PFAS

PER- AND POLY-FLUOROALKYL SUBSTANCES

Management of Environmental & Health Risks

June 16, 17, 18 & 19, 2026 – Paris

Potential for PFAS transfer through the passive barrier of a hazardous waste landfill

Potentiel de transfert des PFAS à travers la barrière passive d'une installation de stockage de déchets dangereux (ISDD)

Maxime COCHENNEC[1], Timothée JALLOUX[2], Jean-Yves RICHARD[2]
[1]: BRGM, F-45060 ORLÉANS, France - m.cochennec@brgm.fr
[2]: VEOLIA Hazardous Waste Europe, 78520 LIMAY, France - jean-yves.richard@veolia.com

brgm Géosciences pour une Terre durable

VEOLIA

SYPRED

Context

In Europe, there are 3 types of waste storage facilities

- ISDI : for inert wastes = no containment
- ISDND : for non hazardous wastes = sealed containment
- ISDD : for hazardous wastes = reinforced sealed containment (AM du 30/12/2002)

PFAS have been used for several decades in a wide variety of industrial sectors but :

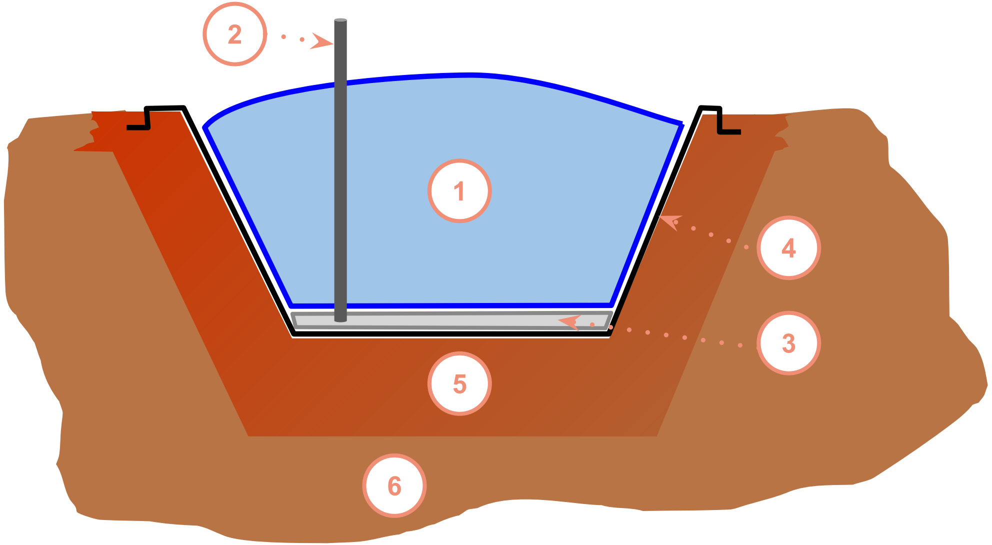
- Awareness of the health and environmental problems generated by PFAS is recent
- European regulation did not require PFAS analysis before landfilling

Hazardous Waste Landfill (HWL) have received wastes containing PFAS for years

- Does the storage of PFAS wastes generate an environmental risk?
- Should the intake of PFAS wastes into HWL be regulated to ensure long-term storage safety?

Study funded by SYPRED

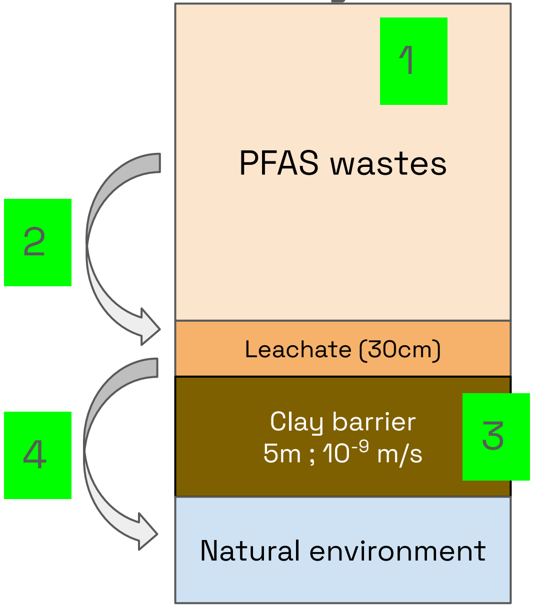
Safety barriers of a hazardous waste landfill



