1st International Conference on LWR Fuel Performance, Modelling and Experimental Support

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Nessebar, Bulgaria

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VVER Water Chemistry Compatibility with Westinghouse Fuel

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Outline

- Background
- Coolant chemistry in VVER and PWR comparison
- Westinghouse fuel performance experience in VVER environments

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Background

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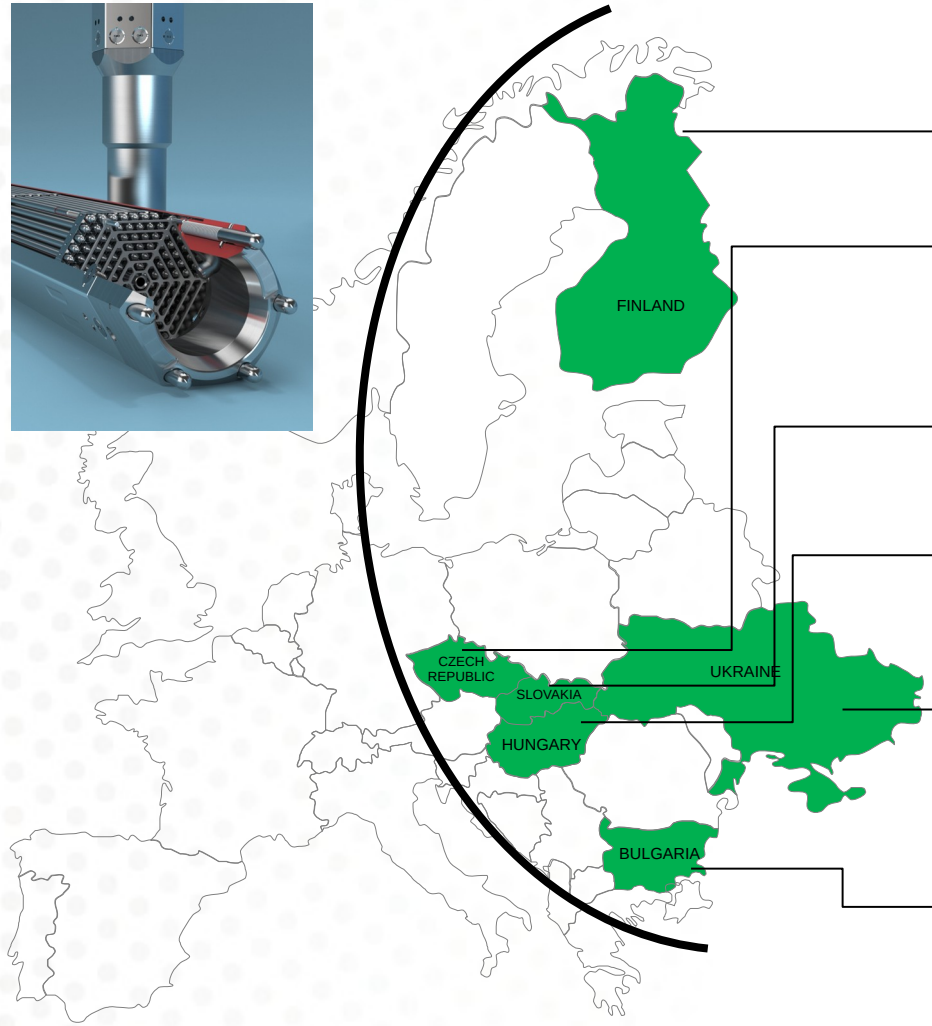
Westinghouse VVER fuel market in Europe



2x units
VVER-440
Finland (Loviisa)

6x units
4 VVER-440
2 VVER-1000
Czech rep. (Dukovany,Temelin)

4x* units
VVER-440
Slovakia (Mochovce, Bohunice)

4x units
VVER-440
Hungary (Paks)

15x units
2 VVER-440
13 VVER-1000
Ukraine (South Ukraine, Zaporizhzhia, Rivne, Khmelnytskyi)

2x units
VVER-1000
Bulgaria (Kozloduy)

In total 16* VVER-440 and 17 VVER-1000 units in Europe

Westinghouse has fuel contracts and licensing ongoing for the green ones and negotiating with the red plant

*Two are new (Mochovce unit 3 starting-up, unit 4 close to completion)

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Background

- VVER and PWRs:
  - Many similarities in their thermohydraulic principles and their coolant chemistry.
  - Differ both in the design of the primary system and auxiliary systems.
- Can Westinghouse fuel be used in VVERs from a chemistry perspective?

