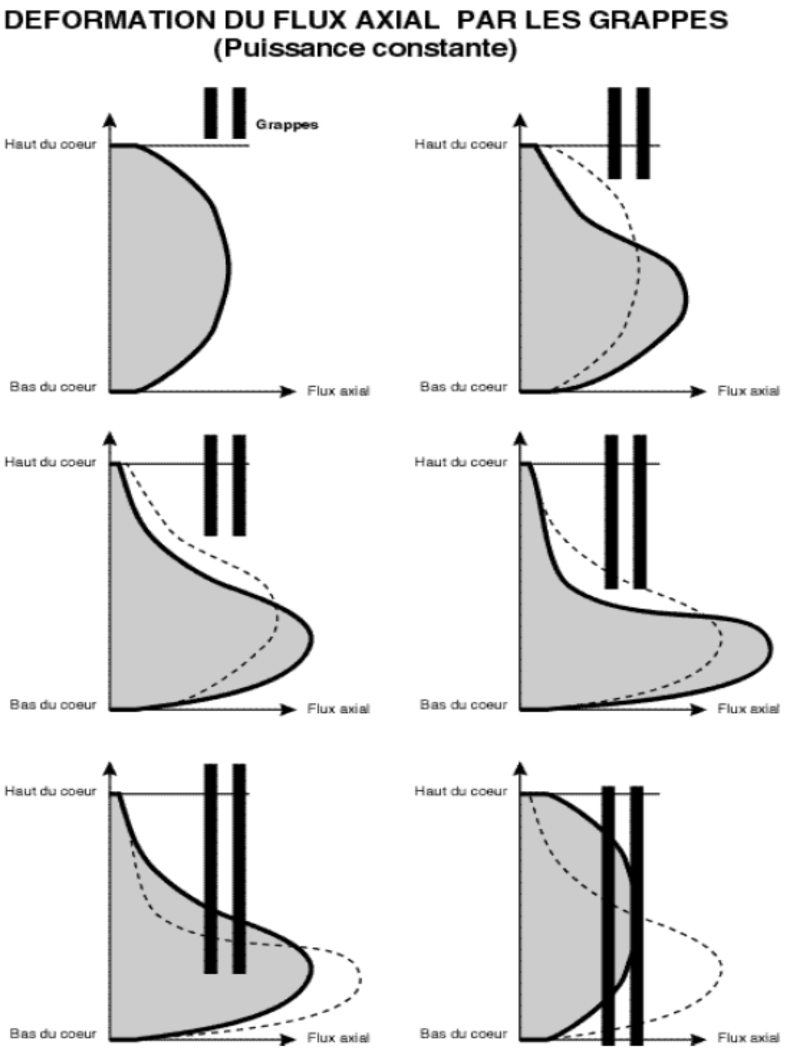
How does it work ?

Reactor control : rods position

Nuclear power is adjusted thanks to rods : neutron absorber elements inserted in / extracted from the core.

