ANALYSIS OF APR1400 RESTARTING AFTER UNPLANNED SHUTDOWN: AN INVESTIGATION ON XENON OSCILLATION AND BORON DILUTION RATE

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INTRODUCTION

- Accidental scrams happen with a considerable frequency in Nuclear Power Plants. This kind of event represents a significant economic impact, and for this reason, all companies make a big effort in order to refrain them.
- However, in some occasions, unplanned shutdowns are unavoidable and it is necessary search for the best alternatives to restart the plant as soon as possible, while the safety aspects are kept under control.

OBJECTIVES

- This work aims to help plan the NPP restarting after an unscheduled shutdown, providing more economical alternatives to the current scenario, without forget safety aspects.

- The present study has also as objective, to reduce the operator burden and to prevent Boron Dilution Accident (BDA).

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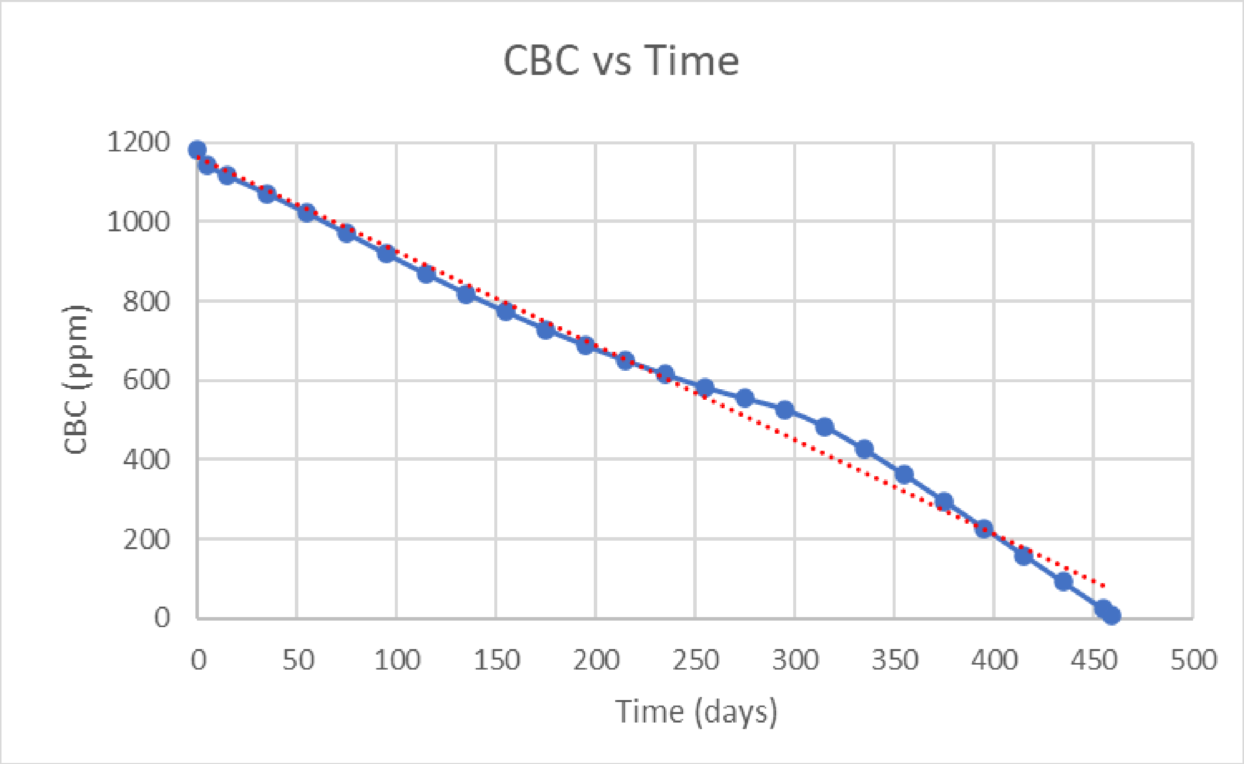
Simulation characteristics

- The chosen cycle was a typical second cycle of the APR1400, where the biggest oscillations regarding to cycle length and pin peak factors are observed.