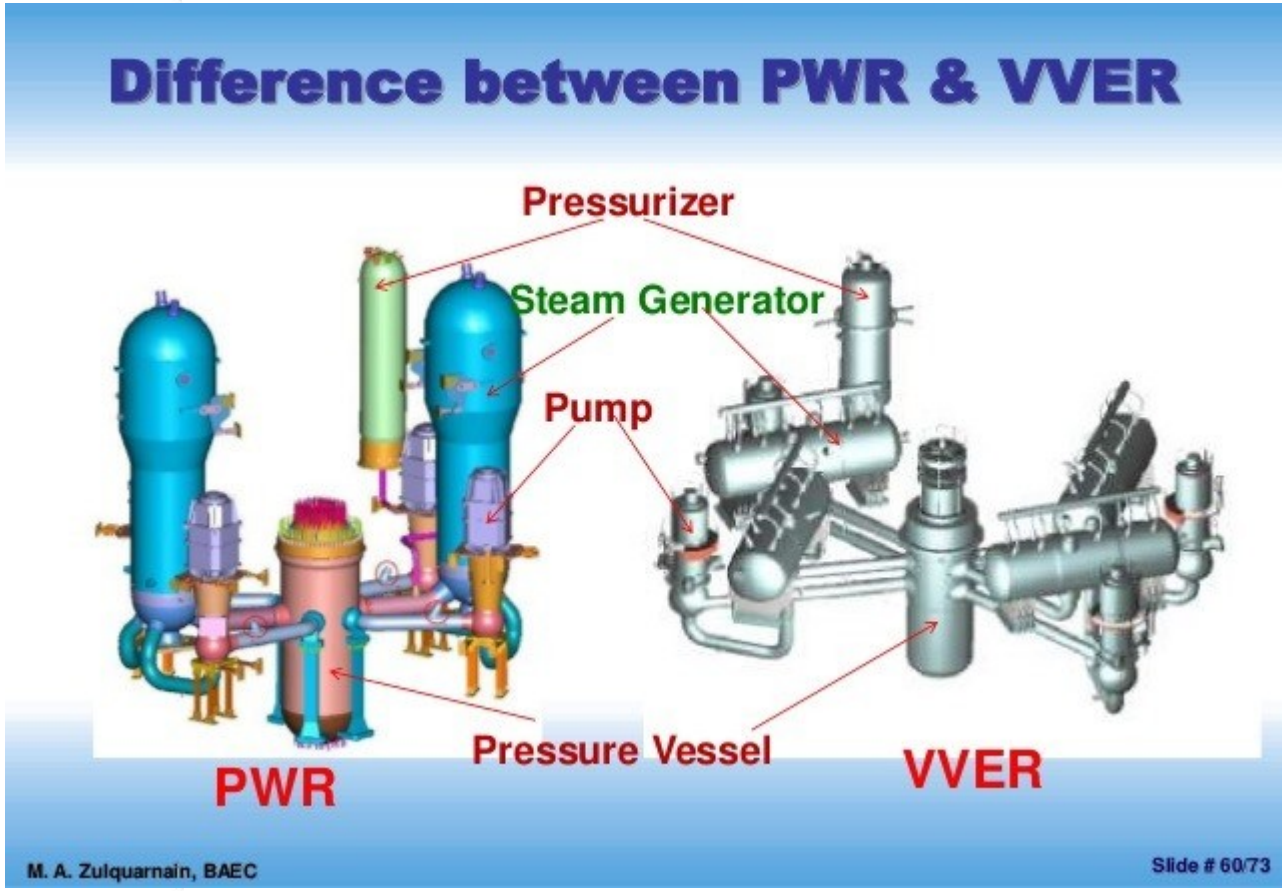

Figure taken from:
https://neutronbytes.com/2021/09/06/ukraine-opens-for-new-nuclear-business-with-america/

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Chemistry Comparison

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Main chemistry differences between PWR and VVER

- Reactor coolant alkalinity.
- Reducing conditions (H_2).
- Control and diagnostic parameters.

