

Simulation of the Power Maneuvering of PWRs using new ATF

J. Marín et al. (Grupo INGENIA 2019-2020)

MASTER IN INDUSTRIAL ENGINEERING

E.T.S. de Ingenieros Industriales

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❑ PWR-Westinghouse (157 FA) after loading of **48** new FAs:

Case	LABEL
UO ₂ /3.60wo – Zr/0.5715mm	UO ₂
UO ₂ /3.86wo – CSi/0.82mm	CSi
UO ₂ /3.99wo – FeCrAl/0.30mm	FeCrAl
UO ₂ /3.75wo – Zr+30mcTi ₂ AIC	30micron_Ti ₂ AIC
UO ₂ /3.71wo – Zr+20mcCr	30micron_20Cr

Case	LABEL
U ₃ Si ₂ /3.747wo – FeCrAl-300μm	U ₃ Si ₂
95%UO ₂ /3.439wo+5%BeO – Zr/0.5715mm	5BeO
90%UO ₂ /3.403wo+10%BeO – Zr/0.5715mm	10BeO
TRISO – Zr/0.5715mm 84FCM: 5%wo-80%VF 180UO ₂ : 3.4wo	TRISO

❑ Power Maneuvering: Return to power after a short (**9 hours**) shutdown

- BOC
- EOC

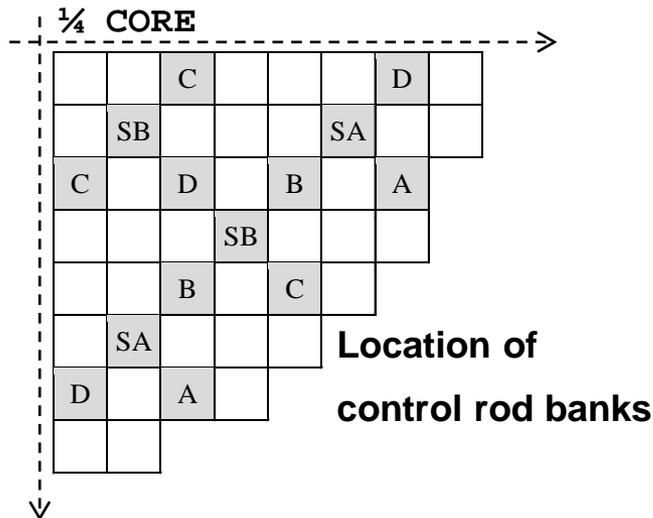
❑ Analysis of simulations

- Xenon Level versus time
- Boron Concentration versus time
- Control Rod position versus Relative Power
- Axial Flux Difference (AO·P_{rel}) versus Relative Power
- P·F_Q versus time

Control Rod Insertion : Limiting Condition for Operation

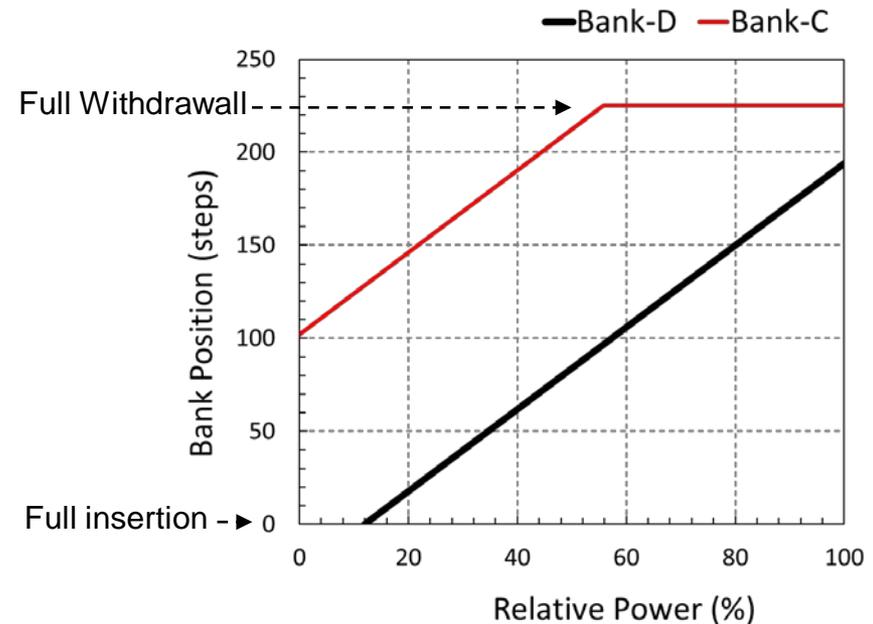
Rod Cluster Control Assemblies (RCCAs) are uniformly located in the core