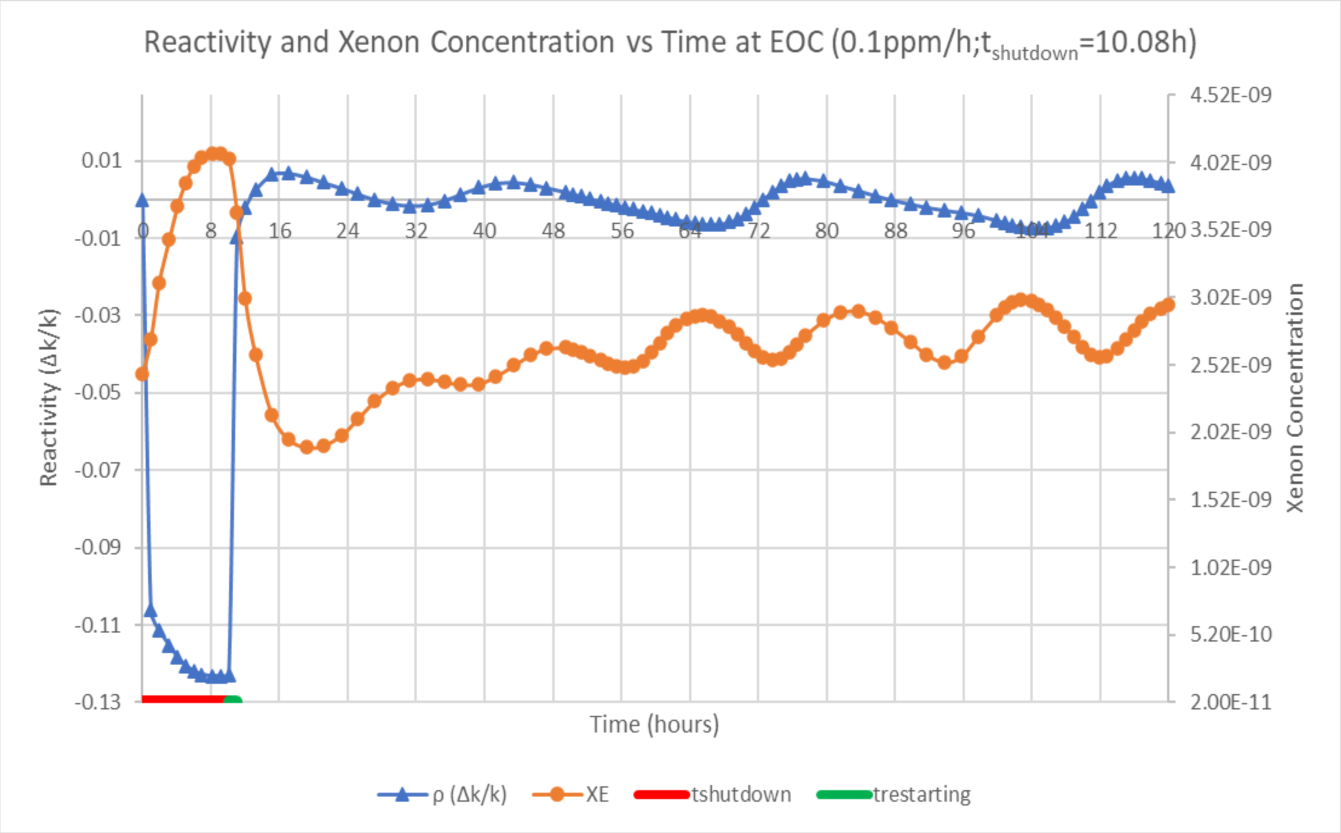
- A reactor trip was simulated (MASTER 3.0) at the End of Cycle (EOC), when boron concentration was 50 ppm and at the Begin of Cycle (BOC) when boron concentration was 950 ppm.

Simulation characteristics



- The cycle length found after simulating this core was 17.61 GWD/MTU and the changes in Critical Boron Concentration (CBC) over the cycle are depicted in the Figure beside. Based on this picture, it is possible to conclude that boron dilution is occurring under a rate of approximately **0.1 ppm/h.** This value will be used as reference for the simulations in the next steps of this work.

Analysis of APR1400 restarting at EOC



- Boron Concentration (BC) when trip occurred: 50 ppm.
- Boron dilution rate: 0.1ppm/h (cte. rate)
- Shutdown Period ($t_{shutdown}$): 10.08 hours.
- Control Banks strategy: All Rods Out (ARO) 1 hour after the beginning of restarting attempt ($t_{restarting}$=1hour).