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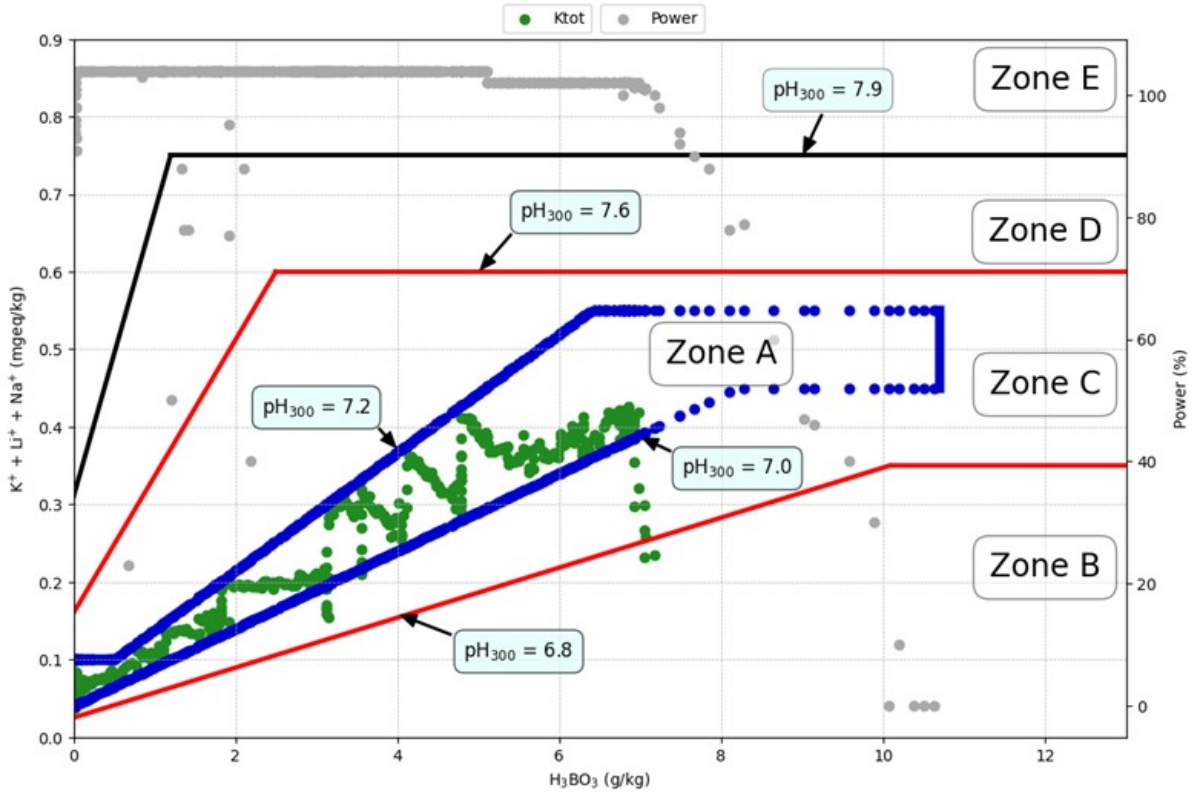
Alkalinity Control

- PWRs: Lithium (LiOH).
- VVERs: the sum of of K^++Li^+ +Na^+ or $K_{tot.}$
- Maximum K_{tot} seen is equivalent to a maximum lithium concentration of 3.8 mg/L:
  - For comparison, Westinghouse maximum lithium concentration is 3.5 mg/L.



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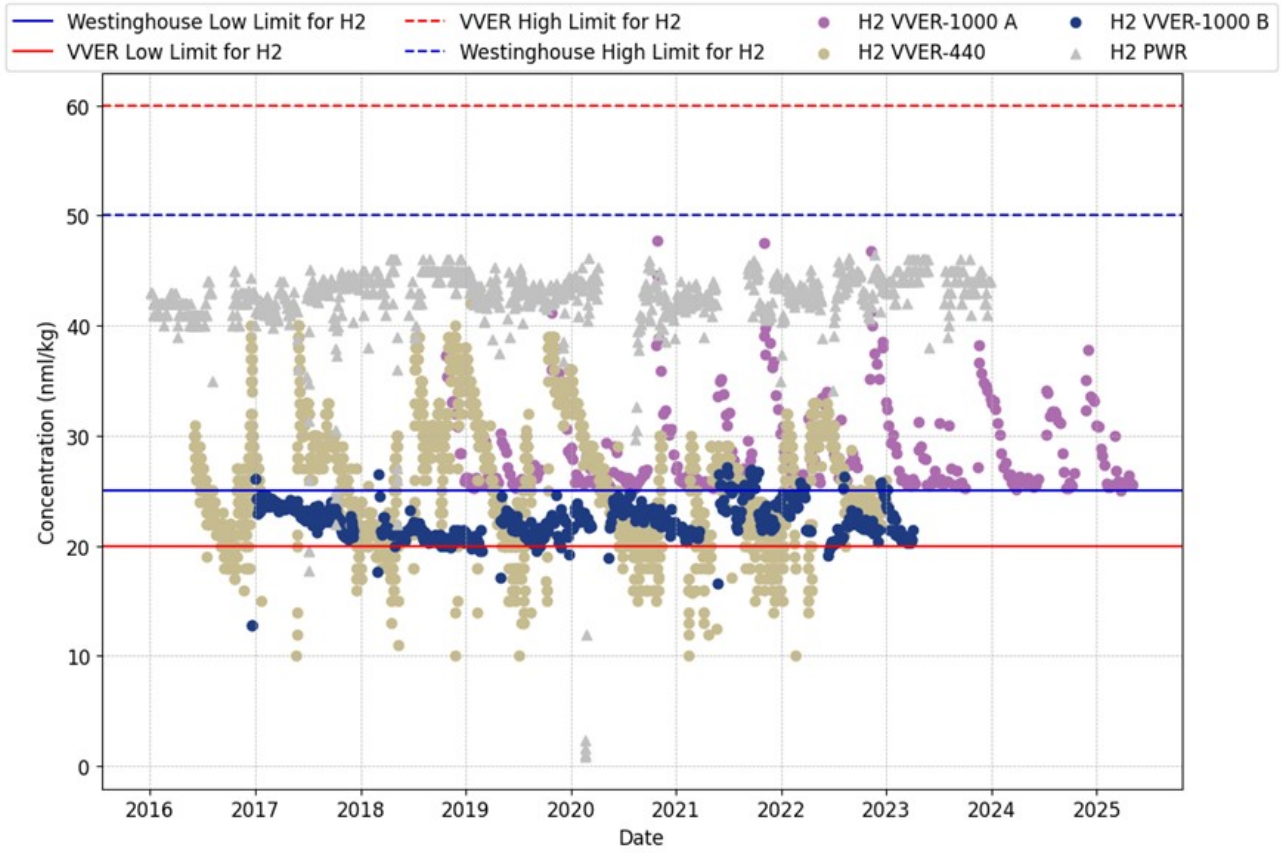
Reducing conditions (H_2)

