

INGENIA 2020-21 - MACHINE LEARNING in Reactor-oriented applications.

1. Optimal design of PWR fuel loading pattern
2. Manoeuvres optimization and modelling
3. Control of Xenon oscillation

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INGENIA-MACHINE LEARNING 2020-21

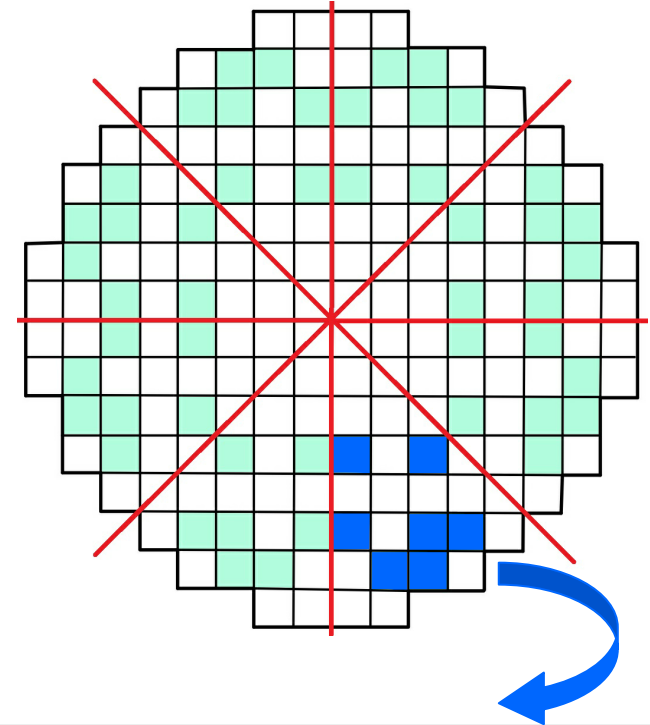
Fresh fuel reloading optimization for a PWR Westinghouse nuclear plant of 1000 MWe

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Ángel Iglesias Fontán
Marina Ruiz Izu

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Problem

- Fresh fuel reloading optimization.
- 7 different locations on each 1/8 of the core.
- Use of 4 different fresh fuel elements:
 - Fuel type 19 → UO₂ 3.6 wo% -0 wabas
 - Fuel type 20 → UO₂ 3.6 wo% -4 wabas
 - Fuel type 21 → UO₂ 3.6 wo% -8 wabas
 - Fuel type 22 → UO₂ 3.6 wo% -12 wabas



4^7 ↓

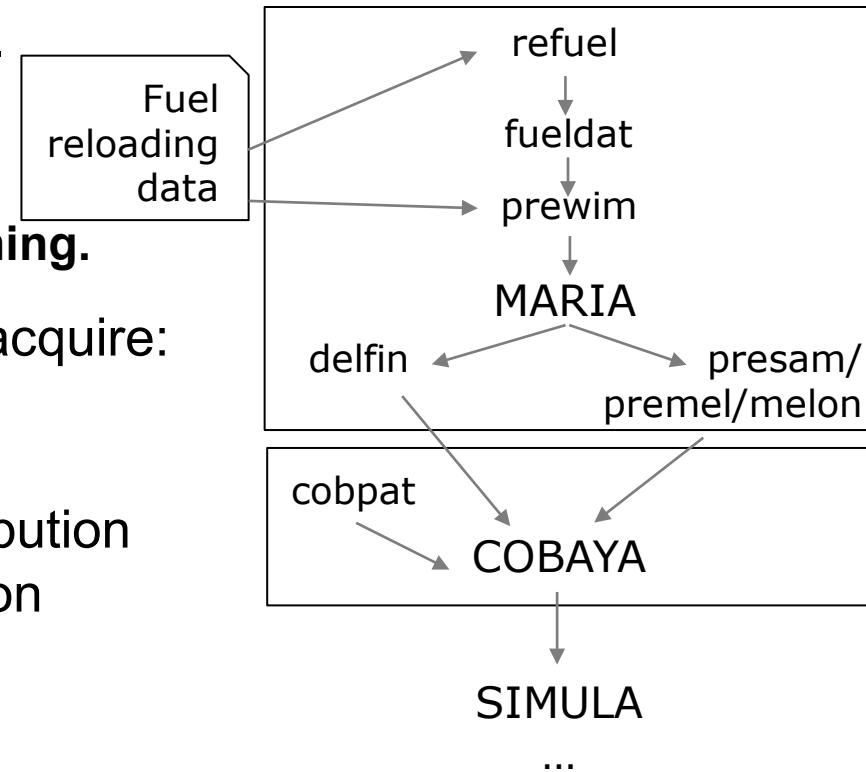
16384 possible combinations of fresh elements to place

