Uncertainty quantification and sensitivity analysis for a steam generator clogging simulation code

E. Jaber[1,3,4]

E. Remy[1], V. Chabridon[1], M. Baudin[1], Q. Feng[2], M. Mougeot[3], D. Lucor[4]

[1] EDF R&D, PRISME dpt., 6 quai Watier, 78400 Chatou, France

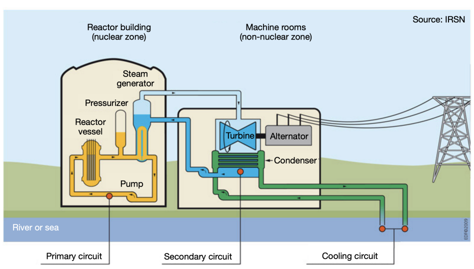
[2] EDF R&D, MFEE dpt., 6 quai Watier, 78400 Chatou, France

[3] ENS Paris-Saclay, Centre Borelli, 4 av. des Sciences, 91190 Gif-sur-Yvette, France

[4] LISN, Bât. 507, rue du Belvédère, 91400 Orsay, France

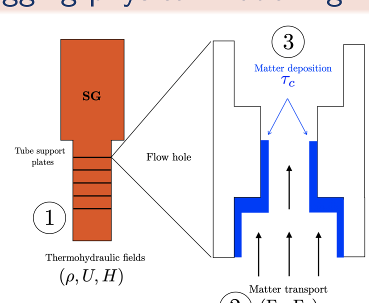
1. Industrial context

- The **steam generator** (SG) → heat exchanger between the primary and secondary circuits of a nuclear power plant (NPP).



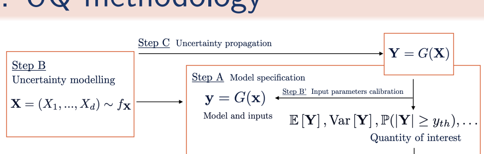
- Corrosion in the secondary circuit produces iron oxide impurities → **clogging** of the SG over time.
- Clogging is measured during NPP outages using image processing techniques.
- Chemical cleanings can be performed to reduce it → aging, environmental and economic impacts.
- Challenges for maintenance planning and optimization.

2. Clogging physical modelling



1. Thermohydraulic stationary two-state vector quantities are computed.
2. Solid and soluble iron-oxide particles are transported to the flow hole.
3. Clogging kinetics is characterised by the clogging rate τ_c.

3. UQ methodology



4. DEPOTHYC module

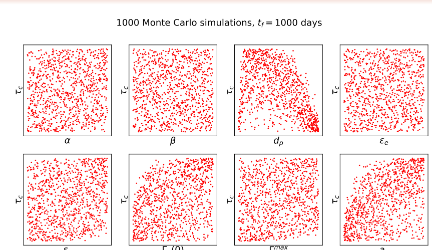
- The numerical implementation of block 2. is the DEPOTHYC module [1].
- This module allows to predict clogging kinetics on **short periods of time**.
- Unitary call ~ 15 min.

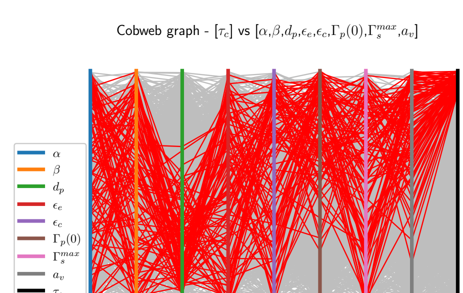
5. Input variables

$$\mathbf{X} = (\alpha, \beta, d_p, \epsilon_e, \epsilon_c, \Gamma_p(0), \Gamma_s^{\max}, a_v)$$

- α, β: empirical correlation parameters.
- d_p: diameter of particles.
- ϵ_e, ϵ_c: clogging deposit porosities.
- $\Gamma_p(0), \Gamma_s^{\max}$: initial solid particles fraction and solubility map.
- a_v: calibration parameter.

6. Monte Carlo simulations

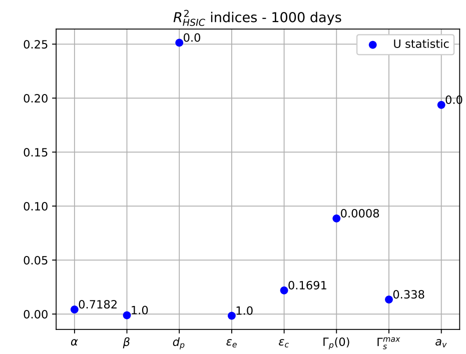


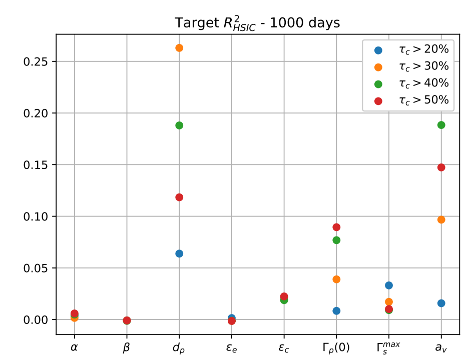


7. Sensitivity analysis (SA)

- We studied Sobol' indices as in [3] working with PCE metamodels.
- HSIC indices [2] allow to uncover deep input-output dependency structures.
- We can perform **global** and **target** with HSIC indices [2].

8. Numerical results





9. Conclusion and perspectives

- We have recovered part of the SA results obtained in a previous study [3] with Sobol' indices.
- We refined the analysis by computing target HSIC indices and observe changes in the input sensitivity hierarchy for different thresholds.
- Perspectives: applying UQ methodology to a more advanced clogging simulation chain on **long periods of time** (to develop better physical understanding and a robust decision making tool).

References

[1] T. Prusek, *Modélisation et simulation numérique du colmatage à l'échelle du sous-canal dans les générateurs de vapeur*, Doctoral thesis, MFEE department, EDF R&D, 2012

[2] A. Marrel and V. Chabridon, *Statistical developments for target and conditional sensitivity analysis: application on safety studies for nuclear reactor*, Reliability Engineering and System Safety, 214, pp.107711, 2021

[3] L. Lefebvre and al., *Improving the predictivity of a steam generator clogging numerical model by GSA and Bayesian calibration techniques*, Conference paper, Physics of Reactors, 2022