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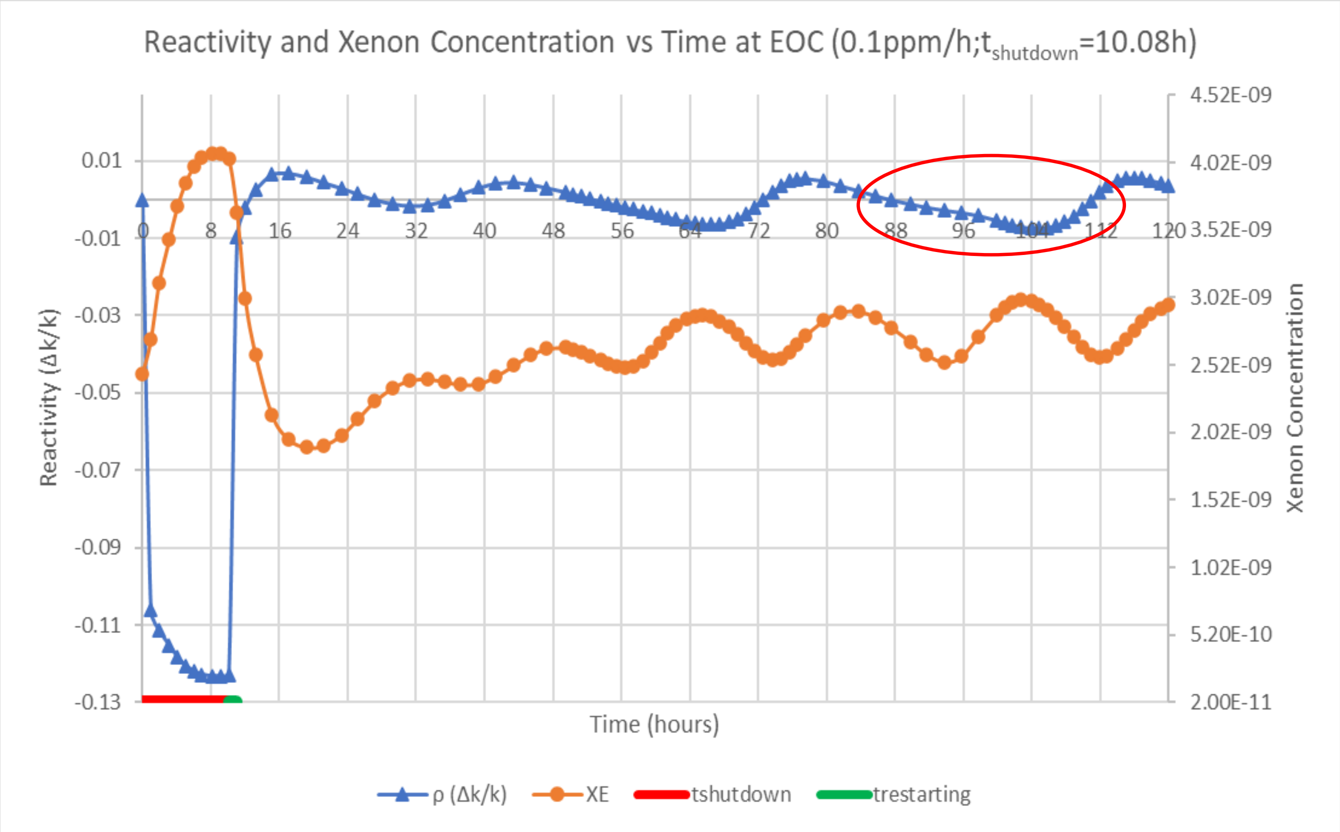
Analysis of APR1400 restarting at EOC



- According to the graph, the reactor could be restarted, however, observing the reactivity behavior during 5 days after scram, it turns out that reactor become subcritical for three times, where the biggest oscillation starts after **87.48 hours** and finish after **111.02 hours**, with the lowest reactivity observed of -0.00743 Δk/k or **-743 pcm**.