- Control group (D+C) for power control
- Shutdown group (A+B+SA+SB + ... D+C)



- Control Rod “Groups” are divided into “**banks**” to :
 - avoid the effect on the power distribution
 - avoid large reactivity change in control insertion

Figure. Control Rod insertion limit



Control Rod insertion limit will allow to:

- reduce the decrement of reactivity worth
- limit $F_{\Delta H} * P$
- secure shutdown margin

Constant Axial Offset Control (CAOC) technique

□ Axial Flux Difference : Limiting Condition for Operation

Axial power distribution can be controlled by the Constant Axial Offset Control (CAOC)

○ Axial Flux Difference (AFD)

$$\Delta I(\%) = AO \cdot P_{rel}(\%)$$

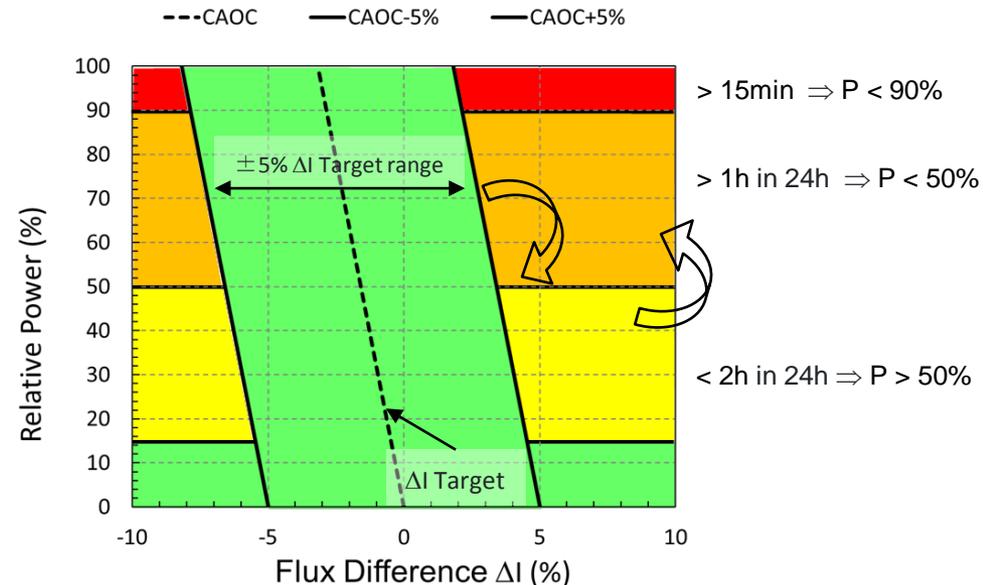
○ ΔI Range: $\pm 5\%$ to:

- ensure peaking factor limits: Low $\Delta I \Rightarrow$ low F_Q
- reduce $^{135}\text{Xe}/^{135}\text{I}$ axial oscillations