- PWR/Westinghouse:
  - limit of 25 – 50 cc/kg.
- VVER: limits can go from 20 to 60 cc/kg
  - Values usually closer to the lower end of the range.
- Not expected to cause fuel-chemistry-related issues since levels of hydrogen required to suppress radiolysis during power operation are in the range of 5 mL/L.



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Control and Diagnostic Parameters

- Guidelines Similarities between VVER and EPRI/Westinghouse PWR:
  - Anions (Cl, F, SO_4), H_2, pH_T, O_2.
- Guidelines difference VVER plant and EPRI/Westinghouse PWR:
  - Most VVERs do not have a specific limit for silica and zeolites (Al, Ca, Mg).
  - VVERs have limits for parameters that Westinghouse does not, (e.g. Fe, NO_3, TOC).
- VVERs plants normally respect the limits for all parameters.

Parameters	EPRI/Westinghouse PWR	VVERs*
Cl, µg/L	<50	<50
F, µg/L	<50	<50
SO_4, µg/L	<50	<50
H_2, µg/L	25-50	20 – 60
pH_T	6.9 – 7.4	7.0 – 7.2
O_2, µg/L	<5	<5

*Only the strictest limit is listed for power plants.
*Most of the power plants do not have a limit for these parameters or might have looser limits.