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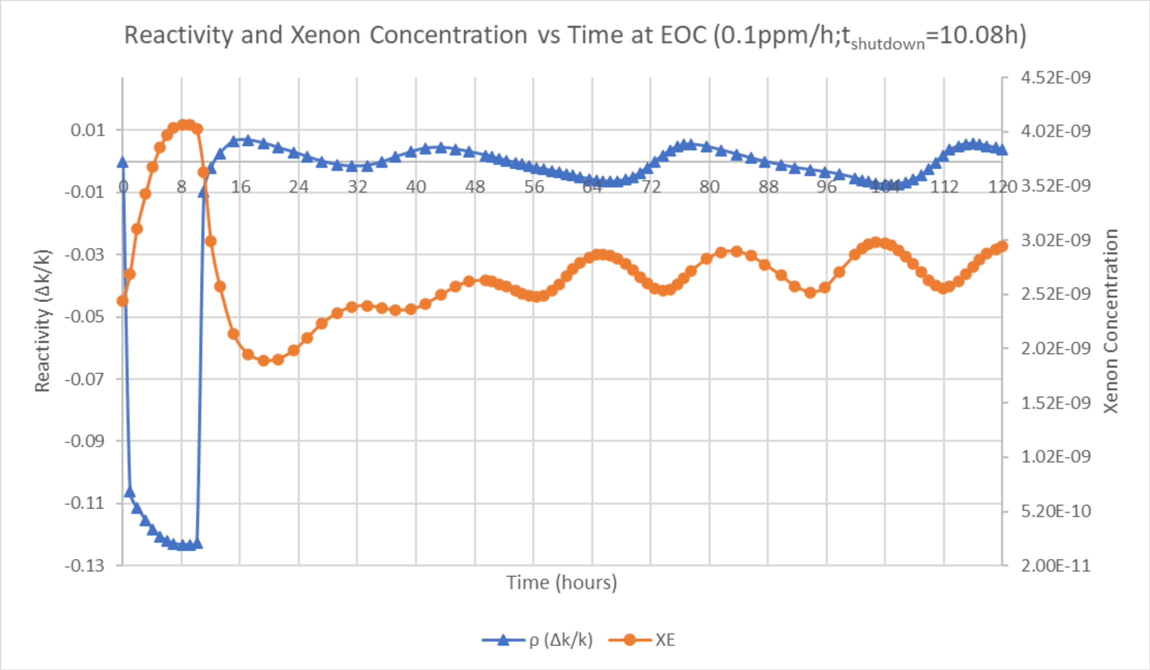