1	Hazardous wastes
2	Leachate pumping and control well
3	Draining bed
4	HDPE geomembrane (black) and protective geotextile (active barrier)
5	Compacted clay layer 5 m, 10^{-9} m/s (barrière passive)
6	Natural environment

Safety barriers of a hazardous waste landfill

HWL (=ISDD) conceptual diagram



A study in 4 parts :

1 - Data acquisition on hazardous wastes containing PFAS

2 - Potential for PFAS migration from wastes to leachate

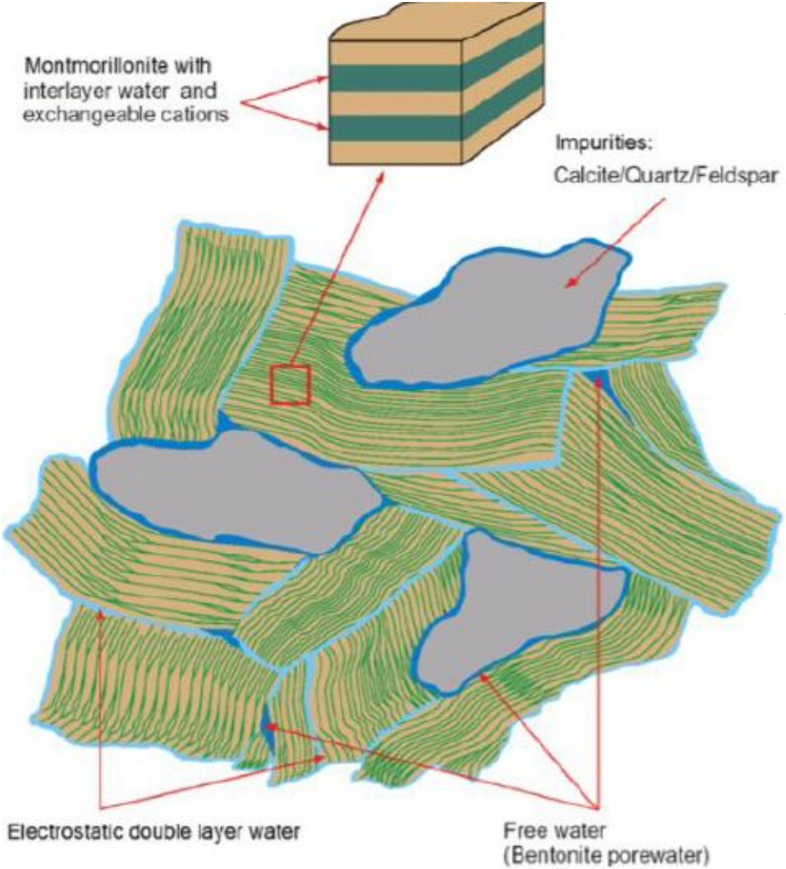
3 - Modeling of PFAS transfer through the clay barrier

4 - Evaluation of transfer to natural environment

Modeling strategy – a simple approach for a not-so-simple system

- Clay is a multiscale system (up to 3 scales!):
- Free and bound water: anions (as PFAS) have different behavior in both
- In clay interlayers, the negative effective charge produces **anion exclusion**

Approach used: lumped everything in effective/averaged parameters (e.g., partitioning coefficient)



Tournassat and Appelo (2011)

Starting from the traditional advection-diffusion-adsorption equation (1D)

$$\underbrace{\left(1+\frac{\rho_b}{n}K_d\right)}_{\text{Retardation factor }(R)}\frac{\partial C}{\partial t}=\underbrace{\frac{\partial}{\partial x}\left(\left(\frac{D^*}{\tau^2}\frac{\partial C}{\partial x}\right)\right.}_{\text{Diffusion}}\underbrace{\left.+\,vC\right)}_{\text{Advection}}$$

- In this system, diffusion should be much more important than advection (because v is very small)

An analytical solution is known (van Genuchten, 1982)

$$C(x,t)=\frac{C_0}{2}\times\left(\operatorname{erfc}\left[\frac{Rx-vt}{2\sqrt{DRt}}\right]+\exp\left(\frac{vx}{D}\right)\operatorname{erfc}\left[\frac{Rx+vt}{2\sqrt{DRt}}\right]\right)$$

K_d is found in the literature, but effect of salts and pH should be studied in depth