	15	4	8	18	2202	-1	'V5K'	/	COBAYA-Tf-Gd	1/4	nucleo
1											
2		13		4	21	6	21	16	14		
3	13		15	2	16	6	20	7			
4	4	15		8	21	8	22	19	0		
5	a(1) 21		a(4) 21		18	20	5	0			
6	6	16		8	18	18	17	0	0		
7	a(2) 21		a(5) 22		a(7) 7		0	0	0		
8	16	20		19	10	0	0	0	0		
9	14	a(3) 7		0a(6) 0	0	0	0	0	0		

Methodology

- Use of the simulator called **SEANAP – COBAYA (2D)**.
- Analysis of the data through different **optimization methods. Machine Learning.**
- The optimization techniques follow to acquire:
 - Maximum burnup
 - Maximum peak power limits
 - Homogeneous nodal burnup distribution
 - Homogeneous FA power distribution

SEANAP FUNCTIONAL SCHEME



Objective function

$$f(\text{Burnup}, \text{power peaks}, \text{power and burn up distribution}) = \text{burnup} \cdot w_q - |Fa - 1.52| \cdot w_p - |Fdh - 1.40| \cdot w_p - \text{std_FApower} \cdot w_p - \text{std_nodalburnup}$$



Data from the designed core distribution (PWR Westinghouse of 1000 Mwe)

Objective Function	Burnup	Peak F-ele	Peak Fdh	FA Power distribution	Nod burnup distribution
5.5184	11.6886	1.4	1.52	0.2936	3.2339

Result Parameters from the Machine Learning Techniques

<u>Methodology</u>	Objective Function	Burnup	Peak F-ele	Peak FdH	Power distribution	Burn-nod distribution
Brute Force	5.5575	11.8012	1.38	1.513	0.2981	3.2624
Random Search	3.3527	11.7442	1.483	1.631	0.3108	3.3433
Hill Climbing	5.5575	11.8012	1.38	1.513	0.2981	3.2624
Bayesian Method	3.608	11.6471	1.47	1.591	0.3256	3.3732
Genetic Algorithms	5.5187	11.6627	1.359	1.511	0.292	3.2243

Optimized fuel reloading distribution

Fuel position changes between optimized results and original configuration

Changed positions
Similar positions

5th cycle core designed PWR Westinghouse 1000 MWe

a(1)	a(2)	a(3)	a(4)	a(5)	a(6)	a(7)
21	21	20	21	22	19	20

Brute Force

20	22	19	20	22	19	20
----	----	----	----	----	----	----

Hill Climbing

20	22	19	20	22	19	20
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Genetic Algorithms

21	22	20	21	22	19	20
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POLITÉCNICA