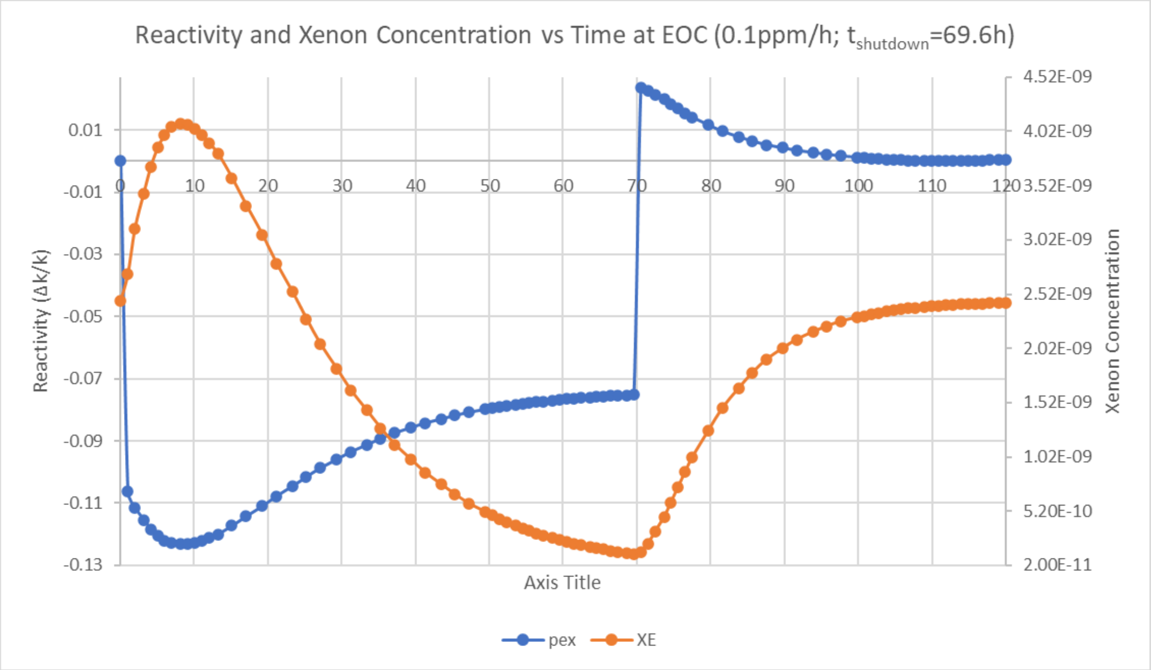
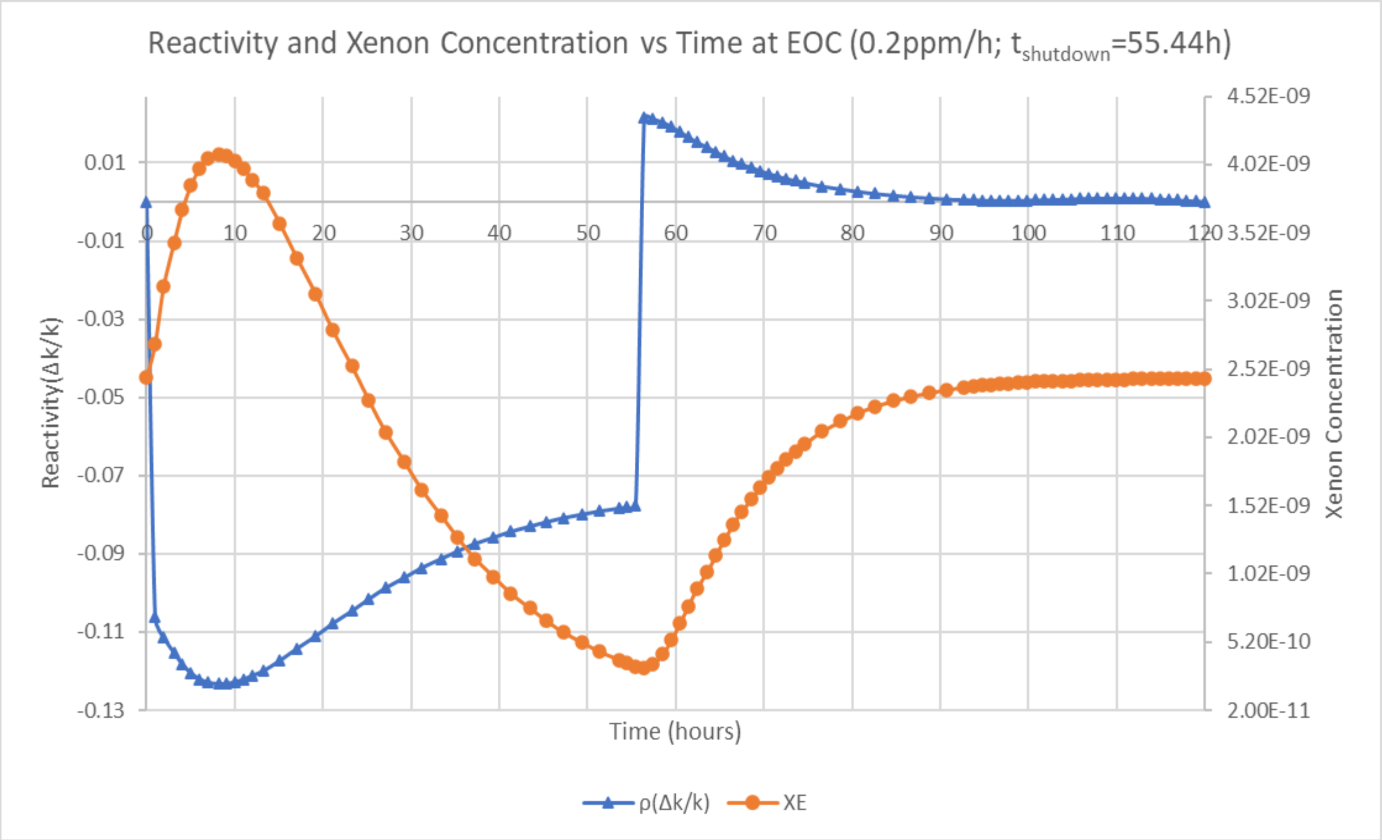
Analysis of APR1400 restarting at EOC