Inserting rods creates power distortion between lower and upper part of core

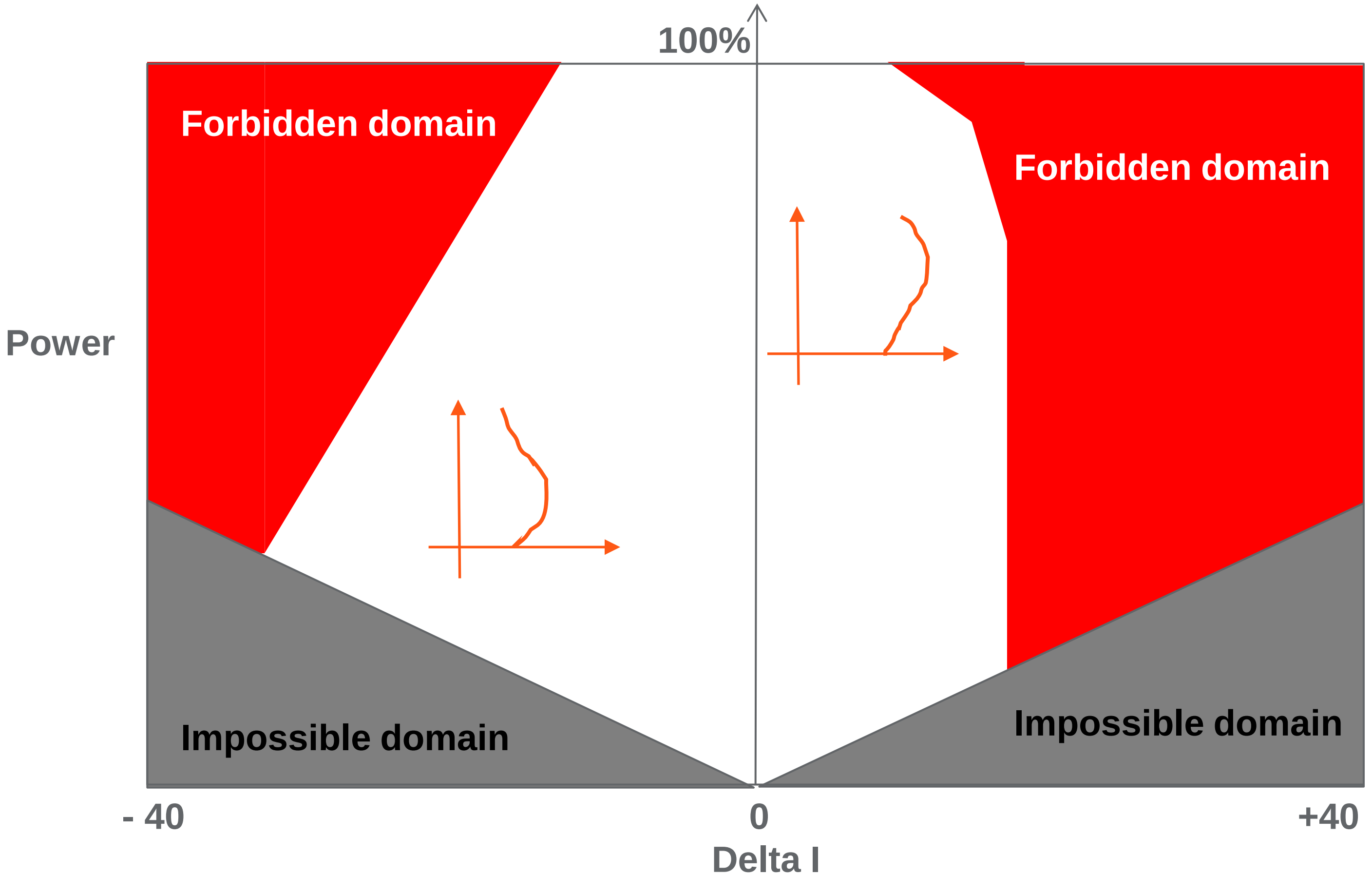
To reduce power by the same amount, it is better to have a light rod completely inserted than a heavy rod half inserted



How does it work ? Reactor control

Reactor is controlled within a Power / Core distribution diagram.

The diagram is the result of safety studies. Inside the diagram, if an event occurs, the reactor can be driven to a safe issue (no meltdown).