Optimization of Operational Manoeuvres

Juan Antonio Monleón

Cristina Ratero

Jorge Herranz

Pablo Fernández

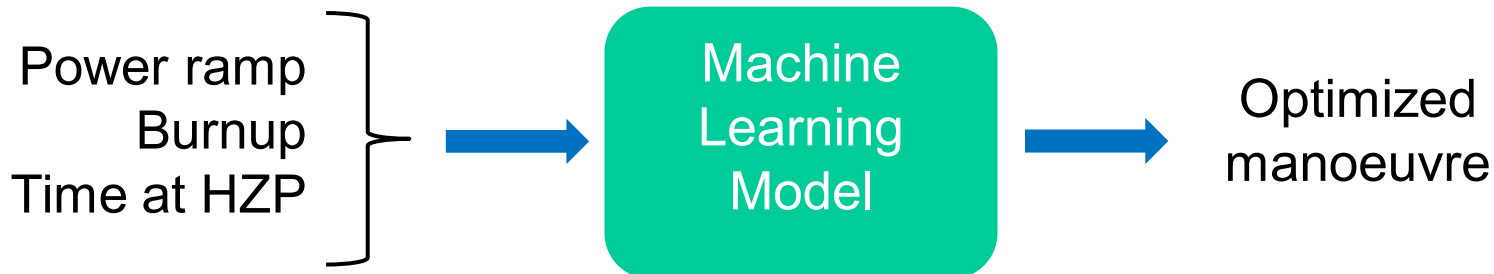
Juan Corona

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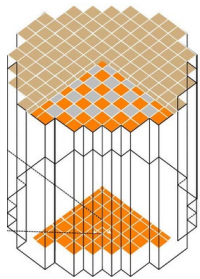
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Introduction

- ❑ Control levels of boron to maintain k_{eff}
- ❑ ↓Boron - ↓Radioactive waste - ↓Environmental impact



Methodology



SEANAP

1. Simulation
 - SEANAP
 - Python
 - Automate process

2. Optimization
 - Brute force
 - Variation of parameters



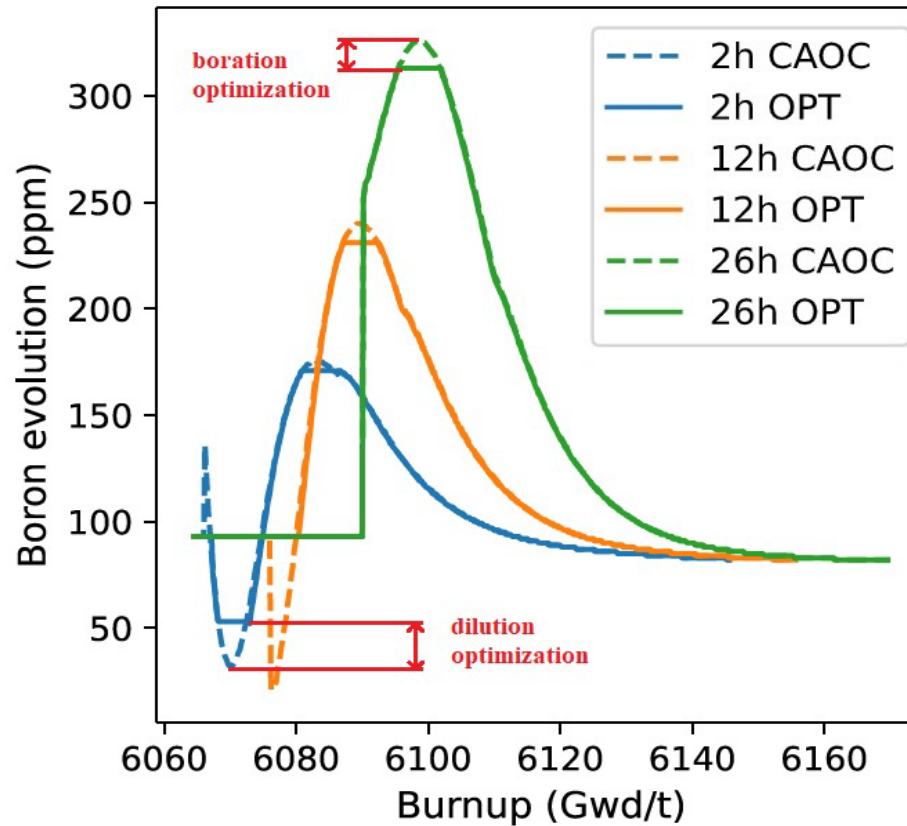
3. Analysis
 - Python
 - Operational limits