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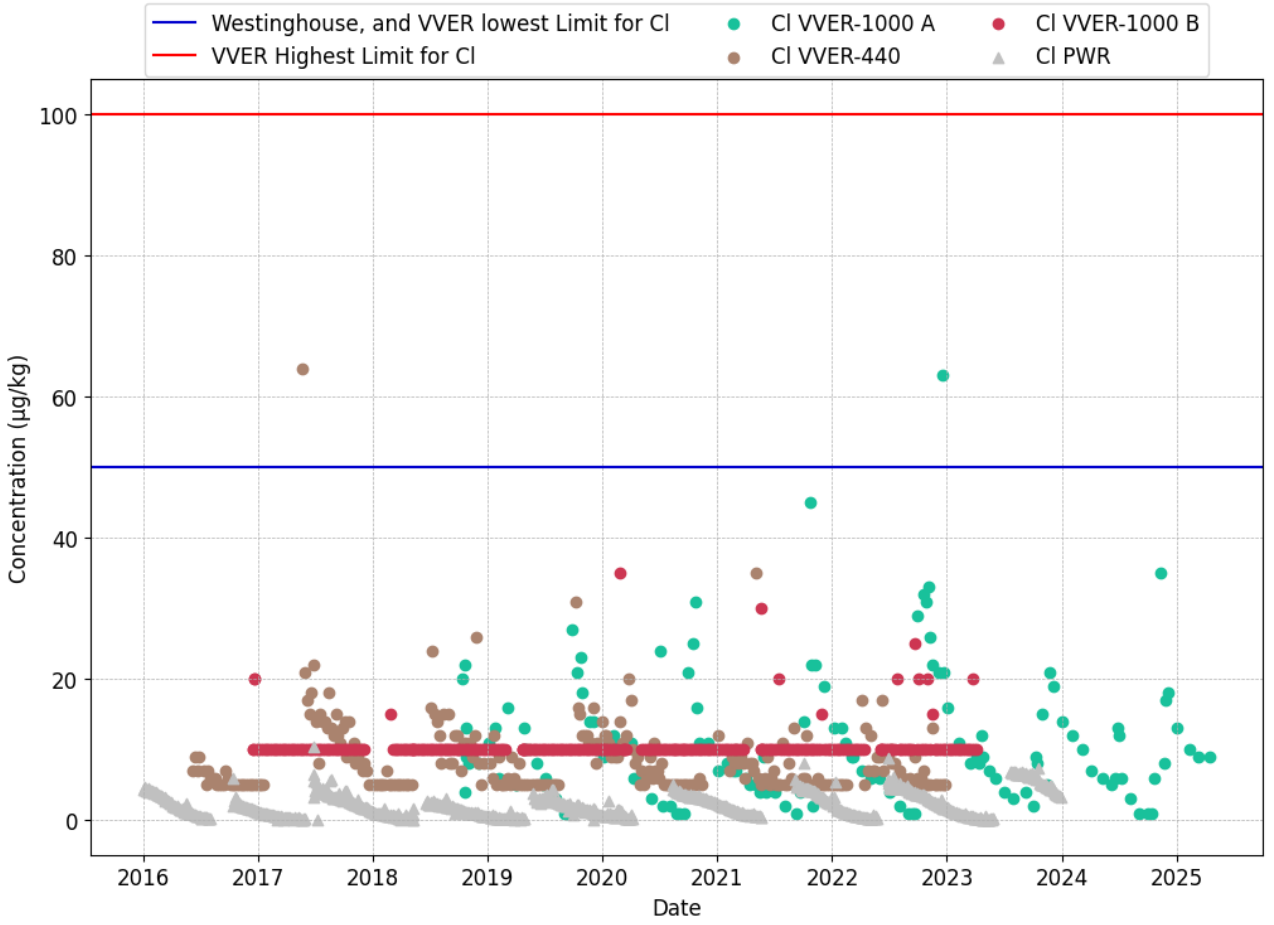
Control and Diagnostic Parameters