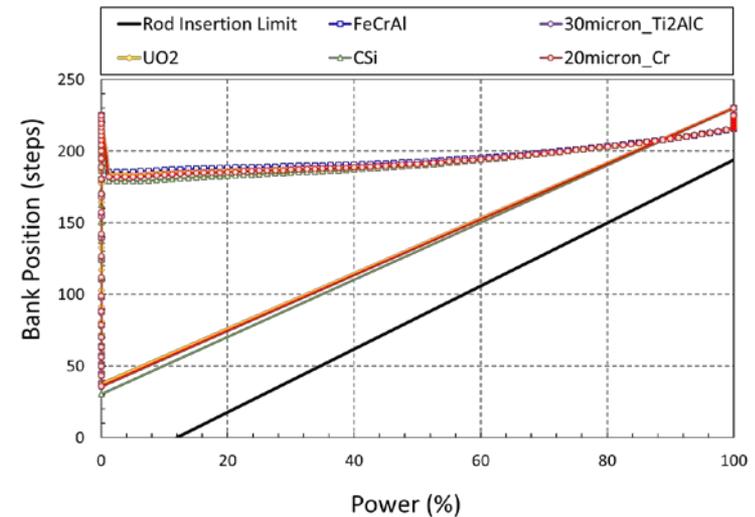
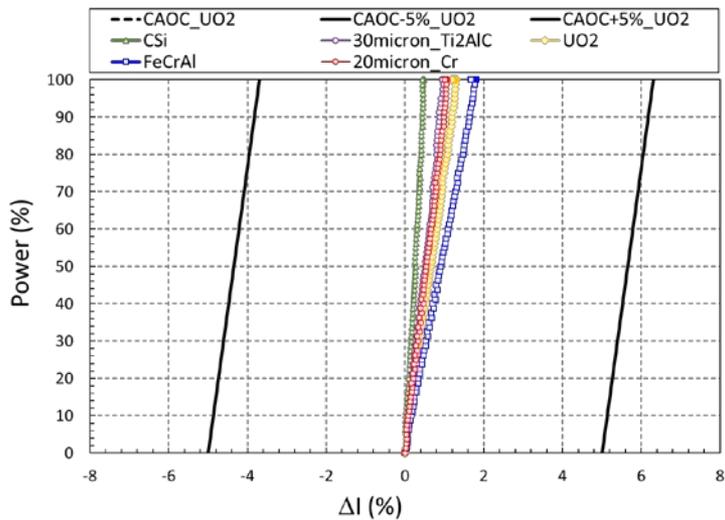
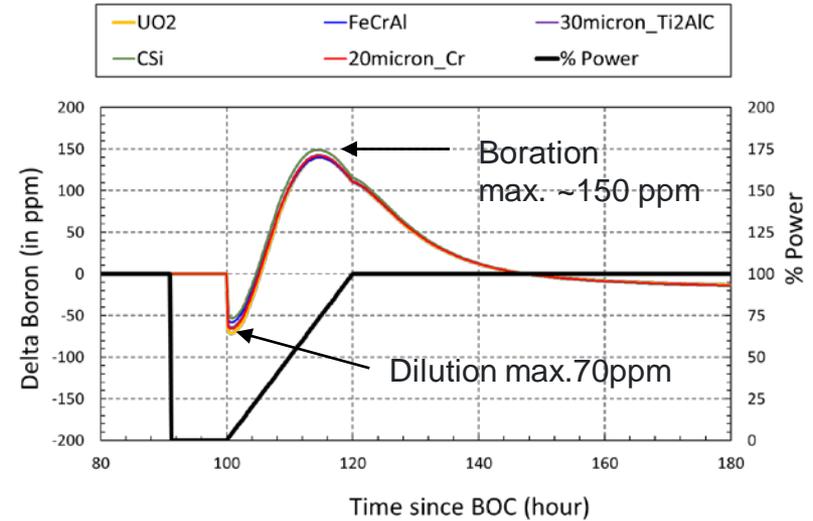
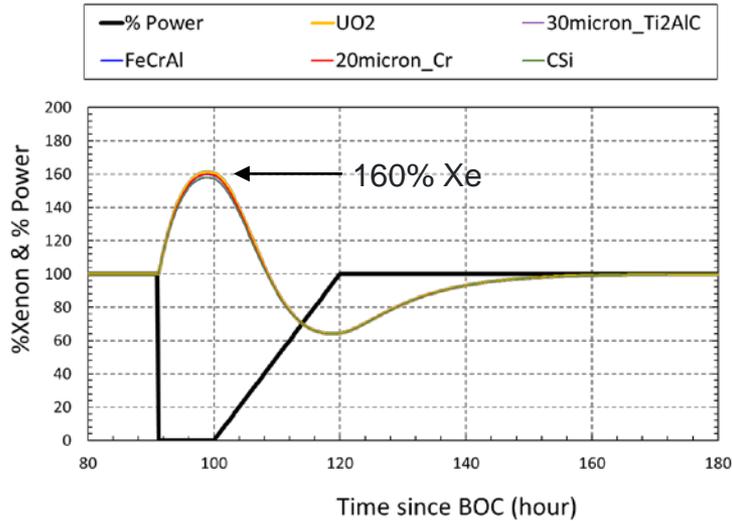
○ Relaxation in CAOC restrictions will allow to:

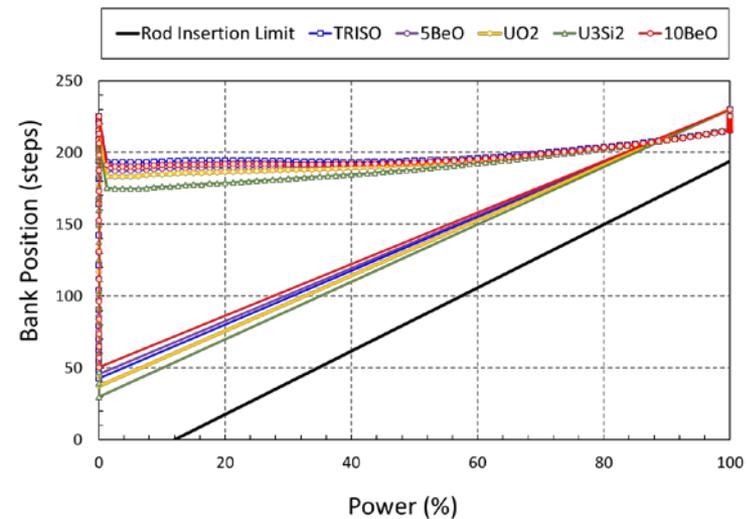
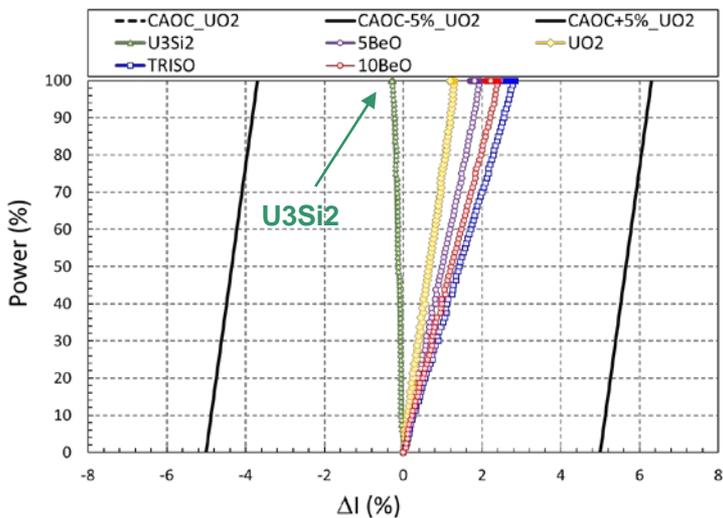
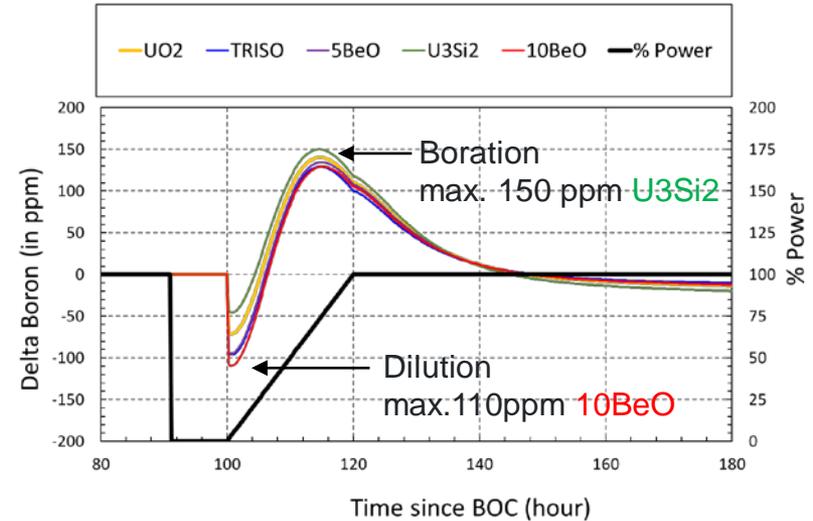
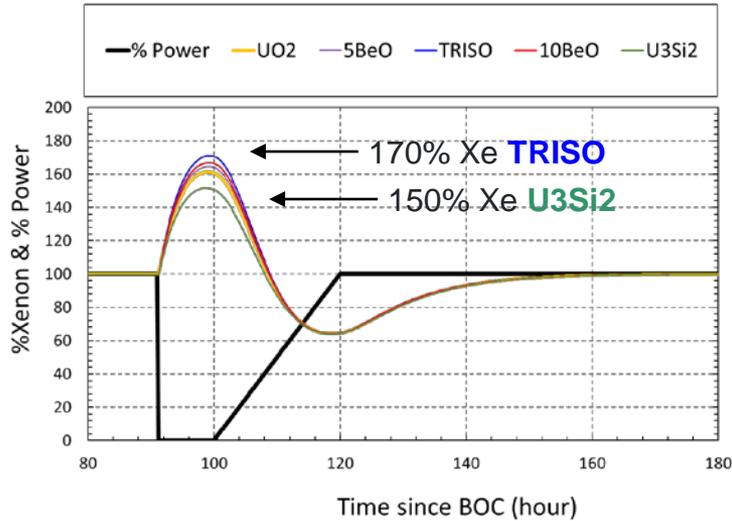
- enhance load follow capability by allowing control strategies that minimize dilution/boration
- increase the ability to return to power after shutdown