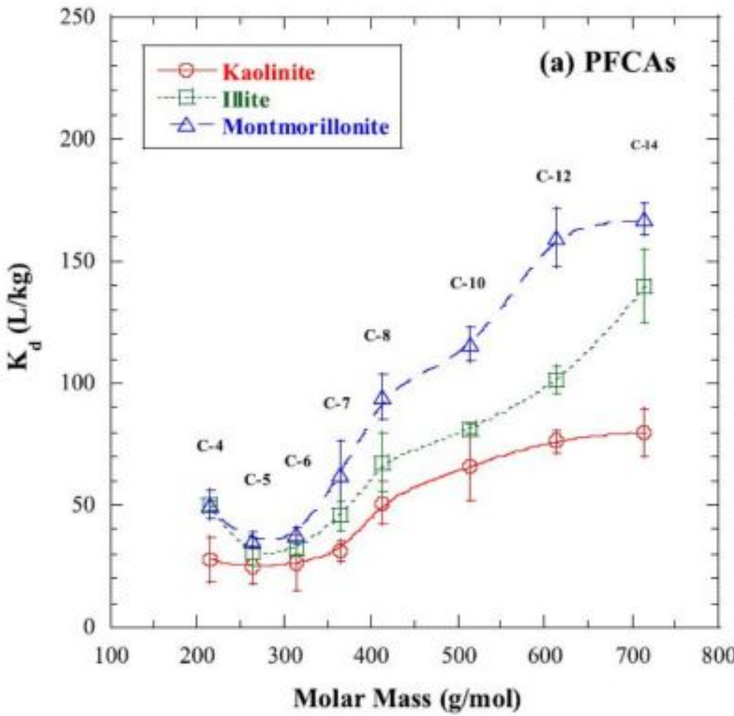
- Partitioning coefficient K_d **is valid only for a given matrix/solute/sorbent system**

- Hopefully, a study experimentally measured it for 20 PFAS and in three different clays (illite, kaolinite, and montmorillonite)

- Based on their observations, they proposed a predictive equation with two parameters:

  - Molar mass (M)
  - Cation Exchange Capacity (CEC)

$$K_d = -137.71 - 0.0005 \times M^2 + 0.675 \times M + 0.374 \times CEC$$



Ahmad et al. (2023)

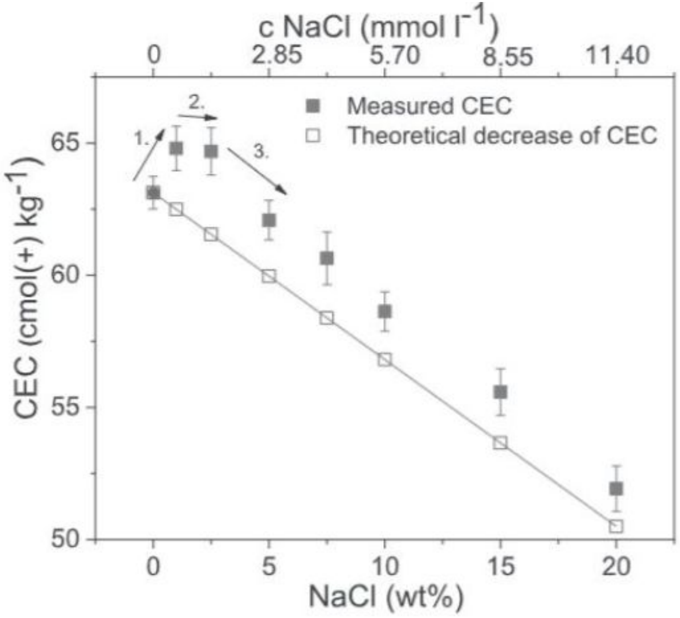
The expected impact of salts is higher PFAS adsorption/retardation

- At first glance, higher salt concentration implies lower CEC, so a lower K_d according to our model

- At a closer look, all studies conclude with a higher K_d for PFAS (experimentally and with molecular dynamics)

- Two likely reasons:

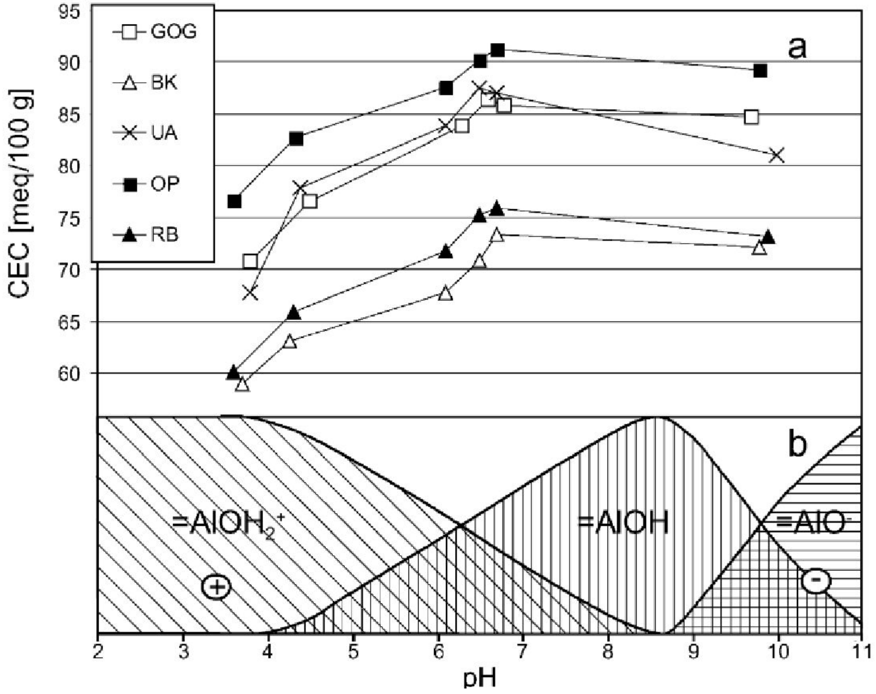
  - **Cationic bridge**: multivalent cations create a bridge with anions
  - **Salting-out effects**: cations enhance apparent hydrophobicity of PFAS



Bohac et al. (2019)

The expected impact of pH is generally higher PFAS adsorption/retardation, or neutral at pH > 7

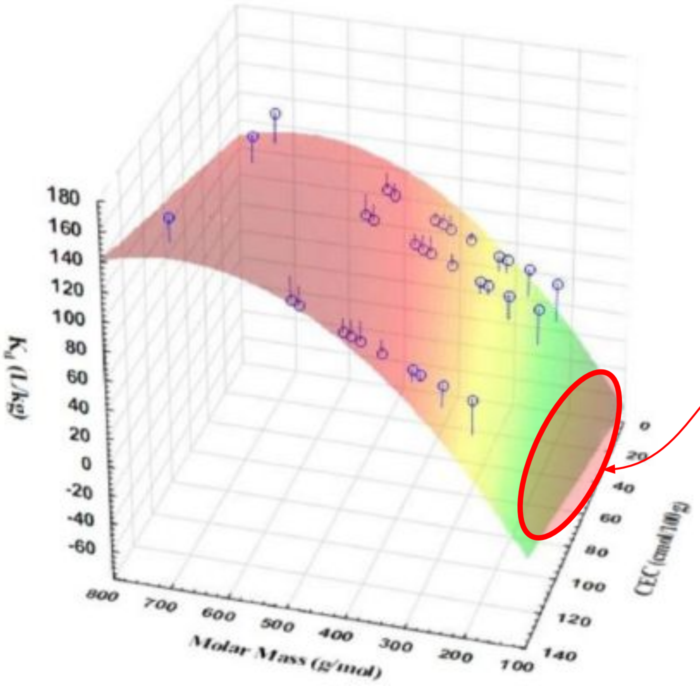
- PFAS speciation at pH > 8, fully dissociated
- CEC increases with pH for montmorillonite, up to ~pH 7
- Above pH 7, only a slight decrease that will be neglected in the following



Kaufhold et al. (2002)

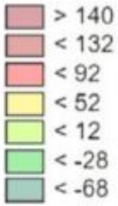
The predicivite equations gives negative K_d values for small PFAA

$$K_d = -137.71 - 0.0005 \times M^2 + 0.675 \times M + 0.374 \times CEC$$



Ahmad et al. (2023)