4. Modelling
 - Linear regression
 - K-neighbours
 - Random forest

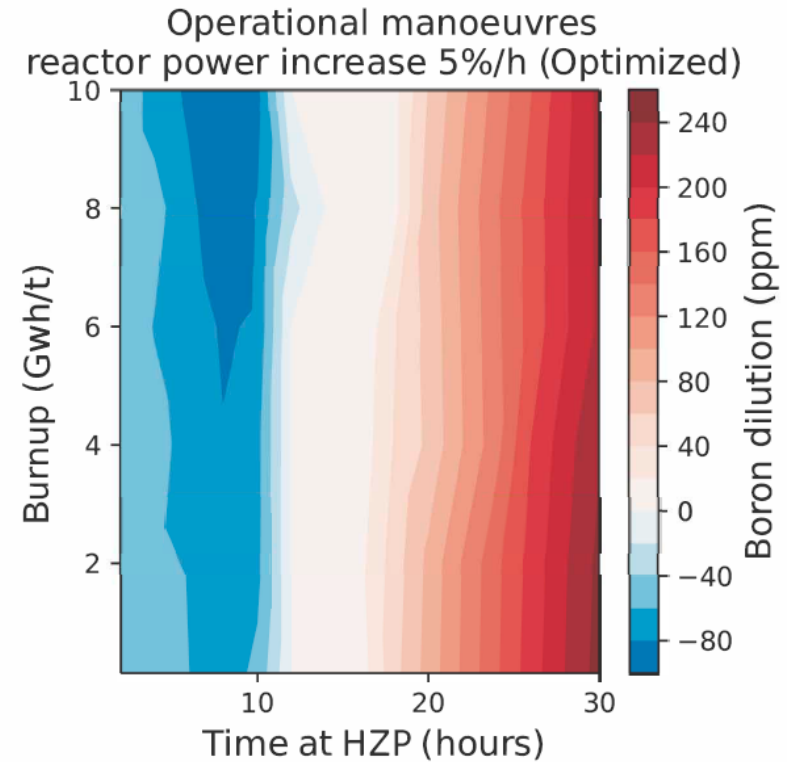
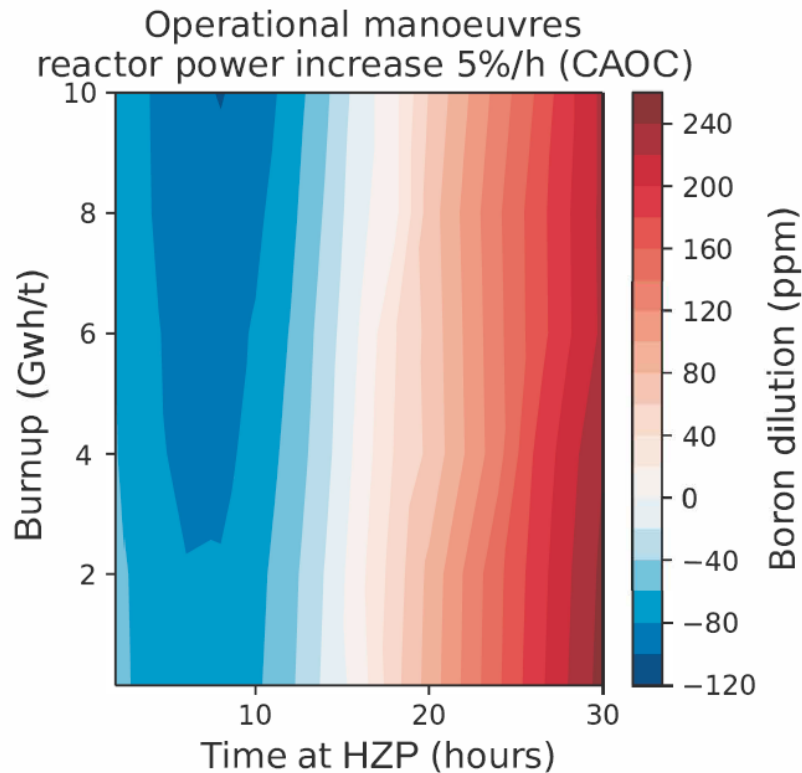
*CAOC: Constant Axial Offset Control