- Using similar dilution rate, 0.1ppm/h, the $t_{shutdown}$ was increased until the subcritical areas could be avoided. This happened when $t_{shutdown}$=69.6h.

Analysis of APR1400 restarting at EOC



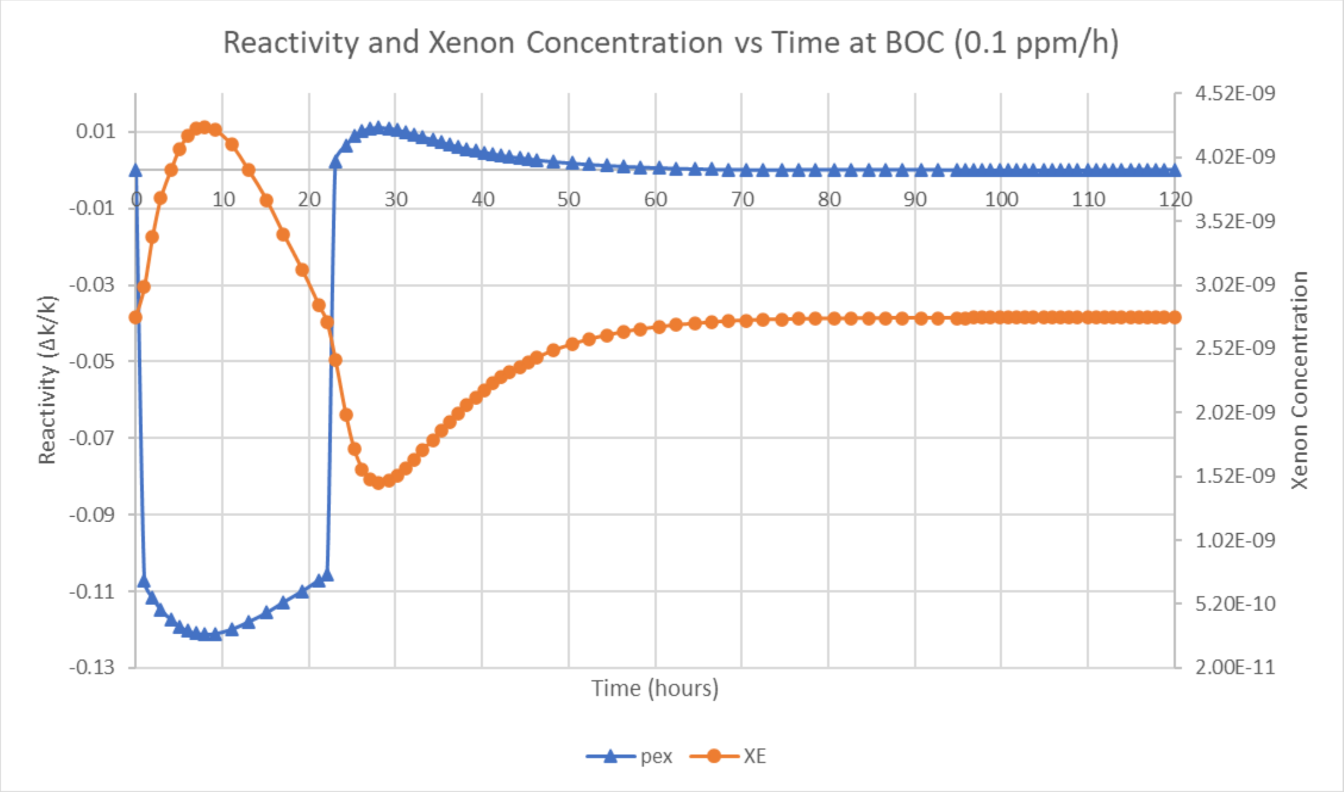
Fixed Boron Dilution Rate (ppm/h)	Shutdown Period $-t_{shutdown}$ (hours)
0.1	69.6
0.2	55.44
0.3	50.4
0.4	38.4

Analysis of APR1400 restarting at BOC

- A similar procedure was applied to reactor at BOC when boron concentration was 950 ppm.
- The comparison between proper $t_{shutdown}$ at BOC and EOC, according boron dilution rate, it is shown in this Table.

Fixed Boron Dilution Rate (ppm/h)	$t_{shutdown}$ at BOC (hours)	$t_{shutdown}$ at EOC (hours)
0.1	22.08	69.6
0.2	any time	55.44