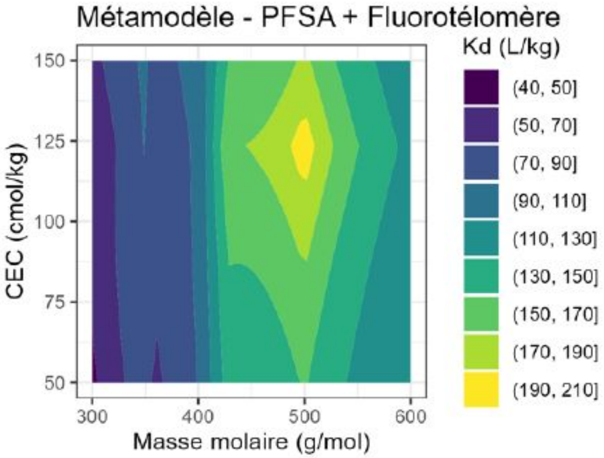
Zone of negative K_d

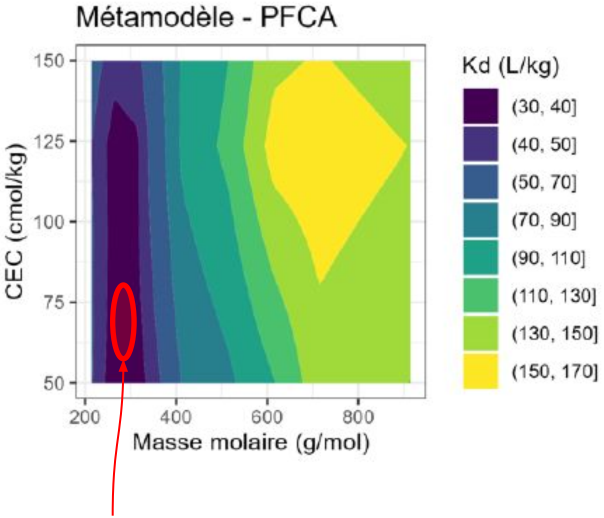


- The predictive model gives negative values for small PFAS!
- \+ The local K_d minimum for PFPeA is not predicted

Our approach: building a « metamodel »

$$K_d = -137.71 - 0.0005 \times M^2 + 0.675 \times M + 0.374 \times CEC$$





Local minimum of K_d is well predicted

K_d surface response + analytical solutions = complete model

- Using a kriging approach, the experimental data are converted into a surface response with two entries (CEC and M)
- No negative K_d values for small PFAS (very important because more mobile)
- The local K_d values are read into the surface response and then used in the equation for concentration(x,t)

Evaluation of transfer to natural environment

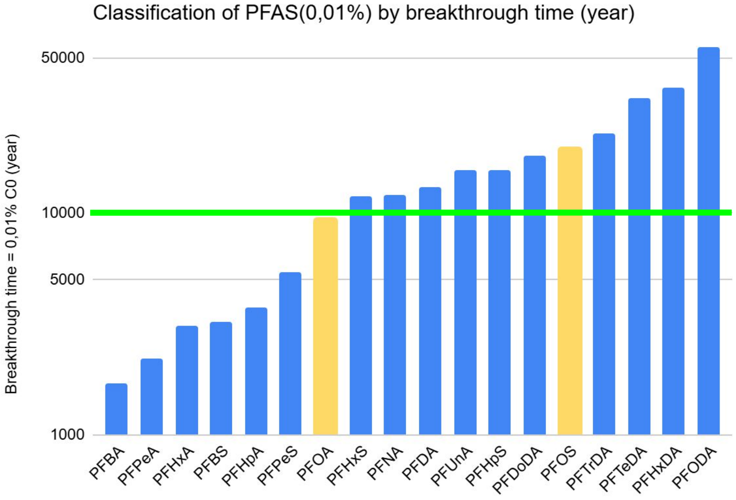
Model input data

- $K=10^{-9}$ m/s
- PSB thickness = 5 m
- porosity = 0,35
- CEC = 60 cmol/kg
- [PFAS]= 1 µg/L
- Breakthrough time defined as :

[PFAS] under clay layer = [PFAS] leachate / 10 000

Main results

- The most mobile PFAS is the PFBA = 1,700 years
- PFAS with more than 8 carbons > 10,000 years
- PFOA and PFOS are very well confined in ISDD



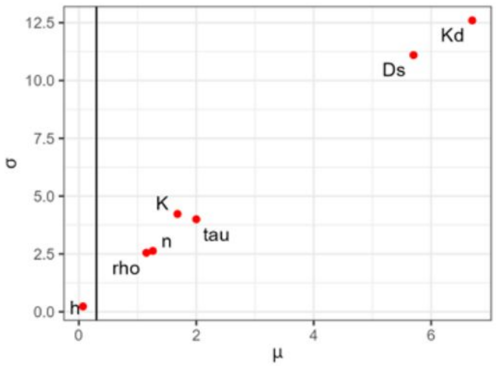
PFAS are very effectively and safely contained in ISDD (including PFOS, PFOA, 6:2 FTS)