Figure. Axial Flux Difference (AFD) Limits as a functions of rated thermal power



$P > 90\%$	<ul style="list-style-type: none"> • AFD outside of target band, within 15 min. restore the AFD to within the target band or $P < 90\%$
$50\% < P < 90\%$	<ul style="list-style-type: none"> • AFD outside of target band $< 1\text{h}$ in 24h. AFD within limits $\Rightarrow P > 90\%$ • AFD outside of target band $> 1\text{h} \Rightarrow P < 50\%$ within 30min.
$15\% < P < 50\%$	<ul style="list-style-type: none"> • AFD outside of target band $< 2\text{h}$ in 24h $\Rightarrow P > 50\%$
$P < 15\%$	<ul style="list-style-type: none"> • No restrictions

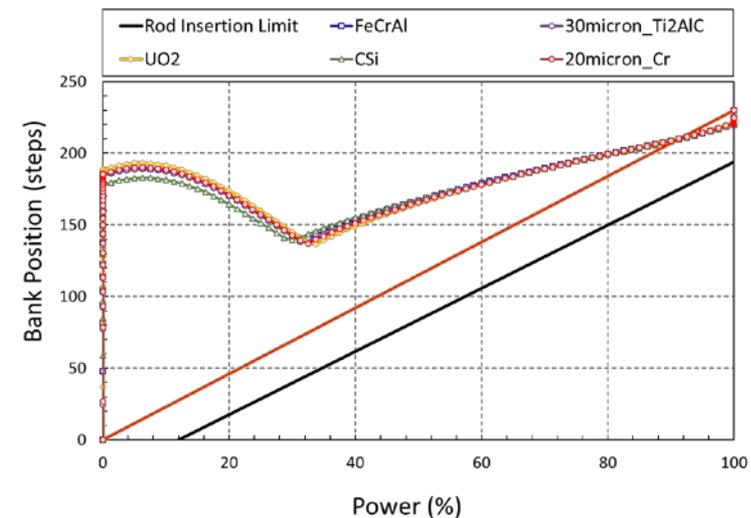
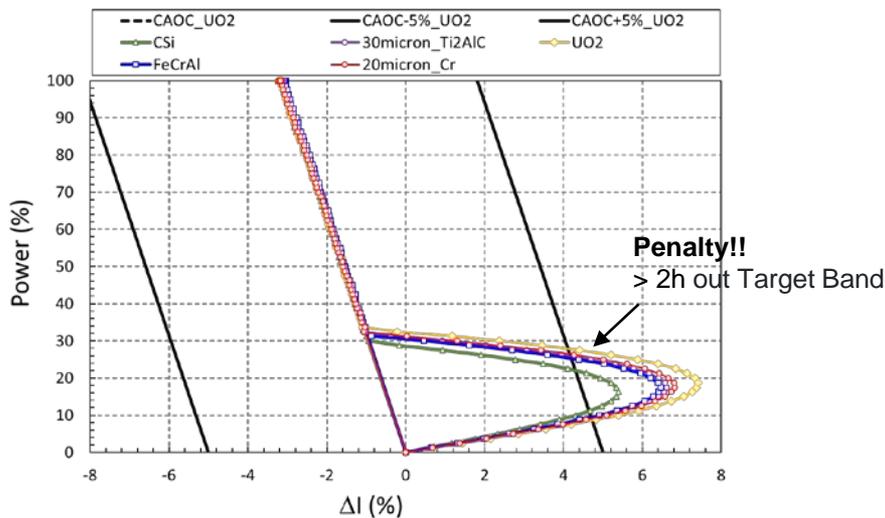
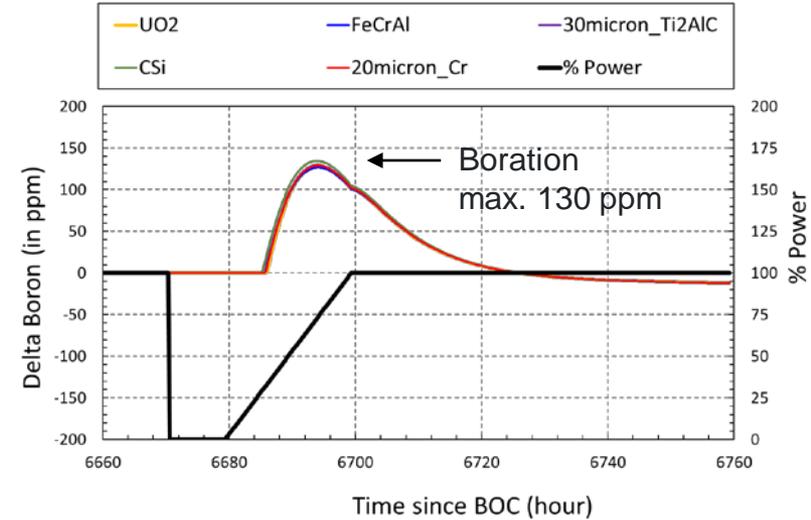
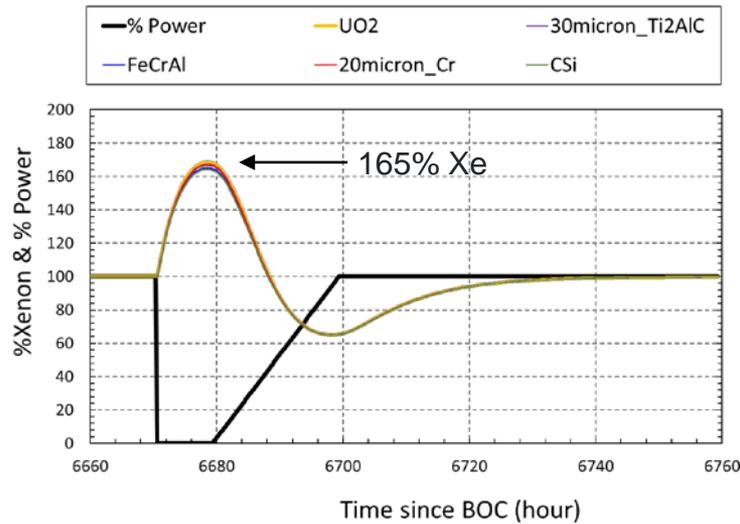
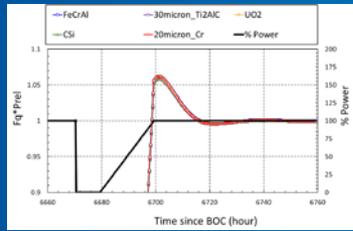