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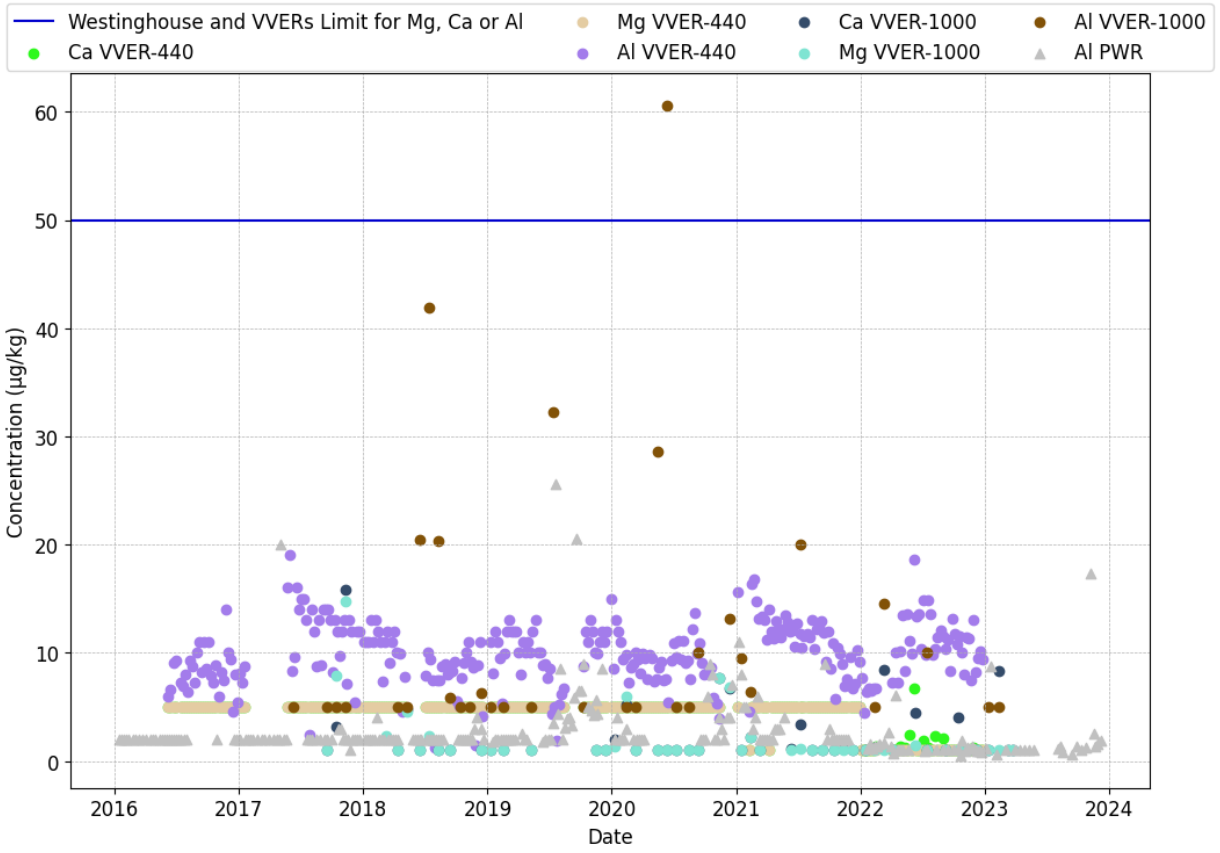
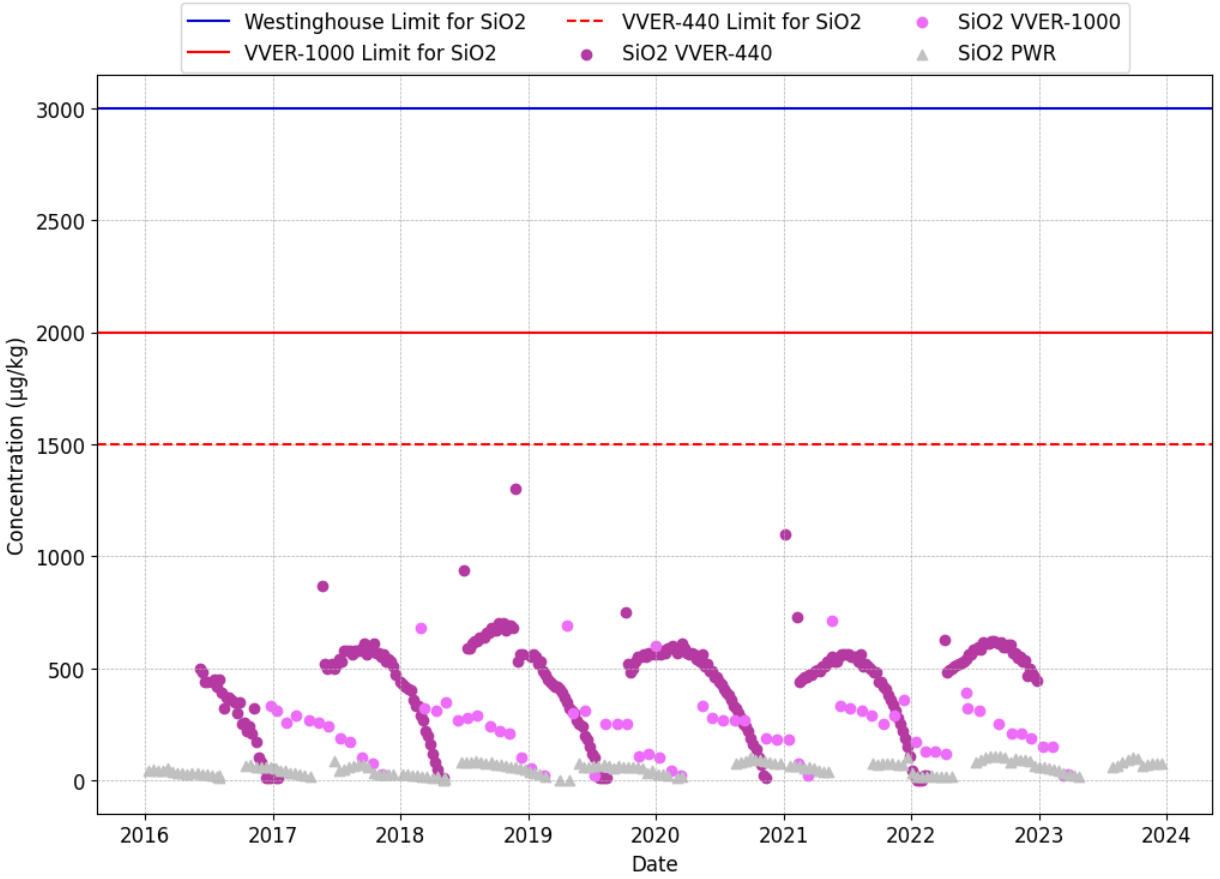
Control and Diagnostic Parameters