Results

Comparison between CAOC* and optimized manoeuvres



Results



Results

Random forest model

Power ramp (%/h)
Time at HZP (hour)
Burnup (GWd/t)

```
In [15]: model3.predict(pd.DataFrame([[5,11,3]]))
```

```
Out[15]: array([[ 66.   ,  11.44 , 136.21 ,  26.808]])
```

1 2 3 4

```
In [18]: print("accuracy:", model3.score(x_test, y_test)*100)
         y_pred = model3.predict(X)
         accuracy: 98.24557794438891
```

1. Dilution required (ppm)
2. Time at peak of dilution (hours)
3. Boration required (ppm)
4. Time at peak of boration (hours)

INGENIA NUCLEAR -MACHINE LEARNING 2020-2021

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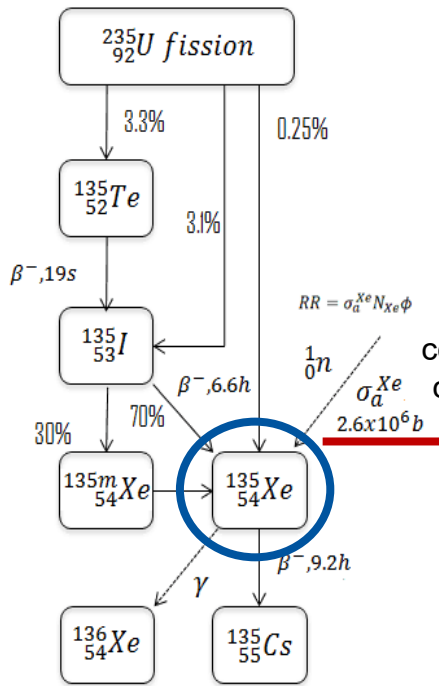
Xenon-135 Oscillations' Forecasting in PWR's Operation Manoeuvres

Guillermo Gabarain
Miguel de la Mata
Carlos Antonio Isasi

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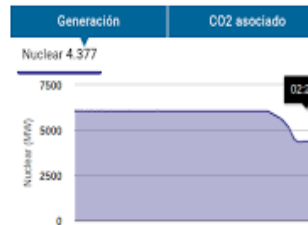
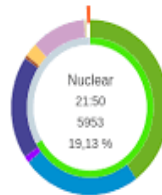
Problem

PWR's nominal operation



What if conditions change?

Grid tracking



Shutdown

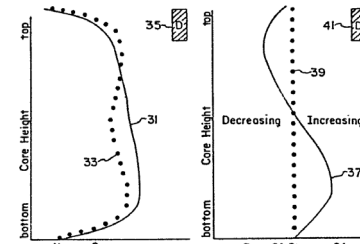


FIG. 2

FIG. 3

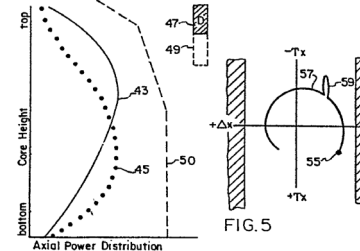


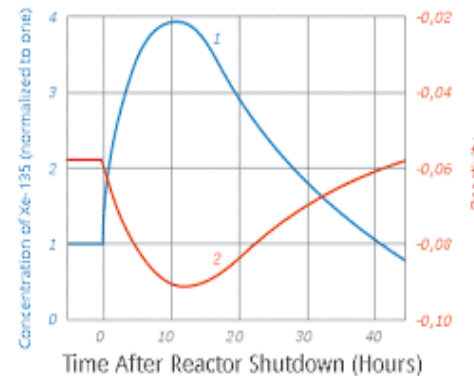
FIG. 4

FIG. 5

Xenon and Iodine oscillations'