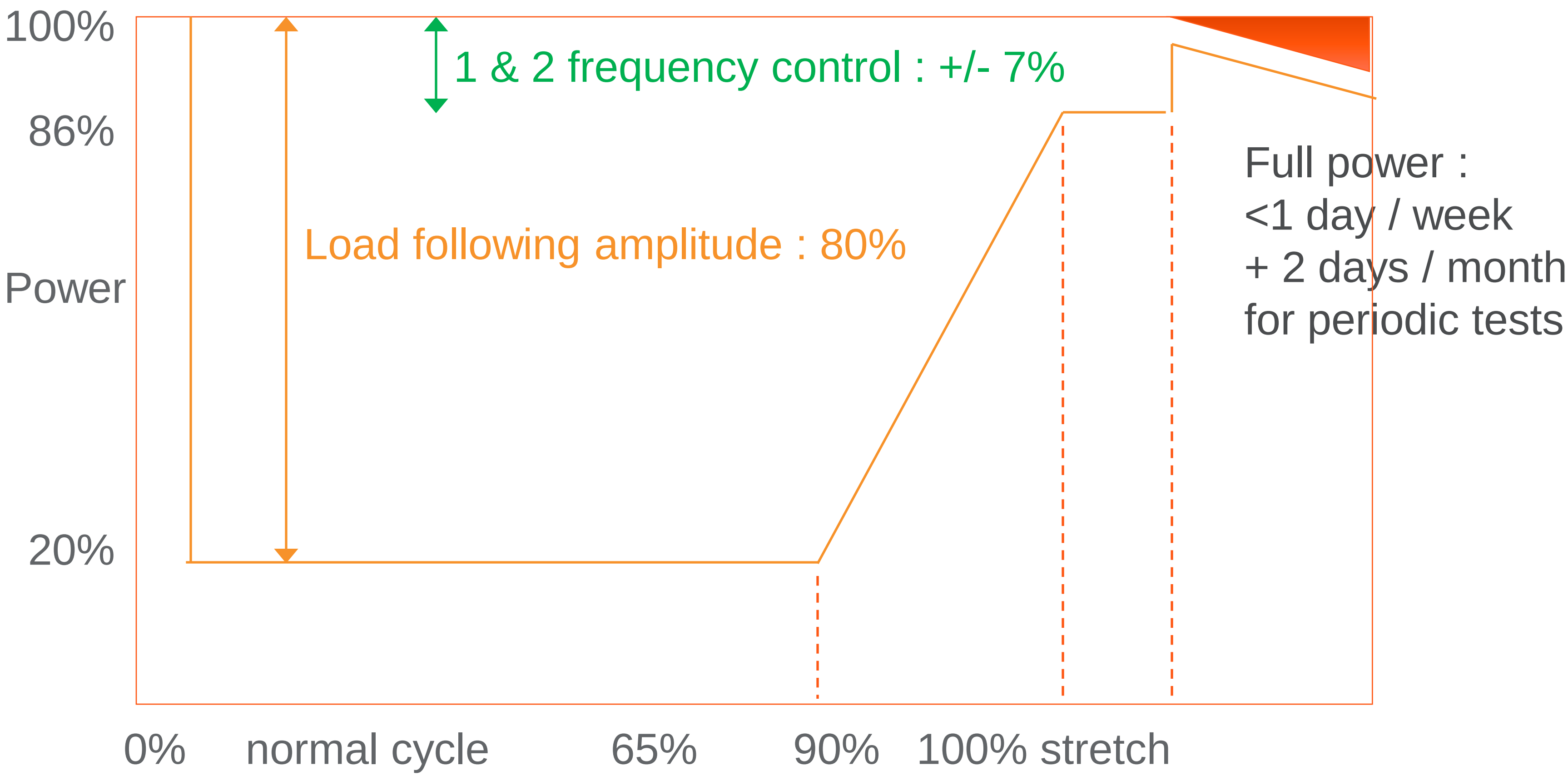


Delta I = (FU – FL) / (FU + FL)
with F = Flux Upper / Lower part of reactor

How much and when ? Cycle / Year

Capacity for load following depends on reactor control capability to deal with xenon thanks to water / boron (see part 3)

So it is easier at beginning of cycle when boron concentration is high, and when a few litres of water have a high efficiency



How does it work ?

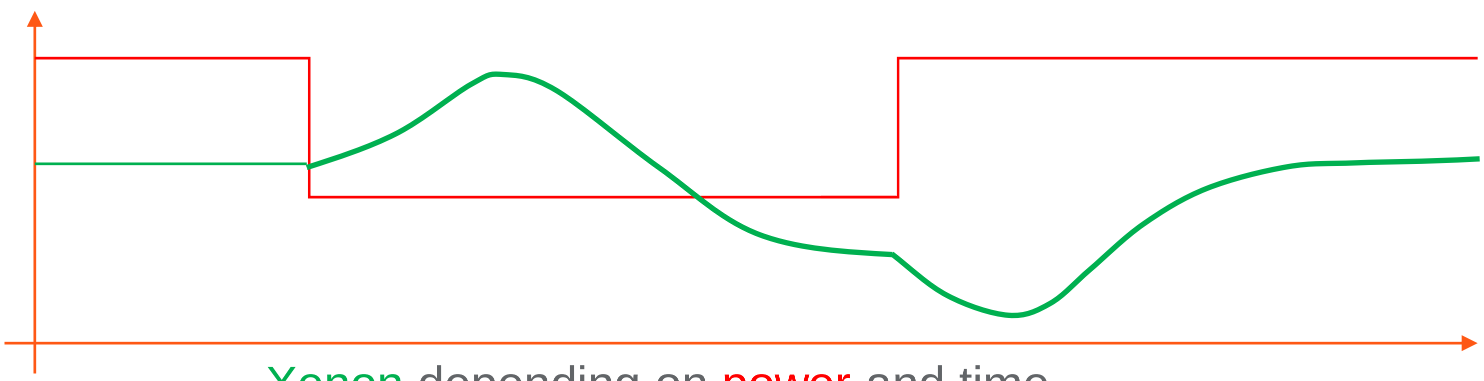
Water, Boron, Wastes

If power compensation is provided by rods, load following requires water and boron to counteract xenon during the next hours.

Xenon and boron absorb neutrons. Xenon is a fission by-product, boron is an element voluntarily added in or withdrawn from the reactor.

When Xenon increases, you add water to reduce boron concentration and vice versa.

Large volumes in tanks are necessary to load following. Water and boron extracted from the reactor enter wastes treatment equipment and are mainly recycled.



Xenon depending on power and time