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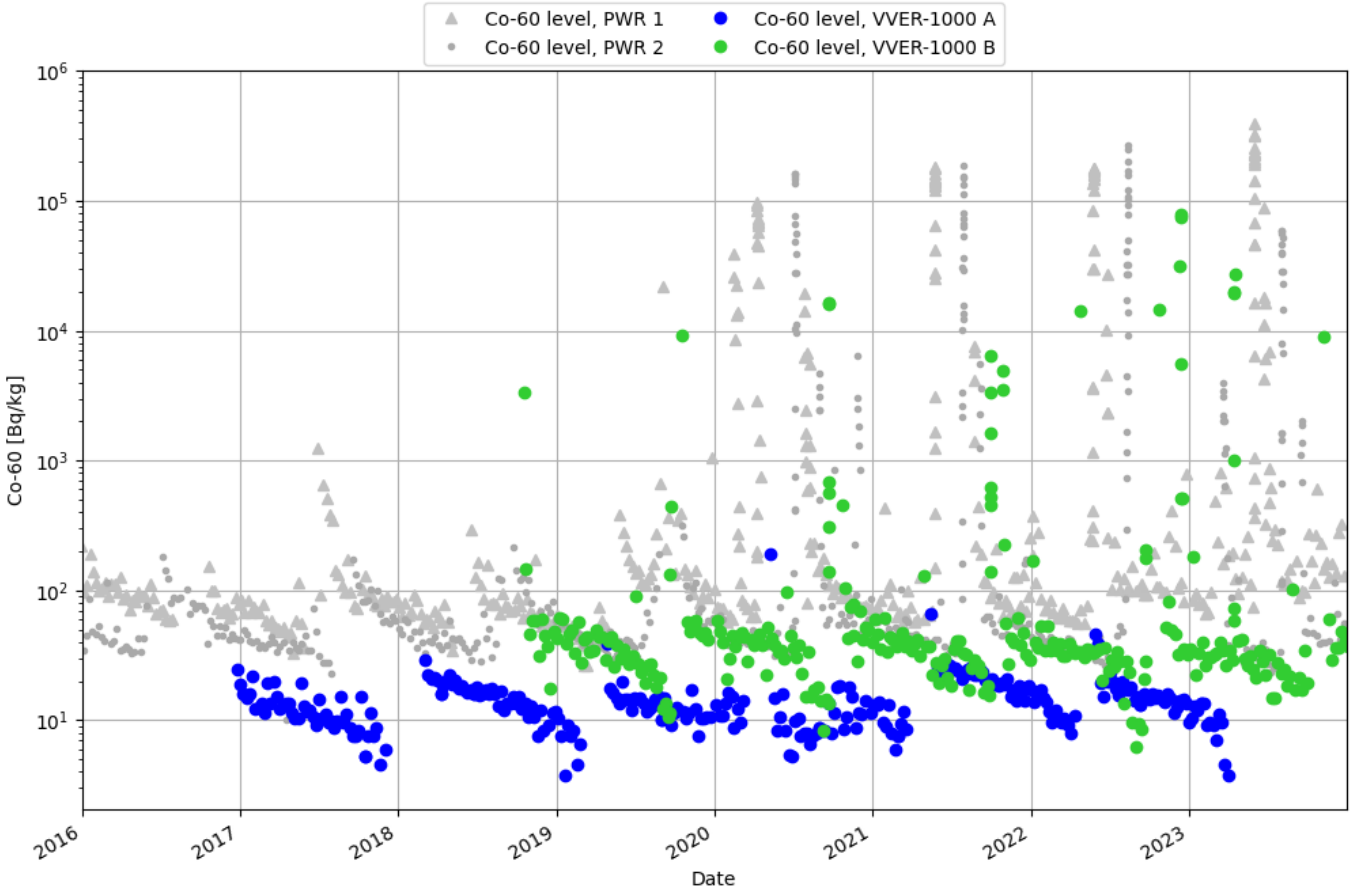
Steam generators

- In PWR: Ni-based alloys
  - Higher levels of Co-58 are expected.
- In VVER: stainless steels
  - Co-60 will not be severely affected.