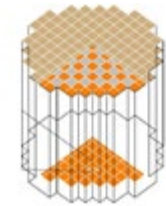
- Control
- Availability
- Manoeuvring
- Waste generation
- Wear and tear



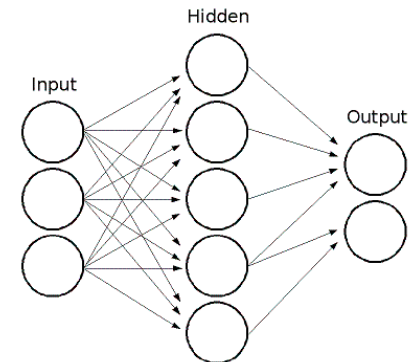
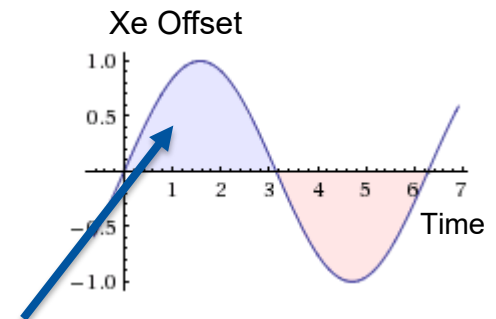
Poisoned reactor

Methodology

- Use of the **ETSII's** developed simulator called **SEANAP** and Data Analysis on **Python**.
- Generation of **12,000** different simulations, combining:
 - Rod Insertion (**10-30 steps**)
 - Disturbance Duration (**2-64 hours**)
 - Reactor Power (**90-100%**)
 - Fuel Burnup (**0.15-12 MW day/kg**)
- **Objective function:** Accumulation of Xe oscillations during disturbances due to the aforementioned factors.
- Use of a **Genetic Algorithm** to optimize a **Sequential Neural Network** that predicts Axial Offsets and Cumulative Xenon Oscillations.



SEANAP

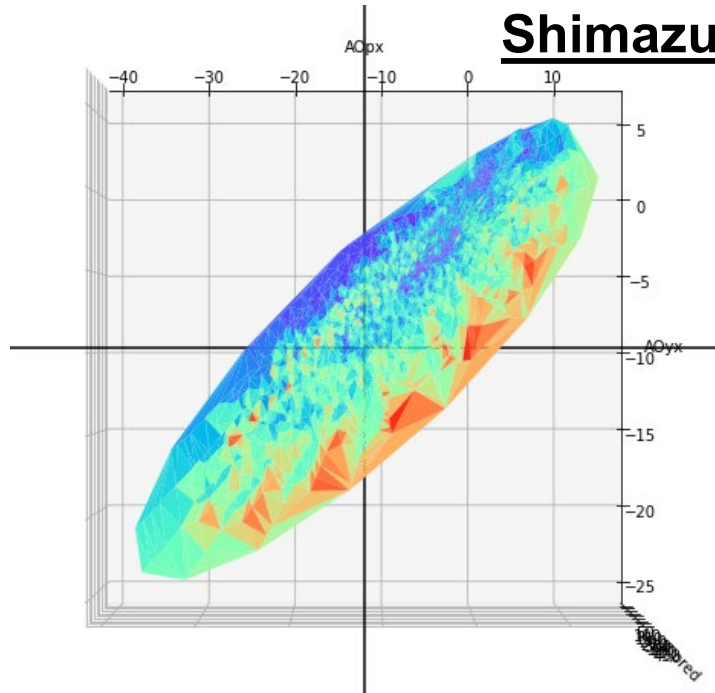


Optimized Neural Network Hyperparameters and Performance

Optimizer	N. of Deep Layers	Neurons/ Layer	Batch size	Epochs	MSE	R Squared
'Adam'	4	220	200	400	7.7996e-04	99.889