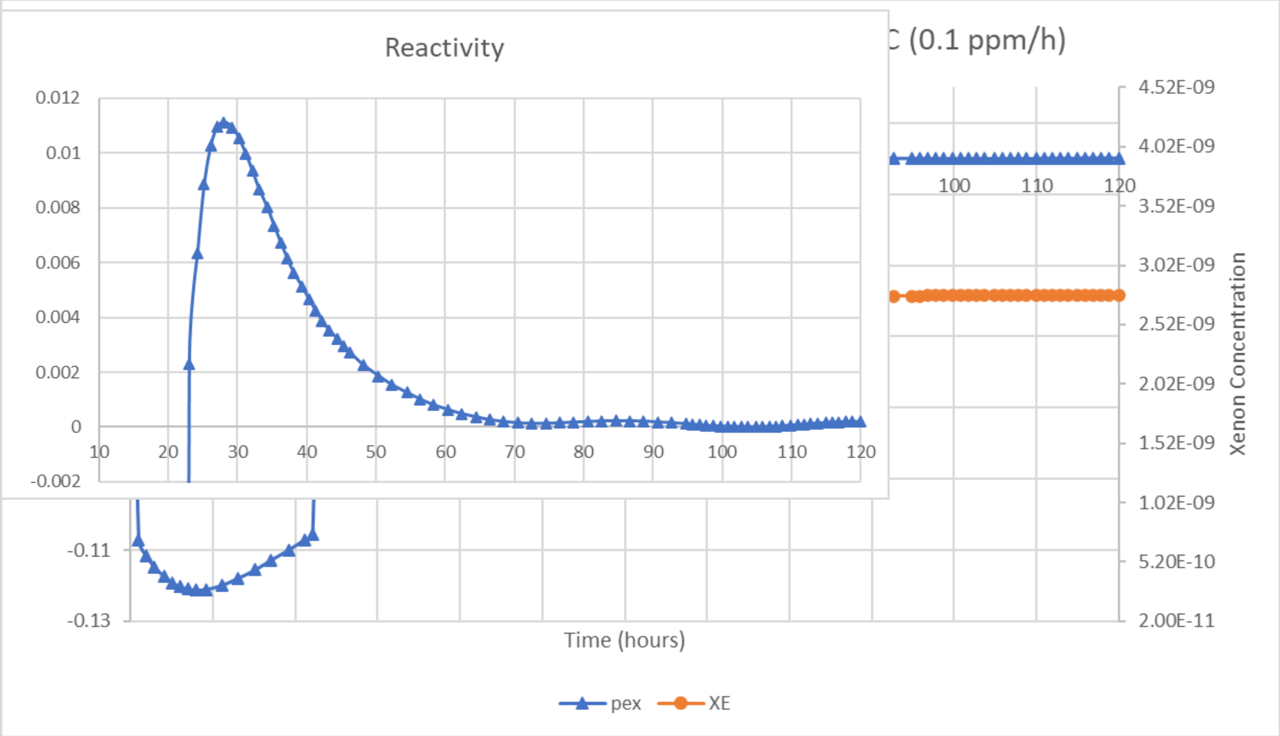
Analysis of APR1400 restarting at BOC



Fixed Boron Dilution Rate (ppm/h)	$t_{shutdown}$ at BOC (hours)	$t_{shutdown}$ at EOC (hours)
0.1	22.08	69.6
0.2	any time	55.44

Suggested Case

- The next step is to suggest a case closer to reality.
- In order to eliminate the excessive amount of reactivity produced by the ARO condition in the beginning of restarting, a new control banks strategy was searched.