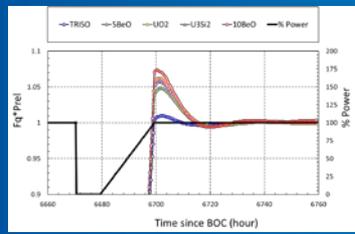
EOC-9h-5%/hour: B.Cte ATF-Cladding



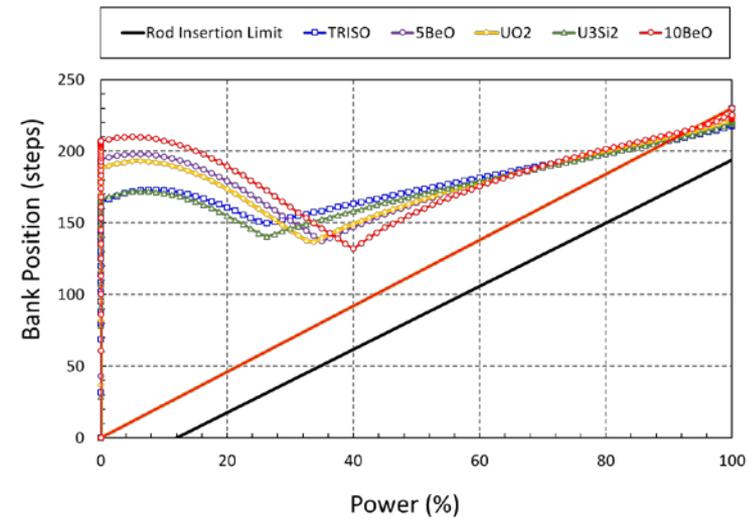
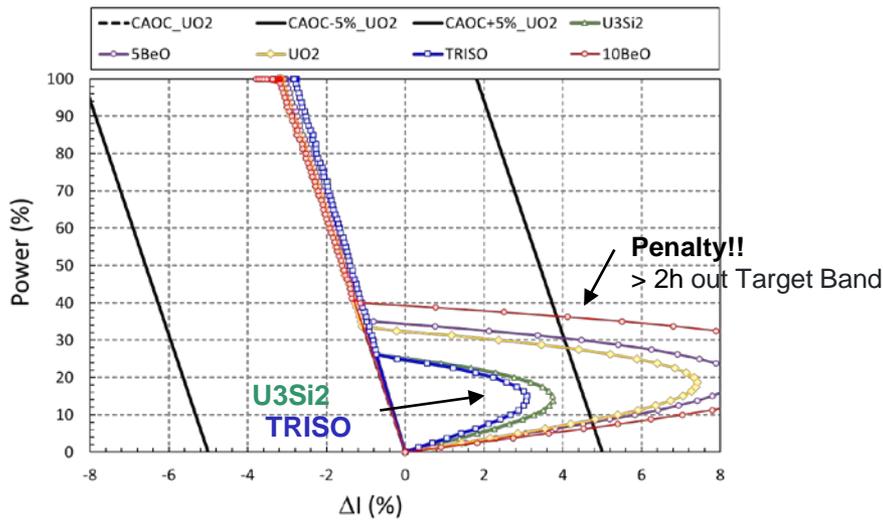
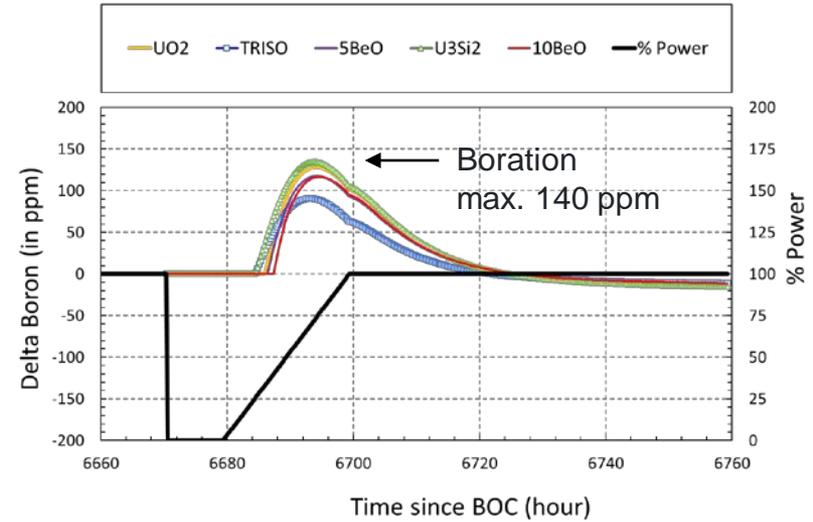
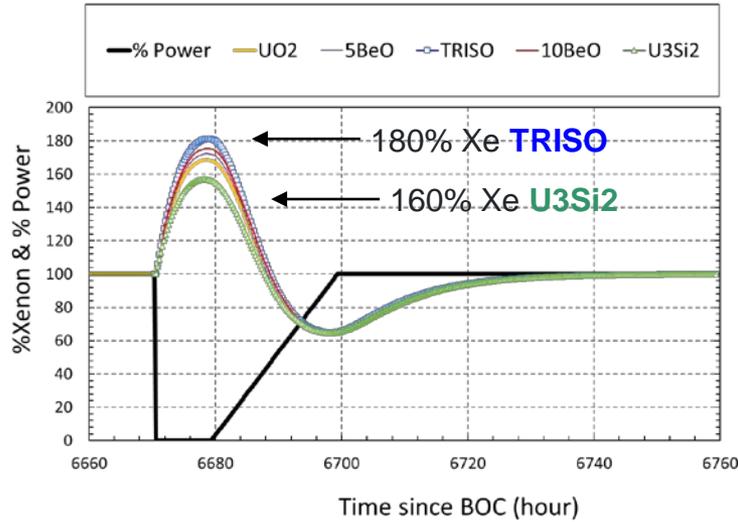
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EOC-9h-5%/hour: B.Cte ATF-Fuel



STRIALES
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- ❑ **PWR-Westinghouse (157 FA) after loading of 48 new FAs:**
 - ATF-cladding ✓
 - ATF-Fuel ✓
- ❑ **Power Maneuvering: Return to power after a short (9 hours) shutdown**
 - BOC ✓
 - EOC ✓
- ❑ **Analysis of simulations**
 - Boron Concentration versus time
 - Axial Flux Difference (AO·P_{rel}) versus Relative Power
 -
 - 1) Low differences UO₂/Zr versus UO₂/ATF-cladding
 - 2) Significant differences in ATF-fuel:
 - ±10% differences in ¹³⁵Xe buildup after shutdown
 - BOC-9h-5%/hour: CAOC: +50 ppm dilution for “BeO” and “TRISO” than UO₂
 - EOC-9h-5%/hour: Boron Constant ... penalty (> 2h out Target Band) UO₂ and Dopped/Be
... no-penalty for TRISO and U₃Si₂