Comparison with Xe Oscillation models

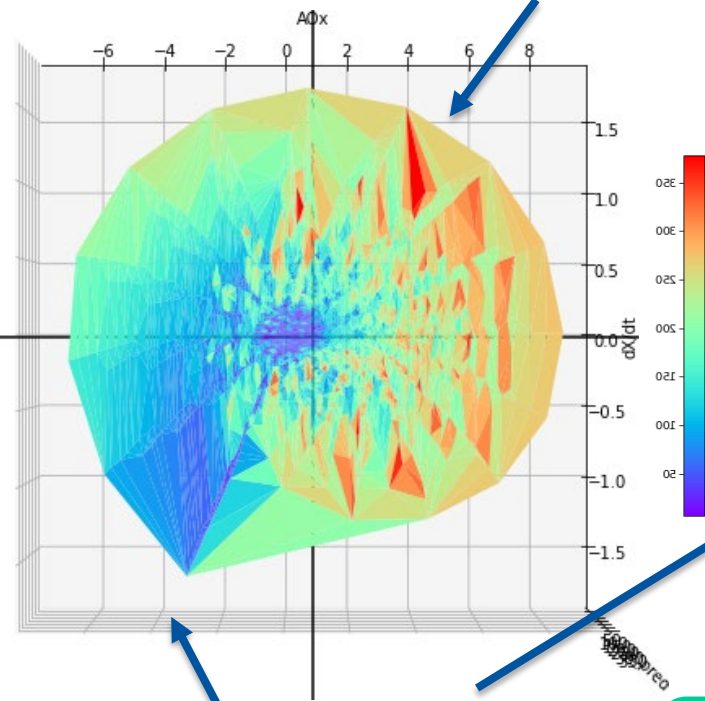
Shimazu's Control Method



- Xe Control based on Iodine, Xenon and Power **Axial Offsets**:
 - X Axis: (*Power A.O. - Xe A.O.*)
 - Y Axis: (*I A.O. - Xe A.O.*)
- Plotting **Oscillation Predictions** against the aforementioned variables at moment of extraction
- Shimazu Algorithm proposes extractions are optimal in **Upper Left Quadrant**

Westinghouse Niquist Diagram

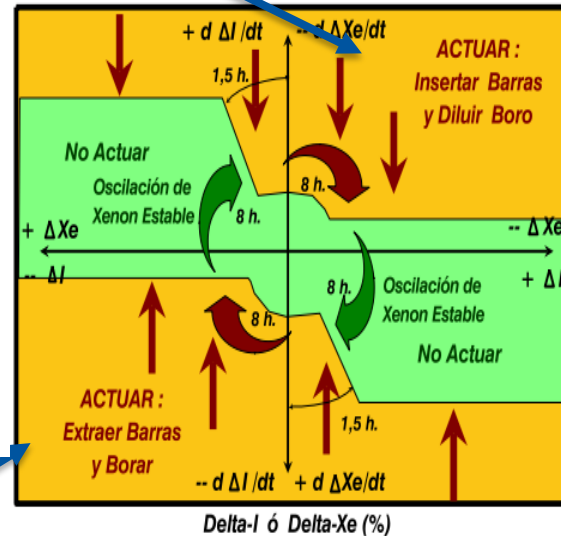
Insert and dilute!!



Extract and borate!!

Control Modal de Oscilaciones del Xenon

Derivada Temporal de ΔI ó ΔXe (%/h)



- Niquist Diagram:
 - X Axis: Xe A.O.
 - Y Axis: $d(Xe \text{ A.O.})/dt$
- A disturbance evolves in a downward spiral towards the centre (**Stable State**)
- Different quadrants reach the centre faster with different actions

Our Results: Extractions after the insertions minimize Xe Oscillations where Niquist Diagrams recommend to extract and borate



Thank you for your attention!