Evaluation of transfer to natural environment

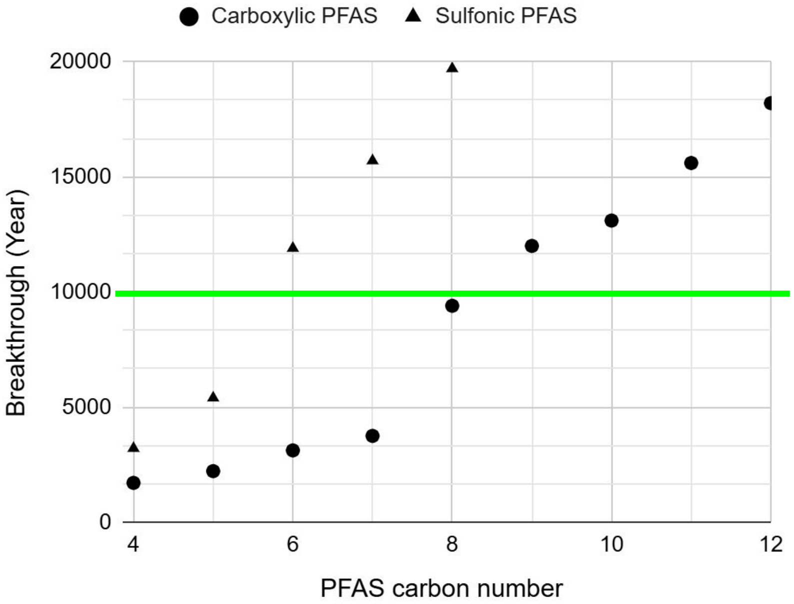
Main results

- Carboxylic PFAS are more mobile than sulfonic PFAS for a same number of carbon
- Coefficient distribution (Kd) is the most significant parameter
- Height of leachate is the less significant parameter

PFAS are very effectively and safely contained in ISDD (including PFOS, PFOA, 6:2 FTS)



Abrev.	Nb. C	Compound	Time (year)
PFBA	4	perfluorobutanoic acid	1710
PFPeA	5	perfluoropentanoic acid	2220
PFHxA	6	perfluorohexanoic acid	3120
PFBS	4	perfluorobutanesulfonic acid	3210
PFHpA	7	perfluoroheptanoic acid	3750
PFPeS	5	perfluoropentanesulfonic acid	5400
PFOA	8	perfluooctanoic acid	9400
PFHxS	6	perfluorohexanesulfonic acid	11900
PFNA	9	perfluorononanoic acid	12000
PFDA	10	perfluorodecanoic acid	13100
PFUnA	11	perfluoroundecanoic acid	15600
PFHpS	7	perfluoroheptanesulfonic acid	15700
PFDoDA	12	perfluorododecanoic acid	18200
PFOS	8	perfluooctanesulfonic acid	19700
PFTrDA	13	perfluorotridecanoic acid	22900
PFTeDA	14	perfluorotetradecanoic acid	33100
PFHxDA	16	perfluorohexadecanoic acid	36800
PFODA	18	perfluorooctadecanoic acid	56100



Conclusion / Perspective

- Modeling is a powerful tool to evaluate performance of hazardous landfill over the very long term
- Specific environmental conditions of hazardous waste storage (pH, salinity…) are favorable to the PFAS retention
- The most significant parameters is the distribution coefficient (Kd), followed by the molecular diffusion coefficient
- PFOS and PFOA are confined for several thousand of years in hazardous waste landfill (ISDD)
- Particular attention should be paid to smallest PFAS (4, 5 and 6 carbons) and carboxylic PFAS which are the most mobile under the studied conditions
- **Hazardous waste landfill is a very effective and very safe method for the long-term management of PFAS contaminated wastes**

Perspectives

- Integration of ultra short chain (USC) PFAS in progress (TFA)
- PFAS waste stabilization and/or Kd optimization to improve containment

Merci pour votre attention

Jean-Yves RICHARD (VEOLIA Hazardous Waste Europe - jean-yves.richard@veolia.com)
Maxime COCHENNEC (BRGM - m.cochennec@brgm.fr)