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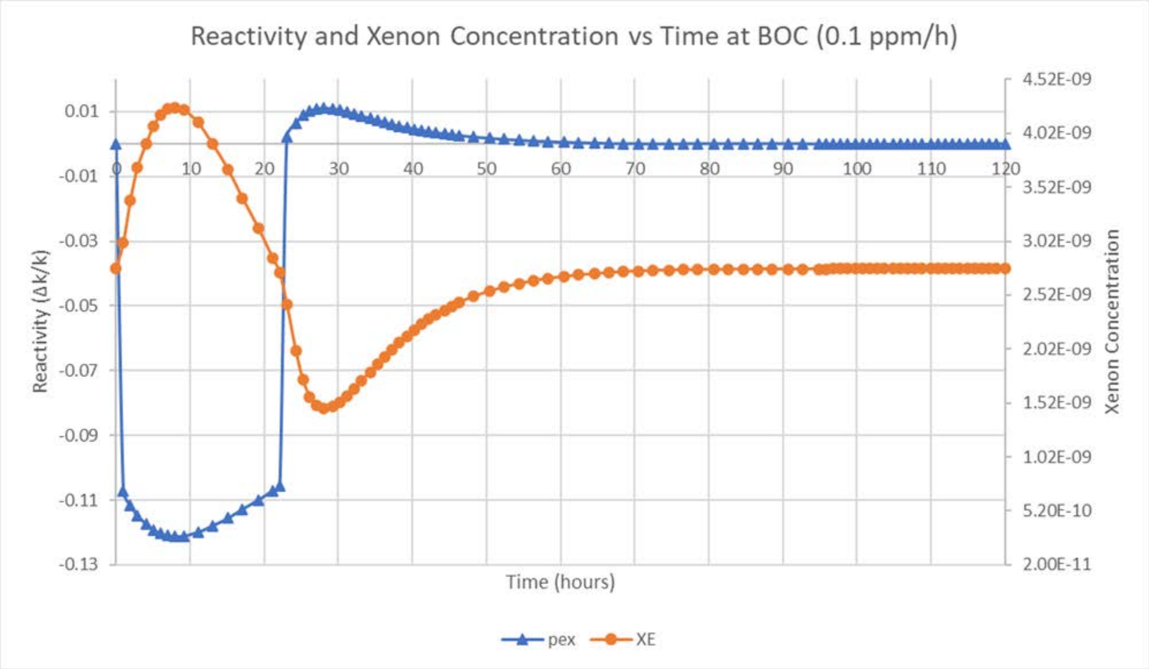
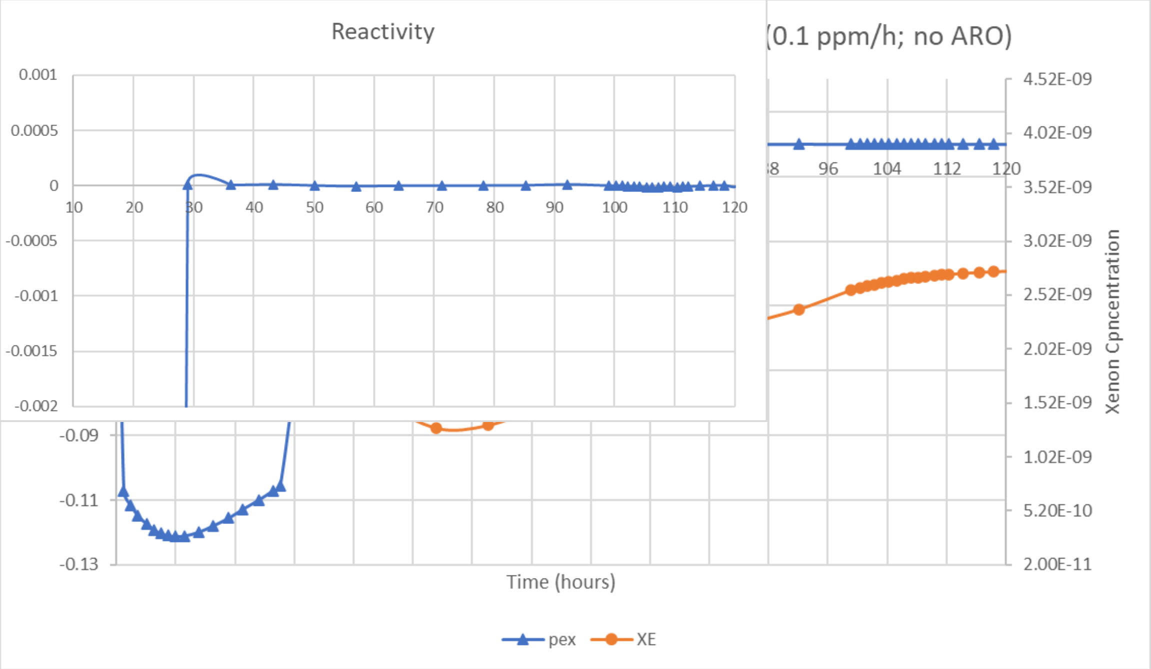
Suggested Case

- Control banks strategy: critical height position searched taking account the time interval of 70 hours ($t_{restarting}$ =70h) to reach 100% of power and $t_{shutdown}$=22.08h.





CONCLUSION

- Regardless if at EOC or BOC, there was a reduction in shutdown period ($t_{shutdown}$) when the constant dilution rate was increased.

- When restarting attempts during core life are compared, it is clear that values of $t_{shutdown}$ are smaller at BOC.

- The analysis about the relation to dilution rates and its proper times to restarting the reactor contributes to reduce the shutdown period and thereby to reduce the costs due to unscheduled shutdowns.

CONCLUSION

- Regarding to the reduction in the probability of BDA and in operator burden, the use of constant boron dilution rate proves to be a good option for both.

Thank you!

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