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Fuel Experience

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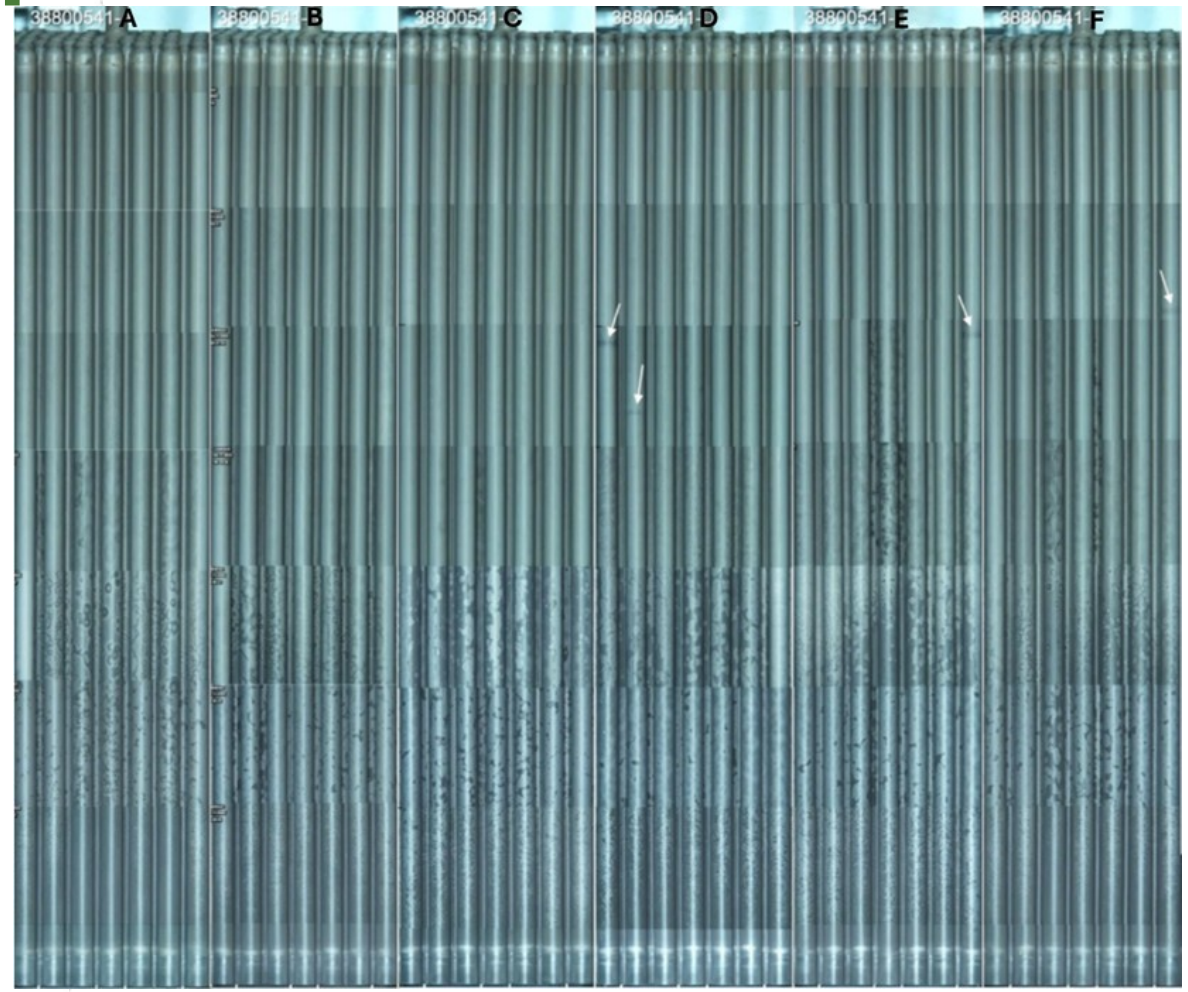
Fuel Performance Experience

- LTAs and fuel assemblies sent to different VVERs.
- Experience shows even lower corrosion than PWRs.
- Fuel rods looked good with corrosion within expected levels.
- Generally low crud levels.



Example taken from S. El Jamal, S. Buddas, L. Javanainen, L. Oliver, B. Helmersson, R. DeVito. Comparison between Loviisa VVER-440 and PWR Operating experience. To be presented in NPC conference. 2025.

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Crud Data

- Crud has been observed in one VVER-440, which can be compared to PWR:
  - Mainly zirconium and iron oxide on both.
  - High nickel oxide content in the PWRs due to the materials of the SGs.
  - Presence of Ca and Si in the VVER: Zeolite formers which can potentially densify crud

Element composition	PWR (%)	VVER-440 (%)
Ni	54.8	-
Fe	34.5	10.3
Cr	8.3	-
Ca	-	7.1
Si	-	4.9
Unknown	-	77.7

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Conclusions

- Most parameters measured in VVERs are in accordance with the operating levels and guidelines used for Western PWRs.
  - Hydrogen levels have been low but acceptable in Westinghouse experience.
- Low corrosion and crud has been observed.
- Westinghouse fuel is compatible with the coolant chemistry of VVERs if conditions are maintained.

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